Human Factors Evaluation of Remote Afterloading Brachytherapy

Supporting Analyses of Human-System Interfaces, Procedures and Practices, Training and Organizational Practices and Policies

Manuscript Completed: June 1995
Date Published: July 1995

Prepared by
J. R. Callan, R. T. Kelly, M. L. Quinn, R. A. Moore, F. A. Muckler, J. Kasumovic, J. C. Easterly,
Pacific Science and Engineering Group
W. M. Saunders, R. P. Lepage, E. Chin, University of California at San Diego Medical Center
I. Schoenfeld, D. I. Serig, U.S. Nuclear Regulatory Commission

I. Schoenfeld, NRC Project Manager

Pacific Science & Engineering Group
6310 Greenwich Drive, Suite 200
San Diego, CA 92122-5918

Subcontractor:
Division of Radiation Oncology
University of California at San Diego Medical Center
San Diego, CA 92103

Prepared for
Division of Systems Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code L1116

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
Yhr

MASTER

DISCLAIMER NOTICE

This document was prepared under U.S. Nuclear Regulatory Commission (NRC) Contract No. NRC-04-90-074. The opinions, findings, conclusions, and recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the NRC. The statements of strengths and weaknesses related to specific (commercial) Remote Afterloading Brachytherapy systems are the authors' conclusions based on their expertise and should not be interpreted to be regulatory or evaluative positions of the NRC.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Abstract

A human factors project on the use of nuclear by-product material to treat cancer using remotely operated afterloaders was undertaken by the Nuclear Regulatory Commission. The purpose of the project was to identify factors that contribute to human error in the system for remote afterloading brachytherapy (RAB). This report documents the findings from the second, third, fourth, and fifth phases of the project, which involved detailed analyses of four major aspects of the RAB system linked to human error: human-system interfaces; procedures and practices; training practices and policies; and organizational practices and policies, respectively. Findings based on these analyses provided factual and conceptual support for the final phase of this project, which identified factors leading to human error in RAB. The impact of those factors on RAB performance was then evaluated and prioritized in terms of safety significance, and alternative approaches for resolving safety significant problems were identified and evaluated.

CONTENTS IN BRIEF

ABSTRACT	iii
EXECUTIVE SUMMARY	vii
ACKNOWLEDGMENTS	x
GENERAL INTRODUCTION	1
SECTION A: HUMAN-SYSTEM INTERFACES	3
SECTION B: PROCEDURES AND PRACTICES	85
SECTION C: TRAINING AND ORGANIZATIONAL PRACTICES AND POLICIES	161

Executive Summary

Introduction

Brachytherapy is a cancer treatment process that uses radioactive material (sources) to retard or destroy tumors with ionizing radiation. Manual brachytherapy is a version of brachytherapy in which the radioactive sources are inserted and withdrawn manually from the treatment area of the patient's body. Remote afterloading brachytherapy (RAB) is a version of this process in which a computerized control unit remotely inserts and withdraws the radioactive sources from tumor locations. The term "afterloading" refers to source placement techniques using tools which permit staff exposure to be reduced. This report addresses RAB only.

Two types of RAB are practiced in the U.S. today: high dose rate (HDR) and low dose rate (LDR). High dose rate RAB uses a high activity source, typically iridium-192, to achieve short treatment times of 5–10 minutes. Low dose rate RAB uses a lower activity source, typically cesium-137, and has much longer treatment times, often 2–3 days.

The Nuclear Regulatory Commission (NRC) reviews reports and investigates events related to the medical use of radioactive materials (i.e., nuclear by-product materials, including brachytherapy sources). These reports and investigations indicate that human error has resulted in therapy misadministrations in which (1) radiation was delivered to a patient from a source other than the one intended, (2) radiation was delivered to the wrong patient, (3) radiation was delivered by a route of administration other than that intended, or (4) a radiation dose differing from the prescribed dose by more than 20% was given.

To better understand the causes of human errors in RAB, the NRC initiated a research project, *Human Factors Evaluation of Brachytherapy Using Remote Afterloaders*, to identify factors contributing to human error through a series of analyses of data collected at facilities throughout the United States.

The project's objectives were to

- identify factors (root causes) which contribute to errors in RAB systems
- evaluate the impact of these factors on the performance of functions and tasks essential to meet system goals
- prioritize function and task performance problems related to human errors in terms of their safety significance
- identify and evaluate alternative approaches for resolving safety significant problems related to human errors

To accomplish these objectives, the project included the following major phases: (1) a function and task analysis, (2) an evaluation of human-system interfaces, (3) an evaluation of RAB operating, maintenance, and emergency procedures and practices, (4) a training and qualifications evaluation, (5) an evaluation of organizational practices and policies, and (6) identification and prioritization of human error in RAB and alternative approaches for improving error prevention, detection, correction, and damage control. This report documents the results of the analyses of Phases 2–5. The results of the function and task analysis are presented in NUREG/CR-6125, Volume 2, and the results of the Phase 6 analysis are presented in NUREG/CR-6125, Volume 1.

The research was conducted by a multi-disciplinary team consisting of scientists experienced in applying human factors principles to medical system evaluation and design. A radiation oncologist, two medical physicists, and a chief dosimetrist served as RAB subject matter experts.

Method

A representative sample of RAB facilities was selected for visits to collect data for the four phases covered by this part of the study. Facility selection criteria were afterloader manufacturer, geographic region, dose rate, licensing authority, caseload, and RAB experience. Eight facilities were visited to identify and evaluate the human-system interfaces and the procedures and practices used in the RAB process. An additional eight facilities were visited to determine the training and organizational practices and policies provided for RAB.

A comprehensive data collection protocol was devised prior to the site visits in order to ensure that the data that was collected would meet the needs of the study. In addition, several data collection tools were developed specifically for this study that permitted human factors analysts to gather information about the characteristics of the equipment and of each medical facility (human-system interfaces, procedures and practices, and training and organizational practices and policies). Unique aspects of each facility were also noted, including physical layout, potential distractors, organizational and administrative structures, jobs performed by various categories of workers, and local organizational, training, and treatment goals. Emphasis,

Executive Summary

throughout, was on identifying factors that could lead to patients receiving radiation dosages that differed significantly from the prescribed dosage or to inadvertent staff exposure.

Data were collected from the following sources:

- documentation supplied by the manufacturers and distributors of RAB equipment
- documentation used on-site by RAB staff, including locally developed documents
- interviews with all available RAB staff at each site
- observation and recording of RAB activities as they were being performed or demonstrated
- directed walk-throughs in which RAB staff performed tasks on simulated cases

A human factors research team analyzed all the data gathered during this part of the project and identified factors that could increase the likelihood of human error in RAB. Analysis of these data yielded findings that could be applied in the last phase of the project to identify critical RAB tasks and to propose alternative approaches for resolving safety significant problems related to human error in those tasks.

Results

Phase 2: Human-System Interfaces

Phase 2 evaluated the human-system interfaces used by RAB staff. These evaluations followed established human factors standards and guidelines for interface design. Four classes of human-system interfaces were evaluated based on the results of the Phase 1 function and task analysis: equipment, software, documents, and workspaces. Deficiencies that impede error-free human performance were identified for each of these four types of interfaces.

General human-system interface findings across all RAB functions and tasks showed that

- RAB staff were often unfamiliar with RAB interfaces that they had not used frequently.
- Operators could not see some essential treatment controls and displays from their workstations.
- System status information often was unavailable to system operators.

Phase 3: Procedures and Practices

Phase 3 evaluated the procedures and practices used to perform RAB tasks. The only tasks that were performed in exactly the same way at different facilities were those involving the actual operation of the RAB treatment delivery equipment. Very little written documentation was found that could be used to guide RAB task performance. Instead, verbal communication and demonstration was used to guide staff in RAB activities.

Phase 3 also identified the methods used to link the tasks together and the communications procedures used to pass information and material between the tasks. These linkages were crucial but often overlooked aspects of task performance. Without a well-established system of linking tasks, information that is critical to the correct performance of RAB can be lost. Similarly, verification procedures are often needed to confirm that certain actions occurred at the appropriate time and place in the RAB process. Verification procedures tended to either be absent, poorly structured, or inconsistently used at many facilities.

Phase 4: Training Practices and Policies

Phase 4 evaluated the training and qualifications of RAB staff. Although all RAB staff at the visited sites had received on-the-job training in RAB, most sites had no formal training programs, little written training material, and little, if any, follow-up or refresher training of any type. In addition, there are currently no state or national standardized training programs that RAB staff are required to complete, nor are there standardized assessment procedures for RAB training.

Certification examinations for RAB staff positions were required only for radiation therapy technologists at most sites (national certification is offered by the American Registry of Radiologic Technologists; in addition, some states have their own registry examinations). However, these certification procedures do not substantially address RAB-specific topics. Most RAB staff had therefore not been required to take formal written or oral examinations on RAB skills and knowledge. At the present time, there are no certification procedures specifically designed for RAB.

Phase 5: Organizational Practices and Policies

Phase 5 evaluated the organizational support provided RAB at each site. Eight organizational functions for RAB were identified and the way they affect RAB performance was assessed:

- Establishing Goals
- Defining Tasks
- Acquiring Staff and Equipment
- Designing Procedures
- Allocating Tasks
- Communicating Goals and Procedures
- Monitoring Progress Toward Goals
- Directing Progress Toward Goals

RAB was found to have been organized to meet different production, service, and treatment goals depending on local requirements and pre-existing staffing, workspace, and organizational structures. Although RAB staff and equipment had been acquired and assigned tasks, only a few sites had formally defined those tasks or produced written procedures to guide staff in performing them. Communication linkages during RAB task performance were particularly error-prone. Quality assurance procedures designed to identify RAB errors and address their consequences were incomplete and often failed to pass the information needed by staff to verify that the RAB process had been performed correctly.

Conclusion

The analyses documented in this report supplied specific and detailed information that was used to elaborate the function and task analytic framework developed in Phase 1. The resulting enhanced framework was used to guide the collection and assessment of information necessary to identify factors contributing to human error in RAB systems. During Phase 6, the potential influence of human-system interfaces, procedures and practices, and training and organizational practices and policies were evaluated. Based on these evaluations, the most problematic RAB tasks were identified, and alternative approaches were proposed that featured innovations or modifications to one or more of these four major classes of RAB system components.

Acknowledgments

The authors thank the many members of the radiation therapy community who generously contributed their time, knowledge, and expertise to this project. The radiation oncologists, medical physicists, dosimetrists, radiation therapists, and department administrators consulted during this project were helpful and informative. The efforts of these individuals have resulted in increased understanding of human factors aspects of remote afterloading brachytherapy. This understanding can aid in making remote afterloading brachytherapy safer, more reliable, and more effective for both patients and the dedicated workers who serve them.

General Introduction

A human factors project on the use of nuclear by-product material to treat cancer using remotely operated afterloaders was undertaken by the Nuclear Regulatory Commission (NRC). The purpose of the project was to identify factors that contribute to human error in the system for remote afterloading brachytherapy (RAB).

Historically, RAB has evolved from manual brachytherapy by the reallocation of some tasks previously performed by humans to machines, computer software and specially designed hardware. Some of the more difficult and dangerous tasks, including that of placing the radioactive sources in the patient's body, have been automated so that most steps in the tasks can be performed without user intervention.

As with most such evolutionary systems, users have been required to fill in the gaps in the automation by performing all nonautomated tasks, by linking the output of each task into a treatment delivery system, and by continuing to monitor and verify their own performance and the performance of the system itself.

The NRC reviews reports and investigates events related to the medical use of radioactive materials (i.e., nuclear by-product materials, including brachytherapy sources). These reports and investigations indicate that human error has resulted in therapy misadministrations in which (1) radiation was delivered to a patient from a source other than the one intended, (2) radiation was delivered to the wrong patient, (3) radiation was delivered by a route of administration other than that intended, or (4) a radiation dose differing from the prescribed dose by more than 20% was given.

Volume 3 documents the findings from Phases 2-5 of the project, which involved detailed analyses of four major aspects of the RAB system linked to human error. Section A documents the results of the human-system interface analysis conducted during Phase 2; Section B reports the findings from the procedures and practices evaluation conducted during Phase 3; and Section C presents the results of the training and organizational analyses conducted during Phases 4 and 5, respectively.

Section A
Human-System Interfaces

CONTENTS

		Page
1	INTRODUCTION	7
1.1	Organization of Section A	7
1.2	Definition of Human-System Interfaces	7
1.3	Human-System Interfaces Identified in this Study	7
2	METHOD	9
2.1	Data Collection Procedures	9
2.2	Human Factors Engineering Standards and Guidelines	9
2.3	Analysis of Human-System Interfaces	9
3	RESULTS	15
3.1	Equipment	15
3.1.1	Simulation with Dummy Sources	15
3.1.2	Treatment Planning	17
3.1.3	High Dose Rate (HDR) RAB Systems	19
3.1.4	Low Dose Rate (LDR) RAB Systems	31
3.1.5	Auxiliary Equipment	43
3.2	Checklists and Worksheets	46
3.2.1	Document Format	47
3.2.2	Document Content	47
3.2.3	Format Evaluation	48
3.2.4	Content Evaluation	50
3.3	User Manuals	50
3.3.1	GammaMed Ili HDR Remote Afterloading System Operator's Manual	51
3.3.2	GammaMed 12i HDR Remote Afterloading System Operator's Manual	51
3.3.3	GammaMed GammaDot HDR Treatment Planning System Operator's Manual	52
3.3.4	Nucletron Brachytherapy Planning System User's Manual	52
3.3.5	Nucletron microSelectron-LDR/MDR User's Manual	53
3.3.6	Nucletron Selectron-LDR/MDR User's Manual	53
3.3.7	Nucletron microSelectron-HDR User's Manual	54
3.3.8	Summary of Findings	54
3.3.9	Site Visit Comments on User Manuals	54
3.4	Workspaces	54
3.4.1	Simulation	57
3.4.2	Treatment Planning	61
3.4.3	High Dose Rate RAB Treatment	66
3.4.4	Low Dose Rate RAB Treatment	75
4	DISCUSSION	77
4.1	Impact on RAB Tasks	77
4.1.1	HSI Influences on High Dose Rate RAB	77
4.1.2	HSI Influences on Low Dose Rate RAB	80
4.2	Implications for the RAB System	80
4.2.1	Simulation	80
4.2.2	Treatment Planning	81
4.2.3	High Dose Rate RAB Treatment	81
4.2.4	Low Dose Rate RAB Treatment	81
4.2.5	Quality Assurance	82
5	REFERENCES	83

LIST OF FIGURES

Figure		Page
1	Nucletron simulation reference frame.....	18
2	GammaMed simulation reference frame.....	18
3	Typical treatment planning system	19
4	microSelectron-HDR afterloader	20
5	Connecting source guide tube to the indexer ring.....	21
6	Source retraction cranks	22
7	microSelectron-HDR afterloader control unit.....	23
8	Emergency stop panel	25
9	GammaMed Ili afterloader	26
10	GammaMed 12i afterloader	29
11	GammaMed 12i afterloader control panel	29
12	GammaMed 12i afterloader control unit	30
13	GammaMed 12it afterloader and afterloader control unit.....	32
14	GammaMed 12it packed for transport	32
15	microSelectron-LDR source preparation station.....	33
16	microSelectron-LDR mobile storage container	34
17	microSelectron-LDR afterloader and afterloader control unit	35
18	microSelectron-LDR afterloader control panel.....	35
19	microSelectron-LDR remote control unit	36
20	microSelectron-LDR/Selectron-LDR nurse station display	38
21	Selectron-LDR afterloader and afterloader control unit	40
22	Selectron-LDR control panel	41
23	Selectron-LDR remote control unit.....	42
24	Source guide tube storage rack	45
25	Nucletron source position check ruler	46
26	GammaMed source step viewer	46
27	GammaMed kerma rate measuring device	47
28	microSelectron-LDR autoradiograph jig.....	48

LIST OF TABLES

Table	Page
1 RAB Functions and Tasks and Associated Interfaces	8
2 Format Evaluation of 72 Checklists and Worksheets	49
3 Content Evaluation of 27 Checklists and Worksheets Used in Patient Preparation, Treatment Planning, and Treatment Delivery	49
4 Content Evaluation of 22 Checklists and Worksheets Used in Quality Assurance	50
5 Summary of User Manual Findings	55
6 Human-System Interface Influences on High Dose Rate RAB Tasks	78
7 Human-System Interface Influences on Low Dose Rate RAB Tasks	79

1 Introduction

Section A, consisting of four parts, documents the work performed for Phase 2 of the project, in which the human-system interfaces (HSIs) used to perform RAB tasks were evaluated in relation to the RAB task performance requirements and human capabilities. The analytic efforts reported here are based on the RAB function and task analysis performed during Phase 1 (NUREG/CR-6125, Vol. 2) and on recognized human factors engineering standards and design guidelines. The HSI evaluation identified strengths and weaknesses of the interfaces to RAB equipment, software, documents, and workspaces. Volume 1 in this report series also contributed to this section by addressing human error and critical tasks in RAB and by proposing alternative approaches for improving performance on the critical tasks. Volume 1 established that numerous RAB problems and errors are attributable at least in part to inadequate HSIs.

1.1 Organization of Section A

The introduction presents an overview of the HSIs and describes their relationship to the function and task analysis. Following a description of the methods used to collect HSI data, the results of the HSI evaluations for RAB equipment, software, documents, and workspaces are summarized. The potential impact of these different types of interfaces on the performance of RAB tasks is then considered in the discussion section, which also notes the ways in which the interfaces influence other parts of the RAB system. A reference list of human factors standards and guidelines for HSIs is also provided.

1.2 Definition of Human-System Interfaces

Human-system interfaces comprise those components of a system with which a human operator interacts in order to accomplish various tasks, which taken together enable system objectives to be attained. In RAB, these components include equipment controls and displays, human-computer dialogs, documentation, and workspace layout. A well designed human-system interface will promote error-free human performance by making task performance requirements consistent with human cognitive, sensory, perceptual, psychomotor, and physical capabilities and limitations.

1.3 Human-System Interfaces Identified in this Study

The function and task analysis, performed during Phase 1 of this project, was used to identify the HSIs in RAB. The HSI analysis reported in this section identified additional interfaces by noting local variations from site to site,

particularly in workstation layout and in specific equipment.

An organizing structure for the HSIs was developed. Four classes of RAB interfaces were defined: equipment, software, documents, and workspaces. Subclasses were also defined in order to create functionally meaningful groupings for the HSI evaluations. These HSI classes and subclasses are listed below. Table 1 depicts the interfaces associated with specific RAB functions and tasks.

- equipment
 - simulation systems
 - treatment planning systems
 - high dose rate afterloader
 - high dose rate afterloader control unit
 - low dose rate afterloader
 - low dose rate afterloader control unit
 - auxiliary equipment
- software
 - treatment planning software
 - treatment control software
- documents¹
 - user manuals
 - local procedures
 - checklists
 - forms
- workspaces
 - simulation
 - treatment planning
 - high dose rate treatment
 - high dose rate treatment control
 - low dose rate treatment
 - low dose rate treatment control

The HSI classes and subclasses served not only to organize the RAB interfaces, but also to structure the analysis in terms of recognized human factors engineering standards and guidelines. The HSI classes were referenced to the most relevant technical literature to develop appropriate sets of evaluation attributes, which in turn could be used to assess the interfaces at the RAB sites visited.

¹ Only user manuals have been examined in this phase. Available HSI standards are less suitable for the shorter forms of documentation. Thus, locally developed procedures, checklists, and forms have been considered more extensively in Phases 3 and 4 of this project.

Table 1. RAB Functions and Tasks and Associated Interfaces

	Equipment	Software	Documents	Workspaces
Patient Preparation				
Patient scheduling, identification, and tracking	–	–	Form	Var
Patient instruction	–	–	Proc	Var
Life support monitoring	Aux	–	–	Var
Applicator placement and stabilization	Aux	–	Manl	Var
Patient transportation	Aux	–	–	Var
Treatment Planning				
Simulation with dummy sources	Sim	–	Proc	Sim
Target volume localization	Plan	Plan	Manl	Plan
Radiation prescription	–	–	–	Var
Dwell position localization	Plan	Plan	Manl	Plan
Dosimetry	Plan	Plan	Manl	Plan
Treatment plan selection and approval	–	–	Form	Var
Treatment Delivery				
Treatment set-up	Aft	–	Manl, Cklst	Tmt, Ctrl
Treatment plan entry	Ctrl	Ctrl	Manl	Ctrl
Verify treatment data prior to treatment	Ctrl	–	Proc	Ctrl
Treatment session monitoring	Ctrl	Ctrl	Manl	Ctrl
Treatment session control	Ctrl	Ctrl	Manl	Ctrl
Post-Treatment				
Source guide tube disconnection	Aux	–	–	Tmt
Applicator removal	Aux	–	–	Tmt, Var
Patient transportation	Aux	–	–	Var
Treatment verification	Ctrl	–	Proc, Form	Ctrl
Record-keeping	Ctrl	–	Form	Ctrl
Quality Assurance and Maintenance				
Source exchange	Aft, Ctrl	Ctrl	Proc, Cklst, Form	Tmt, Ctrl
Source calibration	Aft, Ctrl, Aux	Ctrl	Proc, Cklst, Form	Tmt, Ctrl
Equipment and software updates	All	Plan, Ctrl	–	Plan, Tmt, Ctrl
Troubleshooting	Plan, Ctrl	Plan, Ctrl	Manl	Plan, Ctrl
Routine quality assurance	Aft, Ctrl, Aux	Ctrl	Form, Cklst	Tmt, Ctrl
<hr/>				
<u>Equipment</u>	<u>Software</u>	<u>Documents</u>	<u>Workspaces</u>	
Auxiliary Equipment (Aux)	Treatment Planning (Plan)	Forms (Form)	Various Other (Var)	
Simulation (Sim)	Treatment Control (Ctrl)	Local Procedures (Proc)	Simulation (Sim)	
Treatment Planning (Plan)		User Manuals (Manl)	Treatment Planning (Plan)	
Afterloader (Aft)		Checklists (Cklst)	Treatment Room (Tmt)	
Afterloader Control Unit (Ctrl)			Treatment Control (Ctrl)	

2 Method

This section describes the methods used to conduct the RAB HSI analysis. Four broad classes of human interfaces with other elements of the RAB system (equipment, software, user manuals, and workspaces) were defined based on observations made during the Phase 1 function and task analysis. Eight RAB facilities were then visited in order to collect human factors engineering and ergonomic data on these interfaces. These data served as the basis for evaluating the HSIs in terms of human factors engineering standards and guidelines.

2.1 Data Collection Procedures

A representative sample of RAB facilities was selected to collect data in the first five phases of the study. Two distributors of RAB devices and twenty-three facilities using those devices were visited. Facilities were chosen by afterloader manufacturer, geographic region, dose rate, licensing authority, caseload, and RAB experience.

Project data were collected in three stages. During the first stage, the two distributors of RAB devices and a sample of seven facilities using those devices were visited to collect data for a function and task analysis of the RAB process (see NUREG/CR-6125, Vol. 2). During the second stage, another eight facilities were visited to identify and evaluate the HSIs and the procedures and practices used in the RAB process. During the third and final stage of data collection, an additional eight facilities were visited to determine the training and organizational support provided for RAB. Sections A, B, and C of this volume, respectively, report the results of the evaluations of RAB HSIs, RAB procedures and practices, and RAB training and organizational practices and policies.

The data collected at the visited sites included quantitative measurements, observations by the research analysts, and interview data from the RAB staff about HSI issues. In addition, engineering drawings and photographs were used to record certain details about the RAB interfaces.

An extensive set of forms, checklists, and interview questions was prepared before starting the site visits in order to assure that all of the data necessary to evaluate the RAB interfaces were collected. While some interfaces were common among several sites (e.g., remote afterloader equipment), other interfaces (e.g., workspace layouts) differed markedly between sites. As a result, flexibility was required by the research analysts in order to adapt the data collection protocol to the unique characteristics found at each RAB site.

RAB user manuals were obtained during site visits to the two RAB device distributors. Additionally, user manuals located at each of the 23 visit sites were evaluated. Any

differences between the manuals supplied by the distributors and those at the medical sites were noted. As new manuals or revisions to existing manuals became available, copies were requested from the distributors. In this way, the most recent version of each manual was available.

Seven current user manuals were evaluated according to human factors guidelines for instruction manual design and evaluation of medical device labeling. These guidelines were derived from over 100 monographs and journal articles from the literature of human factors, instructional technology, adult learning, reading, typography, and human-computer interaction. The most relevant are cited in the reference section. The following user manuals were assessed:

- GammaMed Ili HDR Remote Afterloading System Operator's Manual (Mick Radio Nuclear), circa 1984
- GammaMed 12i High Dose Rate Remote Afterloading System Operator's Manual, Draft Version, March 8, 1990
- GammaMed, GammaDot HDR Treatment Planning System Operator's Manual, September, 1991
- Nucletron Brachytherapy Planning System User's Manual, UPS V 9.11, June, 1989, and UPS V10.1, May, 1991
- Nucletron MicroSelectron LDR/MDR User's Manual, w/ Error codes V2.4, undated
- Nucletron Selectron LDR/MDR Users Manual, January, 1986
- Nucletron MicroSelectron HDR Remote Afterloading System User's Manual V3.20, undated

2.2 Human Factors Engineering Standards and Guidelines

Numerous relevant human factors engineering standards and guidelines were reviewed in detail in order to identify the types of data required to comprehensively evaluate the RAB HSIs. Human factors engineering evaluation criteria for RAB interfaces were derived from numerous technical sources (see reference section). These data requirements were then organized into field data collection forms for use during the site visits.

2.3 Analysis of Human-System Interfaces

Following the site visits, the HSI data were evaluated with respect to relevant human factors engineering standards and guidelines. The evaluations focused on the fundamental components of the interface (e.g., controls, displays,

Method

labeling, input modes, user manuals). These evaluations were very detailed, covering all aspects of the RAB interfaces. A structured checklist was used in conducting the evaluations to assure that all aspects were examined for each of the RAB interfaces. Significant deviations from recognized human factors engineering design guidelines were noted and summarized. These deviations included both exceptionally good and particularly weak (error-prone) interfaces.

The major interface components evaluated for each class of interface are listed below. Each of the interface components listed below was broken down further in order to define the specific attributes of each. For example, attributes of push button controls included positioning, separation, feedback, surface, size, displacement, resistance, and legends. The characteristics of these attributes were then compared against appropriate human factors engineering (HFE) standards and guidelines:

(1) equipment

(a) controls

- general issues—selection of type and number; prevention of accidental activation; direction of movement; coding of controls
- push buttons—positioning; separation; feedback; surface; size; displacement; resistance; legends
- rotary controls—direction of activation; shape coding; key-operated controls; continuous adjustment controls; selector controls
- miscellaneous switches—thumbwheels; slide switches; toggle switches; rocker switches; discrete push-pull controls; levers; displacement joysticks; track balls; grid and stylus devices; mouse; light pen; pedals; high-force controls; miniature controls; touch-screen controls; program card reader
- general purpose keyboards—type and arrangement; key size; key separation; key displacement; key resistance; feedback; slope; relevant keys
- computer-controlled function keys—functional grouping; labeling

(b) displays

- general issues—information displayed; display scale format; character readability; labeling on the display; scale marking; color coding

- meter displays—direction of movement; pointers; zone marking; orientation of markings; meter type
- indicator lights—special issues; non-legend indicators; legend indicators
- graphic recorders—general issues; recorder type
- printers—use and type; format; alarm messages; graphs and tables; printer operation; printer maintenance; output paper content; output paper quality; output paper accessibility
- counter displays—mechanical counters; electronic counters
- warning displays—alarm parameters; priority and sequence coding; auditory signal detectability; auditory coding; visual warning panels; visual alarm recognition and identification; visual alarm arrangement; visual alarm legends; visual alarm readability; silence warning and volume controls; reset warning controls; test warning controls; positioning and coding warning controls
- auditory displays—use and type; signal meaning; auditory coding; signal frequency; signal intensity; reliability
- CRT displays—reflected glare; screen luminance; luminance contrast; geometric distortion; screen resolution; refresh rate; screen controls; character size; character width-to-height ratio; stroke width-to-character height ratio; graphics resolution; character separation; character style

(c) panel layout—grouping logic; layout within groups; enhancement techniques; layout consistency; separation of controls; clusters of similar components

(d) control - display integration

- single control-display pairs—proximity; obscuration; association
- multiple controls - single display; single control - multiple displays; display selectors
- location and arrangement of control-display groups—functional integrity; sequence of use
- single panel arrangements—consistent practice; control/display packages

- controls and displays in separate planes—separated controls and displays; facing panels
- general movement relationships—rotary controls; linear controls; display response time lag
- control-display ratio—controls; displays; excess precision; feedback
- accessibility of displays and controls—physical; visual

(e) labeling

- general issues—appropriate usage; hierarchical scheme
- label location—placement; mounting; spatial orientation; visibility
- label content—kinds of information; word selection; consistency; symbols; brevity; similarity; functional groups; control position labeling; hazard labeling
- label lettering—readability; style
- temporary labels—use and type; administrative controls
- location aids—use and type; demarcation; color; mimics

(f) miscellaneous interfaces

- connectors—type; accessibility; separation; protection from damage; coding; labeling; alignment aids
- lines and cables—access; preformed cables; protective placement; storage
- covers, cases, and shields—purpose; general characteristics; shape; mounts; fasteners; labeling; case characteristics; cover characteristics
- handles—type and intended use; location; dimensions; design
- biomechanics—lifting; pushing and pulling; gripping and grasping

(2) software

(a) information display

- information coding—color codes; shape codes; blinking codes; brightness codes; alphanumeric codes
- information density—items displayed simultaneously; relevance to user tasks

- labeling—highlighting; wording; position; units
- format—prompts; tabular data; graphics; textual data; numeric data; alphanumeric data
- screen layout—organization; spacing; highlighting; consistency; balance
- audio displays—coding; density; consistency; format

(b) dialogue modes

- form filling—default values; feedback; screen layout; data entry procedures
- computer inquiry—Q/A dialogues; prompting; examples; location; organization
- menu selection—order of options; selection codes; menu layout; menu content; control sequencing
- command languages—command organization; command nomenclature; defaults; editor orientation; user control; command orientation; system lockout
- formal query languages—dialog; feedback; confirmation; consistency; ease of use

(c) user input device

- selection of input device—modes available; mode shifts; alternatives
- keyboard—special function keys; cursor control.
- direct pointing controls—touch panels; light pens; selection area
- continuous controls—trackballs; joysticks; mice; feedback
- graphics tablets—size; interfacing; usage
- voice analyzers—N/A (none were in use)

(d) feedback and error management

- feedback—status messages; error messages; printed output; system response time
- error recovery—immediate user correction; user correction procedures; metering and automatic error checks; automatic correction; stacked commands
- user control—recall; prompts; validation; system messages; help format
- help documentation—off-line documentation; on-line documentation

Method

- computer aids—debugging aids; decision aids; graphical input aids
- (e) security and disaster prevention
 - command cancellation—confirmation; undoes; changes; escapes
 - verification of ambiguous or destructive actions—prompts; confirmation; recovery
 - sequence control—error messages; recovery; sequencing
 - system failures—backup; recovery; alternatives
- (f) multiple users
 - message preparation and transmission—interference; identification
 - separating work areas—cursor identification; private and shared storage
 - communications record—message record; response record
- (3) user manuals
 - (a) highlighting—Highlighting is the use of typographic tools to draw attention to areas of the document that require emphasis. Six highlighting characteristics were used to evaluate RAB user manuals:
 - color
 - white space (margins and spacing)
 - borders
 - typographic cueing (typeface, caps, bold, italic, underline, reverse, etc.)
 - type size
 - (b) illustrations and graphics—Illustrations and graphics increase understanding of technical information. The characteristics of illustrations and graphics used to evaluate the RAB user manuals were
 - clarity of the graphic
 - relevance to the topic
 - proximity to applicable text
 - (c) information organization—A manual for using a device or piece of equipment should be logically sequenced, with explicit, procedural steps. Effective organization of information facilitates rapid and easy location and enhances the manual's role as a reference source. The characteristics of information organization applied to the RAB user manuals were:
 - table of contents, index, and headings
 - separators and dividers
 - information organization and flow
 - (d) language and readability—Effective technical communication requires the correct, succinct, and unambiguous use of language in order to convey ideas and instructions in an easily understood way. User manuals are intended to be used repeatedly as job aids; therefore, they must be written to inform quickly, clearly, and consistently. Readability is an indication of the difficulty readers may have with a set of written instructions. Good technical writing minimizes reading effort and makes a user manual intelligible to the intended readers. Although several measures have been devised to assess readability, the Flesch-Kincaid method was used in this study because of its suitability for technical writing. The characteristics of language and readability applied to RAB user manuals were
 - simple, short sentences
 - direct statements and active voice
 - abbreviations and acronyms
 - reading grade level (Flesch-Kincaid method)
 - (e) legibility—Legibility determines the ease with which material can be read under normal conditions. Legibility should facilitate reading RAB user manuals, especially by persons who are under time pressure to locate information while following complex processes. The characteristics of legibility applied to the RAB user manuals were
 - type size
 - font style
 - type spacing (proportional or fixed)
 - print contrast
 - print sharpness
 - line length and justification
 - (f) physical features—Physical features influence the ease of use and subjective appeal of user manuals. They also determine the range of options for presenting textual and graphical information. The only physical characteristics examined in respect to RAB user manuals were

size and binding. Binding was included because of the requirement for a manual to lay flat when fully opened, so that users may have both hands free to operate keyboards and equipment controls.

(4) workspaces

(a) workspace layout

- accessibility of equipment—presence of critical controls and displays; arrangement
- compatibility of staffing with layout—coverage; additional personnel
- furniture and equipment layout—viewing; communications; operator access; circulation patterns; operator maneuvering space; equipment to opposing surface; openings
- document organization and storage—accessibility; location aids; convenience of use; protection; dedicated sets of procedures
- spare parts, operating expendables, and tools—supply; accessibility; tools; storage space; coding; inventory
- personnel access—supervisor access; communications with supervisor; non-essential personnel access

(b) workstation ergonomics

- stand-up workstations—console height; control height; benchboard slope; control distance from the front edge of the console; display positioning; lateral spread of controls and displays; foot room
- sit-down workstations—console height; control height; benchboard slope; control distance from the front edge of the console; display positioning; lateral spread of controls and displays; leg and foot room; writing space on consoles
- sit-stand workstations—control and display positioning; chair height; knee room
- VDT workstations—viewing distance; viewing angle; screen location (seated); screen location (standing)
- desk/work areas—working space; chair positions; operator comfort; work surface height; work surface area; knee room
- chairs—mobility; backrests; armrests; cushioning; seat area; seat adjustability; footrests

- use of records, reference materials, and job performance aids—document placement during task performance; presence and location of job aids

(c) multi-unit control workspace—equipment arrangement; sharing of personnel; sharing of procedures; shared equipment

(d) emergency equipment

- operator protective equipment—types used; anthropometry; periodic checks; quantity; marking; expendables; accessibility; training; procedures
- fire, radiation, and rescue equipment—periodic checks; accessibility; training; procedures; automatic warning system
- emergency equipment storage—proper storage; access
- safety labels and placards—presence; placement
- general workspace hazards—alerting device; stairs; obstructions; illumination
- general equipment-related hazards—interlocks and alarms; access

(e) environment

- temperature, humidity, and ventilation—comfort zone; temperature differential; air quality; air velocity
- personal storage—storage locations; storage suitability
- ambiance and comfort—decor; restroom and eating facilities; staff lounge
- lighting—illumination levels; uniformity; supplemental light; task area luminance; shadowing; glare; reflectance; color; emergency lighting
- ambient noise—background noise; noise distractions; sound absorption

(f) communications systems

- telephone systems—instructions; handset; cord; mounting
- announcing systems—intelligibility; coverage; loudspeaker location; volume
- point-to-point intercom systems—intelligibility; controls
- video monitoring systems—placement; zoom, pan, and focus controls

Method

The analyses of each of the interface components listed above were then aggregated to form a summary evaluation of the strengths and weaknesses of each equipment, software, document, or workspace being examined in terms of task performance requirements and human capabilities and limitations.

3 Results

This section describes the results of the HSI evaluation. It is organized according to four major categories of RAB interfaces: equipment; checklists and worksheets; user manuals; and workspaces. Within each of these areas, results are presented in terms of specific RAB functions, tasks, or types of RAB systems.

3.1 Equipment

3.1.1 Simulation with Dummy Sources

Simulation with dummy sources involves visualizing the location of the applicator(s) relative to the target volume and the location of the sources relative to the applicator(s). The principal equipment used in treatment simulation consists of fluoroscopes and simulation reference frames.

3.1.1.1 Fluoroscope Control Panel

Most sites use fluoroscopy before simulation to aid in positioning the patient and positioning the applicators. Fluoroscopic images are displayed on a video monitor that has standard video controls (power, brightness, contrast, vertical hold, horizontal hold). Several types of fluoroscope controls panels were observed.

Many of the panels display settings and other quantitative information via colored, transilluminated 7-segment numerals against a dark background. The dimensions of these numerals meet human factor engineering (HFE) display standards for legibility. Older units use fixed scale, moving pointer meters to display quantitative information. The pointer and the scale markings were generally found to meet HFE standards. Colored indicator lights are commonly used to advise operators of system status.

Several types of controls are used on these panels. Binary actions (e.g., power, reset, operating modes) are controlled via pushbuttons (mechanical or membrane) or rocker switches. When operators need to select from several possible discrete settings (e.g., 60, 65, 70, ... kVp), knurled rotary selector knobs are often used. Arrays of pushbuttons are also used for this purpose, but arrays necessarily require much more panel space. Continuous control is provided to operators via continuous adjustment rotary controls. Some of these include knob skirts labeled with the range of possible values. As the knob is adjusted, the values displayed on the skirt would move relative to a fixed pointer on the panel. The dimensions of these controls meet design criteria specified by HFE standards.

The fluoroscope panels also include controls for remote operation, so that physicians or others could activate the unit without standing at the control panel. These remote controls include hand-held wands and foot pedals. The

hand-held wands (with a thumb-activated button) enable operators to move freely around the workspace. Foot pedals permit hands-free operation. Some foot pedals are enclosed in protective boxes to minimize accidental activation. The dimensions of these remote controls meet HFE standards.

Fluoroscope control panels are large enough to permit adequate spacing between individual controls and displays. As a result, minimal interference was noted, and panel layouts were considered to be acceptable. The labels for the controls and displays were generally found to be appropriate and legible.

3.1.1.2 Simulator Control Panel

Many types of simulators were observed in the sites visited, with corresponding differences in their user interfaces. In general, the interface design of the newer devices was found to be in better conformity with HFE guidelines than that of the older devices.

The older simulator control panels often used meters to display quantitative information. Most had fixed scales with moving pointers. Many of these meters met the HFE standards for such display devices. A few notable exceptions had sub-optimal pointer shapes (head obscured the numbers), fixed pointers with moving scales, non-linear scales (logarithmic), and unlabeled scale units. The newer simulator control panels relied more on 7-segment red light emitting diode (LED) numerals to display quantitative information. These displays conformed to HFE standards and were found to be legible. The simulator displays at a few sites used a color video display terminal (VDT), which provided flexibility for information display.

Similarly, the types of controls used on the panels varied considerably. For the most part, these controls were consistent with HFE standards. Toggle and rocker switches with a spring-return, 4-way rocker panels, and finger-operated joysticks were used and are among the types of controls that are considered effective for continuous adjustments (e.g., patient bed positioning). Entering quantitative values was done using continuous rotary controls, rotary selector knobs, button arrays, and numeric keypads. Labels were often placed on the rotary controls themselves rather than on the panel. While labeling the control is generally considered a good design practice, here it reduced label legibility, since the angle of the label depends on the position of the knob. When button arrays were used they were usually labeled on the buttons themselves and were often back-lit to provide an additional cue that a particular button had been selected. Button arrays are considered to have some HFE drawbacks concerning the amount of panel space that they require, possible operator confusion when linear arrays are lengthy, and the

Results

likelihood of damage to the button surface (e.g., broken membrane surfaces or rubbed-off labels).

Nearly all displays and controls were found to be labeled. Labels were generally visible and well positioned, although the lettering in many labels was too small for easy legibility. Older control panels tended to rely exclusively on words, while newer panels made use of icons and symbols in their labeling. Icons and symbols are considered to be an appropriate way to communicate certain control relationships quickly with minimal training. However, some foreign-made simulator control panels used icons whose meaning was not obvious to the staff and which did not convey the information needed to use the controls. In response to this deficiency, some staff had attached text labels to these devices to clarify the meaning of the icons.

The layout of these panels was generally considered to adhere to HFE standards and to be acceptable to the users in performing RAB simulation tasks. Several panels used demarcation and enhancement techniques to help define functional groups of controls. This made the devices easier to use by reducing the perceived complexity of the panel for the operator.

In addition to the simulator control panels discussed above, remote controls were used in the simulation room at some sites. Three types of simulator remote controls were observed: a wand controller, a retractable panel located under the patient's bed, and a free-standing control panel.

The wand controller was a hand-held control panel connected by a cable to the simulator. The model examined contained several high contrast (white on a black background) back-lit buttons and several toggle switches. The black toggle switches offered poor contrast against the black panel (especially in a dimly lit room). The numeric display associated with the wand was positioned on the adjacent wall of the simulation room. Large, yellow, 7-segment numerals provided excellent visibility against the black display background. Each of the display and control areas was labeled appropriately and unambiguously with large, high contrast lettering. The functional groups on the wand and on its associated display were separated by demarcation lines and header labels.

The retractable control panel provided a subset of the most necessary controls appearing on the full control panel, which was located in the simulation control workspace. It included the identical types of buttons, rocker switches, and indicator lights as were found on the full control panel, and these were arranged in approximately the same configuration on the two panels. Labels used the same symbols and icons as used on the full control panel. This entire panel could be slid out from under the patient's bed and then pushed back when not in use.

Other sites used a free-standing control panel, which was mounted on its own stand. Wheels permitted the stand to be moved around the simulation room. The model examined contained several large rocker switches, which conformed to HFE standards. Each of these switches (and the switch positions) was labeled on the panel using appropriate words, icons, or symbols. The panel was divided into four functional groups by demarcation lines. The rocker switches within each group were oriented appropriately for their function (e.g., vertical orientation for up-down, horizontal orientation for forward-back).

For the most part, user interfaces for simulator control panels were adequate for RAB simulation tasks and met HFE design standards. At many sites, simulation was such a common activity that several simulators purchased at different times were in use concurrently. The technologists, who operated the simulators, tended to rotate between workstations. A salient human factors issue involves the compatibility of the user interfaces across different simulators at a site. If a technologist usually uses one simulator and then switches to another, it is important that the two simulator interfaces be consistent. Otherwise, errors may occur because of different operating procedures, control-display relationships, and labeling schemes used by different simulators.

Most simulation errors resulting from difficulties in control panel interfaces would be obvious to the users (e.g., image too dense) and would slow down the production of acceptable images rather than producing errors that would directly effect other tasks. There were two notable exceptions. View angle was reported using different references on the panels of some machines so that a 30 degree angle recorded for one machine corresponded to a 60 degree angle on the other. Magnification measurements were also sometimes referenced differently on different machines. Confusion or inconsistency in either of these measurements could result in improper reconstruction of positions and distances when the simulation images are used in subsequent RAB tasks.

3.1.1.3 Simulation Reference Frames

The designs of the Plexiglas reference frames available from the principal manufacturers of RAB systems (Nucletron and GammaMed) for orthogonal/semi-orthogonal simulation were found to possess several strengths. Their small size and light weight made it easy for the simulation operator to maneuver the frames. The dimensions of the frames were adequate to accommodate both a 5th percentile female and a 95th percentile male¹

¹To approximate the range of body sizes possible in RAB equipment users, bideltoid (shoulder) breadth, interscye (chest breadth), and sitting hip breadth measures were used for a 5th percentile 40-year-old Japanese female (i.e., a subject from the 5% of the population with the smallest

The frames are designed so that x-ray films can be inserted and removed easily without disturbing the patient. The connectors that secure the frame onto the base are simple to operate and give a good positive indication when connected. The connectors are spring-loaded pins that lock through corresponding holes in the base. One style of connector pin is pulled out and then released when the frame is inserted into the proper slot in the base. Another style of connector pin is turned counterclockwise to release it and then turned clockwise to lock it to the base. Red markers, which are positioned near the connector pins, are concealed by the base when the frame is properly seated. This provides a visual aid so that simulation operators can determine if the frame is properly positioned.

The Nucletron simulation reference is designed so that the entire frame can be removed from the base (see Figure 1). The GammaMed design permits only one side of the frame to be released from the base; the other side of the frame is joined to the base by a pair of hinges (see Figure 2). The Nucletron design has the advantage that the entire frame could be removed, permitting easier patient movement and access. On the other hand, the removable frame could subsequently be mounted backwards onto the base. A frame mounted backwards would cause the markers etched on the frame, which are used to denote the patient's left and right sides, to be positioned incorrectly on the simulation x-ray films. However, a protection against this error has been designed into this frame. The connector pins on the two sides are different styles (pull-release; turn), and the pins and their corresponding holes are different diameters. It would not be possible for a user of the GammaMed design to misalign the frame with respect to its base, since they are never separated. Nevertheless, this design not only reduces patient access but also increases the chances that the frame will be damaged (e.g., broken hinges). Moreover, if not stored properly, either of these frame designs could be damaged.

3.1.2 Treatment Planning

Treatment planning is the function in which the dose distribution specified by the radiation prescription is transformed into positions within a three-dimensional coordinate system. Treatment planning is most often done using a computer with specialized software. The computer determines the dwell positions and dwell times for the source material, based on the radiation prescription. A hand-held digitizer is often used to input coordinate points to the planning program from x-ray images. Results are displayed graphically on a plotter and numerically on a printer.

Several treatment planning systems were examined in detail at the sites visited. The primary differences between these systems are in the computational algorithms and in the user dialogue. The equipment used in the treatment planning systems is a collection of "off-the-shelf" commercial products. These include at least one color VDT, a full keyboard, a computer central processor with disk drive(s), a light table, a digitizer, a color plotter, and a dot-matrix line printer. The Nucletron Planning System may also include a specialized unit to store the treatment plan on a program card. A typical treatment planning system is shown in Figure 3.

The primary display is a color VDT. Some treatment planning systems include two VDTs in order to present alphanumeric and graphic data separately. The screens examined were all found to meet HFE standards concerning screen luminance, luminance contrast, geometric distortion, resolution, refresh rate, screen controls, and character dimensions. In some treatment planning workspaces, substantial reflected glare was noted. In addition to the visual information display, the treatment planning system uses short tones (beeps) to acknowledge receipt of entered data, to prompt operator actions, and to alert operators to errors. The beeps are brief but loud enough to be heard in most office settings.

Full computer keyboards are used to interact with the treatment planning system. All keyboards use a QWERTY key arrangement, with additional computer-controlled function keys. The characteristics of the keys on the keyboard conform to HFE standards. The function keys are grouped together above the QWERTY keyboard, are well labeled, and employ suitable color and spatial coding.

The computer unit itself is a standard IBM PC-compatible computer. Operator controls include a key switch to limit access, a toggle switch to turn the unit on/off, and flexible disk drive(s). The program card used with the Nucletron Planning System is often mounted on or near the unit. When arranged in the "tower" configuration, the unit is typically located on the floor beneath the work surface. In this arrangement, the computer tower can restrict operator leg room or access to other equipment. The alternative arrangement places the computer unit horizontally on the work surface. The VDT is generally mounted on top of it. Even though this arrangement adds more equipment to the work surface, it provides unrestricted leg room and may improve the operator's viewing angle of the VDT screen.

The light table and digitizer define an important work area in the treatment planning system. The operator uses this equipment to enter RAB treatment positions, critical anatomical points, and other information critical to treatment planning. The light table, which is a fluorescent back-lit translucent surface, must be large enough to accommodate two x-ray films (A-P, and lateral) concurrently. The illumination level from the light tables

average measurements) and for a 95th percentile 40-year-old American male (i.e., a subject from the 5% of the population with the largest average measurements) (NASA-STD-3000).

Figure 1. Nucletron simulation reference frame

Source: Nucletron Planning System brochure.

Figure 2. GammaMed simulation reference frame

Source: GammaMed Applicators and Accessories brochure.

Figure 3. Typical treatment planning system

Source: microSelectron LDR/MDR ^{192}Ir ^{137}Cs brochure.

was adequate for good visibility of critical structures in the x-ray films. The digitizers use different designs, but all include a magnifying lens with crosshairs and control button(s). It is particularly important that the crosshairs be mounted on the bottom of the magnifying lens so as to minimize parallax.

The color plotter is used to make a hard copy of the isodose curves around the treatment positions. The dot-matrix line printer is used to print a record of the quantitative parameters of the treatment plan. Both of these devices are used at the end of the treatment planning function, so minimal operator interaction is required. Consequently, they are often located peripherally to the primary treatment planning work area (i.e., the light table, computer screen, and keyboard). The controls used to operate the plotter and printer are simple and easy to use. Similarly, maintenance and resupply is simple and generally requires no special tools or disassembly. Even if printer/plotter problems occur, they can be quickly corrected, and the plan can be reprinted. The quality of the printer/plotter output is good and easily understood.

Considering that the equipment in the treatment planning systems use commercial, off-the-shelf products, it is not

surprising that these component products meet HFE standards. It is noteworthy, however, that the HSIs of the components are compatible. Often, systems that have been assembled from independent products introduce serious user interface incompatibilities, even though the user interface for each of the component products is adequate. The more significant HSI issues for treatment planning systems are associated with their software interface (user dialogue), with the instructions for their use provided in the user manuals, and with the way their components are arranged in the workspace. Each of these topics is considered in subsequent sections.

3.1.3 High Dose Rate (HDR) RAB Systems

High dose rate (HDR) RAB uses a high activity source of iridium-192 (^{192}Ir) to deliver a therapeutic dose of ionizing radiation in a short treatment session (usually 5–10 minutes). This short treatment time permits many HDR treatments to be conducted on an outpatient basis. To enhance the biological effectiveness and patient tolerance of an HDR treatment, patients often receive those treatments in 2–3 fractions separated by a few days. Four HDR RAB systems were examined: the microSelectron-

Figure 4. microSelectron-HDR afterloader

Source: microSelectron HDR ^{192}Ir brochure.

HDR, the GammaMed Ili, the GammaMed 12i, and the GammaMed 12it.

3.1.3.1 microSelectron-HDR System

Afterloader

The microSelectron-HDR afterloader is located in the treatment room. It contains the source. The source guide tubes are attached to it in order to transport the source into the applicators, which have been implanted in the patient. The device is simple, with few user interfaces (see Figure 4). The principal parts of the afterloader with which users interact are (a) the indexer ring, (b) the emergency stop button and system status indicator panel, (c) the cranks for manual withdrawal of the source, and (d) the handle for moving the unit, including the switch for raising and lowering the source head.

The user interfaces to the afterloader were found to possess several strengths. The emergency stop button is located on a small panel with system status indicator lights directly in

front of the handle that is used to move the afterloader. This panel is on the opposite side of the source head from the indexer ring. The emergency stop button is considered to have a good interface design, promoting rapid and accurate use when required. It is identical in appearance to the button on the emergency stop panel, located elsewhere in the treatment room and in the treatment control workspace.

Since these buttons serve an identical function, it is very appropriate for them to look the same, minimizing operator confusion and training requirements. The button is large, red, and labeled "STOP" directly on the button. These design features capitalize on highly over-learned expectations by users, encouraging rapid and accurate response even with minimal training and under stressful conditions. Other dimensions of the button (e.g., displacement, resistance) meet HFE standards. The protective collar around the button and its placement make accidental activation unlikely. The button is found to be visually and physically accessible by short as well as tall persons when the source head was extended to its maximum height.

Figure 5. Connecting source guide tube to the indexer ring

Source: microSelectron HDR ¹⁹²Ir brochure.

Two separate fingertip cranks are provided for source and test cable retraction during source exchange and during emergency conditions. These cranks are appropriate for this task, and their dimensions and separation are adequate with respect to established HFE standards. The fingertip cranks turn in opposite directions for retraction. The cranks are inside the unit, protected by a cover. The cover is well designed for simple, one-handed operation. A spring-loaded fastener enables push-to-open and push-to-close operation, which is a natural interface appropriate for emergency use. The cover swings out of the way (and remains secured) to provide sufficient clearance for hands and tools.

A fixed, T-bar type handle on the carriage is used to pull the unit. The handle is well located, and its dimensions meet HFE standards. A three-position toggle switch is located on the post below the handle. This switch is used to raise and lower the source head. Despite its poor visual contrast (black switch against black handle) and no labeling, the switch is well designed with respect to HFE standards. The force required to move the unit on linoleum flooring is well within the capacity of operators. Foot operated brakes on the back wheels are used to secure the carriage. These brakes are accessible and easy to engage/release.

The indexer ring is a circular arrangement of female connector receptacles into which the source guide tubes would be inserted (see Figure 5). Each of the receptacles is labeled with its channel number along its outside radial. The labeling is of adequate size (visible to 27 inches) and contrast. After connecting the source guide tubes, the indexer ring requires a small (approximately 10°) clockwise turn to lock it before treatment can begin. Specially coded quick-release connectors are used on the

source guide tubes so that they could not be inserted into the wrong channel. Moreover, internal checks by the system alert the operator if the indexer ring is not locked. These interface design features help assure that accurate connections are made and reduce operator training requirements.

HSI weaknesses of the microSelectron-HDR afterloader concern the emergency source retraction crank, cabling, and the status indicator lights. The emergency source retraction crank is gold colored and is located next to a similar black crank used during source exchanges (see Figure 6). While the black crank would be rotated counter clockwise to withdraw a source, the gold (emergency) crank must be rotated clockwise to withdraw the source. Even though arrows are printed on the cranks to indicate the direction that they should be rotated, this design could promote operator confusion. Not only is the direction of rotation for the two cranks inconsistent, but also the emergency crank's direction of rotation may be incompatible with operator tendencies. Clockwise rotation is generally associated with advancing or increasing something; so, withdrawing the source would be more commonly associated with counter-clockwise rotation².

²It should be noted that this movement relationship stereotype is not universally held. One's expectation about the direction of rotation to retract the source may result from different associations or "mental models." Using a screw as a model, counter clockwise rotation would be expected to retract the source. On the other hand, operators may expect clockwise rotation to retract the source if their association is with a valve, which is turned clockwise to tighten or to close.

Figure 6. Source retraction cranks

Source: microSelectron HDR ^{192}Ir brochure.

Moreover, while other emergency interfaces are color coded as red, gold is used to identify the emergency crank. Gold not only has no general association with emergency conditions but also differs from the emergency color code (red) used in other parts of the microSelectron-HDR system. Electrical cabling from the unit could be a problem in the workspace. The preformed cables are located to provide operators with good physical and visual access to them, but they typically remain scattered on the floor. This could present a tripping hazard for patients or staff or could restrict access to other adjacent equipment.

Yellow and green lights are located on the emergency stop panel to indicate system status. Color coding conventions are consistent with other parts of the system. Yellow is used to indicate that the source is extended and treatment is in progress; green is used to indicate that the source is stored in the safe. These lights are arranged vertically with the green "safe" light above the yellow "treatment" light. This arrangement is opposite from that used with the low dose RAB systems (Selectron-LDR and microSelectron-LDR)

and from accepted HFE standards (where "on" or "active" is in the upper position). Moreover, the labels for these indicator lights use lower case letters and are too small to be read easily (visible to approximately 13.5 inches).

The analysis also suggested that the relatively small wheel base (40 centimeters) could make the unit unstable when the source head is extended to its maximum height. Attempts to move the unit with the source head extended could possibly cause it to fall over, and one such case was reported to our site visitors.

Afterloader Control Unit

The microSelectron-HDR afterloader control unit is a small, custom designed device (see Figure 7) used to program and to control the afterloader. It contains a liquid crystal display (LCD), a thermal dot-matrix printer, indicator lights, buttons, key switches, and a program card reader. Several strengths and weaknesses of the user interface of this device were noted.

Figure 7. microSelectron-HDR afterloader control unit

Source: microSelectron HDR ^{192}Ir brochure.

The LCD screen is the primary information display. It is positioned in the upper portion of the panel and presents characters and graphics as dark dots on a green background. The screen provides adequate visibility under normal illumination, although the contrast between the characters and the background is low. Screen glare from overhead lighting was found under many viewing conditions, and visibility is impaired by off-angle viewing (viewing angle is limited to less than 55° from the midline). Character size, style, and dimensions were found to meet HFE standards. The content of the information displayed on the screen was easy to understand. In particular, a graphic analog of the treatment channel is displayed, showing an "X" for treated locations, an arrow for the source's current location, and a "*" for locations yet to be treated. Most of the alphanumeric information is also presented in an easily understood format. However, the date is displayed in an unconventional YY MM DD format. Time is displayed in a 24-hour format, although hours, minutes, and seconds have suffixes of H, M, and S. Some problems in character spacing reduce readability.

The thermal dot-matrix printer is integral to the control panel. The printer provides a paper record of some of the treatment information displayed on the LCD screen. It also produces a sequential record of all events and alarms during treatment set-up and treatment. The black dot-matrix characters printed on white pressure-sensitive paper were of consistent contrast and were easily read by the users.

The paper output was typically stored with patient records. The pressure sensitivity of the paper was a hindrance to archival storage since it allowed printed characters to be obscured or modified by subsequent manipulation of the paper. Most of the information printed out was in directly usable format with unambiguous units. System errors were displayed in code numbers that required interpretation by reference to the user's manual, however. The format used for presenting tabular data met HSI standards. Printer operation was relatively silent. While no paper take-up device was provided, the paper curled back away from the panel and would rarely exceed 12–18 inches. The most recently printed line could not be read; however, a paper advance control button was provided. Reloading paper was simple and required no special tools or disassembly.

Indicator lights are used throughout the afterloader control unit panel to the left of buttons to inform the operator of allowable actions at each point in the programming and treatment sequences. This was considered to be an excellent design feature. Not only does it prompt operators by showing them the actions that are allowable but it also locks-out inappropriate actions. An automatic self-test occurs during start-up. The lights are LEDs below a non-glare cover, so they do not incorrectly appear to be lit under high ambient illumination. All of these indicator lights are red and are easily detected against the panel under normal viewing conditions. Three other lights, not associated with buttons, are used to indicate system status during treatment.

Results

viewing conditions. Three other lights, not associated with buttons, are used to indicate system status during treatment. These lights are the same size and type as the red button prompts. A yellow LED is used to indicate that treatment is in progress, and an adjacent green LED indicates that the source has been withdrawn into the safe. The association of yellow with "treatment" and green with "safe" is consistent with other displays in the microSelectron-HDR system and with general conventions in the nuclear materials community. The third status indicator light is red and alerts the operator to a system alarm. The predominant use of red lights on the panel makes it very difficult for operators to detect the "alarm" indicator light rapidly. Moreover, the placement of the "alarm" indicator light in the lower right of the panel (away from the section of the panel used during treatment) further reduces its detectability.

Fortunately, redundant auditory signals are provided. Pure tones are used to alert operators to changes in system status. These tones are distinctive from other sounds in the workplace and are easily detected (approx. 1000 Hz at 78 dB). A long beep at system start-up provides an automatic test that the auditory signals are working. The tones are associated with system states by pulse and duration coding; longer and more numerous tones indicate more serious or significant alerts. A repeating five-tone sequence is used to indicate an alarm. Staff were observed to use these auditory signals to identify the presence of alerts during treatment although their ability to differentiate between the different auditory codes was not tested. No training program to teach or refresh recall of auditory codes was found at any site. Besides the red "alarm" LED, visual indications of system alarms are presented on the LCD screen and on the printer.

The buttons on the afterloader control unit panel are used to enter the treatment plan and to initiate/interrupt treatment. They were of adequate size and provide good feedback, but, characteristic of micro switches, they had minimal displacement, resistance, and separation. All of the buttons were square, and all but two of the buttons were black, providing poor contrast against the black panel. In particular, the "interrupt" button was the same black color as the others, and did not stand out unambiguously so that it could be located easily during treatment emergencies.

For the most part, the buttons were positioned logically in a left-to-right sequence of operation. Button clusters tended to represent the choices available at different points in the sequence. A few weaknesses were found. The arrow buttons (→ and ←) used for cursor control were positioned vertically rather than horizontally. Another weakness in button layout concerns the buttons and lights in the treatment control grouping. The location of the "treatment" and "safe" lights, which provide feedback after pushing the "start" and "interrupt" buttons, to the left and below those buttons breaks the expected left-to-right sequence. Finally,

the "cancel" button was used for two different functions – (a) eliminating the last programmed setting and (b) resetting the system following an alarm.

Although all of the buttons were labeled in accordance with most HFE guidelines, the labels were very small and were printed in lower case letters, restricting their viewing distance to less than 14 inches. The high contrast of the labels against the panel improved their visibility, however. Labels were in good proximity to the buttons and were positioned to the left of the button. While this placement departs somewhat from HFE standards and may be harder to interface with for left-handed users, it was considered acceptable given the strong left-to-right arrangement of the panel (even left-handed users customarily read English from left to right). To some extent, the arrangement of labels on the panel helps guide the operator in the proper button sequence. Dashed lines from the key switch positions in the lower left lead the operator to either the programming sequence or to the start treatment button. Many of the buttons in the programming sequence, which are labeled to their left, also have icons of a keypad to their right. This icon placement is intended to prompt operators to use the keypad after pressing the button.

A 12-button keypad is provided for numeric data entry during the programming sequence. The keys are arranged in a 3x4 matrix using a calculator format. The lower left key is used as a "return" or "enter" key; the lower right key is used for entering a decimal point. All keys are black with white labels, providing excellent visibility. The design of the enter key, however, was considered likely to promote entry errors due to its placement and similar appearance to the other keys.

The control unit panel is grouped into programming and treatment areas. Moreover, the hierarchical steps in the programming sequence have also been grouped together. The functional groups are arranged from left to right. Spatial separation has been used effectively to define these functional groups.

Two separate key switches are used to change operating states/modes. This is an appropriate use for key switches, particularly when access needs to be restricted. The keys that operate them are difficult to discriminate and are not interchangeable. The keys can only be removed from the key switches when in the "off" or "normal" modes. Key switch dimensions and movement relationships were found to meet HFE standards.

The program card reader enables operators to transfer the treatment plan from the treatment planning computer to the afterloader control unit. This capability increases both the speed and accuracy of treatment plan entry into the afterloader control unit relative to manual procedures. The

program card can only be inserted one way into the slot of the card reader, which is located on the front-left edge of the control unit panel. The label on the card faces toward the operator when the card is inserted into the slot; however, this slot is difficult for operators to see from their normal working position. The card release control surrounds the slot and must be pressed from opposite sides simultaneously in order to eject the card from the slot, requiring an awkward hand movement.

Emergency Stop

This small panel is used to cause a backup motor to retract the source in case the stepper motor has failed to fully retract the source. Since the motor controlled by the emergency switch retracts the source more rapidly than the stepper motor controlled by the "Interrupt" switch on the afterloader control panel, this emergency panel might also be used to abort treatment in emergencies in which staff were present in or entering a treatment room containing an exposed source. Rapid access to the panel is essential in such emergencies, and to facilitate such access, provision has been made for the installation of multiple emergency stop switches at different locations in the treatment and treatment control workspaces. All of the emergency switches for a single afterloader were controlled from a single master panel which contained a single pushbutton, two status indicator lights labeled "armed" and "activated," and a key switch to reset the emergency stop circuitry (see Figure 8). Once activated, the emergency stop circuitry must be reset from the key switch on the master panel before treatment can continue. Additional emergency stop switches were controlled from slave panels which contained only the pushbutton and a single "activated" indicator light. Emergency stop panels were found at various locations in the treatment control workspaces and in the treatment rooms.

Figure 8. Emergency stop panel

Several strengths were noted in the user interface for this device. The panel layout was found to be simple and consistent with HFE standards. The size and placement of the primary control, the "STOP" button, are appropriate for its function. Its wall mounting and protective ring minimized accidental activation. Moreover, the appearance of the "STOP" button is consistent throughout other panels in the microSelectron-HDR system (i.e., the "STOP" button on the afterloader). The visibility of the primary labels, "EMERGENCY" (visible to 34 inches) and "STOP" (visible to 47 inches), is excellent. Color coding is used very well for both the status indicator lights and the "STOP" button. The intensity of the red and green status indicator lights is adequate to be detected even in brightly lit workspaces. The use of exclusive positive indicators of system status (so that "off" does not mean "normal") was also considered a strength of the interface design. These interface design strengths all promote rapid and accurate information transmission, correct control actions, and minimal operator training requirements.

The emergency stop panel was considered to have a few user interface weaknesses, however. Labeling of the status indicator lights is ambiguous. The terms "armed" and "activated" are unique to this panel and could easily be confused; "ready" and "stopped" may be more suitable labels. The visibility of these labels is also problematic; they are small (visible to 14 inches) and in lower case font. The two positions for the key switch used for resetting the panel are not labeled. While relatively minor, these interface weaknesses could cause confusion about system status, leading to a delayed operator response. The location of the panels was not consistent at the sites and varied in placement in relation to the source of information that might be used by the staff when deciding whether to press the emergency stop button. There was a master panel near the afterloader control unit and a slave switch on the afterloader at all sites. At some sites the master stop panel was within reach of the TV monitors used for monitoring treatments and slave panels were placed in the treatment room near the radiation detectors and near the treatment room door. At others, the panels were hidden behind equipment or in locations that were inaccessible to staff during treatment. The protruding shielded stop button on slave panels was occasionally used by staff as a hook to hang clothing or other objects that obscured the panel at some sites.

3.1.3.2 GammaMed Ili System

Afterloader

The GammaMed Ili afterloader is shown in Figure 9. The height of the source head is adjustable, and the unit is relatively large, so that it is stable even with the source

Figure 9. GammaMed Ili afterloader

head fully raised. The total length of the unit, however, increases as the head is raised (which could limit accessibility in small treatment rooms). The source head is raised/lowered by a rocker switch located on the side of the unit near the source head. The size and other relevant HFE dimensions of the rocker switch are acceptable. The switch is labeled on the panel beneath it. While the size and contrast of the label lettering is acceptable, lower case letters are used and the rocker switch positions are not labeled.

To the left of this rocker switch is a large, red emergency stop button. The button is positioned to provide good operator access, and it is labeled effectively, although the label is below the button and uses lower case lettering. To the left of the emergency stop button is a radiation warning light. This large yellow light (with a diffusing lens) is easily visible from across the room. It also is labeled below the light using lower case letters.

Behind the source head is a storage cabinet. The cover for this cabinet lifts off via two hand grips. The cabinet contains plugs and fuses but is also used to store the patient grounding strap and other miscellaneous supplies. If the cabinet is full, access to the plugs and fuses in it could become difficult. At many sites, the hand cranks on metal shafts (approx. 24 inches) that are used to retract the source manually are stored in this cabinet. Two different cranks (silver and black) are provided: one for source exchanges and another for emergency operations. The shafts of these cranks get inserted into the source head on the opposite side from the indexer. To retract the source, the cranks are rotated clockwise, as indicated by the arrow label above the crank shaft. The dimensions of these hand cranks meet HFE design standards.

The indexer is located on the other side of the source head and contains 12 receptacles into which the source guide tubes can be connected. The receptacles are arranged in sequence clockwise around a semi-circle beginning in the upper right. Despite the somewhat unconventional starting position, the clockwise arrangement of increasing channel numbers conforms to user expectations. The receptacles are labeled with their channel number on the inside radial. This permits the labels to be read even when the source guide tubes are inserted (and hang down). Source guide tube connectors interlock with the indexer to prevent the unit from operating unless the tube is fully seated. A knurled ring on the source guide tube connectors can be turned towards the indexer to prevent the tube from being removed accidentally.

The unit carriage is large enough to enable an emergency storage container (lead pig) to be placed on it for rapid access. The unit is mounted on large wheels that permit it to be moved easily around the treatment room. A two-handed

bar handle runs the width of the unit. Its dimensions and clearance meet HFE standards. The height of the handle is appropriate for use by both a 5th percentile female and a 95th percentile male. The force required to move the unit is within the capacity of a 5th percentile female. An L-shaped lever with a large knob on the end is used to secure the unit from moving. While the design of this brake makes its operation obvious, a label with an arrow further clarifies its usage.

Some labels, particularly in the maintenance areas, were in German. For example, the warning, "Vor Öffnen Netzstecker ziehen!," is provided. Fortunately in this case, it was accompanied by an icon that helps operators understand that they need to unplug the unit before opening that panel.

Afterloader Control Unit

The GammaMed Ili afterloader control unit is located in the treatment control workspace, outside of the treatment room. It consists of a VDT and a custom control panel. Cabling plugs into connectors in the back of the control panel. The connectors are well separated (providing good accessibility), are well labeled, and use different types of plugs (minimizing the chances of improper connections).

The primary display interface is a VDT mounted on top of the control panel. This configuration assumes that operators will use it from a seated position. The human factors engineering characteristics of the VDT meet recognized design standards. As a result, the alphanumeric characters presented on the screen are readily visible under a wide range of viewing conditions. A paper tape printer is provided on the left side of the control panel. The printer maintains a sequential record of all events and alarms occurring before and during treatment. The characters are printed with a dot-matrix impact printer using blue or black ribbon on white paper. The characters were easily read when the printer ribbon was new but lost contrast as the ribbon was reused. A blue printer ribbon in use at one site was found to produce characters of particularly low contrast. The use of uncommon mnemonics (based on German spellings) and the printout of the total time that had elapsed since the start of treatment at each treatment position rather than the source dwell time at that position was confusing to some users. A paper advance button is provided on the panel. Remaining paper supply can be seen through a semi-transparent plastic cover. Paper resupply is simple and requires no special tools or disassembly.

A key switch in the lower right of the panel is used to limit access to turning the unit on. The key switch has two positions: off and on. Turning the unit on requires a clockwise 90° rotation, as recommended by HFE standards.

Results

The key switch positions, however, are labeled in German and English (e.g., "AUS/OFF").

A digital counter is used on the right side of the panel to display treatment time. This counter uses six 7-segment LED numerals. The size and dimensions of these numerals is acceptable with respect to human factors engineering standards. The counter is labeled adequately with "Sec."

A calculator format numeric keypad is provided toward the center of the panel for data entry. Ten keys are arranged in a 3x3+1 configuration, with a wide zero key. The keys are black with white numerals on them. The key surface is indented, and their size and other dimensions meet HFE standards. The keypad is separated spatially from other buttons on the control panel.

Most of the control panel is comprised of arrays of back-lit legend lights and buttons. All are the same size and general appearance. The HFE dimensions of the legend buttons meet accepted standards. The legend buttons and lights are labeled on their surfaces. The black lettering provides good contrast, but the letters are small and lower case. Nevertheless, label visibility is adequate for viewing distances of 16–20 inches, particularly because active buttons and lights are back-lit. Most of the legend lights and buttons are white (26 of 30). This is appropriate and promotes visibility. A few, especially important ones are colored. Legend lights indicating that the source is in (out) of the safe container are colored green (red). The emergency stop legend button, which terminates treatment and causes a backup motor to return the source to the safe more rapidly than possible with the stepper motor used in treatment, is appropriately colored red. However, the "start" button is green and the "interrupt" button is white. While green is the color that people normally associate with "start," this color coding may introduce operator confusion since it logically conflicts with the use of the green legend light on the same panel to indicate that the source is in the safe container. The "interrupt" button is used to stop treatment and return the source to the safe using the stepper motor. This feature allows treatment to be continued from the point at which it was interrupted after the conditions necessitating the interrupt have been resolved. The potential problem with using white for this "interrupt" button is that this does not help it to stand out against the overall panel. Operators should be able to locate the "interrupt" button rapidly upon glancing at the panel. For the most part, the wording of the labels is adequate. In some cases, however, improvements could be made.

3.1.3.3 GammaMed 12i System

Afterloader

The GammaMed 12i afterloader, shown in Figure 10, is similar to the GammaMed Iii, except that it accommodates up to 24 channels. This newer model is also somewhat smaller and uses a simpler user interface. The unit can be moved easily via its wheels and two-handed bar handle. Dimensions of the handle meet HFE standards. Handle height is appropriate for a full range of operators (5th percentile female and 95th percentile male). The unit maintains the same footprint regardless of the position of the source head, which moves straight up and down. The source head can also be rotated 270° to permit optimal positioning with respect to the patient. The source cable retraction crank is fixed in position on top of the treatment head, providing easy access and unambiguous use. The indexer and source guide tube connectors are identical to the GammaMed Iii, except that there are 24 receptacles.

The primary operator interface for the unit is on one of the control panels shown in Figure 11. These panels are located on both sides of the unit near the source head. The panel contains a large red emergency stop button, a large radiation warning light, and several foil-contact buttons. The size, placement, and contrast of the emergency stop button and the radiation warning light make them visible from across the room on one of the panels no matter which side of the unit is in view. Foil-contact buttons are used to raise and lower the source head and the electromagnetic brake on the unit. These sets of buttons are arranged vertically, which provides an appropriate spatial code. The buttons are large enough for easy operation, and they are well labeled with both words and arrows. Since this type of button provides no travel or displacement when pressed, it is important to provide some alternate form of feedback to the operator. Small LEDs in the corner of these buttons are provided for this purpose. Note that by placing these lights in the corners, they can still be seen while the button is being pressed. Additional status indicator lights inform operators whether the brake is free or locked and whether the head is up or down.

Afterloader Control Unit

The GammaMed 12i afterloader control unit, shown in Figure 12, looks much like a standard personal computer. It includes a VDT as the primary display, an extended keyboard, and a special control panel. The VDT is a standard commercial color screen. The characteristics of the screen (luminance, geometric distortion, resolution, refresh rate, and controls) meet HFE design standards. Similarly, the dimensions of the characters displayed (size, width-to-height ratio, stroke-width-to-character-height ratio,

Figure 10. GammaMed 12i afterloader

Source: GammaMed12i brochure.

Figure 11. GammaMed 12i afterloader control panel

Source: GammaMed12i brochure.

Figure 12. GammaMed 12i afterloader control unit

Source: GammaMed12i brochure.

separation, and style) are acceptable. By mounting the VDT on top of the computer unit, the operator's viewing angle is improved. This configuration is most suitable for seated operation. Use of a VDT permits considerable flexibility in how the information is displayed to operators.

The keyboard is the primary means for operators to interact with the system. The keyboard includes a standard QWERTY set of keys as well as function keys, cursor control keys, and a numeric keypad. Two shades of gray are used to distinguish between functionally different types of keys. The dimensions of the keys meet HFE standards. The keyboard is sloped for comfortable use, and it is not attached to the computer console, so it can be moved to the most comfortable working position for the operator.

The special control panel is mounted on the front of the computer unit. This panel resembles the one on the afterloader, and uses brightly colored foil-contact buttons and indicator lights. The buttons are large and well labeled.

They are color coded and provide colored status indicator lights. The indicator lights are important because this type of button does not provide operators with feedback by moving when pressed. The buttons and indicator lights are arranged well on the panel so that functionally related ones are collocated. Functionally related groups are separated spatially. Two key switches are provided on the right side of the panel to control the operating mode of the system (normal or special) and the power to the system (off or on). Both key switches are well labeled; indicator lights confirm the system status dictated by the key position. Activation requires a clockwise 90° rotation, as recommended by HFE standards.

It should be noted that the GammaMed 12i afterloader control unit is also used for treatment planning with the GammaDot program. By adding a light table, digitizer, printer, and plotter, an entire treatment planning workstation can be created. The main benefit of this is that the transfer of the treatment plan to the control unit is

automatic, saving time and removing an opportunity for user error. A drawback to this integrated configuration involves the potential impact on other types of treatment that share the treatment control workspace. The amount of apparatus that would necessarily be required and the unavailability of the area during treatment planning may interfere with other types of treatment (i.e., teletherapy). The integrated GammaMed 12i configuration would seem to be most suitable in sites with a dedicated RAB treatment area.

3.1.3.4 GammaMed 12it System

The GammaMed 12it is a compact and transportable version of the GammaMed 12i. It is particularly useful when RAB must be performed at different sites or intraoperatively. The system consists of the afterloader, carriage, and afterloader control unit, as shown in Figure 13. These components can be stacked up and packed for transport (see Figure 14). The afterloader has the large red emergency stop button mounted on top next to the fixed emergency retraction crank. The 24-channel indexer is located at one end of the unit. The indexer is the same as used on the GammaMed 12i, including the safety interlocks to prevent inappropriate or incomplete connection of the source guide tubes. A two-handed bar handle is located on each end of the unit to enable it to be lifted if necessary.

The carriage on which the afterloader rests is stable, and its wheels permit it to be moved easily. Two-handed bar handles are located on each end of the carriage. A hand-operated lever is used to set the brake when the unit is properly positioned. The bed on which the afterloader rests can be raised or lowered as necessary for optimal placement with respect to the patient.

The control console includes a portable computer, a line printer, and a special control panel. These components are positioned on a metal frame that serves as a table. The portable computer has an LCD screen that flips up during use, revealing a QWERTY keyboard below it. A flexible disk drive is located in the front right edge of the computer. Since none of the sites visited were using this system, the quality of the display could not be measured. However, most portable computers using this type of display provide moderate visibility under normal office lighting levels. The dimensions of the characters on these displays meet HFE standards. By using a display screen, the system has considerable flexibility in how to present information to operators. For example, it provides status messages to operators throughout treatment. Operators are alerted to system errors by descriptive phrases rather than by arcane error codes. The dot-matrix line printer provides a continuous, permanent record of the events before and during treatment. The printer is compact and uses standard 8.5 x 11 inches tractor feed paper from a shelf beneath it.

The printer appears to be simple to operate and to resupply. The power switch is well positioned at the front of the printer.

The special control panel is identical to that used on the GammaMed 12i. Two key switches control system power and operating mode. Color coded indicator lights and foil-contact buttons are arranged well on the panel to advise operators of system status and to provide necessary controls.

3.1.4 Low Dose Rate (LDR) RAB Systems

Low dose rate (LDR) RAB uses lower activity sources than HDR RAB, often cesium-137 pellets (^{137}Cs) or iridium-192 wire of a few hundred millicuries of activity, depending on the number of pellets or length of wire chosen. LDR RAB treatment sessions are conducted as inpatient procedures that duplicate manual afterloading treatment times (about 2–3 days). LDR treatments are similar to manual afterloading with the addition of an automated delivery system. Two LDR RAB systems were examined: the microSelectron-LDR, which has 15 channels and can be used for interstitial treatments, and the Selectron-LDR, which has 6 channels for intracavitary and intraluminal treatments and can treat two patients concurrently.

3.1.4.1 microSelectron-LDR System

Source Preparation Station

This device, shown in Figure 15, is used to prepare iridium-192 ribbon or wire sources. It enables operators to cut source ribbons or wires to the required lengths and prepare them for use with the microSelectron-LDR by attaching them to the inactive part of the source. When complete, sources are then transferred to the 45-channel mobile storage container. The source preparation station is designed to minimize exposure to operators during the process of cutting, attaching, and storing the sources. The source preparation station includes a knob for maneuvering the source cable, pushbuttons for activating the heater (sealer) and cutter, a grip handle for crimping the source onto the cable, and scale markings on a reference display to determine cable length. The dimensions of the various controls are adequate with respect to HFE standards. The controls are large and have good contrast with the case. The pushbuttons are color coded, but they are not labeled. Sites using this device were found to add their own labels to overcome this problem. The grip handle is positioned for left-handed operation. The force required to operate it is acceptable for a 5th percentile female. Scale markings are provided as a reference display so that operators can measure the length of source cables precisely. Even though these scale markings are viewed indirectly via a mirror,

Figure 13. GammaMed 12it afterloader and afterloader control unit

Source: GammaMed 12it brochure.

Figure 14. GammaMed 12it packed for transport

Source: GammaMed 12it brochure.

Figure 15. microSelectron-LDR source preparation station

Source: microSelectron LDR/MDR ^{192}Ir ^{137}Cs brochure.

their visibility is adequate. Operators using this device manipulate the source cables manually from the left and right sides. They lean over the source preparation station in order to view the source cable position. Altogether, this requires operators to adopt an awkward working position.

Mobile Storage Container

The iridium-192 and cesium-137 sources are stored in the 45-channel mobile storage unit, shown in Figure 16. The connector tubes extending from the 45 channels are arranged in two concentric rings. Operators connect the cables to these tubes to permit up to 15 channels of the microSelectron-LDR to be loaded with their appropriate sources.

The cables and connector tubes can be secured by a locking cover when not in use. When in use, the cover lifts and swings out of the way to provide unrestricted access. The entire storage container is mounted on a carriage that can be rolled to patient rooms or to other locations as necessary.

The primary operator interface to this device involves the 15 connector plugs that can be attached to the 45 channels to load appropriate sources into the microSelectron-LDR. The connector plugs are identical, black quick-release type. Each plug is labeled on two sides with its channel number (1–15). Labeling is easily read, since it uses high contrast and large numerals. The connector tubes are so close together, however, that adjacent plugs would be touching. Their close proximity requires that care be taken when selecting the channels for a treatment session. When not in

use, the connector tubes are covered by protective plastic caps. Ribbing on the connector tubes serves as a visual aid to assure that the plugs have been positioned properly (viz., on all the way). The cables extending from the connector plugs interfere with each other physically and visually.

All of the connector tubes are on the top surface of the device and are equally accessible, except as restricted by adjacent plugs and cables. The connector tubes are all labeled on their outside radial with their channel number (1–45). Adjacent labels do not appear to run together. The numerals are oriented toward the operator's position, and they meet visibility requirements. The connector tube labels are visible even when the plugs are in place. No differential coding or labeling for the 45 channels is provided that might be used to distinguish the channel contents. Toward the back of the top surface, several posts are provided that could be used to "park" connector plugs when not in use, getting them out of the way and protecting them from damage.

The 15-channel transfer tube hose is attached to a connector ring on the mobile storage container. To protect it from damage, the connector ring has recessed pins and a protective collar. Three asymmetric alignment pins permit the hose to be attached in one way only.

The connector tubes, plugs, and cables are protected by a cylindrical cover that can be locked in place. Clockwise rotation of the key in the lock on top of the cover releases the spring-loaded cover. The inner section of the storage container is colored yellow, so it is apparent when the white cover is not secured. The cover can then be lifted and rotated away from the unit (180° counter clockwise) to its

Results

Figure 16. microSelectron-LDR mobile storage container

Source: microSelectron LDR/MDR ^{192}Ir ^{137}Cs brochure.

resting position. Lifting the cover requires a one-handed pull using a fixed bar handle on top of the cover. The dimensions of the handle were found to meet HFE standards, and the force required to lift the cover (5 kg) was well within the capability of a 5th percentile female. When the cover is rotated to its resting position, it does not restrict operator access to the device.

The mobile storage container was mounted on a carriage with four large wheels. A fixed two-handed bar handle was used to move the container. The handle was mounted at an acceptable height for both a 5th percentile female and a 95th percentile male. The dimensions of the handle met HFE standards. The force required to move the container using a standing two-handed pull with moderate traction was within the capability of a 5th percentile female.

Afterloader Control Unit

The microSelectron-LDR, shown in Figure 17, includes the afterloader device, a control panel, and a preformed hose containing the 15 source guide tubes that connect to the implants in the patient. In addition to the 15-channel hose with a quick-release coupling, conventional electrical and air connectors are used. The unit is mounted on wheels for mobility. A fixed two-handed bar is used to move the unit. Since the bar handle is mounted in front of the control panel, it also serves to protect the panel from damage due to bumping into walls, etc. Dimensions of the handle conform to HFE standards for a device of this weight and size.

The control panel, shown in Figure 18, was the main user interface. While this panel shows treatment and alarm status, it is used primarily for entering the treatment plan. Controls include a key switch, an array of pushbuttons, and a numeric keypad. All controls are found to be within the standing reach envelope of both a 5th percentile female and a 95th percentile male. The key switch is used to change operating modes between "off," "prepare" (enter the treatment plan), and "remote control" (ready to initiate treatment). These operating positions are labeled, arranged for clockwise activation, and are 90° apart, as recommended by HFE standards. The key is only removable in the "off" position. The black keys are labeled with white numerals on their surface. A single "enter" key is located above the keypad. This arrangement minimizes accidental activation; however, the white labeling for this button on a yellow background is difficult to read.

Displays on the control panel include colored indicator lights, numeric readouts, and a paper tape printer. Fifteen pairs of yellow and green LED lights are used to indicate the status of each of the 15-channels. Yellow lights indicate that the sources are in the treatment position, and green lights indicate that the sources are in the afterloader safe. The colors are clearly distinguishable and are used consistently throughout the system. The spatial separation of the light pairs provide a redundant cue for channel status. The "either - or" use of the lights to provide a positive indication of channel status was considered to be a good design feature (i.e., the panel doesn't use the absence of lights to mean "safe"). Back lit red lights are used to

Figure 17. microSelectron-LDR afterloader and afterloader control unit

Source: microSelectron LDR/MDR ^{192}Ir ^{137}Cs brochure.

Figure 18. microSelectron-LDR afterloader control panel

Source: microSelectron LDR/MDR ^{192}Ir ^{137}Cs brochure.

Results

An array of six red LEDs along the bottom of the panel is used to alert the operator to various types of system alarms. The relatively unique use of red indicator lights and the positioning of the alarm lights make them easy to detect. Each of the alarm indicator lights is labeled, but the labels are difficult to read. Not only are they small size and lower case (limiting viewing distance to approximately 14 inches) but also they are arranged diagonally. A "reset" button is appropriately positioned adjacent to these alarm indicator lights for use after the problem has been corrected.

Two sets of four 7-segment red LED numerals are provided in the upper left of the panel. These sets are used to show the treatment time remaining (during treatment) or source registration information (during programming). White and yellow labeling helps to distinguish between these modes. The dimensions of these numerals meet HFE standards, and the characters were visible to approximately 6 feet.

A paper tape printer is integral to the panel and makes a permanent record of all treatment events, interruptions, and alarms. Most information is presented in a directly usable format, except for the alarms. Alarms are indicated by an error code number that must be interpreted via the users manual. The dot-matrix (5x7 dots, 1x3 mm) printer uses metallic paper. The low contrast of the print on the paper and the unconventional character dimensions (too high for their width) reduce printer output legibility. While operators cannot read the most recently printed line, the paper can be pulled out for inspection and can be annotated with pen or pencil. Reloading paper tape rolls is simple and requires no special tools or disassembly.

Overall, the panel contents are grouped functionally, with good spatial separation between groups. Within groups, layout tends to be sequential from left-to-right. Demarcation and enhancement techniques effectively separate the key switch, alarm indicators, and numeric keypad from the rest of the panel. The horizontal 15-channel array of indicator lights, buttons, and labels is arranged well, but the equal spacing between channels could be confusing. Labeling is used appropriately throughout the panel, although the readability of labels is limited by the use of small, lower case letters.

Remote Control Unit

The remote control unit, shown in Figure 19, is typically located directly outside the treatment room door. This is the primary device used to start and interrupt treatment. It is partly redundant with the nurse station display, but it provides more information than would be available at the nurse station. In addition, it includes a phone handset with which to communicate with the patient.

Figure 19. microSelectron-LDR remote control unit

Source: microSelectron LDR/MDR ¹⁹²Ir ¹³⁷Cs brochure.

Three buttons appear on the face of the panel: a red one for starting treatment, a green one for interrupting treatment, and a black one for silencing auditory alarms. Other than color and placement, these buttons are identical. Their characteristics (size, separation, feedback, displacement, and resistance) conform to HFE standards. The black

"audible off" button offers poor contrast against the black panel background. The red and green buttons are easily detected, but the colors have a different meaning on this panel than the population stereotype for red and green (here, red means "start" and green means "interrupt" or stop, which is consistent with electric industry standards). This color coding scheme may cause operators to press the wrong button should they fail to read the labels for the red and green buttons and be unfamiliar with electrical industry color coding conventions. Additionally, this color coding scheme is the reverse of that used with the GammaMed III afterloader. Additional confusion may therefore arise at sites that use both the Nucletron and GammaMed III afterloaders.

A small key switch is located in the lower right of the panel. This key switch is used to enable/disable the buttons to restrict unauthorized access. The key positions appear to be 90° apart as recommended by HFE standards; however, the key positions are not labeled, leading to operator confusion. None of the sites visited used this key switch.

The visual displays on the panel include a series of colored indicator lights and a four digit numeric read-out. The numeric read-out displays the treatment time remaining in hundredths of an hour (xx.xx hours). The numerals are red 7-segment LEDs. Except under bright lighting (such as direct sun light), they are quite visible against the background (visible to 4.5 feet). The dimensions of the numerals conformed to HFE standards. The level of precision displayed may be excessive and could lead operators to confuse it with a display of hours and minutes. Furthermore, it is not immediately clear whether the time displayed is the elapsed time since a treatment session began or the time remaining in a treatment session. Improved labeling would aid in preventing confusion in this regard.

A vertical array of eleven LED indicator lights is used to display treatment status, alarms, and patient call requests. The lights have good visibility, except when viewed under high ambient illumination. There is no test mode to insure that all lights are operational, although they can be tested during QA by simulating the conditions that cause them to activate. Three lights are used to indicate treatment status. A green light indicates that treatment has been interrupted and the room is safe to enter. Above it, a yellow light indicates when treatment is in progress. Above this light, a red LED indicates when the system is ready to begin treatment (i.e., when the afterloader is ready and the door to the room is closed). The yellow "treatment" and the green "safe" lights are labeled, but the red "ready" light is not. The meanings associated with the yellow and green lights are consistent throughout the microSelectron-LDR system. Red does not carry an inherent association with "ready,"

and its arrangement above the "treatment" light does not convey its meaning.

Six types of alarms are indicated by separate red LEDs. Red is an appropriate color to use for alarm indicators, and the lights are labeled appropriately. The use of small, lower case lettering for the alarm labels limits their readability, however. A red indicator light is also used to remind operators that the auditory alarm signals have been silenced. Finally, patient call requests are indicated by a red indicator light as well. Neither of these last two indicator lights needs to be red, and the use of this color code detracts from the detectability of the alarm lights. A back-lit legend button may be a suitable alternative for the "audible off" light-button pair.

Auditory signals are used redundantly with the visual indicator lights to alert operators to alarms and treatment interrupts. The auditory signals are easily detected above the background noise in the area. Distinctive and easily interpreted signals are used for alarms and for treatment interrupts. Even if silenced via the "audible off" button, new alarms will sound. Moreover, the auditory signals will recur if no action has been taken for a certain period of time.

The phone handset provides adequate voice quality communication with the patient. The handset, whose red color makes it easy to detect, is comfortable to hold and is easily reattached to its cradle. The coiled cord provides adequate length for unconstrained use in the area.

All displays, controls, and panel areas are labeled appropriately. Labeling is white against the black panel background, providing excellent contrast. However, the use of small, lower case lettering restricts the readability of the labels. The terms used are brief and meaningful to operators³. "Sound" may be more readily understood than "audible," however.

The panel is grouped effectively into four functional areas: treatment time, treatment control, alarms, and other. This grouping reduces the panel's visual complexity and promotes more rapid information transfer to the operator. Highly visible dashed demarcation lines are used to separate these areas. The layout within these groups is generally consistent with other microSelectron-LDR panels⁴.

³Some uncertainty was found among operators on the meaning of the alarms. In particular, "leak" was misinterpreted as a radiation leak rather than an air leak.

⁴The arrays of indicator lights (e.g., alarms) are arranged horizontally on the controller and the nurse station displays.

Figure 20. microSelectron-LDR/Selectron-LDR nurse station display

Source: microSelectron LDR/MDR ^{192}Ir ^{137}Cs brochure.

Nurse Station Display

A nurse station display is installed at the nurses' office for each microSelectron-LDR or Selectron-LDR unit available for treatment. This display unit, shown in Figure 20, provides an indication of alarm states, patient calls, and treatment status. In addition to the indicator lights, auditory signals are used to alert staff to alarms and to treatment interrupts. This is intended to be a secondary display that would advise RAB staff of key events. The remote control unit would be the primary operator interface to the microSelectron-LDR.

There is a single button on the panel. This button is used to silence audible alarms and alerts. The button is black, offering poor contrast against the panel. The button's positioning, size, displacement, and feedback were found to meet HFE standards.

The panel uses seven LED lights to indicate alarms, treatment status, and patient call requests. All but one of these indicator lights is red. This does not consider the potential impact of red as a code for alarms or emergency conditions. A yellow light is used to indicate that treatment is in progress. This color code is consistent with other indicator lights used by the microSelectron-LDR and Selectron-LDR systems for the same purpose. Under bright ambient illumination, the LEDs could give the false impression of being lit. In normal office lighting conditions, however, the indicator lights would be easily visible against the dark panel.

A single red indicator light is used to alert operators to the presence of any of several system alarms. The detectability of this light was considered to be relatively low due to its location in an array of red system status lights. Auditory

signals, redundant with the indicator lights, are also used for alarms and for treatment interrupts. Alarms are signaled by an oscillating, two-frequency sound that is easily detectable above background noise levels typically found in nurses stations. Treatment interrupts are indicated by an intermittent tone that is readily discriminable from the alarm signal. The "audible off" button can be pressed to silence these auditory signals.

When pressed, an adjacent red indicator light illuminates. The auditory alarms will reactivate after a certain period if not serviced, and new alarms will sound even if the "audible off" button has been pressed. Both of these interface features were considered to be excellent. There is no test mode which operators can use to test that the indicator lights and the alarm signal are operating properly during treatment other than creating the conditions that activate the alarms.

The indicator lights are all labeled with brief, high contrast words. Labeling is placed below the lights, which is inconsistent with HFE guidelines. The lettering is lower case and very small, limiting its readability to approximately 14 inches. The wording of the labels is generally understandable, although some confusion is possible due to the use of the term "audible off" to label the "silence alarm" button. This button does not turn off all audible alarms but rather silences the current alarm for a while to allow the user to deal with the alarm condition. Two lights, labeled "1" and "2," are used to indicate a patient call. With the microSelectron-LDR, only one light could be lit since only one patient is treated on the unit. When two patients are being treated with the Selectron-LDR system, both patient call lights would be used. The panel makes no provision for temporary labels that would identify patient names or room numbers. This type of

additional labeling would be required on the nurse station display, particularly when multiple microSelectron-LDR and Selectron-LDR units are in use. In fact, such local labels were observed at sites visited.

The panel's small size and simple design make it easily understood with minimal training. A dashed demarcation line effectively separated the panel into two areas: system status and patient call. This reduces the visual complexity of the panel and promotes rapid detection of system status changes and patient calls (especially since redundant auditory signals occur). The layout of the system status area of the panel differs from that used on the remote control unit. On both the control panel and the remote control unit, a green LED labeled "safe" indicates that the source has been withdrawn and treatment interrupted. On the nurse station display, this condition is indicated by a red LED labeled "interrupt." On this panel, the "treatment," "interrupt," and "ready"⁵ lights are arranged horizontally, but these are arranged vertically on other microSelectron-LDR panels. Also, the "audible off" light – button arrangement differs between the nurse station display and the microSelectron-LDR remote control unit.

3.1.4.2 Selectron-LDR System

Afterloader Control Unit

The Selectron-LDR control panel is on top of the afterloader device itself (see Figures 21 and 22). The control panel consists of a complex display area and a control area, with buttons, indicator lights, and a printer. The unit is mobile on four wheels. A storage rack is provided for the source guide tubes. The control panel is primarily used to program the treatment plan into the unit. A single, three-position key switch is used to change operating states of the unit from "off" to "prepare" (i.e., enter treatment plan) to "remote control" (i.e., ready to initiate treatment). The key switch is used appropriately to restrict access, and the control positions were separated by the recommended 90°. However, the direction of activation is opposite to HFE conventions and to other Selectron devices. The key is rotated counter clockwise from "off" to "prepare" to "remote control."

The pushbuttons are positioned in a logical (left-to-right) order of procedural sequence. Button dimensions (size, separation, feedback, surface, displacement, and resistance) are acceptable with respect to HFE standards. The black buttons provide limited visibility due to their moderate to low contrast against the dark gray panel background.

⁵The "ready" light is not meaningful or necessary at the nurse station display and could be eliminated.

A flexible program card could be inserted vertically into a card reader slot at the lower-center of the control panel. This permits the treatment plan to be entered automatically. The card reader slot is of adequate size for easy operation. There are no indicator lights or buttons in the area surrounding the card reader slot, so its use would not restrict visual or physical access to other displays and controls.

A calculator style keypad, in a 3x3+1 arrangement, is provided on the control panel for numeric data entry. The keys are black squares with white numerals imprinted on them. The dimensions of these keys meet accepted HFE design standards. A round, black "enter" key is positioned directly below the zero. While this key is not labeled, its unique location and shape distinguish it. Its location is considered likely to promote unintended activation, however. Preferred locations would be above or to the right of the keypad.

Red indicator lights are used to the left of the buttons on the control panel to prompt operators with the allowable actions. This is an excellent design feature, decreasing the chances of erroneous entries and minimizing operator training requirements. However, a few minor weaknesses in the interface design may add some operator confusion. Under high illumination, the LEDs could incorrectly appear to be lit. Also, these prompting lights are located somewhat too far from their associated buttons.

In the upper section of the control panel, a series of LED displays indicate the total number of active and spacer pellets selected and the selected pellet positions and treatment times for each channel. Three types of displays are provided: status indicator lights, numeric counters, and analog displays of the pellets in the six channels. All of these displays are red and are clearly visible, although it may be difficult for operators to detect which were lit when viewed under high ambient illumination.

The analog displays representing pellet locations for the six channels were considered to be excellent. The relative location of the lit and unlit LEDs provides a clear representation of the channel loading. Scale markers and labeling made it easy for operators to determine source length and pellet positions.

Electronic counters are used for the treatment time on each channel and for the number of source and spacer pellets used. All of these counters use red 7-segment LED numerals. The dimensions of the numerals meet HFE standards, and they were calculated to be visible to 72 inches. The treatment time counters present the time remaining in xx.xx hours. This degree of resolution may be excessive, considering that low dose rate treatments typically last for 2–3 days. Moreover, the presence of two

Figure 21. Selectron-LDR afterloader and afterloader control unit

Source: Selectron LDR/MDR ^{137}Cs brochure.

digits to the right of the decimal point may cause operators to incorrectly interpret them as minutes rather than as hundredths of an hour⁶.

Status indicator lights are used in the upper area of the control panel to notify operators of various system alarms and of the unit's current operating mode. The red LEDs are detectable and are labeled appropriately on the panel. The principal weakness with these status indicator lights is that they did not stand out from the rest of the panel, and alarms could easily be missed. All of the displays are red, and no demarcation of special areas (e.g., alarms) is used.

A paper tape printer that keeps a sequential record of system status and alarms is integral to the control panel. The information recorded on the printer is generally presented in a directly usable format, although system alarms and errors are displayed in code numbers that must be interpreted via the users manual. Printer operation is relatively quiet. Reloading paper is simple and requires no special tools or disassembly; no printer ribbon is required. Black dot-matrix characters (5x7 dots, 1x3 mm) on silver metallic paper provide low contrast, and the characters are not highly legible (too tall for their width). Operators cannot read the most recently printed line, although tape can be pulled to advance it. The paper tape can be annotated with pen or pencil.

⁶The "worst-case" magnitude of this misinterpretation would be 23.6 minutes if xx.59 hr was mistaken for xx hours and 59 minutes.

Figure 22. Selectron-LDR control panel

Source: Selectron LDR/MDR ^{137}Cs brochure.

The contents of the control panel are grouped according to system function. Groups are separated by spacing; no demarcation or color shading is used. Within these groups, a left-to-right arrangement is used. Some lines are placed on the control panel to indicate the procedural flow. The displays are positioned in good proximity to the operator's field of view, and it was considered unlikely for them to be obscured during use. The controls are well within the reach envelope of both a 5th percentile female and a 95th percentile male.

Nearly all displays and controls are labeled clearly and appropriately according to HFE standards. The white labels offer good contrast against the dark gray panel. However, they are lower case and are too small to be read easily beyond 14 inches.

The design of the quick-release connectors for the six channels was considered to be quite good. They required a quarter turn to lock/release and are well labeled. Alignment

pins assured proper positioning. Shaped finger grip points are provided for secure control. They have good physical and visual accessibility when connected. When not used, the connectors attach to special pins on the storage rack. This assures that the source guide tubes are stored out of the way and that the connectors will not be damaged. During use, excess tubing and cabling on the floor could be a tripping hazard. The Selectron-LDR unit includes a metal bar around the area where the source guide tubes enter it. This bar provides an excellent way to protect these connections from damage, such as when the unit might be pushed up against a wall.

Two one-hand bar handles are provided on opposite sides of the unit. These handles are used not only to move the unit but also to protect it from damage from knocking into walls, etc. The handle dimensions are adequate to accommodate the force needed to pull the unit.

Results

Figure 23. Selectron-LDR remote control unit

Source: Selectron LDR/MDR ^{137}Cs brochure.

Remote Control Unit

The remote control unit (see Figure 23) is mounted outside of the patient's room and is used to initiate and to interrupt treatment. It includes a phone set to talk with the patient, a numeric counter showing treatment time remaining, indicator lights for system status and alarms, and buttons used to initiate and interrupt treatment. A key switch on the right side of the unit can be used to disable the buttons to prevent accidental or unauthorized use of the remote control unit.

The remote control unit contains three buttons that are used for starting treatment, stopping treatment, and for silencing audible alarms. The "start" button is red, the "stop" button is green, and the "audible off" button is black. The black button has limited contrast with the dark gray panel. The other characteristics of the buttons are identical, and they were found to meet HFE standards.

The indicator lights are either red (for alarms), yellow (for channels treating), or green (for channels not treating). This color coding scheme is considered to be effective and to be

consistent with common associations held by RAB personnel. The presence of both the yellow and green treatment lights is considered to be a good interface design feature since they provide a positive indication of treatment status (i.e., the absence of a light did not mean that the source had withdrawn). Another nice design feature is that the red alarm indicator lights are all collocated in the lower left area of the remote control unit. This area of the remote control unit also includes a red light to indicate when the audible alarm had been turned off. All of the indicator lights are LEDs, which are easily detected but may appear to be lit when viewed under bright light.

A single electronic counter is used to display the maximum treatment time remaining. The display used four 7-segment LED numerals with a fixed decimal point. The time scale is in xx.xx hours. As discussed with the microSelectron-LDR afterloader control unit, this level of precision may be excessive and could lead to misinterpretations by operators. The dimensions of the numerals meet HFE standards. The contrast, style, and size of the numerals make them quite visible (calculated maximum viewing distance of 72 inches).

The remote control unit panel is divided into three functional groups: (a) alarms, (b) treatment status and control, and (c) treatment time and patient communications. Within groups a left-to-right arrangement is used. Dashed lines are used to separate the functional groups. In the alarms section of the remote control unit, the alarm indicator lights are arranged horizontally, although they are vertically arranged on the Selectron-LDR unit control panel. They are located in the lower portion of the panel, meaning that they would be temporarily obscured while an operator was pressing the "audible off" button. In the treatment status and control section of the panel, the spatial association between the buttons and the six pairs of channel indicator lights is good. The "call" light, which is located to the immediate left of the phone set, could be obscured by the handset if viewed from the right side.

Auditory signals are used to alert operators to alarms and to treatment interrupts. Alarms use a distinctive, alternating two-frequency sound, which continues until silenced via the "audible off" button. If another system alarm occurred, the alternating alarm tones would resume even if the "audible off" button had been pressed previously. During treatment interrupts, an intermittent tone would sound to remind operators of the interrupt. This signal could also be silenced via the "audible off" button. If not attended to after being silenced, both of these auditory signals would recur after a preset period of time.

Appropriate and brief labels are in good proximity to all of the displays and controls (and functional panel groups). Many of the labels, however, are located below their display or control, which is counter to HFE standards. In particular, the "start" label should appear above the red button to reduce confusion and to ease readability. This would also eliminate the need for the arrowheads associated with the "start" and "stop" labels. The wording of several of the labels was considered to be ambiguous and to introduce operator confusion. The wording of the four types of alarms is consistent throughout the Selectron-LDR system. The lettering used with the second level labels is simple and has good contrast with the panel background. However, its small size and lower case style limit its readability (viewing distance calculated to be approx. 14 inches). No provision was observed for temporary labels, but it may be useful for nursing staff to note certain information on the remote control unit (e.g., which channels the patient in the room is using).

The display for the treatment time remaining was labeled "TIME" (Figure 23). This label was ambiguous since it did not allow a user to determine at a glance whether the display represented (1) the time that had elapsed since the start of treatment or (2) the time remaining until treatment was completed. The location of a "TREATMENT" label of the same font, style, and size on the middle section of the

panel to the left of the "TIME" label allowed the two labels to be connected and the display contents interpreted (incorrectly) as "TREATMENT TIME" rather than "TREATMENT TIME REMAINING."

Nurse Station Display

The nurse station display for the Selectron-LDR is identical to the one used with the microSelectron-LDR, which has been discussed above. There are a few unique HSI issues regarding its use with the Selectron-LDR system, however. These concern the fact that one nurse station display would be used for each Selectron-LDR or microSelectron-LDR unit available for treatment. At sites where several units are available, several nurse station displays would also be present. Moreover, if two patients were being treated from a single Selectron-LDR unit, both of them would be monitored via a single nurse station display. To keep track of which patient and which unit go with each nurse station display, RAB staff need to add labels with room numbers, patient names, or other unique codes.

3.1.5 Auxiliary Equipment

3.1.5.1 General Treatment Support Apparatus

Primalert Radiation Monitor

The user interface to this device was found to possess several strengths. The excellent use of color and spatial coding for the indicator lights promotes rapid and accurate detection of the ambient level of radiation. The redundant, dual-bulb primary display provides an excellent back-up for the main display, reducing chances of non-detection due to a burned out light bulb. The primary warning light is positioned well for good visibility. Good panel layout and labeling help to minimize user errors in understanding displayed information and help to minimize user training requirements.

A few weaknesses in the user interface to this device were noted, however. Users could become confused about the setting of the alarm level selector, since either the pointer arrow or the control position bar could be used as the indicator. The consequence of this user error would be to set the alarm threshold lower than desired. Poor contrast of the aural alarm on-off slide switch against the panel could lead to a mistaken switch setting. This user error would result in unwanted or absent audio alarms.

Intercom

Point-to-point audio intercoms are used for communications between the patient in the treatment room

Results

and the personnel in the treatment control workspace. Various brands and models of intercoms are used at the sites visited. The AI Phone intercom was used at the treatment control workspace at several sites, and its interface is typical of most intercoms.

This intercom consists of a speaker, enclosed in a case, along with an array of several buttons. The intercom case could be mounted vertically on the wall or positioned horizontally on a desk or shelf. The voice quality from the speaker is adequate, and volume could be adjusted via a thumbwheel on the side of the case. The buttons are used to turn the unit on, to select which of several channels to monitor, and to allow the operator to talk to the patient. The buttons are arranged in a horizontal row and were color coded by function. The colors used are readily distinguishable, even under low illumination. The dimensions of the buttons (size, shape, displacement, resistance, feedback, surface) are consistent with HFE standards. Most are exclusively toggled, so operators could see which channel was selected (by noting the indented button) and could only select one channel at a time. When the operator wished to talk to the patient, the "talk" button needed to be held down continuously; when released, monitoring of patient verbalizations would resume. This simple panel layout was considered to be adequate for the functions involved. Labeling for the buttons is, however, problematic. Small white lettering is placed below the buttons on a black background. While the contrast is adequate, the size and placement of these labels restricts their readability. Space for sites to enter their own button labels is provided below the standard labeling. This is a good design feature that enables sites to create more meaningful labels.

Source Guide Tube Storage Racks

Racks for storing source guide tubes are used in many high dose rate RAB treatment rooms. These Plexiglas racks are wall mounted, permitting the tubes to hang down from their connector plugs (see Figure 24). Each rack contains many adjacent slots for storing tubes. When mounted properly, the racks provide excellent visual and physical access to the tubes for both a 5th percentile female and a 95th percentile male. Labeling at the base of the connector plugs facilitates correct identification. The placement of the slots in which the tubes are stored is far enough apart to allow access by thumb and fore finger without interference from adjacent tubes. The primary advantages of these storage racks are to promote easy access to the source guide tubes and to provide a safe way to store them (in contrast to coiling them up in a drawer).

3.1.5.2 Quality Assurance Apparatus

High Dose Source Position Check Rulers

Reference devices used to verify source positions are available from Nucletron (Figure 25) and GammaMed (Figure 26). Both designs are similar in that a source guide tube could be connected to the left side of the device to permit the source to travel through a clear tube to be viewed against a metric ruler. Thus, the quality assurance operator could use this device to check that the source did in fact travel to the distance programmed into the afterloader control unit.

Several design strengths were observed in these devices that promote easy and accurate use. Both designs provide good visual contrast by using a black background against which to view the source. The scale range shown on the rulers is adequate, and the dimensions of the graduations are consistent with HFE standards for visibility. The size of the numerals on the Nucletron check ruler permits adequate readability to approximately 14 inches. The GammaMed design includes a magnifying prism to enable the ruler to be viewed from greater distances.

The GammaMed check ruler is designed to enable quality assurance operators to directly observe it via the video monitor during the source position check. The display surface is mounted at a 45° angle, and the magnifying prism is provided. To use this device effectively, the operator would need to have the video camera zoom in and focus on the check ruler scale and to have sufficient resolution on the video monitor to permit fine discriminations (1–2 mm).

The Nucletron check ruler could also be viewed directly via the video monitor to determine source positions. In addition, source positions could be checked after the source was retracted by noting the position of an indicator bar. When the source is extended, it pushes the indicator bar ahead of it through the transparent tube. When the source is withdrawn, the indicator bar remains at the most distal position to which it was pushed by the source cable. The quality assurance operator could then determine the maximum source position by noting the position of the left edge of the indicator bar and adjusting for the length of the source capsule (subtract 3 mm). Of course, this technique can only check the maximum source position. Separate iterations would be required to check multiple source positions. To obtain accurate readings, quality assurance operators would need to be diligent to reset the indicator bar to its left-most position before each test. While this is an easy and convenient technique for verifying source position, problems could result from the indirect nature of the viewing. That is, if the indicator bar fit too loosely in

Figure 24. Source guide tube storage rack

Source: GammaMed Applicators and Accessories brochure.

the transparent tube, inertia could carry the indicator bar a few millimeters past the maximum position of the source⁷. Likewise, it may be possible for the indicator bar to be pulled backwards by suction created by the source as it is withdrawn. Therefore, unless validated by another technique, such as direct viewing or autoradiographs, erroneous conclusions may be made regarding the accuracy and precision of source positioning.

The Nucletron check ruler provides a single male connector on the left side; the GammaMed device provided three connectors, for an interstitial needle, applicator tandem, and applicator probe. All of these connectors were found to be accessible and simple to operate. The Nucletron design includes "legs" on either side of the connector that protected it from damage. This was considered to be a particularly desirable design feature, since the check rulers are often stored in drawers or cabinets with other supplies.

⁷This situation was reported at several of the sites visited. At these sites, the problem was corrected by inserting another cable into the right side of the transparent tube. This cable provided sufficient resistance against the indicator bar to keep it from moving beyond the position of the source.

High Dose Source Calibration Jigs

Various types of jigs for calibrating source strength were observed at the sites visited. Some were locally manufactured. The operator interface to these devices is simple and unambiguous. The only weakness found was the potential instability of the GammaMed kerma rate measuring device, shown in Figure 27, due to the considerable length of the calibration track relative to its small, triangular base. In spite of this weakness, this jig was the most popular because of its ease of use and readability.

Autoradiograph Jig

Several local configurations for making autoradiographs were found at the sites visited. These are usually used when verifying source positions with high dose rate RAB units, since only one channel need be checked. In the microSelectron-LDR system, shown in Figure 28, where up to 15 channels can be used simultaneously, a standard jig was used for making autoradiographs. This device was a Plexiglas plate with 15 tubes arranged in parallel that joined at a connector to which the unit could be attached. An x-ray film would be placed over the Plexiglas plate and the sources extended for a short period. The positions of the

Figure 25. Nucletron source position check ruler

Source: microSelectron HDR ^{192}Ir brochure.

Figure 26. GammaMed source step viewer

Source: GammaMed Applicators and Accessories brochure.

radioactive sources could then be checked on the exposed x-ray film.

This device was found to be very simple to operate. The connector from the microSelectron-LDR afterloader could be attached to the jig in only one way, so no confusion among channels was likely. Also, the separation between the parallel channels on the Plexiglas plate is adequate to permit unambiguous measurement of source positions and to allow handwritten annotations on the exposed films.

3.2 Checklists and Worksheets

Checklists and worksheets guided task performance at some RAB sites. Checklists provide space for users to indicate

that steps in a procedure had been performed, often by a check box. Worksheets provide space for the results of a procedure to be entered. Checklists show that a sequence of actions has been performed; worksheets show that certain actions were performed in the correct (or incorrect) manner.

Seventy-two checklists or worksheets were collected and evaluated from the visited sites. (Several additional documents that had no provision for checking off completed tasks or for entering information were collected but not evaluated.) The format features of the 72 checklists or worksheets were evaluated by comparing them to human factors document design standards and guidelines.

Figure 27. GammaMed kerma rate measuring device

Source: GammaMed: Proceedings of the Third International HDR Remote Afterloading Symposium, 1988.

The content of 49 of the 72 documents was evaluated to determine whether the documents supported the tasks in which they were used. (The remaining 23 documents were not content evaluated because they either duplicated or differed only slightly from the other documents.) Of these 49 documents, 27 were used in Patient Preparation, Treatment Planning, or Treatment Delivery; the remaining 22 documents were used in Quality Assurance.

3.2.1 Document Format

The format evaluation centered on five human factors guidelines for printed information: legibility, language, printing format, illustrations and highlighting, and comprehensibility. Each criterion was described by two or three specific features that was evaluated for each document by a research analyst experienced in document design and evaluation with a "yes," "sometimes," "no," or "not applicable" response. The results for each response

category were tallied, the percentages for each feature calculated, and the results displayed in Table 2.

3.2.2 Document Content

In the content evaluation, worksheets and checklists used during patient preparation, treatment planning, treatment delivery, and quality assurance were evaluated. Documents used in training or record-keeping for non-RAB tasks, and documents for source calibration methods were not evaluated. Contents of existing documents and discussions with subject matter experts determined the appropriate information content for these documents. Table 3 summarizes the content evaluation of the 27 worksheets and checklists used in Patient Preparation, Treatment Planning, or Treatment Delivery; Table 4 does likewise for the 22 Quality Assurance documents that were evaluated.

Figure 28. microSelectron-LDR autoradiograph jig

Source: microSelectron LDR/MDR ^{192}Ir ^{137}Cs brochure.

3.2.3 Format Evaluation

3.2.3.1 Legibility

Most of the documents used a font that was simple, legible, and non-stylized. However, many documents (43 %) lacked sharp and crisp printed characters. Most of these problems stemmed from bad photocopies in which smudges and fading made the print difficult to read. Thirty-eight percent of the documents were printed in font sizes that were too small to be easily read at normal working distances. Many were well below 12 points, and some were so small that they were almost illegible. Such small print poses a problem when rapid and accurate transfer of information is crucial.

3.2.3.2 Language

Forty percent of the worksheets and checklists contained abbreviations that might be misinterpreted by staff performing the task. Only 10 percent of the documents explained those abbreviations.

3.2.3.3 Printing Format

In many instances, lines were used to separate text or to link text items; however, these lines were often difficult to

follow. Worksheets and checklists require enough space between lines for information to be easily written and seen. The spacing between lines of text was insufficient for these purposes in many of the documents. Insufficient space can lead to skipped items or misunderstood information.

3.2.3.4 Illustrations and Highlighting

Twenty-one percent of these documents had illustrations to clarify the meaning of their descriptions. Several worksheets also had space in which an illustration could be drawn by a task performer to amplify the information contained in the document. The lack of illustrations is unfortunate because many treatment planning, treatment delivery, and QA tasks are suited to the use of illustrations, which can clarify the meaning of text passages.

Highlighting consisting of boldface type, capitals, font changes, underlining or color changes was used to emphasize important information in 35 percent of these documents.

3.2.3.5 Comprehensibility

Most of the documents were logically organized to follow an expected sequence of RAB events. They were occasionally difficult to follow due to inconsistent entry

Table 2. Format Evaluation of 72 Checklists and Worksheets

	Yes (percent of total)	Sometimes (percent of total)	No (percent of total)	Not Applicable (percent of total)
Legibility				
Simple, non-stylized font	88	1	11	0
Printed characters are sharp and crisp	57	21	22	0
Font size legible	62	21	17	0
Language				
Brief line length	71	25	4	0
Familiar words	96	4	0	0
Clear meaning	53	42	5	0
Printing Format				
Sufficient spacing between text	42	25	33	0
Capitals and italics used appropriately	55	18	7	20
Lines separating text are easy to follow	44	31	19	6
Illustrations and Highlighting				
Drawings or figures used to facilitate understanding	21	0	79	0
Boldface, font change, underlining, or color change used to emphasize important information	15	25	60	0
Comprehensibility				
Text is organized into logical statements and sections	82	3	4	11
Abbreviations are explained	10	14	39	37

Table 3. Content Evaluation of 27 Checklists and Worksheets Used in Patient Preparation, Treatment Planning, and Treatment Delivery

Item	Percent of Documents with Item
Prescription or prescription copy	48
Applicator - site map	41
Applicator - channel map *	33
Dwell points	63
Dwell times	52
Verification record	59

*The applicator-channel map was often missing at sites performing single-channel treatments.

Table 4. Content Evaluation 22 Checklists and Worksheets Used in Quality Assurance

Item	Percent of Documents with Item
Date	95
Space for checker to initial	100
Door interlocks	84
Interrupt of treatment	74
Console lights	63
Source activation	58
Source retraction	53
Cables	26
Intercom	53
Cameras and monitors	58
Timer	53
Sufficient printer paper	16
Operating/Emergency procedures posted	37
Source activity	42

formats for adjacent items. Instead of always using a check to indicate a passed test or a completed procedure, some checklists required checks for failed tests. Others were inconsistent in their entry requirements. Not all checklists were arranged so that missing items or failed tests would be obvious at a glance.

3.2.4 Content Evaluation

3.2.4.1 Patient Preparation, Treatment Planning, and Treatment Delivery Documents

Most of the checklists and worksheets used in the patient preparation, treatment planning, and treatment delivery tasks had some method (dates or fraction numbers) to identify the treatment fraction to which the document corresponded. Roughly half carried the dose prescription and therefore provided enough information to verify adherence to the treatment directive. Several contained a description of applicator-channel connections, and a few had space to write planning calculations for later verification.

3.2.4.2 QA Documents

All the worksheets and checklists used during QA tasks provided space for the initials of the person performing the QA check. Most documents included the date the QA was

performed and a check of the safety interlocks used during treatment. Some documents also noted whether source activity and positioning accuracy had been verified.

3.3 User Manuals

Effective user documentation is important to the correct operation and maintenance of complex medical systems such as RAB. Human factors research has shown that document format and presentation contribute to the effectiveness of user manuals. During the introduction of RAB to the U.S. in the 1960s and 1970s, English user manuals were translations of European manuals. As the supply of RAB systems to the U.S. increased, and as American support systems were established, manuals were developed especially for the U.S. market. Both GammaMed and Nucletron offer extensive documentation to support the use and care of their systems; however, the manuals used in this evaluation were only those labeled as user or operator manuals.

Overall, RAB user manuals were not examples of good technical documentation. Older versions appeared to have been typed on office typewriters or first generation word processor systems and reproduced on office photographic reproduction machines. More recent versions were developed with greater attention to detail but still lacked human factors considerations, professional instructional design, typographic design, and printing features. Detailed

findings on each of the user manuals assessed in this study are summarized below.

3.3.1 GammaMed Ili HDR Remote Afterloading System Operator's Manual

3.3.1.1 Highlighting

The most common highlighting technique was text underlining. Words in all capital letters were used for abbreviations and acronyms and in portions of the troubleshooting and emergency procedures.

3.3.1.2 Graphics

Illustrations were of poor quality. Procedures needed more illustrated examples to minimize confusion about difficult tasks. Most of the illustrations were circuit diagrams that were grouped together at the end of the manual with little, if any, supporting text.

3.3.1.3 Information Organization

A table of contents was provided, but it did not include page numbering. The manual did not have an index or any other type of referencing tool. Engineering and operational information were presented together in the same sections of the manual, and there were no visual aids, such as flow diagrams, for clarification.

3.3.1.4 Language and Readability

Sentence structure was lengthy and awkward to read. Acronyms were used appropriately to abbreviate technical terminology. The reading level was grade 12.

3.3.1.5 Legibility

Font size varied between 10 and 12 points, with serif style fonts being used throughout. Text was proportionally spaced, but characters were fuzzy and indistinct in the copy provided for evaluation. High, black on white contrast helped ease reading effort. Line length was longer than recommended (6.5 inches). Right justification was not used.

3.3.1.6 Physical Characteristics

The binding was a standard 3-ring notebook, with a page size of 8.5 x 11 inches.

3.3.2 GammaMed 12i HDR Remote Afterloading System Operator's Manual

3.3.2.1 Highlighting

Space and borders were used to separate text, give the reader cues for warnings, and highlight VDT display examples. The only typographic cues provided for the reader were underlining and capital letters for section titles and capital letters for abbreviations and acronyms.

3.3.2.2 Graphics

Illustrations were only of fair quality. A few helpful illustrations of displays and menus were provided, and a detailed drawing of the source head, and a specification of physical dimensions for the emergency source container were presented. Procedures and program data need more illustrated examples to minimize confusion about complex tasks.

3.3.2.3 Information Organization

A table of contents was provided, with page numbering to reference the topics listed, but the manual did not contain an index. Engineering design and operational matters were discussed in the same sections of the manual, making it difficult to use as an operator's manual. Flow charts should have been included for clarification of treatment program processes.

3.3.2.4 Language and Readability

Sentence length and simplicity was acceptable, but technical knowledge was required to understand much of the jargon. Acronyms were used to abbreviate variables and methods but were kept to a minimum. The reading level was grade 14.

3.3.2.5 Legibility

Font type size was 12 points using Times Roman style, and text was proportionally spaced. Character sharpness was minimal, but high, black on white contrast helped ease the reading effort. Line length was longer than recommended at 6.5 inches, and right justification was not used.

3.3.2.6 Physical Characteristics

The manual was bound with a comb binding and had a page size of 8.5 x 11 inches.

3.3.3 GammaMed GammaDot HDR Treatment Planning System Operator's Manual

3.3.3.1 Highlighting

Borders were used to give the reader cues for display examples, but not consistently. The only typographic cue was the use of boldface for titles, but this technique also was used inconsistently. Capital letters were used for abbreviations and acronyms, and quotation marks were used to highlight computer program input choices, a practice that could be confusing and distracting.

3.3.3.2 Graphics

The only illustrations were drawings of isodose representations (without explanation) and copies of VDT display pages. Procedures and program data needed more illustrated examples to minimize confusion about difficult treatment planning tasks.

3.3.3.3 Information Organization

The manual had a table of contents but did not have an index. Flow charts should have been provided for clarification of complex aspects of treatment program planning.

3.3.3.4 Language and Readability

Several typographical errors were found in this manual. Acronyms were used to abbreviate variables and methods and were kept to a minimum. The reading level was grade 13.

3.3.3.5 Legibility

Type size was 12 points, using serif style character fonts. Character spacing was fixed, making reading difficult, but sharp, black on white characters, and high contrast helped ease the reading effort. Line length was satisfactory at 5.5 inches. Right justification of text and fixed spacing made the manual difficult to read, particularly if operating the treatment planning computer.

3.3.3.6 Physical Characteristics

A standard 3-ring binding was used, with a page size of 8.5 x 11 inches.

3.3.4 Nucletron Brachytherapy Planning System User's Manual

3.3.4.1 Highlighting

The only typographic cues provided as highlighting for the reader were boldface and capital lettering of displayed text from the screen and underlining of section headings. These methods were so extensively used that they risked losing their impact.

3.3.4.2 Graphics

Illustrations were of good quality, with helpful examples of dose points and orthogonal reconstructions. Procedures and program data needed more illustrated examples to minimize confusion about difficult tasks. Related text and graphics did not appear together. An appendix section defining VDT color codes was useful but would be improved by color examples.

3.3.4.3 Information Organization

A table of contents was provided, but it confused readers by intermingling operational and engineering design information. The manual did not have page tabs or other sectional separation or an index. One or the other would have been of great benefit. Diagrams or visual aids were not provided for clarification of the treatment planning process. This manual was cited by users as being so difficult to follow as to be of little practical value.

3.3.4.4 Language and Readability

Sentence structure was lengthy and required extensive knowledge of the technical area. The reading level was grade 13.

3.3.4.5 Legibility

Type size was 12 points, using several serif fonts; however, the non-proportional spacing of text required extra effort in reading. The print was sharp and clear and line length was acceptable at 5.25 inches. Right justification of text in addition to the non-proportional character spacing made the manual difficult to read and scan for information.

3.3.4.6 Physical Characteristics

The binding was standard 3-ring, with a page size of 8.5 x 11 inches.

3.3.5 Nucletron microSelectron-LDR/MDR User's Manual

3.3.5.1 Highlighting

Open space was used to separate text or give the reader cues for different tasks and procedures, and borders were used to highlight error codes. The only typographic highlighting cues provided for the reader were underlining and capital letters for section headings. These methods were overused, reducing their influence on the reader.

3.3.5.2 Graphics

Illustrations were of good quality, but additional illustrated examples of procedures and program data would have helped reduce confusion about difficult tasks. A preventive maintenance checklist was provided.

3.3.5.3 Information Organization

A table of contents was included but there was no index. Flow diagrams or visual aids were not provided for clarification. Engineering design and operational materials were discussed in the same sections of the manual.

3.3.5.4 Language and Readability

Acronyms were used to abbreviate variables and methods. The reading level was grade 10.

3.3.5.5 Legibility

Type size was 10 to 12 points, using elite style fonts. Overall, the type size was too small. Fixed character spacing decreased the effectiveness of presentation, although the character sharpness for the printed text and an acceptable level of contrast helped ease the reading effort. At 6 inches, line length was slightly too long for ease of scanning and reading.

3.3.5.6 Physical Characteristics

The binding was a non-standard 4-ring, with a European page size of 8.25 x 11.5 inches.

3.3.6 Nucletron Selectron-LDR/MDR User's Manual

3.3.6.1 Highlighting

Color was not used to highlight text or illustrations, but white space was used to separate text or give the reader cues for different tasks and procedures. Borders were used to highlight notes and special information for the reader. Underlining and capital letters for section headings were the only typographic cues provided, and these methods were overused, reducing their impact.

3.3.6.2 Graphics

Illustrations were of good quality. Procedures and program data needed more illustrated examples to minimize confusion about complex tasks.

3.3.6.3 Information Organization

A table of contents was provided, but not an index. Engineering design and operational materials were intermixed in the same sections of the manual. While there were no diagrams or visual aids for clarification of treatment program planning and control, a preventive maintenance checklist was included.

3.3.6.4 Language and Readability

The reading level was grade 10.

3.3.6.5 Legibility

Font type size was calculated to be 10 to 12 points, too small for ease of reading. Elite style fonts were used, and the fixed character spacing made reading difficult, although the absence of right justification helped. Character sharpness and an acceptable black on white contrast ratio helped ease the reading effort. Line length was about 6 inches.

3.3.6.6 Physical Characteristics

The binding was a non-standard 4-ring, with a European page size of 8.25 x 11.5 inches.

3.3.7 Nucletron microSelectron-HDR User's Manual

3.3.7.1 Highlighting

Red print was used effectively to highlight warnings and precautions, and open space was used to separate text or give the reader cues for different tasks and procedures. Borders were used to highlight notes, warnings, cautions, and tables. The typographic cues included bold lettering and capital letters to identify VDT displays.

3.3.7.2 Graphics

Illustrations were of good quality, with helpful photographs and line drawings of equipment and auxiliary devices.

3.3.7.3 Information Organization

The manual had a table of contents and page tabs to separate sections. However, tabs were labeled with the section number rather than the title, requiring the reader to refer to the table of contents, thus defeating the purpose of section tabs. An index of pertinent information was provided before each section. This manual had the best organization of all user manuals evaluated.

3.3.7.4 Language and Readability

Sentence structure was acceptable and minimized technical jargon. The majority of the instruction was stated in the active voice. Acronyms were appropriately used to abbreviate variables and methods that were described. The reading level was grade 9.

3.3.7.5 Legibility

Font type size was very small, from 9 to 10 points, depending on the section. Effective, proportional spacing of text was used, but character sharpness was fuzzy, and right justification of text spacing made following instructions more difficult. Line length was a comfortable 3 inches.

3.3.7.6 Physical Characteristics

The manual used a three ring binder, with a page size of 6 x 8.25 inches. This size was convenient for use in cramped workspaces.

3.3.8 Summary of Findings

Table 5 summarizes the findings of the user manual evaluation.

3.3.9 Site Visit Comments on User Manuals

Given their overall poor quality, the manuals were not used extensively on site. In fact, most brachytherapy personnel were not even aware of the existence of many of the manuals and had trouble locating the others. At best, the manuals were occasionally reviewed when specific information about an aspect of system operation was needed, such as to interpret the meaning of a system error code. Although manuals were often the only reference available on site that could be used by staff to interpret the numeric error codes reported by many RAB devices, they were not always accessible to the users presented with those codes. Users were often observed to rely on memory of a few frequently seen codes and to redo entry procedures rather than to identify the exact meaning of the error codes. Manuals were almost never used in conjunction with clinical treatment, treatment planning, or quality assurance activities. They were occasionally used as aids in learning or recalling RAB procedures.

The lack of use of the manuals by RAB staff cannot be attributed solely to manual quality, since even the best manual (that for the Nucletron microSelectron-HDR afterloader) was infrequently used. RAB requires trained, skilled personnel to perform complex operations in a short amount of time, leaving little time to refer to the manuals. For the most part, personnel had learned to use RAB systems from one another through informal, on-the-job training rather than from manuals and were accustomed to seeking information on RAB from people rather than from written references.

Better documentation would be welcomed by RAB system personnel. Even the expert users reported that they would like to refer to documentation from time to time, to check an unfamiliar system response or to recall an infrequently used action.

3.4 Workspaces

Another major type of HSI is the workspaces in which RAB functions and tasks are performed. Here, the emphasis was placed on the relationship between the physical characteristics of the workspace and the ergonomic characteristics of the personnel who perform tasks within these workspaces. However, even workspaces that are poorly matched with their users are unlikely to be the primary cause of an error; in daily operation, users learn to adapt to workspace problems. However, poor workspace design is certainly a risk factor that can increase the chances of an error, particularly when other problems are also present.

Table 5. Summary of User Manual Findings

Factor	Characteristic	Finding
Highlighting	Color	Only one manual used color: red for warnings and precautions.
	Open (White) Space	Open space was widely used to highlight information, but not consistently.
	Borders	Borders were used extensively, but indiscriminately.
	Typographic cueing	Underlines and capital letters were not consistently used, compromising their effectiveness.
	Type size	Type size ranged from 9 to 12 points. The smaller of these made reading difficult.
Graphics	Clarity	Older manuals had fuzzy pictures. More recent manuals had very clear graphic reproductions.
	Subject matter focus	Older manuals had simple pictures and copies of engineering line drawings. Newer manuals added helpful graphics on concepts such as x-ray magnification, isodose curves, and optimization.
	Proximity	Proximity of graphics to text was a problem with older manuals, but was improved as modern graphics techniques were used. For example, modern word and graphics processing equipment permits graphics reduction to fit small areas near text and text to flow around graphics.
Information Organization	TOC/Index and Headings	Tables of contents were brief, sketchy, and not as detailed or informative as they could have been.
	Separators and dividers	Only one manual provided physical separation between sections.
	Flow diagrams	More and better flow diagrams are needed in all manuals, especially to aid the treatment planning system user.

Table 5 (continued)

Factor	Characteristic	Finding
Language and Readability	Simple, short sentences and active voice	Language was not a problem for the highly educated audience, but short, simple sentences and direct, active voice would aid retention and location of material.
	Abbreviations	Not widely used; meanings well understood by the specialist user of RAB equipment.
	Reading level	Reading level was not a problem for the educated users, but it could be reduced to enhance ease of understanding. The best manual was written at the grade 9 level.
Legibility	Type style	The sans serif style was satisfactory in the larger type sizes, but serif styles are superior for reading ease, especially in smaller print.
	Proportional or fixed type	Fixed character spacing was commonly used in the manuals and was very difficult to read, especially when combined with right justification.
	Contrast and sharpness	The manuals had excellent black on white contrast. Older manuals displayed some fuzzy printing due to nonprofessional photographic reproduction, but newer versions were greatly improved.
	Line length	Line length of most manuals was slightly longer than recommended, but was not a major problem.
	Justification	About half the manuals were right justified. Right justified text, especially when combined with fixed character spacing, was hard to read or scan.
Physical Properties	Binding	Manuals were properly bound so that they would stay open when laid on a flat surface.
	Manual size	Most manuals were printed on standard U.S. letter size paper. A few were larger in accordance with European standards, but size usually was not a problem in the RAB workspaces. One manual used a smaller size that appeared to be convenient for use in a crowded workspace.

To approximate the range of body sizes likely to be found among RAB staff, anthropometric reference measurements were used. Design limits are generally based on a range of user population from the 5th percentile to the 95th percentile; this range theoretically provides coverage for 90 percent of the users. The low end of the range was represented by a 5th percentile 40-year-old Japanese female (i.e., an individual who is smaller than 95 percent of persons who have some of the smallest average measurements). The high end of the range was represented by a 95th percentile 40-year-old American male (i.e., an individual who is larger than 95 percent of persons who have some of the largest average measurements). Taking stature as an example, this percentile range corresponded to heights ranging from approximately 4 feet, 11 inches to 6 feet, 3 inches (NASA-STD-3000).

The procedures for high and low dose rate RAB were considered to impose such substantially different requirements on the workspaces that they were analyzed separately. Simulation and treatment planning workspaces, however, are uniform for both high and low dose rate RAB, so these have been reported together.

In addition, the relationship of these workspaces to each other was examined. In this analysis of the overall workspaces, the arrangement of key RAB areas was examined with respect to their functional collocation, circulation patterns, and separation distances. The extent to which RAB workspaces were used for other purposes was also determined.

3.4.1 Simulation

3.4.1.1 Workspace Layout

The majority of sites (19/23) for which workspaces were analyzed had a dedicated simulation room and simulation control area separate from the treatment and treatment control areas. One additional site performed simulations for endobronchial RAB treatments in a separate, dedicated area; simulations for the more common gynecological RAB treatments at that site were performed in the treatment room. The other three sites examined performed all simulations in the same room as RAB treatments.

The human factors assessment of simulation and simulation control workspaces, reported below, has been based on data from the dedicated simulation and simulation control workspaces only. The assessments of the layout of workspaces in which simulation is performed in the same workspace as treatment are reported as part of the treatment and treatment control workspace assessments since the layout for combined workspaces must support both activities.

Essential equipment in the simulation control workspaces was considered to include a fluoroscope control panel and viewing screen, a simulator control panel, x-ray film viewers, visual and auditory patient monitoring devices, a work surface for completing forms, and storage for unexposed film, forms, patient records, etc. Simulation rooms were expected to contain a patient bed, simulator, and fluoroscope. If applicators were placed in the simulation room, storage for applicators, dummy sources, anesthetic, and other general medical supplies would be expected.

Accessibility of Equipment

In most sites examined, no problems were observed in the arrangement of the workspace to provide access to all of the critical controls and displays. In one site, access to the simulation control panel was restricted by an adjacent control panel. At most sites, the dark room was adjacent to the simulation control workstation, providing excellent accessibility for these functionally related work areas.

Compatibility of Staffing with Equipment Layout

The simulation control areas were all found to be arranged to permit a single operator adequate access to task relevant displays, controls, and auxiliary equipment. That is, one operator could manipulate the device controls, monitor the displays, and interact with the patient and medical staff in the area. A single operator was sufficient only because the fluoroscope control panel and screen, used for verifying patient and applicator position before the simulation films are taken, were not used at the same time as the simulator control panel. The lateral arrangement of the fluoroscope and simulation control panels made it difficult for a single operator to use both concurrently although pedal controls or movable pushbutton wands sometimes made it possible to control both devices from a single location.

Besides the technologist who operates the devices, additional personnel were often present in the simulation and simulation control workspaces, including physicians, nurses, and physicists. While most simulation control workspaces were large enough to accommodate several additional personnel, a few were so small that more than one extra person would be likely to interfere with the simulation operator. In at least two sites, two technologists were used during simulation. Their duties were coordinated and differentiated so that one dealt with the patient while the other operated the devices.

Furniture and Equipment Layout

The devices in the simulation control areas were typically found to be within the full view of the primary operator. All

Results

sites used a glass window between the simulation and simulation control rooms, permitting direct viewing of the patient during the simulation.

The layouts of the simulation control rooms were all adequate to accommodate voice communications among the staff. Intercoms in the simulation control areas were used to communicate with the patient in the simulation room.

In several of the simulation rooms, the space between the patient bed and adjacent walls or equipment was very constrained (13 inches at one site). Some simulation rooms were cluttered with apparatus that restricted equipment access and staff circulation patterns. This was most often the case when fluoroscope screens and control panels were located in the simulation room. Most simulation rooms were well organized and uncluttered. Cabling and other potential tripping hazards were minimized, and operators could move around the room and position themselves conveniently to perform necessary tasks.

In the simulation control rooms, the layout was generally adequate, providing operators with unrestricted physical and visual access to the simulation control units. In contrast, the placement of the simulation control panel at one site constrained visual and physical access to it. Maneuvering space in the simulation control rooms was generally adequate (40–50 inches) for the primary operator but was occasionally severely limited when several additional personnel were also present. Most control panels were arranged so that there were no gaps or unguarded openings. In the few cases where there were panel openings, the space behind the control panel did not allow easy access to hazards but tended to be used to store papers and user manuals.

Simulation control rooms tended to be functionally organized for ease of access by the various staff in the work area. Particularly at sites where two technologists and several medical staff were all present in this workspace, the device control panels tended to be at the far end of the simulation control room while the x-ray viewer tended to be at the other end, closer to the simulation room door. This permitted the control room to accommodate both the technologist (who produces the film) and the others (who review and analyze the film) in the same workspace without interfering with each other.

Document Organization and Storage

Few documents were found to be present in the simulation control workspaces. Most often the documents that were present included procedures and announcements posted on walls or bulletin boards, local forms, and patient log books. The documents were readily accessible to the users,

convenient to use, and well labeled. Staff at sites which used bulletin boards for posting data entry forms occasionally had trouble locating the current RAB forms in the ever-changing bulletin board topology. At a few sites multiple or outdated versions of data entry forms and procedures were found to be in use when older versions were not removed from their old (known) locations after the changes had been made. At several sites, a videotape recorder was used to record activities.

Spare Parts, Operating Expendables, and Tools

Supplies were usually found to be grouped functionally. Unexposed x-ray films were stored near the dark room. Film labels, tape, pencils, rulers, etc. were kept in the simulation control area near the x-ray viewer. Other medical supplies were likely to be stored in the simulation room itself. At some sites, RAB applicators and supplies were stored in another room and were brought to the simulation room as required. This permitted controlled, dedicated storage space for these specialty items, but they were less readily accessible. At one site, the labels were ambiguous and did not always clearly distinguish the tool.

Personnel Access

The simulation control workspaces all had intercoms and telephones to provide rapid access to supervisors and others in case of problems. Moreover, the workspaces readily accommodated voice communications among the staff present, who typically included the physician in charge of the case. At most sites, simulation control was in a room so that access by nonessential personnel was limited. At a few sites, however, the simulation control area was in a hallway, where access by nonessential personnel could not easily be limited and could be a distraction.

3.4.1.2 Workstation Ergonomics

Simulation control workstations tended to be designed as stand-up or as sit-stand workstations. Only one sit-down workstation was observed. The ergonomic properties of each of these workstations was evaluated with respect to established HFE guidelines for the design of consoles. Anthropometric reference measurements were used for a 5th percentile female and for a 95th percentile male.

Stand-Up Workstations

The stand-up workstation configurations were found to be within the reach envelope of the 5th percentile female as well as the 95th percentile male. The control panels were about 40 inches high, sloped, with sufficient clearance from the front panel to minimize inadvertent activation.

The controls and panel displays were positioned well so as to provide an adequate viewing angle for both the 5th percentile female and the 95th percentile male without restricting visual access to the window to the simulation room. Lateral spread of controls and displays was adequate (approx. 19 inches) since only one panel (fluoroscope or simulator) was in operation at a time. Visual access to wall mounted video monitors was adequate, but table-top mounted VDTs were found to be difficult for a 95th percentile male to view comfortably at an acceptable viewing distance—requiring him to sit. Foot room was found to be adequate for the stand-up workstations. One site used a protective metal box around the pedal used to activate the fluoroscope.

Sit-Down Workstations

The single sit-down simulation control workstation examined was essentially a video display terminal workstation, with two VDT displays and a keyboard control panel mounted on a desktop. The viewing distance was adequate (18–24 inches) for the 5th percentile female and the 95th percentile male. The VDT viewing angle was acceptable, even though the screen was low for a 95th percentile male. The screens were adjustable so that they could be angled toward the operator. Adequate leg and knee room was provided under the table, and writing space was available.

Sit-Stand Workstations

Some sites adopted a sit-stand configuration for the simulation control workstation. The controls were found to be within the reach envelope for a 5th percentile female and a 95th percentile male in both sitting and standing positions. The displays were positioned so that the viewing distance and the viewing angle were adequate for the 5th percentile female standing or sitting and for the 95th percentile male sitting. The viewing angle was too large for the 95th percentile male standing. Adequate leg and knee room was provided underneath the table or console.

Desk/Work Area Dimensions

Most of the sites provided some desk space either at the simulation control workstation or nearby. The work areas were adequate for task-related records and forms (approx. 16 x 30 inches). The height of the work surfaces was acceptable.

Use of Records and Reference Materials

Other locations were also available in the simulation control room at some sites as work areas where records and reference materials may be consulted. It was particularly

valuable for the medical staff who were not directly involved in producing the simulation films to have a separate work area so as not to interfere with the technologist operating the control panels. Local job performance aids were common in the simulation control workspaces and, to a lesser degree, in the simulation rooms. Most often, these were posted procedures or checklists. Other job performance aids included stick-on labels to identify x-ray films, tables of recommended exposure settings, and magnification references.

Chairs

Chairs and stools were seldom used in the simulation control area (even if available) and were only rarely used in the simulation room. If provided, chairs tended to swivel, to have 4–5 wheels or casters, to provide a backrest but no arm rests, and to be cushioned. The chairs provide operators with a mobile and comfortable working position, but they were clearly not intended for prolonged use.

3.4.1.3 Multi-Unit Control Workspace

The simulation and simulation control workspaces contained both fluoroscope and x-ray units, and these devices differed from one simulation room to another even within the same site. Operation of these devices did not interfere with each other, because they were used sequentially in different phases of the simulation task by the technologist. Each device had its own set of procedures and its own unique equipment. As a result, there was minimal mutual interference.

3.4.1.4 Emergency Equipment

Operator Protective Equipment

Protective equipment for the staff included film badges, which were checked periodically according to site policy. Lead aprons were also provided for personnel who remained in the room during fluoroscopy and x-ray.

Fire, Radiation, and Rescue Equipment

Fire extinguishers were usually readily accessible in simulation control areas. Little other radiation or rescue equipment was present in the immediate vicinity of most simulation and simulation control workspaces.

Emergency Equipment Storage

At sites where applicators were inserted in the simulation room, medical emergency equipment that might be needed,

Results

such as life support equipment, was present in the simulation room.

Safety Labels and Placards

Conspicuous safety warning labels and signs were found to be present at all sites.

General Workspace Hazards

Cabling and extraneous equipment were generally kept out of the operating area so that tripping hazards were minimal. Many sites provided step stools with a railing to aid patients in getting onto the bed. A problem was detected in one site where there was a ramp step-up from the hallway to the simulation room. Since the ramp was not visually detectable, it promoted falling or slipping by patients entering the room.

General Equipment-Related Hazards

No general equipment-related hazards were detected at any of the sites.

3.4.1.5 Environment

Temperature, Humidity, and Ventilation

These were adequate in all sites examined. Temperature, humidity, and ventilation were controlled centrally by the building air-conditioning system.

Personal Storage

Personal storage areas for staff were typically provided in the simulation control area. These storage areas were adequate to hold the notes and other personal material used by the staff during simulation.

Ambiance and Comfort

The general appearance and ambiance in the simulation workspaces was neat and orderly in all sites examined. Some sites added wall paper or murals to help the patients feel more comfortable.

Lighting

The sites visited tended to use overhead fluorescent lighting at adequate illumination levels (approx. 25 foot-candles). Several sites used supplementary incandescent lighting with an adjustable illumination level. Some sites used low level illumination during the simulation procedure in order to

keep the patient more relaxed, to reduce glare on the viewing window, and to maximize the visual contrast when reading the x-ray films. Since most control panels were transilluminated, low level lighting did not create a problem in viewing the displays, although labels and other printed characters were less visible. One site used such low level lighting (approx. 2 foot-candles) in the simulation room, however, that it was difficult to discriminate colors, to read characters, and to monitor the patient closely.

Some sites used glare reduction techniques such as egg crate luminaries and colored wall paper. Generally, glare was not found to be a problem because of matte finish on the control panels and work surfaces. One contrasting example was provided by an older control panel with a glossy finish.

Ambient Noise

In the simulation rooms, background noise levels were measured to range from 50–62 dB(A) (mean = 56 dB) due primarily to equipment fans, fluorescent lights, and background music. Background noise levels in the simulation control rooms were approximately 3–6 dB quieter. Voices (62–68 dB) were found to be easily detectable over the background noise level at both workspaces. Phones, voices from other personnel, and intercom paging were among the auditory distractions in the simulation control workspaces.

3.4.1.6 Communications Systems

Telephone Systems

Standard telephone sets were found in the simulation control workspaces. Most often, these telephone sets were wall mounted with sufficient cord length for the operator to remain at the simulation control panel while using the telephone. Typically, a telephone directory with emergency phone numbers highlighted was posted near the telephone. These directories often showed evidence of active updating (numbers were crossed out and re-entered) and some had single-touch buttons for frequently called numbers. In some cases updating had made a directory more difficult to use when old and new numbers were not readily distinguishable.

In many sites, this unit served as both an interoffice intercom and a telephone for outside calls. Other sites used two separate units, arranged side-by-side, for these functions.

Announcing Systems

Most sites also had a general announcing intercom system that was audible in the hallways and common areas. Such announcing systems were detectable in the simulation control workspaces.

Point-to-Point Intercom Systems

The simulation control workspaces typically included an intercom with which the operator could speak and listen to the patient in the simulation room. This intercom (with microphone) was typically located directly in front of the simulation control panel.

Video Monitoring Systems

Several sites used a video monitor in the simulation control workspace to observe the patient in the simulation room. This practice was not universal because of the viewing window which was more commonly used for patient monitoring.

3.4.2 Treatment Planning

3.4.2.1 Workspace Layout

The essential equipment in treatment planning workspaces include the computer, disk drives, screen, keyboard, light table, digitizer, printer, and plotter. Other planning system-specific devices, such as the Nucletron program card writer, may also be present. A telephone/intercom within the workspace is highly desirable. Various supplies, such as rulers, pencils, and tape, should be present. The workspace should also accommodate the storage of disks, program cards, printer and plotter paper, printer ribbons, plotter pens, planning system user manuals, dosimetry reference charts, and reference materials.

All of the sites had a treatment planning area for RAB. Most sites performing high dose rate RAB had dedicated RAB planning workstations (71%) – due to their use of specialized RAB treatment planning systems (e.g., Nucletron, GammaDot). The other sites used third-party treatment planning systems that could accommodate both brachytherapy and teletherapy. Some sites had two separate areas that could be used for RAB treatment planning. Typically, this was enabled by the use of a particular type of treatment planning system that allowed multiple workstation configurations (e.g., CMS or Theraplan). In a few cases, however, two different specialized RAB treatment planning workstations were present, reflecting that site's use of RAB systems from two different device manufacturers. In all of the sites performing low dose rate

RAB, the treatment planning system used was not unique for RAB. That is, low dose rate RAB treatments were planned using the same systems as were used to plan external beam or high dose rate treatments.

About half (54%) of the sites provided a dedicated treatment planning workstation; the other sites collocated the RAB treatment planning workstation in an office. Some (20%) of the dedicated treatment planning workstations were located in an open area (hallway); the other sites provided a separate room for treatment planning.

The human factors assessment, reported below, has been based on data from all of the treatment planning workspaces.

Accessibility of Equipment

The treatment planning workstations at all sites contained the necessary equipment, displays, and controls. In most sites (70%), fully redundant, dedicated workstations were provided for each planning system (viz., RAB and external beam teletherapy). That is, the treatment planning workstations were predominantly single-function, and their layouts differed. As a result of this tendency to have several, collocated single-function planning systems, available work area was limited. Nevertheless, most treatment planning workstations (60%) provided adequate accessibility to all components. When operator access was limited, it generally involved secondary devices (e.g., printers and plotters), equipment back panels and plugs, and supporting areas (e.g., book cases), none of which were integral to task performance. A potential problem in accessing the program card reader was observed at one site. Due to its placement, access would be difficult, particularly for a tall operator, and could pose a hazard (i.e., scratching a hand on the sharp edge of the table).

Compatibility of Staffing with Equipment Layout

The RAB treatment planning workstations were all suitable for single person operation. Moreover, the observed arrangements of separate treatment planning workstations within the same room permitted different operators to work independently without mutual interference.

While the layout of treatment planning workstations enabled a single operator to perform all necessary activities, it was common for other personnel also to be present. For example, the radiation oncologist may observe treatment planning while waiting to review and approve the treatment plan. All sites provided adequate space to accommodate one additional person; however, relatively small treatment planning workspaces at most sites could become quite crowded with more than one observer. In at least two sites,

Results

two persons were actively involved in treatment planning. The treatment planning work areas at these sites were adequate to accommodate the two operators.

Furniture and Equipment Layout

The primary devices at the treatment planning workstations (light table, VDT, keyboard) typically (80%) satisfied HFE guidelines for viewing by the operator. Visibility at some sites was hindered by the strict lateral arrangement of the light table and the computer work areas (both of which are 24–48 inches wide) so that when the operator was positioned at one of them, the other could not be seen easily. This made performance of some planning tasks more difficult and prevented planners at some of the sites from accessing feedback provided on the VDT during data entry. Some treatment planning workspace layouts successfully minimized this problem by adopting angled, L-shaped, or U-shaped configurations. If such configurations were not possible due to space or furniture constraints, improved viewing could be achieved by angling the computer screen(s) toward the operator's position at the light table. Such adaptations permitted the operator to remain in a central position while retaining good visual and physical access to primary displays and controls, but still required the operator to look away from the primary task to read the information displayed on the screen. The HFE requirement for the operator to be able to view printers and plotters from a central position was not a serious limitation in RAB task performance due to the secondary role of these devices in the treatment planning process. The layouts of the treatment planning rooms were all adequate to accommodate voice communications. Distractions from unrelated discussions, however, were more likely in sites where RAB treatment planning workspaces were shared with staff offices or with other workspaces operating concurrently. Telephones and intercoms were generally available for outside communications.

Most treatment planning workspaces (60%) permitted good operator access to all controls and displays without having to overcome obstacles. Several of the operator access problems that were observed involved the relative positioning of the computer table and light table. The computer tables were often arranged for seated operation, while the adjacent light tables required operators to stand. Other problems involved poor access to telephones or intercoms from the treatment planning workstations and poor placement of the computer central processing unit (CPU) beneath the workspace. Circulation patterns were generally adequate within the treatment planning workspaces. Due to the amount of equipment located in the same room, some problems were noted in accessing treatment planning workspaces when adjacent workspaces were staffed. Similar problems were observed when the RAB treatment planning workstation was positioned

directly inside the room door so that it was in the traffic flow making the operator vulnerable to interruption and interference.

Maneuvering space in the treatment planning workspaces was adequate for the primary operator but could become limited when several additional personnel were present. Most treatment planning workspaces were arranged so that there were no gaps or unguarded openings, and there were no instances where the openings created problems or permitted hazardous access.

Document Organization and Storage

Documents present in the treatment planning workspaces included notebooks containing local procedures, local forms and checklists, old x-ray films, physics reference material, and various user manuals. During a planning session current patient charts and x-ray films, and the charts, films and treatment plans for prior treatment fractions were added to the documents stored at the planning station. Various procedural summaries, reminders, and announcements were often posted on walls, bulletin boards, or on work surfaces directly. Most sites did not keep all of this material in the treatment planning workspace. At a minimum, however, user manuals for the treatment planning system and for other related devices (computer operating system, printer, etc.) were stored in this workspace. The documents were labeled on their bindings or folders but not on their shelves (so their absence would not be noticed). In most sites, the stored documents were accessible to the operators, convenient to use, and well organized. When document storage was unorganized, it was difficult for operators not only to find what they needed quickly, but also to keep documents from getting damaged. Even when labeled, documents can become inaccessible on crowded shelves. What may seem to be convenient storage locations, such as beneath tables, may instead restrict operator's access to important work surfaces.

Since documents specific to the current treatment plan moved through the workspaces and were rarely stored in the planning area, their location during a planning session was at the discretion of the individual treatment planners. This lack of a designated storage position for patient documents and the lack of a standardized labeling scheme to distinguish between x-rays and other documents used for different treatment fractions increased the chance of old charts or x-rays being substituted for current ones at some sites. Many of the sites, at which the caseload for teletherapy treatments was much higher than for brachytherapy, had instituted organized storage systems for teletherapy documents in which data for different treatment fractions were stored in separate color-coded notebooks to distinguish them from current patient data. A few RAB

sites had similar storage schemes for RAB treatment documents although the color code was often used to identify the patients of individual physicians rather than different treatment fractions for the same patient.

Storage of program cards, which can be used with one of the treatment planning systems, usually was casual. Program cards were found sitting on table tops, in drawers, or on other open areas.

Spare Parts, Operating Expendables, and Tools

Various expendables and tools used during treatment planning were generally found stored in this workspace. These included printer and plotter paper, printer ribbons, plotter pens, computer disks, rulers, pencils, and tape. These expendables and tools were typically stored at or very near the location of their use, providing excellent accessibility. The area available for storage, while minimal in some cases, was adequate. Cluttered and poorly organized supply storage made it harder for operators to find things quickly. The physicists and dosimetrists, who operated the treatment planning systems, were responsible for inventory and resupply.

Personnel Access

The treatment planning workspaces all had intercoms and telephones to provide rapid access to supervisors and others in case of problems. Moreover, the workspaces readily accommodated voice communications among the staff present, who often included a physician or senior physicist.

Because of the intensive mental effort (concentration) required during treatment planning, it seemed desirable to limit access by non-essential personnel. Since most sites provided dedicated treatment planning rooms, access by nonessential personnel could be limited. Organizational policy, however, may be more influential than workspace layout in limiting non-essential personnel access. In some sites, RAB staff and even patient family members were allowed to enter the separate treatment planning room and observe the treatment planning process. Other sites actively discouraged all non-essential personnel from entering the room during treatment planning. Nevertheless, when the treatment planning workspace was in an open hallway, access by nonessential personnel is not easily limited and could be a distraction.

3.4.2.2 Workstation Ergonomics

Most of the treatment planning workstations (primarily the computer and the light table) observed were intended for sit-down operation (86%). The others had clearly evolved into sit-stand workstations (14%), where operators used the

computer in a seated position and the light table in a standing position. None of the treatment planning workstations were designed for purely stand-up operation. The ergonomic properties of each of these workstations was evaluated with respect to established human engineering guidelines for the design of consoles.

Sit-Down Workstations

The sit-down treatment planning workstation configurations examined included one or two VDTs, a keyboard, a computer CPU with disk drives, and a light table with a digitizer. Other secondary devices, such as a printer, plotter, and program card writer, were present as well. In the sit-down configuration, the primary devices (VDTs/keyboard and light table) were adjacent and accessible by a seated operator. Most sites arranged these devices laterally (60%), while other sites (40%) used angled or L-shaped configurations. Angled and L-shaped configurations facilitated operator access to both the VDT/keyboard and the light table but limited accessibility to observers. Strict lateral configurations of these devices limited visual and physical access to them, since together they were too wide to remain within 45° of the operator's position. Several adjustments were possible to reduce this accessibility problem. The simplest was to angle the VDT toward the operator's position at the light table, while still permitting it to be viewed from the keyboard. Another type of adjustment was observed in which the VDT and keyboard were positioned above the light table. This permitted the primary devices to remain visually and physically accessible without requiring much head or body movement by the operator.

In all cases, the maximum height of the treatment planning workstations was low enough to permit announcements, reminders, and other job aids to be posted on the wall behind it. The height and depth of the control surfaces were found to vary somewhat, but all were within an acceptable range to accommodate the reach envelope of a 5th percentile female and a 95th percentile male. One particularly notable difference among the treatment planning workspaces concerned whether the light table was flat (40%) or sloped (60%) toward the operator. Sloped work surfaces were angled between 15–20°. Since the light tables tended to be 24–32 inches deep, there were substantial differences between flat and sloped configurations in terms of physical access (reach requirements) and visual access (parallax). When flat light tables were used, operators tended to lean over the work surface in order to improve their reach and to reduce parallax. When sloped light tables were used, operators were more likely to sit in a more comfortable, upright position and were less likely to need to adjust their position to prevent parallax errors during digitization. Light tables with steep slopes, however, created a problem in keeping

Results

pencils and papers from rolling off and in preventing x-rays from slipping downward during the digitization process.

The viewing distance to the VDT was adequate (14–26 inches, mean 20 inches) for a 5th percentile female and a 95th percentile male, even though the viewing distance varied depending on whether the operator was at the keyboard or at the light table. The VDT viewing angle was also acceptable. At sites where two VDTs were mounted vertically, however, a short person would have difficulty viewing the upper VDT and a tall person would find it hard to view the lower VDT.

The leg and knee room provided under the workstations was adequate at most sites (78%). In some cases, inadequate thigh clearance was available below the work surface. This was clearly a result of an attempt to compensate for the accessibility problems of a flat light table. In order to improve the operator's reach and reduce their parallax, the seat pan of the chair was raised. Unfortunately, it was raised too high relative to the table height, allowing as little as 4 inches for leg clearance. In other cases, the light box extended below the light table and interfered with leg room. Other sites constrained leg and knee room below the treatment planning workstation by the position of other objects, such as the computer CPU and reference notebooks.

Sit-Stand Workstations

In some sites, the treatment planning workstation had evolved into a sit-stand configuration. This configuration resulted from the flat light tables being 4–5 inches higher than the computer work surface and from their lateral (side-by-side) arrangement. So, operators sit while using the computer but stand while working at the light table.

The light tables were 30–32 inches high and 32 inches deep, requiring operators (5th percentile female and 95th percentile male) to stand and bend over them to maximize reach and minimize parallax. The light tables were sufficiently large to accommodate the x-ray films, other supplies, and reference material without interference. Foot room below the light tables was adequate for a standing operator.

The computer work areas were 26–27 inches high, which was acceptable for seated operators. All controls at the computer work area (keyboard, program card writer, printer/plotter controls) were arranged to be within the reach envelope of both a 5th percentile female and a 95th percentile male. The keyboard had an acceptable 10–15° slope. The VDTs were positioned so that the viewing distance and the viewing angle were adequate for a 5th percentile female standing or sitting and for a 95th percentile male sitting. The viewing distance and angle

were too large for the 95th percentile male standing. As a result, the VDT could not be viewed easily by a standing 95th percentile male who was moving back and forth between the computer and light table areas. Adequate leg and knee room was available underneath the tables.

Desk/Work Area Dimensions

Less than half of the sites (48%) provided some desk space near the treatment planning workstation. Typically (67%), this was merely a result of the treatment planning workstation being located in the physicist's office. In the other sites, the desk area was provided to support review and verification of treatment plans, examination of x-ray films, and miscellaneous record keeping. These desks provided adequate working surface, and the height of the work surfaces was found to be acceptable.

Use of Records and Reference Materials

Adequate space was available at all treatment planning workstations for writing and for positioning hard copy records or other reference material. In this way, operators would not be forced to lay notebooks and other records on top of the controls or films on the light table. Often this work space was on the desk near the keyboard. The table surface surrounding the illuminated portion of the light table was available at most sites.

Local job performance aids were common in the treatment planning workspaces. Most often, these were posted procedures, reminders, or checklists. Several sites also used references for the magnification factor of the x-ray film and daily tables of source decay.

Chairs

Several chairs were typically available (93%) in the treatment planning workspace. The chairs used by the treatment planning operators tended to swivel (85%), to have 4–5 wheels or casters (85%), to provide a backrest with some lumbar support, arm rests (62%), and to be cushioned. The seat pans were of adequate size, and they were adjusted to an appropriate height for the work areas.

3.4.2.3 Multi-Unit Control Workspace

Multiple treatment planning workstations could be located in the same room. Usually, separate workstations were used for RAB and for external beam treatment planning. These treatment planning systems were distinctly different in appearance and function. Operation of these systems did not interfere with each other because they were completely independent and located in separate areas of the rooms.

Each system had its own set of procedures and its own unique equipment.

In a few sites (30%), the same treatment planning system was used for both RAB and teletherapy. In such cases, multiple workstations were still present, so that two independent treatment plans could be developed concurrently. Output devices (printer and plotter) were generally networked to support both workstations on a common planning system.

3.4.2.4 Emergency Equipment

Operator Protective Equipment

Not applicable.

Fire, Radiation, & Rescue Equipment

None provided in most simulation and simulation control workspaces.

Emergency Equipment Storage

Not applicable.

Safety Labels and Placards

Not applicable.

General Workspace Hazards

Cabling and extraneous equipment were generally kept out of the operating area so that tripping hazards were minimal. At one site, however, a potential tripping hazard existed in the treatment planning workspace because of several pipes protruding from the floor. The pipes were remnants of equipment that had previously been located in that room. In several sites, the treatment planning room was used to store miscellaneous equipment (calibration jigs, etc.). While this equipment storage added clutter to the area and may restrict circulation patterns, it was not found to interfere with the treatment planning.

General Equipment-Related Hazards

No general equipment-related hazards were detected at any of the sites.

3.4.2.5 Environment

Temperature, Humidity, and Ventilation

Temperature, humidity, and ventilation were adequate in most sites examined. Temperature and humidity were controlled centrally by the building air conditioning system. One treatment planning room had temperature differential problems due to the amount of computer equipment operating in it. Here, floor fans had been installed to compensate for temperature differential and air flow problems.

Personal Storage

Personal storage areas for staff were adequate in the treatment planning workspaces.

Ambiance and Comfort

Adequate in all sites examined.

Lighting

The sites visited tended to use overhead fluorescent lighting at adequate illumination levels (approx. 24 foot-candles). Lower level illumination was generally desirable for treatment planning workspaces in order to maximize the contrast ratio for the VDT screen and the x-ray films on the light table. In fact, several sites controlled the illumination levels by turning on only some of the fluorescent light banks. At sites with windows in the treatment planning rooms, curtains or blinds had been installed to control the sunlight entering the room. When necessary, supplementary incandescent lighting was used. Some sites used glare reduction techniques such as egg crate luminaires, wall paper, and matte finished work surfaces.

Ambient Noise

In the treatment planning rooms, background noise levels were measured to range from 44–65 dB(A) (mean = 54 dB) due primarily to equipment fans, fluorescent lights, voices, and background music. Background noise levels in open treatment planning areas were considerably higher (53–73 dB), where intercoms, telephone ringing, voices, and other office sounds interfere. Task relevant speech (62–68 dB) and signal tones (64 dB) were found to be easily detectable over the background noise level. Carpeting and acoustic ceiling tile were found to be the most common methods used for sound absorption in treatment planning workspaces.

Results

3.4.2.6 Communications Systems

Telephone Systems

Standard telephone sets were found in most of the treatment planning workspaces (75%). Most often, these telephone sets were desktop models, and they could be reached and used easily from anywhere in the treatment planning workspace. Typically, a telephone directory with emergency phone numbers highlighted was posted near the telephone. In many sites, this unit served as both an interoffice intercom and a telephone for outside calls. Other sites used two separate units, arranged side-by-side, for these functions.

Announcing Systems

Announcing systems were audible in the hallways and common areas; sometimes they also were audible in the treatment planning areas.

Point-to-Point Intercom Systems

Intercom systems were typically integrated with or placed adjacent to the telephone set.

Video Monitoring Systems

None observed.

3.4.3 High Dose Rate RAB Treatment

3.4.3.1 Overall Workspaces

Functional Separation

The overall arrangement of the radiation oncology workspace was found to be separated into clinical and non-clinical areas in all sites examined. That is, the treatment areas were separated from the staff offices and other non-clinical areas. In most of the sites (81%), the workspaces involved in RAB treatment were contiguous, minimizing the need for patient movement during the course of treatment.

Multi-Function Workspaces

High dose rate RAB treatments are infrequent relative to external beam treatments, and available space is often limited. As a result, most sites choose to share the RAB workspaces with other treatment functions. While this makes more efficient use of available space, multi-function

workspaces necessarily contain more equipment and require coordination.

Few sites (19%) performed simulation and treatment in the same room. Most sites employed dedicated simulation rooms, which required the patient to be moved between the simulation and treatment rooms. Many sites (65%) shared the RAB treatment room and treatment control workspace with external beam treatments. Of course, both RAB and external beam would not be used concurrently; however, the equipment for both would still remain present.

All sites had dedicated storage sites for RAB supplies, applicators, connectors, etc. These were not mixed together with external beam or with general medical supplies. Typically (70%), RAB storage was centralized, either in the treatment room or in another area controlled by the physicists/dosimetrists.

Circulation Patterns

The overall areas were typically configured well, so few bottlenecks developed. In the few configurations where bottlenecks were evident, it was a result of workspaces and waiting areas being located in hallways or in major passageways so that they interfered with normal traffic circulation patterns.

Key RAB workspaces, namely treatment planning and treatment control, were examined to determine whether their configuration limited access by non-essential personnel. Most of the treatment planning workspaces could restrict non-essential personnel access (80%) since they were in separate rooms or offices. By contrast, most of the treatment control workspaces were located in open areas or hallways (65%) so that non-essential personnel access could not be limited and extraneous noises or simultaneous activities could be distracting.

Critical Distances

The distances between several workspaces that are important during RAB were measured at the sites visited. This provided an additional index of the overall suitability of the layout for RAB treatment. For purposes of this report, distances have been reported as near (0–50 feet), moderate (50–150 feet), or far (greater than 150 feet or on different floors).

Applicator Placement-to-Simulation

The distance between the location where applicator placement occurred and where treatment simulation took place depended largely on the type of RAB treatments performed. For example, esophageal and endobronchial

implants were typically done in the simulation area of the radiation oncology suites, while gynecological implants were often performed in the operating room. Nevertheless, most of the time (60%), applicator placement was performed in or near the simulation room. At other sites (15%), applicator placement occurred in the radiation oncology suite, and the patient was then transported to the simulation room. At the remaining sites (35%), applicator placement was usually performed in the operating room, and the patient was subsequently moved to the radiation oncology suite.

Simulation-to-Treatment

At about half of the sites examined (55%), the simulation room was near or adjacent to the treatment room. The remaining sites required the patient to be moved farther after simulation. No sites required patients to be moved a long distance prior to high dose rate treatment.

Physics Office-to-Treatment Control

It may be necessary to call a physicist or dosimetrist who is not present during treatment to the treatment control workspace in certain circumstances. At some sites (32%), the physics office was near treatment control. More commonly, it was located a moderate (47%) or far (21%) distance away.

Planning-to-Treatment Control

While the treatment planning workspace does not necessarily need to be near the treatment control area, patients and attending staff typically stand-by while the treatment plan is being developed, reviewed, and, if necessary, redone. Thus, it is somewhat beneficial for treatment planning to be near the treatment control workspace. Many of the sites (45%) located the treatment planning and treatment control workspaces near each other. The distance between them is moderate at many other sites (35%); only a few sites place these workspaces far apart (20%).

Waiting Area-to-Treatment Control

In several sites (41%), the family waiting area was near or adjacent to the treatment control workspace.

3.4.3.2 Treatment Rooms

Workspace Layout

A few of the sites examined (19%) used the same room for simulations and for RAB treatments. Most sites moved the

patient from a dedicated simulation room to the RAB treatment room. In most of the sites, the room used for RAB treatments was also used for external beam treatments at other times. The human factors assessment of RAB treatment workspaces, reported below, has been based on data from all sites.

Accessibility of Equipment

The RAB treatment room at all sites contained all necessary equipment, displays, and controls. Some sites, particularly free-standing clinics, retain various patient monitoring and emergency equipment, such as oxygen and heart monitor, in the treatment room. A few sites kept bronchoscopy carts and video recording equipment in the treatment room as well.

Accessibility to RAB equipment in the treatment room was generally good. Often, it was functionally arranged so that all RAB equipment and supplies were located together. The presence of other devices in the room created a crowded appearance and restricted access to certain equipment or supplies in a few sites. At one site, the emergency storage container, or "pig," ended up on the opposite side of the room from the afterloader and was partially hidden by drapes. The emergency stop button was well positioned in all sites; several positioned it immediately inside the treatment room door. The management of power cables varied quite a bit between sites. In some, the cables were positioned to remain out of the way of foot or equipment traffic. At others, the power cables themselves limited access to certain areas or were tripping hazards.

Compatibility of Staffing with Equipment Layout

The treatment room layouts were all found to accommodate the necessary staff. In some sites, the various equipment and supplies within the room were arranged so that the personnel involved with the patient and with the simulator or afterloader had separate workspaces.

Furniture and Equipment Layout

The layouts permitted good visibility throughout for personnel in the treatment room. A few sites had taken steps to provide visual access to the radiation monitor panel from the L-shaped corridor inside of the treatment room door but outside of the treatment area. The radiation monitor was positioned to be visible from both the entry corridor and the treatment area at several sites; another site with a longer corridor provided a fish-eye mirror at the end of the corridor so that the radiation monitor in the treatment area could be seen from the corridor entrance. The visual clues provided by the monitor in the treatment area and the mirror were different. In the treatment area, the red light of

Results

the monitor was visible as a change in the color of ambient lighting. In contrast, the monitor appeared as a localized point source of red light in the mirror. Different staff monitoring procedures were therefore required to detect radiation from the corridor and the treatment area. The image of the monitor in the mirror was different from the visual appearance of the actual monitor. However, the prominent position of the large mirror at the end of the otherwise bare corridor combined with the dim corridor lighting to focus staff attention on the mirror and any reflected lights during entry.

Sites used lights outside and above the treatment room door to indicate that treatment was in progress. Unfortunately, these lights were located too high (approx. 8 feet above the floor) to be within the field of view for personnel entering the room.

The layout of the treatment rooms were all adequate to accommodate voice communications among the staff and patient. Intercoms were used to communicate with the patient from the treatment control workspace during treatment.

The treatment rooms provided adequate access to the patient, equipment, and supplies. Depending on how the patient bed and the equipment were arranged, there could be limited clearance, restricting staff circulation paths. A few treatment rooms were cluttered with apparatus that restricted equipment access and staff circulation patterns.

Document Organization and Storage

Few documents were found to be present in the treatment rooms, so no document storage areas were required. Materials that were present included posted procedures and job aids.

Spare Parts, Operating Expendables, and Tools

Most sites stored the various RAB supplies (source guide tubes, applicators) in their treatment rooms. The other sites stored the RAB supplies in special rooms away from the treatment workspace.

The supply of applicators was found to be adequate at the sites examined. Due to the replacement cost of applicators, many were cleaned, sterilized, and reused. Some sites had developed effective ways to organize and label these RAB supplies. Well labeled, separate drawers or bins were found to be a particularly effective way to organize the many RAB applicators, some of which appear very similar to each other. Several sites used wall-mounted storage racks

to hang the source guide tubes when not in use⁸. These storage racks were mounted so that the source guide tubes (a) would hang down but not touch the floor and (b) permit a standing 5th percentile female and a 95th percentile male good visual and physical access to the connectors at the top of the source guide tubes. At other sites, however, the RAB supplies were poorly organized and not labeled. Often, the RAB supplies were simply stored together in an unorganized drawer or cabinet. In these cases, and in others in which distinguishing marks on similar items were on packaging that might be removed prior to use, there was an increased opportunity for staff to make substitution errors when selecting these items.

Various tools were found stored in or near the afterloader. One site even made special adaptations to its afterloader so that emergency tools and other functionally related supplies could be mounted on it. Special equipment used during RAB quality assurance procedures was often stored in the treatment room. This adds clutter to the treatment room and could restrict access to other equipment; however, storing this quality assurance equipment in the area where it will be used is probably beneficial overall.

Inventory and resupply of the RAB and other medical supplies was found to be handled differently at the sites visited. At some, a nurse was responsible for these duties, while at others the chief technologist or physicist took care of inventory and resupply. Another work breakdown divided the duties so that the nurse took care of the general medical supplies and the physicist or dosimetrist took care of the RAB supplies. Only a few sites used a log or other systematic means to keep track of the RAB supplies used.

Personnel Access

Since most of the essential staff were present during RAB treatments, there was ready access to supervisory personnel and to other experts in case of problems. In addition, intercoms and telephones provided rapid access to supervisors and others in case of problems. The physical layout of the treatment room inherently limited access by nonessential personnel.

Workstation Ergonomics

Treatment room workstations were designed for stand-up operations. The ergonomic properties of each of these workstations was evaluated with respect to established human engineering guidelines for the design of consoles.

⁸Some sites preferred not to hang source guide tubes to prevent them from stretching out of tolerance.

Anthropometric reference measurements were used for a 5th percentile female and for a 95th percentile male.

Stand-Up Workstations

Afterloader controls and connectors can be easily reached and viewed by the reference user population. The height of many of the afterloader controls was adjustable to meet patient positioning requirements. For the most part, these controls were found to be easily viewed and reached; however, simulator controls located above the patient's bed were too high for a 5th percentile female to reach without the aid of an 8 inch (minimum) step stool. Simulator controls mounted under the patient bed or on separate panels provided more general physical and visual accessibility.

Use of Records and Reference Materials

Most of the sites provided some open space on a counter in the treatment room that could be used for writing or for temporary positioning of patient records or other reference materials. These work areas provided adequate open space, and their height was found to be acceptable for standing use by a 5th percentile female and a 95th percentile male.

A few local job performance aids were found in the treatment rooms. Most often, these were posted operating or emergency procedures. Other job performance aids were generally associated with the simulator. These aids included such things as wires taped in place to serve as reference crosshairs or reminders about how to position the x-ray film.

Chairs

Seating was rarely present in the treatment room. If provided, seating tended to be a single stool with a padded, swivel seat and a 4-wheel base. The stools provided operators with a mobile yet stable working position.

Multi-Unit Control Workspace

All treatment rooms included other devices in addition to the RAB afterloaders. These other devices were fluoroscopes and simulators, if a combined simulation/treatment room configuration was used. More commonly, an external beam treatment unit was also present. These different devices were distinctly different in appearance and function from the afterloader. Operation of these devices did not interfere with each other because they were not used concurrently. Each device had its own set of procedures and its own unique equipment. As a result, there was minimal interference between devices.

Even in the sites that had two high dose rate afterloaders in the same room, the unique and independent equipment minimized the potential interference between them.

Emergency Equipment

Operator Protective Equipment

Protective equipment for the staff included film badges, which were checked periodically according to site policy. Lead aprons were also provided in many sites. One site also provided lead shields in the treatment room. When the afterloader was not in use, the shields were used to isolate the unit. During RAB treatments, the shields were positioned on the door side of the afterloader so that the operator would be protected somewhat when entering the room in an emergency.

Fire, Radiation, and Rescue Equipment

Radiation monitors and emergency stop buttons were provided in all treatment rooms examined. The radiation monitors were mounted at eye-level or higher and were visible from anywhere in the treatment room. A few sites provided additional emergency stop buttons in the treatment room so that one would be accessible to operators regardless of their location.

Emergency Equipment Storage

Fire extinguishers were usually present and readily accessible. An emergency source container, or "pig," was present at all sites, but was clearly more accessible in some treatment rooms than in others. In some treatment rooms, it was painted to promote visibility and was positioned near the afterloader. At other sites, it was on the opposite side of the room from the afterloader or was partially hidden by other apparatus.

Safety Labels and Placards

Conspicuous safety warning labels and signs were found to be present at all sites.

General Workspace Hazards

Cabling and extraneous equipment were generally kept out of the operating area so that tripping hazards were minimal. Many sites provided step stools with a railing to aid patients in getting onto the bed.

Results

General Equipment-Related Hazards

Door interlocks were provided at all sites so that treatment could not begin (or continue) if the treatment room door was not closed completely. Several sites used temporary labels to assure that critical plugs would not be removed. One site painted the face plates for the electrical outlets red as an aid to locating them. It is possible that the red outlets became an implicit color code in addition to a location aid. If this occurs, it is important that all personnel understand this code. Given that red is widely associated with either an actual or potential hazard, this shared understanding should not be difficult to achieve.

Environment

Temperature, Humidity, and Ventilation

Temperature, humidity, and ventilation were adequate at all sites examined and were controlled centrally by the building air-conditioning system.

Personal Storage

Personal storage was adequate at all sites examined. Curtains were provided at some sites to provide some privacy for patients while they changed clothes.

Ambiance and Comfort

Ambiance and comfort were adequate at all sites examined. Some sites added wall paper or murals to help the patients feel more comfortable. Radios and tape players were present at several sites so that relaxing music could be played for patients during treatment sessions.

Lighting

Adequate illumination levels (16–40 foot-candles) were observed in the treatment rooms. Several sites used supplementary incandescent lighting with an adjustable illumination level. Some sites used low level illumination during treatment in order to keep the patient more relaxed. Operating room lights were present at several sites for use during applicator placement.

Ambient Noise

In the treatment rooms, background noise levels were measured to range from 41–60 dB(A) (mean = 50 dB) due primarily to equipment fans, fluorescent lights, and background music. Voices (62–68 dB) were found to be

easily detectable over the background noise level. No intermittent auditory distractions were noted.

Communications Systems

Telephone Systems

Standard telephone sets, which served as an interoffice intercom and a telephone for outside calls, were found in a few of the treatment rooms. When present, these telephone sets were wall mounted with an adequate cord length.

Announcing Systems

General announcing intercom systems that were audible in the hallways and common areas were not detectable in the treatment rooms.

Point-to-Point Intercom Systems

The treatment rooms all included an intercom with which the operator in the treatment control workspace could speak and listen to the patient in the treatment room.

Video Monitoring Systems

Most sites used two video cameras in the treatment room to observe the patient during treatment. One of the cameras typically remote controlled zoom, pan, and focus. All sites used at least one camera for monitoring patients during treatment.

3.4.3.3 Treatment Control Workspaces

Workspace Layout

Essential equipment for the RAB treatment control workspace included: the treatment control panel, the emergency stop switch, an audio intercom, and a video monitor to the treatment room. Keys to activate various control panels must also be at (or be brought to) this workspace. In addition, a telephone and office intercom, x-ray film viewer, and warning signs on the treatment room door were present. Adequate and convenient storage space was provided for user manuals, checklists, and patient record books.

Some of the sites examined (19%) used the same control workspace for simulations and for RAB treatments. The other sites moved the patient from a dedicated simulation room to the RAB treatment room. In most of the sites, the RAB treatment control workspace was also used for external beam treatment control at other times. The human

factors assessment of RAB treatment control workspaces, reported below, has been based on data from all sites.

Accessibility of Equipment

The RAB treatment control workspaces at all sites contained all necessary equipment, displays, and controls. The emergency procedures were not posted at a few of the sites, although they were available for reference somewhere in the workspaces. Access to the emergency stop button was found to be restricted at a few sites. This was generally due to sub-optimal placement of the button panel so that it was difficult to reach for either a 5th percentile female or a 95th percentile male.

Compatibility of Staffing with Equipment Layout

Most of the treatment control workspace layouts were arranged so that a single operator could monitor both the treatment control panel and the patient (via audio intercoms and video monitors). The other sites were arranged so that it would be difficult for an operator to view the video monitors while positioned at the treatment control panel. These arrangements, therefore, require at least two operators—one to monitor the treatment control panel and the other to monitor the patient. The treatment control areas at all sites were large enough to accommodate additional personnel who may be present during RAB treatments.

Furniture and Equipment Layout

The layouts generally permitted good visibility of the displays in the treatment control workspace. At several sites, the radiation monitor was positioned to be seen from the treatment control workspace from just inside the treatment room door. Several sites used lights outside and above the treatment room door to indicate that treatment was in progress. Unfortunately, these lights were typically located too high (approximately 8 feet above the floor) to be within the field of view for personnel entering the room.

The layout of the primary treatment control areas were all adequate to accommodate voice communications among the staff. The layout at a few sites, however, made it difficult for the operator at the RAB treatment control panel to communicate with someone standing at the treatment room door. Intercoms were used to communicate with patients.

The treatment control workspaces were generally arranged to provide good operator access and maneuvering space. In a few cases, workspace problems were observed, however. These involved placing the afterloader control unit too close to a side wall or an adjacent workspace, limiting room for manuals, etc.

Document Organization and Storage

Most sites used shelves and bulletin boards to store various types of documents in the treatment control workspace. Typical documents found included phone directories, user manuals, operating and emergency procedures, log books, and patient record files or notebooks. These documents were usually labeled and were located for convenient use.

Most sites used color coding schemes for their patient records. Often, colors were used to identify the radiation oncologist treating the patient. Color coding was also used to identify which RAB fraction was being administered. Occasionally, the different colors on folders or notebooks had no corresponding meaning whatsoever.

Spare Parts, Operating Expendables, and Tools

Various tools and expendable supplies (such as paper tape) were often found stored in drawers near the afterloader control unit. Although drawers and cabinets were plentiful at several sites, they often were not labeled. Inventory and resupply was handled by the staff who operated the afterloader control unit—the technologists, dosimetrists, or physicists.

Personnel Access

Since most of the essential staff were present during RAB treatments, there was usually ready access to supervisory personnel and to other experts in case of problems. In addition, intercoms and telephones provided the opportunity for rapid access to others outside of the workspace. In a few instances treatment was observed to be delayed while staff needed to approve or monitor the treatment were located and brought to the workspace. These delays were the result of decisions by the facility administration to staff multiple workstations for different treatments with the same supervisory personnel rather than to any characteristic of the workstations themselves.

The location of the treatment control workspace at many sites inherently limited access by nonessential personnel, since it was in an out-of-the-way area. At the other sites, treatment control was in an open or unrestricted area, such as in a hallway. Curtains were used at a few sites to limit access from adjoining high traffic areas. At a few sites, due perhaps to the novelty of RAB treatments at sites with low RAB caseloads, the patient was accompanied by enough individuals not involved in the RAB treatment to block the flow of communications between RAB staff during the treatment.

Results

Workstation Ergonomics

The ergonomic properties of the treatment control workstations were evaluated with respect to established human engineering guidelines for the design of consoles. The person who operated the afterloader control unit was considered as the primary operator, even though other personnel were typically present in this workspace to monitor the patient during treatment. Anthropometric reference measurements were used for a 5th percentile female and for a 95th percentile male.

Most of the treatment control workstations examined were designed for seated operations. Others were designed as sit-stand workstations. Regardless of configuration, most operators were found to adopt a standing position.

Sit-Down Workstations

The work surfaces at the sit-down workstations were generally 30 inches high. This enabled seated operators to view the displays from an acceptable distance (14–18 inches for a 5th percentile female; 18–24 inches for a 95th percentile male) and to reach the primary controls. In a few sites, the work surface was deep enough that a 5th percentile female would need to lean forward in order to reach wall-mounted controls, such as the emergency stop button. The viewing angles were found to be acceptable for both VDT and table top style control panel displays. Viewing angle and distance for these workstations were, however, found to be excessive if operators were standing.

The operator's chairs generally provided good mobility, with a swivel seat and a caster base (the somewhat less stable four caster base was found to be most common). In a site where a non-mobile chair was used, carpeting further restricted the operator's ability to move into and out of the chair quickly and safely. Standard seat heights (18–19 inches) provided adequate knee and thigh clearance below the work surface. Back rests and cushioning provided adequate operator comfort. Arm rests were rarely used so that they would not restrict operator access to the controls. Leg room below the work surfaces was adequate at all sites.

Sit-Stand Workstations

The work surfaces on which the RAB control panels were mounted for sit-stand workstations were 36–38 inches high. This height provided adequate viewing distance and viewing angle of the controls and displays on the RAB control panels for both a 5th percentile female and a 95th percentile male in either a sitting or standing position. The RAB control panel and other related panels, such as the emergency stop button and the intercom controls, were within the reach envelopes of both a 5th percentile female

and a 95th percentile male from their working positions. Sloped panels facilitated operator viewing and reach.

Chairs for the sit-stand workstations had the seat pan adjusted to a high position so that operators' eye height was approximately the same from either a seated or standing position. These chairs provided adequate operator comfort by a foot rest to compensate for the additional height, cushioning, and small back and arm rests. Adequate mobility was provided by swivel seats and by casters. A five caster base provided good stability for the high chairs.

Beneath the work surface, foot room was found to be adequate for standing operators. Storage below the work surface, however, restricted or eliminated knee and leg room for seated operators. While operators could, of course, compensate for this, the lack of leg room required them to sit further back from the displays and controls, reducing visual and physical access.

Video Monitors

The video monitors used to monitor the patient during treatment were generally positioned so that the person operating the RAB control panel could see them. Both desk top and elevated mounting for the monitors was observed. Desk top mounting provides a good viewing angle, but other equipment can often interfere with operators' view of the monitors. Elevated mounting typically eliminates such problems of interference but may create sub optimal viewing angles. By angling the monitors down and toward operator positions, viewing angles for elevated monitors can be improved.

When multiple monitors were used, they were often stacked on top of each other. While this was generally found to be an acceptable arrangement, care needs to be taken so that the viewing angles for both monitors remain appropriate. That is, the lower monitor should not be too low for a standing 95th percentile male, and the upper monitor should not be too high for a seated 5th percentile female. A few sites mounted the monitors below the work surface and angled them up so that the operator could view them through a transparent table top. This arrangement permitted both the RAB control panel and the monitors to remain within the operator's field of view and was reported to protect patient privacy by restricting the view of the patient to the RAB personnel at the console. This monitor arrangement could, however, introduce glare from overhead lighting that reduced the viewing angle to the point that other RAB personnel in the workspace were prevented from monitoring the treatment. It also allowed the monitor's viewing angle to be reduced or information on the monitor to be obscured when operators leaned over the table or used the glass table top as a temporary repository for charts, notes and other documents.

It is important to recognize that in addition to the treatment control operator, other personnel, who are typically standing, may also need to view the monitors during treatment. Thus, the monitors must be mounted and angled to accommodate viewing by all personnel involved in the RAB treatment.

Use of Records and Reference Materials

Most of the sites provided limited desk space that could be used for writing or for temporary positioning of patient records or other reference materials. These work areas provided adequate open space, and their height was found to be acceptable for use by a 5th percentile female and a 95th percentile male. At sites where no open space was provided at the treatment control workstation, operators tended to use the tops of adjacent equipment. Considering this natural tendency to use any available space, protective covers would seem to be appropriate for sensitive equipment. At one site, a plywood cover was placed over the RAB control panel when not in use so that it would not only be protected but would also provide a needed work surface.

Many treatment control workspaces contained job performance aids. Most often, these were posted operating or emergency procedures. Other job performance aids included such things as checklists, reminders, daily treatment schedules, physics reference tables, error codes, and emergency phone numbers. At some sites, extensive use was made of these performance aids by staff, while at others, few instances of their use were observed. Organizational requirements for the standardization, training, and use of job performance aids are addressed in NUREG/CR-6125, Vol. 3, Section C.

Multi-Unit Control Workspace

All treatment control workspaces included other control panels in addition to the RAB treatment control panel. These other panels controlled fluoroscopes and simulators, if a combined simulation/treatment room configuration was used. More commonly, an external beam treatment control panel was also present. These different panels were distinctly different in appearance and function from the RAB treatment control panel. They were typically arranged so that there was adequate physical separation between them, defining distinct operator workstations. Their operation did not interfere with each other because they were not used concurrently. Each device had its own set of procedures and its own unique equipment. As a result, there was minimal interference between devices.

One site used a common workspace to control concurrent treatments in two separate rooms. Even in this

configuration, little interference was considered likely because of the physical and functional separation of the control panels. Ideally, each control panel included all of its associated apparatus, such as emergency stop panels and video monitors, to create fully functional but independent workstations. Nevertheless, the opportunity for distraction was increased when concurrent operations and discussions were going on at adjacent workstations.

Emergency Equipment

Operator Protective Equipment

Protective equipment for the staff included film badges, which were checked periodically according to site policy.

Fire, Radiation, & Rescue Equipment

Radiation monitors were present in several of the treatment control areas to indicate when the source was exposed in the treatment room. Other sites viewed the radiation monitor in the treatment room via the video monitor. In the absence of either of these, operators relied on the RAB control panel to inform them when the source was exposed.

Several sites used a legend display to indicate when the source was exposed and treatment was in progress. This display was generally mounted near the ceiling, such as above the treatment room door. By being mounted that high, the display was well above the field of view for most operators. More significantly, however, these displays were specific to RAB treatments. Other warning lights found above the treatment room door, which indicated that external beam treatments were in progress, would remain off during RAB treatments. As a result, operators could not rely on a single warning light to advise them when radiation was present in the treatment room. At the least, these two, independent displays should be collocated so that an operator looking at one would be likely to see the other as well.

Emergency Equipment Storage

Emergency equipment was generally stored in the treatment room near where it might be used. Several sites kept hand-held Geiger counters (survey meters) in accessible locations in the treatment control workspace. The reset key for the emergency stop button was found to be left in the panel at all times at some sites.

Safety Labels and Placards

Conspicuous safety warning labels and signs were found to be present at all sites.

Results

General Workspace Hazards

No general workspace hazards were noted in the treatment control areas.

General Equipment-Related Hazards

Door interlocks were provided at all sites so that treatment could not begin (or continue) if the treatment room door was not closed completely.

Environment

Temperature, Humidity, and Ventilation

Temperature, humidity, and ventilation were adequate at all sites examined and were controlled centrally by the building air-conditioning system.

Personal Storage

Most sites provided a storage area in the treatment control workspace for staff to use for their personal belongings (coats, purses, etc.). Although this arrangement has the potential to increase workspace clutter, at the visited sites this storage area was segregated from the working areas to prevent the occurrence of this problem.

Ambiance and Comfort

The ambience in the treatment control workspace was adequate at all sites examined. Most include additional items, such as photos, cartoons, or artwork, to personalize the workspace and to make it more pleasing. Most sites included a lounge or offices elsewhere in the site so that the staff would not need to use the treatment control workspace for eating or for other activities not related to RAB treatment.

Lighting

Illumination levels were adequate (≥ 20 ft-c) in most of the treatment control workspaces examined. Low illumination (5–10 ft-c) created a substantial problem for viewing the screen on the microSelectron-HDR, since liquid crystal displays rely on reflected light. Low illumination levels in the treatment control workspace were less of a problem for the GammaMed afterloader control unit, which used transilluminated (CRT) displays. Supplementary and adjustable lighting were rarely used.

Glare from overhead fluorescent lighting was evident at a few sites. Overhead glare was more of a problem with the

microSelectron-HDR, which has a relatively flat display. Except for the matte finish on table tops and on equipment panels, few glare reducing techniques were used.

Ambient Noise

Background noise levels were measured to range from 40–56 dB(A) (mean = 51 dB) due primarily to nearby talking and to background music. Voices (55–68 dB) were found to be easily detectable over the background noise level. Auditory distractions were most likely to come from talking in adjacent treatment control workspaces and to the announcing system (70–71 dB).

Communications Systems

Telephone Systems

Standard telephone sets, which served as interoffice intercoms and as telephones for outside calls, were found in all treatment control workspaces. These telephone sets were equally likely to be wall mounted or desk top models. They were well positioned for easy access by the treatment control operator and had adequate cord length to permit the operator to remain at their workstation while using the telephone. Important phone numbers were typically posted on the wall near the telephone set.

Announcing Systems

General announcements from the ceiling mounted intercom systems were usually audible in the treatment control workspaces.

Point-to-Point Intercom Systems

The treatment control workspaces all included an intercom with which the operator could speak and listen to the patient in the treatment room. Typically, these intercoms were in a mode to listen to the patient; operators would press and hold a button to talk to the patient. The intercoms were located within the reach envelope of a 5th percentile female operator.

Video Monitoring Systems

Most sites used two video monitors to observe the patient during treatment. One of these cameras typically had controls to adjust the zoom, pan, and focus. All sites used at least one camera for monitoring patients during treatment.

3.4.4 Low Dose Rate RAB Treatment

3.4.4.1 Overall Workspaces

Functional Separation

The overall arrangement of the workspaces involved in low dose rate RAB was found to be functionally separated in all of the five sites examined. That is, the treatment rooms were located together and were separated from the staff offices and other non-clinical areas. No sites clustered the RAB workspaces in the same general area, which required that patients be moved during the early stages of the RAB process.

Multi-Function Workspaces

About half (60%) of the sites examined had dedicated treatment planning areas. The other treatment planning workspaces were shared with staff (physics or dosimetry) offices. All sites used a single planning system for low dose RAB, manual afterloading brachytherapy, and external beam treatments.

Most sites (80%) dedicated the treatment rooms for low dose RAB. A few sites (20%), however, used these treatment rooms for other types of patients as well.

All sites had dedicated storage areas for RAB supplies, applicators, connectors, etc., and all sites kept these supplies in a centralized location. This centralized storage was either in the treatment room or in another dedicated area controlled by the physicists/dosimetrists. At some sites, these storage areas were not well organized, raising the possibility that RAB equipment and supplies may be difficult to locate.

Critical Distances

The distances between several workspaces that are important during RAB were measured at the sites visited. This provided an additional index of the overall suitability of the layout for RAB treatment. For purposes of this report, distances have been reported as near (0–50 feet), moderate (50–150 feet), or far (greater than 150 feet or on different floors).

Applicator Placement-to-Simulation

Low dose rate RAB was generally used for gynecological applications at the sites visited. Consequently, at all of these sites, applicator placement was performed in the operating room, and the patient was then moved several

floors for simulation (often to the radiation oncology suite in the basement).

Simulation-to-Treatment Room

Following simulation, all sites were found to move the patient several floors to the treatment room. In some cases, this distance was considerable.

Physics Office-to-Treatment Room

Since the senior physicist would rarely be present during treatment, he/she may need to be called to the treatment room in certain circumstances. At all sites, the physics office was located far away, but physicists could be paged throughout the hospital.

Nurse Station-to-Treatment Room

The nurse stations were located adjacent to or down a hallway from the treatment rooms. In all cases, the nurse stations were within 50 feet of the treatment rooms, and several were configured so that the outside of the treatment room doors could be viewed from the nurse station.

3.4.4.2 Treatment Rooms

Workspace Layout

The treatment rooms for low dose rate RAB were, for the most part, normal hospital rooms. In addition to the RAB equipment, they included an adjustable patient bed, storage cabinets, television, telephone, restroom, and chairs. The rooms were arranged well to provide adequate space for circulation and for physical and visual access.

Workstation Ergonomics

The primary workstation of concern in the low dose rate treatment room is the RAB unit itself. The height of the controls and displays on these units was found to be appropriate to accommodate the full range of users⁹ in a standing position.

Multi-Unit Control Workspace

All of the low dose rate treatment rooms examined were designed for a single patient. With the microSelectron-LDR

⁹Viewing distance and reach envelope were adequate for use by a standing 5th percentile female and a standing 95th percentile male.

Results

system, a dedicated afterloader served the patient. As a result, no workspace problems could occur due to shared equipment. The Selectron-LDR unit could, however, treat two patients (in separate rooms) concurrently. While multiple use was not observed at sites using the Selectron-LDR system, extra care would be required by technologists and nursing staff in such a workspace to keep track of channels being used by each patient. The potential for an interfacing error in which an operation intended for the channels going to one of the two patients was performed on channels connected to the other was partially reduced at such sites by permanently dedicating channels 1–3 for one room and 4–6 for the other and then using job performance aids at the control console to associate the channel sets with the rooms or patients to which they were attached. In spite of this, the increased opportunity for error in controlling two treatments from the same workstation was expected to require special training and verification procedures for these interfaces to overcome any tendency the user might have from prior treatments to associate the entire afterloader control unit with a single patient.

Emergency Equipment

The low dose RAB systems are designed to withdraw the sources and to interrupt treatment whenever anyone enters the treatment room. Treatment interrupts can be initiated from the remote control units outside the treatment room, but even if not used, a door interlock system will interrupt treatment as soon as the treatment room door is opened. Despite this system safeguard, some emergency equipment was provided in the rooms. Mobile lead shields were used to minimize staff exposure during an emergency. Portable emergency source storage containers and long-handled tongs were present in some treatment rooms. Radiation monitors that operated independently of the remote afterloader were used as a cross-check of the source status displays and the radiation indicators on the remote afterloader and remote control units.

Environment

Temperature and ventilation was controlled via the hospital's central heating and air conditioning system. Treatment rooms all had windows and pleasant decor. The rooms were quiet when the door was closed during treatment. Supplementary lighting (for reading, etc.) was controllable by the patient. Adequate closet and cabinet space was provided for patients to store personal items.

Communication Systems

The rooms included a telephone for outside calls, an intercom linked to the remote control unit outside the room, and a standard nurse call button/intercom.

3.4.4.3 Treatment Control Workspaces

The remote control unit was typically located directly outside the treatment room in the hallway. Each treatment room had its own remote control unit. The remote control units were wall-mounted at a height appropriate for use by the staff¹⁰. One site placed the remote control units for adjacent rooms together in a small desk area near the treatment rooms. Patient record folders were usually kept outside the treatment rooms near the remote control units.

The nurse station displays were wall-mounted in available space at the nurse station. Due to their use of a redundant auditory alarm and the wide viewing angle of the displays, it was not critical that these units be located in the central viewing area at the nurse station. Most sites were configured to treat several patients at the same time. As a result, several display units were mounted together at the nurse station. Sites typically added their own labels to identify which nurse station display went with which treatment room. Most sites relied on their own patient call system, rather than the indicator lights in the nurse station display unit. The nurse station displays were used as a simple way to monitor treatment status and system alarms (i.e., as an alerting mechanism). RAB staff used the remote control unit to obtain more detailed information.

¹⁰A 5th percentile female was used as the lower bound for this measurement.

4 Discussion

The results reported in the preceding section provide a detailed evaluation of the operator interfaces to RAB system components. Many strengths and weaknesses of the RAB interfaces have been identified with respect to recognized human factors engineering standards and guidelines. Despite its thoroughness, the reductionistic approach taken by this HSI evaluation is limited. In particular, this approach is relatively insensitive to how the individual strengths and weaknesses of an interface combine to influence RAB task performance.

So far, the HSI evaluation treats all of the interface attributes equally. That is, panel labels that are too small or workspaces with inadequate leg room are considered as if they were just as important as a system alarm that is difficult to detect. Moreover, it is not apparent from the evaluation conducted so far how the various strengths and weaknesses of a particular interface trade-off against one another. For example, how well suited is an interface for entering a treatment plan if, on the one hand, the color codes used for the indicator lights are ambiguous and the panel labeling is too small but, on the other hand, the panel is arranged well and the device has some automatic error checking? Further analysis is required to determine how much the HSI strengths and weaknesses affect the performance of RAB. Much of this will be assessed as part of the final task of this project, but some preliminary thoughts regarding the influence of HSI on RAB tasks are presented here.

Finally, implications of HSI design for other aspects of RAB systems, such as procedures, training, and organizational policies, are discussed. A well designed HSI can compensate for weaknesses in procedures, training, and organizational policies. Likewise, HSI weaknesses can be mitigated by well designed procedures, training, and/or organizational policies. In some RAB devices, HSI issues that required procedural, training, or organization interventions were noted. Additional analyses of this type are discussed in NUREG/CR-6125, Vol. 1.

4.1 Impact on RAB Tasks

Several human factors analysts assessed RAB equipment, software, documents, and workspaces to determine whether they facilitated or inhibited performance of the RAB tasks. These summary judgments are presented in Tables 6 and 7 for high and low dose rate RAB, respectively. Analysts used a 5-point rating scale: strongly facilitative (+ +), facilitative (+), neutral (o), detrimental (-), or strongly detrimental (- -). For some tasks, HSI issues were not applicable (•). Analysts were encouraged to consider several types of information in making their assessments. They needed to consider not only the findings of the HSI evaluation but also the steps involved in performing each task (as defined in Phase 1), the comments made by RAB

staff during site visits, and other relevant material. The analysts made independent assessments, and then compared their results. The analysts discussed the rationale for differences in their assessments and reached a consensus.

4.1.1 HSI Influences on High Dose Rate RAB

Table 6 shows that there are few HSI influences on the Patient Preparation tasks. This is due to the fact that little equipment, software, or documentation is involved in the performance of these tasks. The HSIs for the life support monitoring task vary considerably in terms of their human factors characteristics, which makes it difficult to assess the overall influence of HSIs on the performance of this task. Most of the applicators are adequately designed and labeled. Discussions of applicator attachment in user manuals and other documents are generally unsatisfactory, however. Patient Preparation tasks are performed at various workspaces in the radiation oncology suite. These workspaces typically have varied HSIs, making it difficult to assess their overall effect on the Patient Preparation tasks. An exception to this general case is Patient Transportation, which is likely to exert a negative effect on the patient as the distances between workspaces increase.

HSI influences on the Treatment Planning tasks were more pronounced than on the Patient Preparation tasks. The equipment design and workspace layouts facilitated Simulation, Target Volume Localization, Dwell Position Localization, and Dosimetry tasks require use of treatment planning systems, which support these tasks well. Of course, these systems rely on the treatment planning software, which has both good and poor features. The major strength of the treatment planning systems is their optimization, which greatly facilitates the Dosimetry task. The user manuals describing the treatment planning systems are confusing and hard to use, especially for Dosimetry. Most treatment planning workspaces are arranged suboptimally for Target Volume Localization and Dwell Position Localization. Most workspaces were arranged well to support the computer-based graphics output from Dosimetry. The other tasks (Radiation Prescription; Treatment Plan Selection and Approval) are done by the radiation oncologist at various workspaces, which have no particular influence on task performance.

The Treatment Delivery tasks are heavily influenced by HSI factors. The equipment and workspaces are adequate for Treatment Set-Up, and they facilitate task performance. User manuals are not particularly helpful for Treatment Set-Up, forcing sites to develop their own (highly variable) procedures. The influence of equipment on Treatment Plan Entry varies depending on the mode used. Equipment that permits treatment plans to be entered automatically or via a

Table 6. Human-System Interface Influences on High Dose Rate RAB Tasks

Function/Task	Equipment	Software	Documents	Workspaces
Patient Preparation				
Patient scheduling, identification, and tracking	•	•	•	0
Patient instruction	•	•	•	0
Life support monitoring	0	•	•	0
Applicator placement and stabilization	+	•	—	0
Patient transportation	•	•	•	+/-
Treatment Planning				
Simulation with dummy sources	+	•	•	+
Target volume localization	+	0	—	0
Radiation prescription	•	•	•	0
Dwell position localization	+	0	—	0
Dosimetry	+	+	--	+
Treatment plan selection and approval	•	•	•	0
Treatment Delivery				
Treatment set-up	+	•	—	+
Treatment plan entry	0	+	0	+
Verify treatment data prior to treatment				
Treatment session monitoring	++	++	0	—
Treatment session control	++	++	0	—
Post-Treatment				
Source guide tube disconnection	+	•	•	+
Applicator removal	+	•	•	+
Patient transportation	•	•	•	+/-
Treatment verification	•	•	0	+
Record-keeping	•	•	0	+
Quality Assurance and Maintenance				
Source exchange	0	++	0	+
Source calibration	0	++	0	+
Equipment and software updates	•	—	—	0
Troubleshooting	+	—	—	+
Routine quality assurance	+	+	—	+

Note: Table entries provide estimates of the influence of relevant equipment, software, documents, and workspaces on the safe and effective performance of RAB tasks. Influences may be strongly facilitative (+ +), facilitative (+), neutral (0), detrimental, (—), or strongly detrimental (— —). HSI issues are not applicable (•) for some RAB tasks.

Table 7. Human-System Interface Influences on Low Dose Rate RAB Tasks

Function/Task	Equipment	Software	Documents	Workspaces
Patient Preparation				
Patient scheduling, identification, and tracking	•	•	•	0
Patient instruction	•	•	•	0
Life support monitoring	0	•	•	0
Applicator placement and stabilization	+	•	—	0
Patient transportation	•	•	•	—
Treatment Planning				
Simulation with dummy sources	+	•	•	+
Target volume localization	+	0	—	0
Radiation prescription	•	•	•	0
Dwell position localization	+	0	—	0
Dosimetry	+	+	--	+
Treatment plan selection and approval	•	•	•	0
Treatment Delivery				
Treatment set-up	0	•	—	+
Treatment plan entry	0	+	0	+
Verify treatment data prior to treatment				
Treatment session monitoring	+	+	0	+
Treatment session control	+	+	0	+
POST-TREATMENT				
Source guide tube disconnection	+	•	•	+
Applicator removal	+	•	•	+
Patient transportation	•	•	•	—
Treatment verification	+	•	0	—
Record-keeping	+	•	0	—
QUALITY ASSURANCE AND MAINTENANCE				
Source exchange	--	•	—	+
Source calibration	0	+	0	+
Equipment and software updates	•	—	—	0
Troubleshooting	+	—	—	+
Routine quality assurance	+	+	—	+

Note: Table entries provide estimates of the influence of relevant equipment, software, documents, and workspaces on the safe and effective performance of RAB tasks. Influences may be strongly facilitative (+ +), facilitative (+), neutral (0), detrimental, (—), or strongly detrimental (--). HSI issues are not applicable (•) for some RAB tasks.

Discussion

program card clearly facilitates accurate task performance. When treatment plans are recalled from computer memory or are entered manually, greater chances of human error are present. The treatment control equipment and software support the tasks of verifying treatment data, monitoring treatment, and concluding treatment quite well. The user manuals describe the various treatment tasks and steps adequately, although their format is by no means easy to use. The treatment control workspaces are fully adequate for one-person tasks, such as Treatment Set-Up and Treatment Plan Entry. The workspace layout, however, is often less suitable for multi-person tasks. At many sites, the patient and the afterloader control unit could not be monitored effectively by one person.

The connectors and other auxiliary equipment used to disconnect source guide tubes and remove applicators are well designed to facilitate task performance, and the treatment rooms where these tasks are done are suitable. Treatment verification is performed at the treatment control workspace using the paper tape on the afterloader control unit. These interfaces support the task well. Each site uses its own forms and procedures for record-keeping, but the workspace available for this task is typically inadequate.

Source Exchange, Source Calibration, and Routine Quality Assurance tasks are well supported by the equipment, software, and workspaces. Troubleshooting is hindered by the use of error codes in the software and by hard-to-understand user manuals. The availability of diagnostics in the equipment and of a telephone in the workspace (to obtain on-line assistance from the manufacturer) help offset these weaknesses, however. Insufficient support is provided to operators via software or documents when computer programs are updated, but here again manufacturer on-line assistance is used as a back-up.

4.1.2 HSI Influences on Low Dose Rate RAB

As Table 7 shows, the influence of HSI on low dose rate RAB tasks is largely the same as for high dose rate RAB tasks (cf. Table 6). Specifically, the tasks in Patient Preparation, Treatment Planning, and Post-Treatment are influenced in the same way for both low and high dose rate RAB. This is primarily due to the fact that the same (or very similar) equipment, software, documents, and workspaces are used for both.

During treatment delivery, the unique equipment, software, and workspaces exerted different influences on task performance. In the tasks performed prior to treatment delivery, the low dose rate RAB equipment was adequate. The 6-channel status display on the Selectron-LDR provided an additional HSI strength for verifying treatment

data prior to treatment. The remote controller and nurse station display facilitated the tasks involved in monitoring and interrupting treatment. The software in the low dose rate devices supported the relevant tasks adequately, providing several safety checks and back-ups. The relevant workspaces were considered to be quite suitable for the tasks required before and during treatment delivery.

Most of the discussion of the HSI influence on Quality Assurance and Maintenance tasks is identical for both high and low dose rate RAB. However, because of the different types of sources, different HSI considerations are relevant for the Source Exchange and Source Calibration tasks. At least for the microSelectron-LDR system, Source Exchange involves using the source preparation station to build source cables. Problems with the interface of this device were considered to be substantial and to interfere with effective task performance. Again, the user manual was not helpful for this task. Source calibration via autoradiographs was adequately supported by the various interfaces involved.

4.2 Implications for the RAB System

This section lists some of the implications of HSI design for other parts of the RAB system. While HSI designs, by themselves, can have facilitating or detrimental influences, task performance depends on the trade-offs among all of the elements of the RAB system. In particular, the human factors issues concerning HSI, operating procedures, staff training, and organizational policies interact to determine how well operators will perform RAB tasks. The strengths and weaknesses of HSI designs can constrain operating procedures, staff training, and organizational policies. Poor HSI design forces these other parts of the RAB system to be strong in order to compensate. Strong HSI designs, on the other hand, permit the quality of the other parts of the system to vary.

The following subsections provide some alternate approaches for how the other human factors elements (procedures, training, organization) could compensate for weaknesses in HSI design. The approaches suggested have been organized by RAB functions, and they are by no means exhaustive. Additions and refinements will be conducted as part of Phase 6 of this project.

4.2.1 Simulation

English labels should be added to equipment as required to make the purpose of displays and controls easy to understand. Damaged or hard-to-read labeling should be replaced or augmented.

4.2.2 Treatment Planning

The VDT screen and keyboard should be positioned so that they can be seen from the light table with minimal head or body movement. This would enable the operator to observe the prompts and messages on the VDT screen while digitizing points on the simulation films.

Light tables should be sloped towards the operator. This would reduce back strain from having to stand and lean over the light table while digitizing points. Perhaps a more significant benefit would be to reduce parallax, which could introduce an error in the location of the dwell (and other) positions.

Since the treatment planning process is complex, mentally demanding, and done under time pressures, the computations leading to a treatment plan need to be checked independently. Extensive use of job performance aids in treatment planning, such as checklists and worksheets, is strongly encouraged.

4.2.3 High Dose Rate RAB Treatment

English labels should be added to equipment as required. Reminders and job performance aids should also be posted to remind operators of unconventional procedures, such as the format for date entry.

Operators need a way to determine unambiguously the identity of pre-stored programs in the afterloader control unit. This reduces the chance of substituting treatment plans.

Announce over the intercom when treatment is about to begin. Since treatment is started remotely, this helps assure that everyone but the patient gets out of the treatment room.

The treatment unit should be positioned within the room so as to be quickly accessible in case of an emergency. The particular concern is that operators be able to reach the emergency cranks and shut-off switch quickly.

Periodic training, including walk-throughs, should be conducted for various types of emergencies. This helps keep operators familiar with the cues that something has gone wrong and with procedures needed to resolve the problem.

Nothing (e.g., notices, announcements) should be positioned to obscure or conceal the emergency stop panel at any time.

The keys for the afterloader control unit should be labeled and stored together, but not on the same key ring because routine operation of the remote afterloader often requires that two keys be simultaneously inserted into physically separated keyswitches on the afterloader control unit. A back-up set of keys should be retained in a location accessible to RAB staff, but preferably not to non-RAB personnel.

Program cards for the microSelectron-HDR system should be labeled with the patient's name and/or identification code, fraction number, and date. This reduces the chances of substituting the wrong treatment plan.

System checks should be conducted regularly as part of the treatment set-up procedures. These checks should include all aspects of the treatment system, including the paper supply in the printer. This not only assures that everything is in proper working condition but it also refreshes operators on safety procedures.

4.2.4 Low Dose Rate RAB Treatment

Prescriptions, written directives, treatment plans, and related records need to be written to show channel treatment times in hundredths of hours (HH.HH) rather than in other conventional formats (e.g., HH.MM). This assures that prescriptions are compatible with the electronic counter displays on the remote control unit and the afterloader control unit display, which show remaining time in decimal (HH.HH) format.

When staff enter the room during treatment, the door must remain open. The remote control unit, which is outside the room, can restart treatment as long as the door is closed.

When restarting treatment by pressing the red button, staff should remain at the remote control unit until the yellow treatment light(s) remain on steadily. Similarly, when interrupting treatment, staff should not enter the room until the green safe light(s) remain on steadily. Because of possible confusion due to the color coding of the "start" and "stop" buttons, staff need to verify that the intended action has been taken.

Patient call lights at the nurse station display should be labeled with room numbers or patients' names. The nurse station display does not accommodate such permanent labeling, but this information is necessary to avoid confusion, particularly when several patients are being treated concurrently.

Before starting, interrupting, or restarting treatment, staff should announce this to the patient via the phone intercom on the remote control unit. Otherwise, the unanticipated

Discussion

sound of the sources being retracted or extended may surprise or disturb patients.

None of the displays (afterloader control unit, remote control unit, or nurse station display) should be positioned so as to be in direct sunlight or other sources of high illumination. Otherwise, the LED indicator lights may appear to be lit when actually off.

The afterloader control unit should be positioned so that it is out of the way of normal and nursing traffic in the patient's room but so that the display can be seen readily by the staff. Once positioned, the unit should not be moved during treatment. This minimizes the chances of moving or stepping on the hose or cables.

Staff should periodically check the positioning of the applicators in the patient, the paper tape status record, and the electronic time counters. This assures that treatment is proceeding normally.

Physicists should attach labels to the intermediate safe channels to indicate their contents. Two possible techniques are (a) overlay collars placed over the safe tubes and (b) a table or chart slipped into a plastic sleeve mounted on the safe cover so that it would face the user when the cover was open and rotated to its holding location. This adjunct labeling is necessary because it is not designed into the device.

4.2.5 Quality Assurance

The position indicated on the Nucletron source position check ruler should be verified via direct viewing on video. This check is required because the indicator, which is pushed by the source cable, may fit too loosely and move further than the source—giving an inaccurate indication of source position.

Special tools (e.g., the removable GammaMed IIi emergency crank, the source exchange connector tube, and two-pronged lock-nut tool) should be stored in a dedicated area at or near their location of use. This helps to assure rapid and unambiguous access.

5 References

- American National Standards Institute/Human Factors Society, ANSI/HFS 100-1988, "American National Standard for Human Factors Engineering of Visual Display Terminal Workstations," Santa Monica, CA.
- Association for the Advancement of Medical Instrumentation, AAMI HE-1993, "Human Factors Engineering Guidelines and Preferred Practices for the Design of Medical Devices," Arlington, VA.
- Bailey, R.W., *Human Performance Engineering*, Prentice Hall, Englewood Cliffs, NJ, 1989.
- Berry, E., "How to get users to follow procedures," *IEEE Transactions on Professional Communications*, 25:22-25 (1982).
- Boff, K.R., and J.E. Lincoln, *Engineering Data Compendium: Human Perception and Performance*, Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH, 1988.
- Callan, J.R., J.W. Gwynne, D. Sawyer, and M.T. Tolbert, *Principles of Medical Device Labeling*, NTIS PB 94-126851, 1993.
- Carroll, J.M., P.L. Smith-Kerker, J.R. Ford, and S.A. Mazur-Rimet, "The minimal manual," *Human-Computer Interaction*, 3:123-153 (1987).
- Coke, E.U., "Reading rate, readability, and variations in task-induced processing," *Journal of Educational Psychology*, 68:167-173 (1976).
- Coleman, E.B., "Improving comprehensibility by shortening sentences," *Journal of Applied Psychology*, (1962).
- Duffy, T.M., and R. Waller, (Eds.), *Designing Usable Texts*, Academic Press, New York, 1985.
- Eastman-Kodak Co., *Ergonomic Design for People at Work*, Vol. 2, Van Nostrand Reinhold Company, New York, 1986.
- Fleming, M.I., "Perceptual principles for the design of instructional materials," *Viewpoints*, 46 (1970).
- Gong, R., and J. Elkerton, "Designing minimal documentation using a GOMS model: A usability evaluation of an engineering approach," *Proceedings of the Association for Computing Machinery*, April 1990.
- Grandjean, E., *Fitting the Task to the Man: An Ergonomic Approach*, Taylor & Francis, Ltd., London, 1982.
- Hartley, J., *Designing Instructional Text*, London: Kogan Page, London, 1978.
- Hartley, J., ed., *The Psychology of Written Communication*, London: Kogan Page, London, 1980.
- Hartley, J., S. Fraser, and P. Burnhill, "A selected bibliography of typographical research relevant to the production of instructional materials," *Audio Visual Communication Review*, 22:181-190 (1974).
- Helander, M., ed., *Handbook of Human-Computer Interaction*, North-Holland, Amsterdam, 1991.
- International Business Machines Corporation, "Human Factors of Workstations with Visual Displays," San Jose, CA, April 1984.
- Monteith, M.K., "How well does the average American read? Some facts, figures, and opinions," *Journal of Reading*, ERIC/RCS, 460-464 (February, 1980).
- National Aeronautics and Space Administration, NASA Reference Publication 1024, "Anthropometric Source Book," Lyndon B. Johnson Space Center, Houston, TX (July 1978).
- National Aeronautics and Space Administration, NASA-STD-3000, "Man-System Integration Standards," Lyndon B. Johnson Space Center, Houston, TX (March 1987).
- Payne, D.E., "Readability of typewritten material: Proportional versus standard spacing," *Journal of Typographic Research*, 1:125 (1967).
- Poulton, E.C., "A note on printing to make comprehension easier," *Ergonomics*, 3:245-248 (1960).
- Poulton, E.C., "Size, style, and vertical spacing in the legibility of small typefaces," *Journal of Applied Psychology*, 56:156-161 (1972).
- Ralph, J.B., "A geriatric visual concern: The need for publishing guidelines," *Journal of the American Optometric Association*, 53:43-50 (1982).
- Robinson, D.O., M. Abbamonte, and S.H. Evans, "Why serifs are important: The perception of small print," *Visible Language*, 5:353-359 (1971).
- Salvendy, G., ed., *Handbook of Human Factors*, John Wiley & Sons, New York, 1987.

References

- Simpson, H., and S.M. Casey, *Developing Effective User Documentation: A Human-Factors Approach*, New York: McGraw-Hill, New York, 1988.
- Twyman, M., "Using pictorial language: A discussion of the dimensions of the problem." (T. M. Duffy and R. Waller, eds.), *Designing Usable Texts*, 245-312, Academic Press, New York, 1985.
- U.S. Department of Health and Human Services, Public Health Service, National Institutes of Health, Pretesting in health communications: Methods, examples, and resources for improving health messages and materials, NIH Publication No. 84-1493. Appendix C, pp. 46-47 (1984).
- U.S. Department of Defense, "Anthropometry of U.S. Military Personnel (metric)," DOD-HDBK-743A, October 3, 1980.
- U.S. Department of Defense, "Human Engineering Guidelines for Management Information Systems," MIL-HDBK-761A, September 30, 1989.
- U.S. Department of Defense, "Human Factors Engineering Design for Army Materiel (metric)," MIL-HDBK-759B (MI), June 30, 1992.
- U.S. Department of Defense, "Manuals, Technical: General Style and Format Requirements," MIL-M-38784B, April 16, 1983.
- U.S. Department of Defense, MIL-STD-1472D, "Human Engineering Design Criteria for Military Systems, Equipment, and Facilities," Washington, D.C., March 1989.
- U.S. Food and Drug Administration, "Reviewer Guidance for Computer Controlled Medical Devices Undergoing 510(K) Review," Center for Devices and Radiological Health, Rockville, MD (1 February 1991 Draft).
- U.S. Nuclear Regulatory Commission, NUREG-0700, "Guidelines for Control Room Design Reviews," September 1981.
- U.S. Nuclear Regulatory Commission, NUREG/CR-6125, Vol. 1, "Human Factors Evaluation of Remote Afterloading Brachytherapy: Human Error and Critical Tasks in Remote Afterloading Brachytherapy and Approaches for Improved System Performance," February 1995.
- U.S. Nuclear Regulatory Commission, NUREG/CR-6125, Vol. 2, "Human Factors Evaluation of Remote Afterloading Brachytherapy: Function and Task Analysis," February 1995.
- Van Cott, H.P., and R.G. Kinkade, eds., *Human Engineering Guide to Equipment Design*, U. S. Government Printing Office, Washington, DC, 1972.
- Weiss, E.H., *How To Write a Usable User Manual*, ISI Press, Philadelphia, 1985.
- Wiggins, R.H., "Effects of three typographical variables on speed of reading," *Journal of Typographic Research*. 1:5-18 (1967)
- Williges, B.H., and R.C. Williges, "Dialogue design considerations for interactive computer systems." (F. A. Muckler, ed.), *Human Factors Review: 1984*, Human Factors Society, Santa Monica, CA, 1984.
- Wright, P., "Issues of content and presentation in document design," (M. Helander, ed.), *Handbook of Human-Computer Interaction*, North-Holland, Amsterdam, 1988.

Section B
Procedures and Practices

CONTENTS

		Page
1	INTRODUCTION	89
1.1	Organization of Section B	89
1.2	Definition of Procedure	89
1.3	Procedures Identified in this Study	89
1.3.1	Task Allocation Procedure	89
1.3.2	Task Ordering Procedure	89
1.3.3	Task Performance Procedure	89
1.3.4	Task Locating Procedure	89
1.3.5	Task Linkage Procedure	89
1.3.6	Task Performance Verification Procedure	90
1.3.7	Task Linkage Verification Procedure	90
1.4	Identification and Collection of Procedures	90
1.4.1	Written Descriptions	90
1.4.2	Checklists	90
1.4.3	Worksheets	90
1.4.4	Physical Constraints	90
1.5	Definition of Practice	90
1.6	Practices Identified in this Study	90
1.7	Identification and Collection of Practices	90
1.8	Conceptual Model of Information Flow in the RAB System	90
2	METHOD	91
2.1	Task Allocation	91
2.1.1	Task Allocation Procedures	91
2.1.2	Task Allocation Practices	91
2.2	Task Ordering	91
2.2.1	Task Ordering Procedures	91
2.2.2	Task Ordering Practices	91
2.3	Task Performance	91
2.3.1	Task Performance Procedures	91
2.3.2	Task Performance Practices	91
2.4	Task Locating	92
2.4.1	Task Locating Procedures	92
2.4.2	Task Locating Practices	92
2.5	Task Linkages	92
2.5.1	Task Linkage Procedures	92
2.5.2	Task Linkage Practices	92
2.6	Task Performance Verification	92
2.6.1	Task Performance Verification Procedures	92
2.6.2	Task Performance Verification Practices	93
2.7	Task Linkage Verification	93
2.7.1	Task Linkage Verification Procedures	93
2.7.2	Task Linkage Verification Practices	93

	Page
3 RESULTS	95
3.1 Summary Evaluations of RAB Procedures and Practices	95
3.1.1 Task Allocation	95
3.1.2 Task Ordering	95
3.1.3 Task Performance	97
3.1.4 Task Locating	99
3.1.5 Task Linkages	99
3.1.6 Verification of Task Performance	101
3.1.7 Verification of Task Linkages	103
3.2 Detailed Descriptions of Individual Tasks	104
3.2.1 Patient Preparation	104
3.2.2 Treatment Planning	112
3.2.3 Treatment Delivery	123
3.2.4 Post-Treatment	130
3.2.5 Quality Assurance and Maintenance	133
4 DISCUSSION	141
4.1 Error Detection	141
4.2 Error Correction	142
APPENDIX A: Figures	143

LIST OF TABLES

Table	Page
1 RAB Task Performance According to Job Category (15 Sites)	96
2 Task Performance Documents (15 sites)	98
3 Task Linkage Documents for Patient Preparation and Treatment Planning Tasks (15 sites)	100
4 Task Linkage Documents for Treatment Delivery and Post-Treatment Tasks (15 sites)	101
5 Task Linkage Documents for QA and Maintenance Tasks (15 sites)	102
6 Performance Verification Documents (15 sites)	103
7 Representative Radiation Prescription Formats	119
8 QA Check Intervals (15 Sites).....	140

1 Introduction

This section reports on the evaluation, conducted during Phase 3, of the procedures and practices employed by RAB staff to link the output of the RAB tasks into an RAB treatment delivery system. In such a linked system of tasks, the users are required to perform tasks, to verify the performance of both human and automated tasks, to link the tasks to other tasks by transferring information and material between them, and to verify the linkages which have been created so that the operation of the system as a whole can be supervised.

1.1 Organization of Section B

Section B is organized into four parts. The introduction defines the terms *Procedure* and *Practice* as they are used in this section and specifies the actions that would fall into each category and the methods used to differentiate between them during RAB site visits. A further distinction was made between a *Medical Procedure* which describes how a patient or disease should be treated, and procedures which address the way in which RAB equipment and material are used to plan and deliver treatment. The former was not included in the scope of this study.

Seven categories of RAB procedures were derived from a conceptual model of RAB. The conceptual model links together the functions and tasks identified in Phase 1 to depict a system for planning, monitoring, and delivering RAB treatments. Each of these seven categories of procedures covers an aspect of RAB:

- (1) Task allocation: who performs the task
- (2) Task ordering: when the task is performed
- (3) Task performance: the steps used to perform the task
- (4) Task locating: where the task is performed
- (5) Task linkage: how information and materials are carried between the tasks
- (6) Task performance verification: how errors in task performance are detected
- (7) Task linkage verification: how errors in task linkage are detected

The methods section describes how the procedures and practices data were collected at the RAB sites for each of the seven categories of RAB procedures listed above.

The results section first summarizes the data collected on the seven categories of RAB procedures and practices and then provides an analysis of the categories for each of the RAB functions: Patient Preparation; Treatment Planning; Treatment Delivery; Post-Treatment; and Quality Assurance and Maintenance.

The discussion section considers error detection and correction in RAB systems as well as the establishment of task linkage and verification procedures.

1.2 Definition of Procedure

The term procedure has various meanings in task analysis, medicine and training contexts, but is narrowly defined for the purposes of this study:

Procedure: An ordered sequence of tasks or steps that has been designed, documented, and approved for some purpose.

Approval may be informal, but the procedure must be documented in a form that permits its use as a reference for task performers and allows deviations from the approved sequence to be detected. There may be more than a single procedure approved for a particular purpose.

1.3 Procedures Identified in this Study

1.3.1 Task Allocation Procedure

A task allocation procedure assigns particular staff or equipment to perform RAB tasks.

1.3.2 Task Ordering Procedure

A task ordering procedure describes when and in what order each RAB task is to be performed.

1.3.3 Task Performance Procedure

A task performance procedure specifies a sequence of steps designed to perform an RAB task.

1.3.4 Task Locating Procedure

A task locating procedure assigns a particular work space for performing an RAB task.

1.3.5 Task Linkage Procedure

A task linkage procedure specifies the steps used to transfer information or objects between the tasks. It is designed to connect the output of one RAB task to the input of another task.

1.3.6 Task Performance Verification Procedure

A task performance verification procedure is a sequence of steps designed to detect and correct errors in RAB task performance.

1.3.7 Task Linkage Verification Procedure

A task linkage verification procedure is a sequence of steps designed to detect and correct errors in task linkage, or in the information transfer between tasks.

1.4 Identification and Collection of Procedures

Three forms of written documentation were accepted as evidence of locally approved procedures. In addition, some procedures had no written documentation, but still compelled task performers to proceed in a certain manner due to unavoidable physical constraints.

1.4.1 Written Descriptions

A written description describes the steps that are to be performed in an approved procedure.

1.4.2 Checklists

A checklist is a list of the steps to be performed that can be marked during task performance to show that a step has been successfully completed.

1.4.3 Worksheets

Worksheets include information identifying a step and an entry location in which the user is expected to enter a derived value after performing a step in the procedure.

1.4.4 Physical Constraints

Some procedures had no obvious written documentation, but had nevertheless been physically constrained so that task performers would be unable to deviate from the designed procedural steps. Such physical constraints were noted separately for each identified procedure.

1.5 Definition of Practice

Practice: Any ordered sequence of tasks or steps used repeatedly for some purpose.

Practices may differ between individuals and may or may not conform to the approved sequence set out in a procedure. Thus both procedures and practices govern the performance of tasks, but procedures are documented while practices are not.

1.6 Practices Identified in this Study

The general definition of a practice above allows for the collection of data on the same categories for which procedures were identified, but also permits collection of RAB data which has not been formalized in approved written documents.

Practices will be identified for the same eight categories for which formal procedures were collected: medical practices, task allocation practices, task ordering practices, task locating practices, task performance practices, task linkage practices, and verification practices for task performance and task linkage.

1.7 Identification and Collection of Practices

Since practices need have no written documentation, data on practices were collected through direct observation or interviews of personnel at the site.

1.8 Conceptual Model of Information Flow in the RAB System

Figure 1¹ shows a conceptual model of how information and materials flow through a portion of the RAB system. Four tasks involving patient contact, shown by the shaded boxes (Applicator Placement, Target Volume Localization, Treatment Set-Up, and Treatment Session Monitoring and Control), are performed concurrently with four tasks that do not involve patient contact, shown by the unshaded boxes (Source Calibration, Radiation Prescription, Treatment Plan Selection and Approval, and Treatment Plan Entry). These tasks are linked together by the movement of the patient and of information and materials between task performers. As a quality control check, a series of task verification procedures determines whether the tasks and their linkages are performed without error.

¹ In order to not disrupt the flow of the text presentation, all figures for Section B are presented in Appendix A.

2 Method

Seven sites were visited to determine the procedures and practices used to perform RAB. Data were combined with procedure and practice data collected from eight further visits during Phases 4 and 5 in order to provide a sample of 15 sites at which data were collected on procedures and practices.

Each site was examined to identify the procedures, personnel, and practices employed in brachytherapy using remote afterloaders. Data were collected on the allocation of tasks to equipment and personnel, the order and timing of task performance, the steps used in task performance, the method of linking tasks to perform an RAB treatment and on the verification of task performance and task linkages at each site.

2.1 Task Allocation

The person or equipment assigned to perform each task was determined at each site.

2.1.1 Task Allocation Procedures

Task allocation *procedures* were identified during the site background interview in which the director of the facility was asked to identify the role that the equipment and each member of the staff played in RAB at the site. Equipment used for simulation, treatment planning, treatment, treatment control and treatment monitoring was identified. Site licenses were examined (when available) to determine the tasks that would be performed by individuals at the site. When licenses or other written corroboration of task allocation procedures were not available, or procedures had been changed since the license application had been written, the site background interview results were used without written corroboration. Five job categories were investigated: Physician, Physicist, Dosimetrist, Technologist, Nurse, and Clerical.

2.1.2 Task Allocation Practices

Task allocation *practices* were identified by direct interviews in which the respondents were asked to identify those RAB tasks which they performed routinely, those tasks which they could be called upon to perform but did not perform regularly, and those tasks for which they supervised or observed task performance by others. When the respondents were not the primary task performers, they were asked to identify the primary task performer at the site. Direct observation of task performance was used to corroborate and amplify these data on task allocation practices at the site.

Task definitions were explained to each respondent during the interview. Differences in task terminology between the local facility and the task analysis used in the study were discussed with each respondent to reduce the incidence of misidentification due to semantic inconsistency.

2.2 Task Ordering

The order in which the tasks were performed and the time that elapsed between the performance of tasks were noted at each site.

2.2.1 Task Ordering Procedures

Written procedures covering the order and interval between tasks were collected (when available) from each site.

2.2.2 Task Ordering Practices

The order in which the RAB tasks were performed and the intervals between successive tasks were observed. These observations were used to guide interviews with the task performers at each site.

2.3 Task Performance

The steps used in performing each RAB task were noted at each site.

2.3.1 Task Performance Procedures

Written procedures for task performance were collected (when available) from each site. These written procedures were evaluated to determine the RAB tasks for which

- a written procedure describing the steps used to perform the task was available
- a check-off list of steps was used during task performance at the site
- a formatted worksheet on which a user was expected to enter results was used during task performance at the site

2.3.2 Task Performance Practices

Each RAB task performed at the site was evaluated using direct observations, user descriptions and walk-through demonstrations of task performance to identify task performance practices for that task at that site. All members of the RAB team were interviewed and either asked to demonstrate the tasks they performed or, when possible,

were observed during task performance on actual treatments.

2.4 Task Locating

The workspace in which each RAB task was performed was described in terms of its physical properties and its spatial relationship to other RAB workspaces. This information was recorded for each RAB site visited.

2.4.1 Task Locating Procedures

Procedures for allocating workspaces for RAB tasks were identified at each site by interviews with system administrators and review of any written descriptions of workspace assignment. Tasks that shared the same workspace were identified, and workspace allocations that differed depending on treatment or staffing protocols were noted.

2.4.2 Task Locating Practices

The place at which each RAB task was performed was noted during observation of task performance and structured walkthroughs with task performers. This information was used to produce a workspace map of each site. The workspace map identified the RAB workspaces, the tasks performed in each workspace, and the physical distances and communication paths between workspaces.

2.5 Task Linkages

The manner in which the output of one task was connected to the input of other tasks was recorded for each RAB task performed at the site.

2.5.1 Task Linkage Procedures

Written procedures for task linkage were collected (when available) from each site. These written procedures were evaluated to determine the RAB tasks for which

- a written procedure describing the steps used to link the tasks was available
- a check-off list of task linkage steps was used to link tasks at the site
- a formatted worksheet on which a user was expected to enter results was used to link tasks at the site

2.5.2 Task Linkage Practices

Task linkages needed to perform RAB were evaluated from the task analysis and identified at the site using observation, user descriptions and walk-through demonstrations of task performance.

Tasks performed at the site were identified and the order of task performance and method of linking the tasks was determined for both the dominant and significant secondary medical procedures performed at the site. The information and material passed between tasks was identified and the personnel involved in the linkage and transfers were identified.

The persons performing each task were identified. The number of times that control of the procedure or information was passed between individuals was noted and the method of transferring control and information between individuals was determined during any RAB treatments observed at the site.

Observed information transfers between tasks were classified by the method of transporting the information between the two tasks. Six methods of transporting information were investigated:

- (1) information written and carried by a single task performer between tasks
- (2) information memorized and carried by a single task performer between tasks
- (3) information stored in hardware by a single task performer between tasks
- (4) information written and transferred between different task performers
- (5) information verbally transferred between different task performers
- (6) information stored in hardware and transferred between different task performers

2.6 Task Performance Verification

Steps used to verify the correct performance of a task were recorded at each site.

2.6.1 Task Performance Verification Procedures

Written procedures for verifying that a task has been performed correctly were collected (when available) from each site. These written procedures were evaluated to determine those RAB tasks for which

- a written procedure describing the performance verification steps was available
- a check-off list of steps was used during verification of task performance at the site
- a formatted worksheet on which a user was expected to enter results was used during verification of task performance at the site

2.6.2 Task Performance Verification Practices

Performance verification practices were identified by direct observation of RAB procedures performed at the site. These observations were supplemented by directed interviews of all RAB personnel at the site. Structured walk-through demonstrations of task performance were used to collect information that could not be collected during task performance. The primary procedures performed at the site were investigated at the task linkage level to determine several characteristics:

- (1) the time at which verification was attempted
 - prior to task linkage
 - during task linkage
 - after task linkage
- (2) the verification method used
 - comparison of redundantly performed tasks or steps
 - comparison with written standards
 - comparison with memorized standards
- (3) the format of the verification
 - written checklists for the task performer
 - written checklists for an independent task verifier
 - verbal question/response comparisons between two individuals
 - visual observation by the task performer
 - visual observation by an independent task verifier
- (4) the verifying agent
 - verification performed by the task performer
 - verification performed by an independent performance verifier
 - verification performed by interaction of two individuals
- (5) the redundant information preserved that was available for use in verification

- (6) the information actually used in verification

2.7 Task Linkage Verification

Steps used to verify that data transferred between tasks was transferred correctly were recorded at each site.

2.7.1 Task Linkage Verification Procedures

Written procedures for verifying task linkages were collected (when available) from each site. These written procedures were evaluated to determine those RAB tasks for which

- a written procedure describing the linkage verification steps was available
- a check-off list of steps was used during verification of task linkage at the site
- a formatted worksheet on which a user was expected to enter results was used during verification of task linkage at the site

2.7.2 Task Linkage Verification Practices

Practices used to verify task linkage and information transfer between tasks and individuals were identified and classified at each site. The primary and significant secondary medical procedures performed at the site were investigated at the task linkage level to determine several characteristics:

- (1) the time at which the verification was attempted
 - during task linkage
 - after task linkage
- (2) the verification method used
 - pre and post-linkage display and comparison of individual linked values
 - comparison of linked information with expected values
 - comparison of linked information with other redundant information
- (3) the format of the verification
 - written checklists or worksheets
 - verbal question/response comparisons between two individuals
 - visual observation by a single verifier

Method

- (4) the verifying agent
 - verification performed by the task linker
 - verification performed by an independent linkage verifier
 - verification performed by interaction of two individuals
- (5) the redundant information that was available for use in verification
- (6) the information actually used in verification

3 Results

This section is presented in two major parts. The first part summarizes the overall findings concerning RAB procedures and practices in terms of the seven analytical categories defined in the Introduction. These categories (allocating, ordering, performing, locating, linking, verifying performance, and verifying linkages) were derived from the RAB conceptual model. As explained in the Introduction, each of these categories covers an aspect of RAB procedures and practices that was assessed during the site visits. The second part of this section discusses in detail the seven categories of procedures organized by function and task.

3.1 Summary Evaluations of RAB Procedures and Practices

3.1.1 Task Allocation

3.1.1.1 Allocation of Tasks Between Humans and Machines

Brachytherapy has evolved from completely manual techniques to RAB, in which some of the more difficult and dangerous tasks, including that of actually placing the radioactive sources in the patient's body, have been automated so that many task steps can be performed by the hardware without user intervention. However, numerous tasks have been left for users to perform and several have been added to verify that linkages between tasks are performed correctly. It is not the purpose of this report to decide whether this allocation of tasks between human and machine is optimal (that topic is considered in NUREG/CR-6125, Vol. 1), but rather to describe the allocation that was observed during the visits to the RAB sites.

Machines were prominent in simulation and treatment planning tasks and in the positioning of the radiation sources during treatment. They were used in these tasks to perform data collection, calculation, and precise mechanical manipulations. Some verifications were also performed by hardware, which used check cables to verify some of the connections between the patient and the afterloader, and software that calculated geometric relationships between digitized entries to check for inconsistencies.

Users performed the tasks that required manipulation of large objects, pattern recognition, and medical experience or knowledge. Users were also required to link the outputs of tasks performed by hardware into a working treatment delivery system.

3.1.1.2 Allocation of Tasks Between Staff

Table 1 shows the combined percentages for RAB task performance for six job classifications found at the RAB

sites. Figures 2–7² graph the relative frequencies of task performance within each job classification. These aggregate figures suggest that task specialization was common in the RAB personnel so that most medical duties and patient contact activities were performed by physicians, nurses and technologists while dosimetry and source calibrations were performed by the physics staff. Although allocation of tasks to different job classifications varied slightly from site to site, evidence of specialization was even stronger at individual sites. For example, at two sites, most of the RAB tasks other than radiation prescription and applicator placement were performed by physicists.

Although the radiation oncology staff was large at some of the visited sites, RAB tended to be performed by smaller teams who specialized in RAB treatments. Many sites had only a single individual assigned to some RAB tasks.

3.1.2 Task Ordering

The detailed descriptions of the procedures developed during site visits allowed construction of a more detailed model of the RAB system than was shown in Figure 1.

Figures 8, 9, 10, and 11 provide graphical representations of those parts of the model that deal with treatment plan generation, treatment plan selection, and treatment delivery. In each of these figures, the flow of information and materials through the RAB system is depicted by filled arrows. Patient movement between workspaces is shown by unfilled arrows. Transfer of information is represented by the movement of the physical medium which contains the information, and is shown as a 2-dimensional box. A 3-dimensional box signifies an RAB task or subtask; shaded boxes denote tasks involving patient contact, while unshaded boxes denote tasks without direct patient contact.

Figure 8 shows the process by which a treatment plan is generated for a patient. The patient is scheduled for a treatment session, applicators are placed in the patient, and treatment simulation with dummy sources produces a set of x-ray films that are used to determine applicator location and potential source dwell positions within the patient. During target volume localization, targets for the radiation dose are either identified in the x-ray images or added to those images using information from other target volume localization techniques. The x-ray images carry this information to the dwell position localization task where dwell positions are refined and limits on source travel are established. This information is used in the radiation

² In order to not disrupt the flow of the text presentation, all figures for Section B are presented in Appendix A.

Results

Table 1. RAB Task Performance According to Job Category (15 Sites)

Function/Task	Job Category					
	MD	Physicist	Dosimetrist	Technologist	Nurse	Clerical
	(percent of sites)*	(percent of sites)*	(percent of sites)*	(percent of sites)*	(percent of sites)*	(percent of sites)*
Patient Preparation						
Patient scheduling, identification, and tracking	7	7	—	47	60	33
Patient instruction	40	7	—	27	67	—
Life support monitoring	20	—	—	13	53	—
Applicator placement and stabilization	100	—	—	7	13	—
Patient transportation	—	7	—	47	47	7
Treatment Planning						
Simulation with dummy sources	13	7	7	100	—	—
Target volume localization	100	20	7	—	—	—
Radiation prescription	100	—	—	—	—	—
Dwell position localization	33	7	—	7	—	—
Dosimetry	13	67	27	7	—	—
Treatment plan selection and approval	87	20	7	7	—	—
Treatment Delivery						
Treatment set-up	13	33	13	60	20	—
Treatment plan entry	13	53	13	33	—	—
Verify treatment data prior to treatment	27	53	13	33	—	—
Treatment session monitoring	27	60	7	60	27	—
Treatment session control	20	53	7	47	—	—
Post-Treatment						
Source guide tube disconnection	20	13	7	47	27	—
Applicator removal	87	20	7	20	40	—
Patient transportation	—	7	—	47	47	7
Record-keeping **	13	47	13	67	20	—
Quality Assurance and Maintenance						
Source exchange	—	20	—	—	—	—
Source calibration	—	100	—	—	—	—
Equipment and software updates	—	80	—	—	—	—
Troubleshooting	—	100	—	—	—	—
Routine quality assurance	—	73	—	47	—	—

* Row sums can be greater than 100 since a task can be performed by more than one job category at some sites.

** Treatment verification has been included as part of record-keeping for the purposes of this summary.

prescription task, along with applicator information, to prescribe a dose of radiation for each target. A written prescription describing each radiation target and the dose to be delivered to that target carries the desired radiation distribution to the treatment plan generation task. In that task, treatment plans are produced by selecting precise source dwell times and dwell positions. The results are carried in three documents: the x-ray, the applicator map that specifies which applicator will be connected to each afterloader channel, and the plan that specifies source dwell positions and dwell times within each channel. Once a set of treatment plans has been generated, the most appropriate plan will be selected by the radiation oncologist.

Figure 9 represents the flow of information and material during the selection of a particular treatment plan for treatment delivery. Dosimetry software is used to calculate the dose that would be delivered to each target from each plan. To do this, the software uses position information transferred from the x-ray images to reconstruct the geometric relationships between the dwell positions and the targets. The applicator map is used to match planned afterloader channels with specific applicators identified in the x-ray images. The dosages for each plan are plotted (the isodose plots) and compared with the desired radiation prescription.

In the plan selection and approval task, the dose distributions from the isodose plots for one or more treatment plans (from either the current planning session or from plans stored in a dose atlas) are compared with the radiation prescription. The most appropriate plan is selected on the basis of how well its isodose plot corresponds to the radiation prescription. When a plan is chosen and approved for treatment, the three major products of the treatment planning process are brought together: the radiation prescription, which specifies the dose to be delivered to each target; the applicator map, which specifies the connections between the afterloader channels and the applicators; and the treatment plan, which details the source dwell positions and times within each afterloader channel.

The same techniques can be used to generate reference plans for a dose atlas that catalogs distributions of sources and targets. Figure 10 details the steps necessary to produce such an atlas. Of particular interest is the description of the data which must be present at each stage of the treatment so that the linkage between the tasks can be performed. An atlas can be used for cases involving generic treatment geometries and applicators. Unusual geometries and custom made applicators necessitate the formulation of treatment plans that take their special characteristics into account.

Figure 11 shows an approved treatment plan being used to deliver an RAB treatment to a patient. The plan is entered in the afterloader control unit, and the applicator map is

used to connect the applicators to the correct afterloader channels.

Major variations among the sites were observed in several treatment planning tasks, including simulation with dummy sources, radiation prescription, dwell point localization and dosimetry tasks; similarly, sites differed in terms of how the treatment planning and treatment functions were performed. For example, dosimetry was performed prior to treatment at nine sites ($9/15 = 60\%$). Dosimetry was performed after treatment to verify that the prescribed dose had been delivered at three sites ($3/15 = 20\%$). The remaining sites ($3/15 = 20\%$) varied the order of dosimetry and treatment depending on the medical procedure and treatment fraction that was being performed. Dosimetry tended to be performed prior to treatment at these sites for multi-channel lung treatments and either after treatment or not at all for simple single channel treatments.

Treatment plans were selected from a pre-planned dose atlas for some treatment procedures at seven sites ($7/15 = 47\%$). At those sites dosimetry preceded treatment, but also preceded applicator placement. Simulation preceded treatment planning at all sites in which the treatment plan was based on simulation data (i.e., the sites which did not use a dose atlas). Simulation was not performed at all for some sites using a dose atlas and was performed to aid in radiation prescription and target and dwell point localization at others which did not use the simulation data for dosimetry. Treatment plan approval was also performed after the treatment session had occurred at several sites.

3.1.3 Task Performance

3.1.3.1 Procedures

Very few written procedures of any kind were found at the visited sites.

Procedures for Task Performance

Table 2 lists the number of sites at which locally produced documents dealing with task performance were found. Figure 12 presents these results graphically. The values for worksheets and checklists represent items actually used by task performers. The values for procedural descriptions represent written descriptions available at the site whether or not those descriptions were used during task performance. In practice, the descriptions were often available only to certain individuals and were not necessarily accessible to the task performers. The final column in Table 2 shows the percentage of sites at which one or more of these documents was found for each RAB task.

Table 2. Task Performance Documents (15 sites)

Function/Task	A description of task steps was available	A checklist was used	A worksheet was used	Any of those procedural documents	
	number of sites	number of sites	number of sites	number of sites	percent of sites
Patient Preparation					
Patient scheduling, identification, & tracking	2	3	—	5	33
Patient instruction	—	—	—	—	—
Life support monitoring	—	—	—	—	—
Applicator placement and stabilization	2	—	—	2	13
Patient transportation	—	—	—	—	—
Treatment Planning					
Simulation with dummy sources	5	—	1	5	33
Target volume localization	—	—	1	1	7
Radiation prescription	3	—	4	7	47
Dwell position localization	—	—	4	4	27
Dosimetry	—	—	—	—	—
Treatment plan selection and approval	2	1	2	3	20
Treatment Delivery					
Treatment set-up	4	—	1	4	27
Treatment plan entry and verification	5	—	2	6	40
Treatment session monitoring and control	3	—	1	4	27
Post-Treatment					
Source guide tube disconnection	2	—	—	2	13
Applicator removal	—	—	—	—	—
Patient transportation	—	—	—	—	—
Record-keeping	2	—	2	4	27
Quality Assurance and Maintenance					
Source exchange	2	2	1	2	67*
Source calibration	7	4	5	9	60
Equipment and software updates	1	1	—	1	7
Troubleshooting	10	—	1	10	67
Routine quality assurance	9	8	4	10	67

*67% = two out of three sites which perform their own source exchanges. All other percentages are for 15 sites.

At two sites, individual task performers had produced personal written descriptions of some of the RAB task steps. Since their personal procedures were not available to the other task performers and had not been approved at the site, they were not included in these findings. Site licenses, which might have specified task performers and task workspaces, were examined at only a few sites at which they could be obtained from the task performers. Other procedural descriptions may indeed have existed and not been recorded during these site visits.

The existence of unrecorded procedures would change the statistics quoted in this study. For instance, written procedures may have existed at some sites but were not readily accessible to task performers. Such procedures were not included in the results of this study given that their value to task performers would be minimal at best.

A checklist can be used during task performance to direct a user's attention to a procedural step. Checklists used in task

performance are graphed in Figure 13 according to the RAB task for which they were used. Worksheets in which task information is written can also direct a user's attention to the need to perform a step in a procedure prior to writing the results of the step on the worksheet.

Figure 14 is a graph of the worksheets used in task performance at the sites and specifies the task for which they were used. A graph of all performance procedures of any type, whether written descriptions, checklists, or worksheets is shown in Figure 15.

Procedural descriptions are useful for task performers and would be expected at a site in which there was a frequent turnover of staff or in which organizational structure was imposed on a large staff to insure that procedures were consistent between individual task performers. Training can be substituted for written procedures to some extent if the training is designed and maintained to refresh the required task performance and linkage skills.

3.1.4 Task Locating

The three patient contact tasks (applicator placement, simulation, and treatment) were always performed in separate workspaces at three of the sites ($3/15 = 20\%$). At three other sites ($3/15 = 20\%$), these tasks were performed in the same workspace in a dedicated RAB room. Workspaces at the other nine sites ($9/15 = 60\%$) were combined for some treatments or treatment fractions and separated for others. At these nine sites, for at least some medical procedures, applicator placement and simulation were performed in one workspace after which the patient was moved to a separate workspace for treatment. Figures 16 and 17 show the grouped workspace and task performance arrangements for two different medical treatment procedures. Workspaces and human-system interfaces for individual tasks have been described separately in Section A of this volume.

3.1.5 Task Linkages

Some information was transferred verbally between task performers at all sites. Worksheets were used at six sites ($6/15 = 40\%$) to carry information between tasks during treatment planning. Tables 3–5 and Figures 18–21 show some of the linkages between tasks identified during the study and whether information required for those linkages was transferred by worksheets or checklists. Worksheets and checklists shown in the linkage tables may not be the same ones that were used to guide task performance. Many of these linkage worksheets were filled out after completion of the task as a means of transferring data and were not used to guide performance of the task. Table 3 shows linkages between patient preparation and treatment

planning tasks, Table 4 shows linkages between treatment delivery and post-treatment tasks, and Table 5 shows QA and maintenance linkages. Task linkages for which descriptions of linkage procedures were available are shown in Figure 18. Linkages mentioned in checklists are shown in Figure 19. Linkages that were performed using worksheets are shown in Figure 20. Figure 21 shows the combined number of sites at which any of those linkage documents were found.

Several weak linkages were identified in which neither a procedure nor a consistent practice could be determined. The most noteworthy of these was that information identifying an applicator, the prescribed dose to be delivered by that applicator, the treatment parameters designed to deliver that dose, and the channel to which each applicator should be connected was inconsistently transmitted between task performers at several sites. At these sites, it could not be guaranteed that an applicator in a multiple applicator treatment would be connected to the afterloader channel specified for it in the treatment plan.

Example: A dosimetrist who planned the treatment reported that the code of the marker strings on the simulation x-rays was always used during planning to identify the applicators since marker # 1 was always inserted into applicator # 1 (as marked and prescribed by the physician). The technologist who inserted the markers into the applicators was unaware of this procedure and reported that no such insertion order was followed since it "didn't matter" which string went into which applicator.

Example: A technologist who connected the applicators to the treatment channels was not aware that any connection order should be preserved and believed instead that the system would not allow the applicators to be connected to the wrong channels. (Connections were standardized by the hardware for some, but not all, applicators in use at that site.)

Weak linkages were also identified in the transmission of the radiation prescription, the identification of the applicator size (and hence the dose to the tissue at its edge) in the transmission of simulation information to the planning task and in the transfer of information from the calibration task to the treatment task. These linkages suffered from inconsistent terminology between task performers and inconsistent human interfaces used to transfer the information.

Example: The view angle recorded from the simulation x-ray machine used a different coordinate system from the planning software so

Table 3. Task Linkage Documents for Patient Preparation and Treatment Planning Tasks (15 sites)

Information comes from TASK, Person or [document]	→	The information is used in TASK or [document]	for	Number of sites using a document describing a				Any Linkage Document *
				Linkage	Chklist	Wksheet		
Patient Preparation								
Physician	→	SCHEDULE	Scheduling treatment	–	–	1		1
SCHEDULE	→	[Schedule]	"Patient, time, & task documentation"	–	–	–		–
[Schedule]	→	ALL TASKS	Specifying RAB tasks to perform	–	–	–		–
Patient	→	IDENTIFY	Identifying patient at workstation	–	–	–		–
IDENTIFY	→	[documents]	Marking docs produced at workstation	–	–	–		–
[documents]	→	TRACKING	Matching patient to transported docs	–	–	–		–
Patient	→	TRACKING	Matching patient to scheduled tasks	–	–	1		1
SCHEDULE	→	INSTRUCT	Choosing patient Instructions	–	–	–		–
SCHEDULE	→	TRANSPORT	Routing requirements	–	–	–		–
SCHEDULE	→	PLACE	Choosing apps and placement sites	–	–	1		1
PLACE	→	[app labels]	Applicator identification labels	–	–	2		2
PLACE	→	[app map]	Applicator specs & placement sites	–	–	7		7
Treatment Planning								
[app labels]	→	SIM	Dummy source insertion	–	–	1		1
[app map]	→	SIM	Simulation view coverage	–	–	1		1
SIM	→	[SIM specs]	Sim view angles & magnifications	–	–	1		1
SIM	→	[SIM map]	App-dummy source correspondence	–	–	–		–
SIM	→	[SIM views]	Simulation images	–	–	–		–
[SIM views]	→	TVLOC	Target info from simulation	–	–	–		–
[SIM map]	→	TVLOC	App-dummy source correspondence	–	–	–		–
[SIM specs]	→	TVLOC	SIM view and magnification info	–	–	–		–
[med records]	→	TVLOC	Other target information	–	–	–		–
PLACE	→	TVLOC	Target info from placement	–	–	2		2
[app map]	→	TVLOC	App specs & placement info	1	–	7		7
TVLOC	→	DOSE Rx	Target location	–	–	–		–
[SIM views]	→	DOSE Rx	Target & app info from Simulation	–	–	–		–
[SIM map]	→	DOSE Rx	App-dummy source correspondence	–	–	–		–
[app map]	→	DOSE Rx	App characteristics & placement info	1	–	7		7
PLACE	→	DOSE Rx	Target info from placement	–	–	4		–
[Med Records]	→	DOSE Rx	Other target information	–	–	–		–
EXCHANGE	→	DOSE Rx	Radio nuclide info	–	–	2		–
DOSE Rx	→	[Tmt directive]	Desired dose distribution	–	–	10		–
[Tmt directive]	→	SELECT	Desired dose distribution	1	–	10		10
TVLOC	→	SELECT	Target locations	–	–	–		–
[SIM views]	→	SELECT	Target & app info from simulation	–	–	–		–
[SIM specs]	→	SELECT	SIM view and magnification info	–	–	–		–
[SIM map]	→	SELECT	App-dummy source correspondence	–	–	–		–
[app map]	→	SELECT	App characteristics & placement info	1	–	7		7
EXCHANGE	→	SELECT	Radio nuclide info	–	–	2		2
CALIBRATE	→	SELECT	Source activity	2	–	5		5
SELECT	→	[app-chan map]	Applicator channel connections	–	–	2		2
SELECT	→	[Tmt Plan]	Dwell positions and times	–	–	4		4

* Note: The values in this column are not additive because a single site may use several types of documents.

Table 4. Task Linkage Documents for Treatment Delivery and Post-Treatment Tasks (15 sites]

Information comes from TASK, Person or [document]	The information is used in TASK or [document]	for	Number of sites using a document describing a				Any Linkage Document*
			Linkage	Chklist	Wksheet		
Treatment Delivery							
[app-chan map] →	SETUP	Applicator-channel connections	—	—	2	—	—
PLACE →	SETUP	App labels	—	—	2	—	—
[Tmt Plan] →	ENTRY	Dwell positions and times	3	1	8	9	9
[Tmt Plan] →	ENTRY	Selected radio nuclide source	—	—	4	4	4
[Tmt Plan] →	ENTRY	Planned source activity	1	—	8	8	8
CALIBRATE →	ENTRY	Treatment source activity	3	1	7	10	10
SETUP →	CONTROL	Patient status	—	—	—	—	—
ENTRY →	CONTROL	Plan entry status	—	—	—	—	—
QA →	CONTROL	Equipment status	—	9	—	9	9
SCHEDULE →	MONITOR	Monitoring needed	—	—	—	—	—
MONITOR →	[Source log]	Record sources placements	—	—	1	1	1
Post-Treatment							
MONITOR →	DISCONNECT	Verify treatment completed	—	1	2	2	2
PLACEMENT →	DISCONNECT	Disconnect requirements	—	—	1	1	1
MONITOR →	RECORDKPG	Record of TMT values	—	1	2	3	3
SCHEDULE →	TRANSPORT	Transport requirements	—	—	—	—	—
SCHEDULE →	REMOVAL	Removal requirements	—	—	1	1	1
[App map] →	REMOVAL	App characteristics and locations	—	—	5	5	5
REMOVAL →	RECORDKPG	Inventory of removed items	—	—	1	1	1

* Note: The values in this column are not additive because a single site may use several types of documents.

that an angle read as 330 degrees from one required entry into the other as 30 degrees. No procedure or worksheet was found documenting or advising about this linkage problem. A new staff member was unaware of the difficulty and was observed to enter the incorrect angle when prompted by the software. The error was detected and corrected by a senior staff member who was watching the planning session.

3.1.6 Verification of Task Performance

Procedures dealing with performance verification of treatment plan entry were found at 40 percent of the sites. Few other tasks had any written descriptions for verification procedures. Table 6 and Figures 22–25 summarize the written procedures that dealt with verification of the performance of each task.

Verification of task performance entails the recognition that a task has been performed and also may require a judgment to be made regarding the quality of performance. All sites had some method of performance verification for treatment planning and for entry of the treatment plan into the

afterloader control unit. These verification methods ranged from self inspection by the task performer to elaborate schemes in which a second verifier was required to make independent measurements to guarantee correct task performance.

Example: At one site, duplicate treatment plans were produced on different planning systems by two different individuals. These plans were then compared and discussed prior to plan selection to verify that a reasonable plan had been produced prior to treatment.

Not all tasks were subject to formal verification. Applicator and target volume localization and treatment set-up tasks were verified at only a few of the sites.

Other tasks, such as those involving patient identification, were subject to repeated verification. These verifications were performed frequently enough so that task performers at several sites expressed concern that their patients were becoming upset at being asked continually for the same personal identification information.

Table 5. Task Linkage Documents for QA and Maintenance Tasks (15 sites)

Information comes from TASK, Person or [document]	→	The information is used in TASK or [document]	for	a document describing a Linkage	Number of sites using a Chklist	a Wksheet	Any Linkage Document*
Quality Assurance							
SCHEDULE	→	ALL TASKS	Matching patient & sched task	—	—	3	3
SCHEDULE	→	ALL TASKS	Info on schedule changes	—	—	—	—
IDENTIFY	→	ALL TASKS	Matching patient & documents	—	—	1	1
TRACKING	→	ALL TASKS	Info on problems	—	—	—	—
ROUTINE QA	→	[RAB log]	Record of RAB process status	—	2	—	2
ROUTINE QA	→	[QA log]	Record of equipment status	—	9	—	9
[QA log]	→	SIM	Verify SIM equipment status	—	—	—	—
[App labels]	→	SIM	Verify identity of apps in [SIM views]	—	—	2	2
SCHEDULE	→	DOSE Rx	Verify that Rx is for sched Tmt Fx	—	—	3	3
[SIM Views]	→	DOSE Rx	Verify [SIM view] is for sched Tmt Fx	—	—	1	1
[SIM map]	→	DOSE Rx	Verify specification of Apps in Rx	—	—	1	1
[QA log]	→	SELECT	Verify planning software status	—	1	—	1
[Schedule]	→	SELECT	Verify that plan is for sched Tmt Fx	1	—	3	4
[Tmt directive]	→	SELECT	Verify that selected plan matches Rx	1	—	7	7
[Tmt directive]	→	SELECT	Verify that [app-chan map] matches Rx	—	1	2	3
[Schedule]	→	ENTRY	Verify that entered Tmt Fx was sched	—	—	3	3
[Tmt Directive]	→	ENTRY	Verify that entered plan matches Rx	—	1	7	8
[QA log]	→	CONTROL	Verify treatment equipment status	—	9	—	9
[RAB log]	→	CONTROL	Verify steps in RAB process	—	2	—	2
MONITOR	→	CONTROL	Verify patient and system status	—	1	—	1
[App labels]	→	DISCONNECT	Identify applicators	—	—	2	2
[App-chan map]	→	DISCONNECT	Verify channel connections	—	—	2	2
[Source log]	→	DISCONNECT	Verify return & disposal of all sources	—	—	1	1
DISCONNECT	→	[RAB log]	Log channel disconnections	—	—	1	1
[App map]	→	REMOVAL	Verify removal of all applicators	—	—	3	3
REMOVAL	→	[RAB log]	Log applicators removed	—	—	1	1
Maintenance							
EXCHANGE	→	SELECT	Radio nuclide info	—	—	1	—
EXCHANGE	→	ENTRY	Radio nuclide info	—	—	1	—
CALIBRATE	→	SELECT	Source activity	1	—	5	5
CALIBRATE	→	ENTRY	Source activity	1	—	5	5
ALL TASKS	→	RECORDKPG	Info on problems	—	—	—	—
RECORDKPG	→	TRBLSHOOT	Info on problems	—	—	—	—
TRBLSHOOT	→	ALL TASKS	Info on problems	—	—	1	1
[equipment mods]	→	ALL TASKS	Equipment and interface specs	—	—	1	1
[software mods]	→	ALL TASKS	New software specs	—	—	—	—
[procedure mods]	→	ALL TASKS	New procedures	—	—	—	—

* Note: The values in this column are not additive because a single site may use several types of documents.

Table 6. Performance Verification Documents (15 sites)

Function/Task	A description of verif procedure was available	A checklist was used	A worksheet was used	Any written verification procedure	
	number of sites	number of sites	number of sites	number of sites	percent of sites
Patient Preparation					
Patient scheduling, identification, and tracking –	–	–	–	–	–
Patient instruction	–	–	–	–	–
Life support monitoring	–	–	–	–	–
Applicator placement and stabilization	–	–	–	–	–
Patient transportation	–	–	1	1	7
Treatment Planning					
Simulation with dummy sources	1	–	–	1	7
Target volume localization	–	–	1	1	7
Radiation prescription	–	–	1	1	7
Dwell position localization	–	–	1	1	7
Dosimetry	–	–	1	1	7
Treatment plan selection and approval	–	–	–	–	–
Treatment Delivery					
Treatment set-up	1	1	–	2	13
Treatment plan entry and verification	4	1	1	6	40
Treatment session monitoring and control	–	1	3	4	27
Post-Treatment					
Source guide tube disconnection	–	1	–	1	7
Applicator removal	–	–	–	–	–
Patient transportation	–	–	1	1	7
Record-keeping	–	1	–	1	7
Quality Assurance and Maintenance					
Source exchange	1	–	–	1	7
Source calibration	1	–	–	1	7
Equipment and software updates	1	–	–	1	7
Troubleshooting	1	–	–	1	7
Routine quality assurance	–	–	–	–	–

3.1.7 Verification of Task Linkages

Worksheets and checklists carried between tasks provided both the means of transport and the method for verifying task linkages at those sites at which documents dealing with task linkages were used. Tables 3–5 show the documents used in linkages between tasks that also provided a record that could be used to verify that the linkage had been performed. Very few of these linkage

documents addressed verification that the linkage had been performed correctly. The linkage descriptions shown in Figure 21 for treatment plan entry and some QA tasks did address verification of some task linkages. In practice, staff at most sites were expected to verify that the parameters from the treatment plan had been correctly entered into the afterloader control unit. Other task linkages were verified only by personal diligence of the task performers. This situation was somewhat ameliorated

Results

by the practice at most sites of having a single individual perform most of the tasks so that problems of information transfer between individuals were minimized. Linkages were often at risk between tasks in which information was transferred between individuals and in procedures which required many individuals to participate in the linkages.

Example: Consistent radiation prescription formats were rare and were likely to depend on which of several physicians was writing the prescription. The format used to transfer the prescription to the treatment planner varied from a simple verbal request to a formal written treatment directive written on a worksheet that contained all the information needed by the planner. Although the process of approving the treatment plan provided the radiation prescriber with an opportunity to correct previous linkage failures, the information presented for approval was often difficult to interpret. In particular, since the isodose presented for approval was usually referenced to the source positions rather than to the patient's body, the isodose plot could not be used to verify whether the dose would be delivered to specific physiological targets.

3.2 Detailed Descriptions of Individual Tasks

Let us now turn to a detailed consideration of individual RAB tasks in terms of the seven categories of RAB procedures that were summarized in the above discussion. This section presents the findings of the procedures and practices evaluation in terms of RAB functions and tasks. Please note that in the following sections, where there is no "Procedures" subsection, this indicates that no written procedures were identified for that type of procedural category at any of the sites visited.

3.2.1 Patient Preparation

This is the function in which a patient is prepared for treatment delivery. It involves treatment scheduling and tracking, patient identification, patient instruction, life support, applicator placement, and patient transport.

3.2.1.1 Patient Scheduling, Identification, and Tracking

This task involves the initial identification of the patient, scheduling the patient's movement through the RAB workspaces, and any transport, tracking and re-identification that is required as the patient and patient records move within the RAB system.

Task Allocation

Procedures

No written procedures describing who should perform this task were found at any site. Although a few sites had written task performance procedures, the collected written procedures did not specify the person responsible for scheduling.

Practices

The task of scheduling an RAB treatment and coordinating the schedules of the personnel and workspaces used in the treatment was usually performed by a nurse or technologist at nine sites ($9/15 = 60\%$), by clerical personnel at five sites ($5/15 = 33\%$), and by a physicist at one site. An informal allocation procedure was used at most sites in which one individual was assigned the responsibility for scheduling, and others involved in the scheduling process would contact that individual to schedule a treatment. When the RAB workspaces were shared with other site activities (e.g., teletherapy), the RAB schedule was coordinated with the people responsible for scheduling the other activities. At four of the sites ($4/15 = 27\%$) the technologists who controlled the schedules of shared equipment (e.g., simulators) were also responsible for scheduling RAB treatments.

A physician (MD) was directly involved in scheduling the exact time of treatment at only one site. However, at every site a physician had decided whether to perform the RAB treatment and had specified both the number of treatment fractions to be performed and the coordination between RAB and teletherapy treatments on each patient.

Task Ordering

Procedures

Since scheduling was required prior to RAB at all sites, scheduling was constrained to take place before most other RAB functions could be performed. In most cases there was physician contact with a patient for evaluation prior to scheduling the RAB treatment session. Patient instruction by the MD on RAB during those evaluations also preceded scheduling of the RAB treatment.

Practices

The interval between scheduling an RAB treatment and the other tasks of the treatment varied greatly both between and within the RAB sites visited. Emergency treatments were observed in which less than one hour notice was given

before placement of applicators. Other sites required several days' notice to plan a treatment.

Task Performance

Procedures

Written task performance procedures for scheduling RAB treatments were found at five sites ($5/15 = 33\%$). At two of these sites ($2/15 = 13\%$) the procedures consisted of written descriptions of how to schedule an RAB treatment session. At three other sites a step-by step checklist was filled out by the scheduler during task performance.

Photographs of the patients were used for identification at six of the sites ($6/15 = 40\%$).

At two sites ($2/15 = 13\%$) RAB treatments were performed only at certain times of the day or on certain days of the week to reduce scheduling conflicts with other equipment in shared treatment rooms.

Practices

At large facilities, the scheduler was often required to coordinate the schedules of several individuals and workspaces in multiple iterations to find a time at which the patient, oncologist, referring MD, technologist and simulation and treatment workspaces would all be available for a treatment session.

Patient identification was performed by a combination of ID matching, verbal interrogation, comparison of chart information and photographs of the patient, and prior recognition. In many cases the RAB treatments took place after a prior series of teletherapy treatments for the same condition so that scheduling would be performed for RAB at the last teletherapy treatment session. In these cases the patients would be identified by the MD prescribing the treatment, and the patients' identities would be known to the scheduler and the treatment personnel from earlier treatment sessions.

Task Locating

Practices

Patient scheduling took place in a wide variety of workspaces and was distributed over several workspaces used for other tasks. The most common workspace was a secretary's or receptionist's workstation. The large number of people and equipment involved in scheduling an RAB treatment also required portions of the task to be performed at the logbooks for the different treatment rooms, at the

offices of referring and consulting physicians, and in the reception room where patients were met and released. Most sites dealt with this distribution of the workspace by connecting the workspaces verbally through telephone communications and physically using treatment logbooks and referral slips.

Task Linkage

Procedures

Some form of written task linkage procedure was available for the carrying information from the scheduling task to other tasks at five of the visited sites ($5/15 = 33\%$). At each of these sites a worksheet was filled out after scheduling and passed, along with other information on the patient, to subsequent task performers. Scheduling logs for treatment rooms were used at all sites. At two sites ($2/15 = 13\%$) patients were given a copy of the photograph in their chart to carry along with them.

Practices

Schedules were maintained separately for physicians and workspaces at most sites. The scheduler was responsible for getting the scheduling information to each workspace and would usually transmit the information by either personal entries in a treatment logbook for each workspace or by calling the logbook keeper (usually a technologist) on the phone to schedule a treatment time. Treatment was scheduled by each patient's name, the date of the proposed treatment session and number of the treatment fraction in the series of RAB treatments that had been prescribed for the patient.

Initial patient identification often occurred at the end of a series of teletherapy treatments so that each patient's identity was known to the scheduler and the site personnel who had previously performed the teletherapy treatments.

Verification of Task Performance

Practices

At each site new patients were questioned upon arrival to determine their identity and whether they were scheduled for treatment at that time. Names of patients and referring physicians were checked against the RAB schedule. At many sites, an ID number or photograph worn by each patient was also checked against information in the schedule or treatment directive to verify that treatment would be given to the correct patient.

Results

At two sites (2/15 = 13%) new patients were also asked their birth date to verify identity. The birth date was then compared with each patient's chart as an independent method of identification unlikely to be available to someone answering to the wrong name.

The physician who was to place the applicator was expected to recognize and verify each patient's identity and scheduled treatment prior to applicator placement.

Verification of Task Linkages

Practices

At most sites, once in the facility, the patients would be transferred by a nurse or technician familiar with them.

At two sites (2/15 = 13%) the patients were each given a copy of the photograph in their chart to carry with them so that staff performing other RAB tasks could identify the patients and determine that the chart they carried was their own.

3.2.1.2 Patient Instruction

Patient instruction can be viewed as a training procedure in which the staff informs patients about the treatment process and then teaches them to perform any tasks that will be expected of them during the treatment process (e.g., movement between workstations, remaining in one position during the treatment, responding to instructions). Some assessment of the patient's understanding and task performance capacity is usually made in conjunction with the instruction. Instruction is particularly important for patients undergoing LDR treatments, since LDR treatments take place over several days and require patient participation throughout the treatment process.

Task Allocation

Procedures

Although no written procedures for patient instruction were found at any site, physicians, nurses, and technologists all considered patient instruction to be one of their expected functions. Three of the 15 sites had no nurses participating in RAB.

Practices

Patient instruction was reported by the physicians at six sites (6/15 = 40%), by the nurses at 12 sites (12/15 = 80%), by the technologists at four sites (4/15 = 27%) and by a

physicist at one site (1/15 = 7%). Nurses performed patient instruction at all 12 (12/12 = 100%) of the sites in which a nurse was a member of the RAB team.

Task Ordering

Practices

Patient instruction was provided prior to the treatment session by the MD prescribing the treatment. These instructions were amplified or repeated (if known) later by the nurse when questioned by the patients and for emphasis and clarification. Instruction was provided during treatment by both nurses and technologists.

Task Performance

Procedures

Written patient instruction procedures were in use at one site (1/15 = 7%).

Practices

Patients received initial general instructions from their examining physicians followed by specific instructions from a nurse or technologist prior to treatment and continued instruction by intercom during treatment. Tasks assigned to patients varied from simple admonitions to remain calm and change or maintain body position during simulation and treatment to much more complicated instructions regarding self-transport between RAB workstations. Instruction given during treatment usually consisted of short messages from technologist or physicist to the patients regarding the expected duration of treatment and admonitions to relax and refrain from moving during the treatment session.

Task Locating

Practices

Communication with the patients took place at all of the RAB workstations entered by the patient during an RAB treatment session. Initial patient instruction was performed by the referring physicians prior to the patients' arrival at the RAB site. Detailed instruction took place in the reception area when the patients arrived and, in some cases, just prior to their leaving the RAB facility. Specific instructions on each patient's treatment and the expected course of treatment were usually given in the examination and applicator placement workspaces. Some communication and instruction was also provided from the

treatment control workstation to the treatment workstation during treatment and in the treatment and simulation workstations themselves in the intervals between placement, simulation and treatment.

Task Linkage

Practices

The patients themselves provided the physical linkage between their instructions and the RAB tasks performed during treatment. A linkage between instruction and RAB task performance would involve an appropriate patient response to a prior instruction that specified what each patient was expected to do during performance of a subsequent RAB task. Task linkage practices by the staff involved identification of the stage in treatment that each patient was entering and reference to the prior instructions regarding the treatment.

Verification of Task Performance

Procedures

All patients were reported to have signed consent forms for treatment that specified that they had been instructed on the treatment to be performed. The forms collected during the site visits required each patient's signature to verify that instruction had been given. No method for assessing patients' understanding of the instructions was specified.

Practices

All the nurses (12/12 = 100%) reported that it was their job to assess whether patients had understood the instructions from the MD and to repeat and rephrase those instructions until the patients showed evidence of understanding the instructions. Patients were reported to be much more likely to ask questions of the nurse than of the physician providing the original instructions. Therefore, nurses were required to understand the original instructions, the tasks assigned to the patients, and the effects of poor performance of those tasks on RAB treatment delivery in order to insure that the intent of the instructions had been conveyed and to assess each patient's ability to perform assigned tasks. It was the practice at many sites for a nurse or technologist to accompany the patients so that their performance in transporting and positioning themselves could be directly monitored. This allowed deviations in patient task performance to be detected and corrected immediately. This practice also aided in assessment of patient understanding of instruction by reducing the need for other forms of patient feedback. The primary forms of feedback used to assess understanding were either these

direct observations of patient performance or verbal interrogation in which patients were asked to explain their instructions to the nurse prior to carrying them out. Deviations from the expected feedback would then be clarified by either rephrasing the original instructions or checking with the original instructor to verify that deviations had been authorized.

Verification of Task Linkages

Practices

Staff generally preferred to re-instruct patients during the current RAB task rather than test whether they had retained the information from a prior task's instruction.

3.2.1.3 Life Support Monitoring

Life support monitoring involves maintenance of the patient's vital functions such as heart rate and blood pressure. The RAB patient frequently needs no life support assistance, but assistance may be provided by medical staff for patients who require special care or who may be under medication, such as sedatives, analgesics, anti-anxiety drugs, or local anesthetics. Patient attendants or RAB staff are required to attach, monitor, and adjust life support equipment during this task which continues throughout the RAB treatment procedure.

Task Allocation

Practices

Life support attachment was the job of nurses at eight sites (8/16 = 53%), physicians at three sites (3/15 = 20%), and technologists at two sites (2/15 = 13%). Not all sites had life support equipment available. At two sites (2/15 = 13%) life support was provided only for those patients who were transferred to the facility already attached to the devices. In those facilities, and at most of the sites visited, life support was expected to be attached and monitored by nurses or technologists not connected with the RAB team. These life support specialists were expected to accompany each patient on life support to the RAB facility and take responsibility for the life support attachment and maintenance independently of the RAB staff.

Life support for patients undergoing surgical implantation of applicators was the responsibility of the surgical team (surgeon, anesthesiologist, etc.) assisting with the implant and was not performed by members of the RAB team. At two sites (2/15 = 13%) nurses familiar with life support equipment had been hired specifically to assist with

Results

attaching life support equipment for surgical and emergency procedures performed at the RAB site.

Monitoring equipment for measuring vital signs of patients was commonly attached by the nurse responsible for the charting their vital signs during the RAB treatment.

Task Ordering

Practices

Life support equipment was expected to have been attached to patients in need of it when the patients arrived at the RAB site. Attachment after arrival was performed on an "as needed" basis.

Task Performance

Practices

Life support attachment by RAB personnel was not observed during any RAB treatment performed during a site visit for this study. Since the equipment accompanying a patient to the site was likely to be unfamiliar to the staff on the RAB team, the practice at most sites was to either leave the equipment in the hands of the people who accompanied the patient or to call for backup support when needed from similar independent life support specialists. Life support equipment was provided for emergency use at four sites ($4/15 = 27\%$). Nurses at two of these sites ($2/15 = 13\%$) reported having employed the life support equipment during RAB treatments for patients who were either heavily sedated or perceived at risk due to pre-existing cardiac conditions. Primary responsibility for the use of the equipment was considered a medical rather than an RAB function and was under the control and supervision of the medical staff of the facility.

Monitoring equipment for non-invasive vital sign monitoring (EKG, blood pressure, oxygen saturation) were attached to patients at five sites ($5/15 = 33\%$) during treatments observed during the course of this study. The practice at these sites was to monitor the vital signs of all sedated or medically compromised patients. Attachment of the monitoring equipment was performed by the nurse in charge of recording the vital signs in the patient's chart.

Task Locating

Practices

Monitoring and life support equipment was expected to follow or accompany patients as they were moved through

the RAB workstations. In the treatments observed that employed monitoring equipment, this required detaching the equipment whenever patients were moved and re-attaching it after the move.

Task Linkage

Practices

Although there was a potential for interference between the monitoring functions and the RAB tasks, no practices related to these potentials were observed during the site visits. Keeping monitoring cables out of the field during simulation was practiced by the x-ray technologist in each simulation observed in which monitoring equipment was used.

Although grounding connectors are provided on some RAB equipment for attachment to the patient's bed, only one site ($1/4 = 25\%$) reported using the grounding cable during an RAB treatment session. At no site was any practice reported dealing with multiple ground connections that might be established between the patient, the RAB equipment and any monitors or life support equipment attached to the patient.

Verification of Task Performance

Procedures

No written procedures describing verification of the performance of this task were found at any site. However, written procedures on the use of monitoring equipment during the RAB treatment monitoring task were found at two sites ($2/15 = 13\%$).

Practices

Verification of monitor attachment was performed by the person in charge of attaching the monitoring equipment. This verification was repeated whenever the equipment was used to produce data to be entered as vital signs in the patient's chart. The chart entries verified that the monitoring equipment was in place at the time of the data entry.

Verification of Task Linkages

Practices

In practice the monitoring equipment could not be used unless it had been attached. Verification of monitor attachment during an RAB task was performed whenever data were taken using the monitors during that task.

3.2.1.4 Applicator Placement and Stabilization

Applicator placement and stabilization is a medical task in which an applicator is placed and secured close to the area to be treated. Applicator placement may require collaboration with different medical specialists, depending on the location of the target and the route chosen to introduce the applicator into the patient's body. For example, lung catheters are applicators which are positioned by a pulmonary specialist, soft tissue needles are applicators that may be positioned by surgeons, and cervical applicators are usually positioned by gynecologists.

Task Allocation

Practices

Applicators were placed by physicians at all of the visited sites (15/15 = 100%). At most sites nurses or technologists assisted in the placement by selecting the appropriate applicator and preparing it for placement by the physicians.

Task Ordering

Practices

The order in which applicator placement was performed was determined by whether the site performed simulations and whether a dose atlas was used. Placement was always followed by simulation at six sites (6/15 = 40%). Placement was followed by treatment without simulation at one site. At three sites (3/15=20%), placement was followed by simulation for the first treatment fraction and the applicator was allowed to remain in place until all subsequent treatment fractions had been performed. Simulation was performed for only the first treatment fraction at those three sites. The remaining five sites varied the order of applicator placement depending on clinical considerations and whether a dose atlas had been compiled from simulations performed prior to placement.

Task Performance

Procedures

Written procedures for applicator placement were found at two sites (2/15 = 13%). Discussions of applicator placement appear regularly in both the manufacturer's newsletters and the RAB literature. These procedural descriptions were not available to the task performers during the placement task, but were available at most sites for reference.

Practices

Placement of applicators was a medical function that was based on experience rather than written procedures at most sites. Written procedures, when available, were used to augment clinical judgment of where the applicators should be placed and the best method for placing them in that location in an individual patient. Information from prior tomographic scans, prior clinical x-rays, and direct observation of the area in which the applicator was being placed were used along with mental models of anatomical variation and measurements from prior teletherapy treatments and surgical interventions.

Small gold seeds were inserted into soft physiologic structures at some sites during placement of the applicators to act as fiducial points for positioning the applicators and to provide a reference for applicator placement in subsequent treatment fractions.

Task Locating

Procedures

Although no written procedures were found at any site, individual sites were found to have adopted internally consistent unwritten procedures for the workspace assigned to applicator placement. In most cases the workspace for applicator placement was determined by either the medical procedure being performed or by the physical arrangement of the workspaces.

At three of the sites (3/15 = 20%) the placement, simulation and treatment workspaces had been combined into a single workspace used for all three functions.

At one site (1/15 = 7%) all applicator placements took place in the simulation workspace and at another site (1/15 = 7%) all placements were performed in the treatment workspace.

At four sites (4/15 = 27%) all interstitial placements were performed in the operating room.

Practices

At most sites (12/15 = 80%) placement of applicators for a particular RAB medical procedure was always performed in the same workspace (operating room, simulation room, or treatment room). A few sites (3/15 = 20%) performed applicator placement in one workspace for the first fraction of a multi-fraction treatment and then used a different workspace for placement during subsequent treatment fractions.

Results

Task Linkage

Procedures

Four sites (4/15 = 27%) had written procedures describing the information to be carried from applicator placement to other RAB tasks. In each of these, applicator information was entered on a worksheet during the placement task and carried to other tasks by physical passage of the worksheet between the tasks. Two sites used color coded worksheets for different types and sizes of applicator.

Practices

Size and Location Information

At all sites, physicians from the radiation oncology department and/or the referring department performed or observed applicator placement and radiation prescription. Size and location information was carried on the worksheets used for treatment planning and radiation prescription at four sites (4/15 = 27%). At sites without worksheets to carry the information (11/15 = 73%) the radiation prescriber was responsible for remembering the placement information between the placement and radiation prescription tasks. At these sites, information on applicator size was either transferred verbally between the person placing the applicator and the planner, or included with the radiation prescription. At two sites (2/15 = 13%) a standard size was presumed unless the planner was informed otherwise.

Applicator Identification Information

Multiple applicators were labeled with tags as they were placed at several sites. These tags were usually invisible on simulation images, but were used to identify applicators by the person connecting the applicators to the treatment channels. Local convention was used to transmit information about applicator placement, planned treatment channels, and afterloader connections at all sites. However, at several sites, some of the personnel involved in this practice were not always aware of the local convention.

A common tagging convention was to label the applicators in order of placement (e.g., 1,2,3...). An alternative (and sometimes complementary) identification method was to label the applicator images in simulation views by placing numbered radio-opaque marker strings in the applicators during simulation.

Verification of Task Performance

Practices

Simulation x-rays and fluoroscopic displays were used by the physicians placing the applicators to check on placement location at most sites (11/15 = 73%). At four sites (4/15 = 27%), no post-placement verification of the applicator position was performed for some of the treatment fractions.

Verification of Task Linkages

Procedures

No written procedures describing verification of the linkages to this task were found at any site. Several sites used worksheets with applicator-channel maps to carry information on applicator placement between tasks.

Practices

Six sites (6/15 = 27%) used marks on taped endobronchial applicators to indicate whether the applicators had moved away from the original placement location in the interval between placement and treatment. Two sites (2/15 = 13%) sometimes took x-rays after treatment to determine the amount of applicator movement between simulation and treatment. Verbal verification of applicator size was performed at several sites whenever a non-standard size was encountered. Sites using color-coded forms for linking applicator information to other tasks provided a much more direct method for verifying that applicator size and type were transmitted correctly. Whenever color coding is used, a second verification method, such as a written description of the applicators, should also be included.

Linkages at sites in which local conventions were used to determine the applicator characteristics and the map between applicators and treatment channels were only rarely verified. Although training in the local practices was provided at many of these sites, no certification or formalized retraining in local conventions was observed. Two sites were identified during the visits at which staff had conflicting opinions regarding the local conventions. Although the purpose of the visits was non-interventional, these and other potentially dangerous human factors problems were brought to the attention of senior staff at the sites during the course of the site visit or during the exit interviews.

3.2.1.5 Patient Transportation

This task involves moving an RAB patient from one location to another. Important steps within this task include locating and identifying the patient, determining the transfer route, moving the patient from the transport equipment to the destination equipment, and passing information about the patient to the destination staff.

Task Allocation

Practices

Transportation was usually handled by the nurse at eight sites (8/15 = 53%) and by technologists at seven sites (7/15 = 47%). Physicists at one site also performed patient transportation regularly. In addition, when multiple treatment fractions were performed with indwelling applicators, applicator and target relationships could be inadvertently changed or moved in the interval between the treatment fractions.

Task Ordering

Procedures

The time and tasks for which transportation was needed was determined by the workspace layout for the particular medical procedure each patient was undergoing at each site. Sites which combined the placement, simulation and treatment workspaces for some RAB treatment procedures required no patient transportation between these RAB functions.

Practices

The workspace layout at each site dictated the possible paths along which the patient could be transported. The time at which patient transportation occurred was determined by activities at different workspaces and the availability of personnel to transport the patient. At several sites at which transportation occurred (number varies with medical procedure) patients would remain in the simulation workstation until the simulation x-rays had been approved at the planning station. Since a considerable interval might occur between simulation and treatment, there would then be a choice of whether to allow patients to remain in the simulation room, to move them to the treatment room, or to move them to some interim workspace while the treatment plan was being generated. Sites which had dedicated RAB treatment rooms would perform the transportation immediately after the simulation results were approved and allow patients to wait for the plan to be produced in the

treatment room. Sites without dedicated RAB treatment rooms would allow patients to remain in the simulation room until either the treatment room was free or the simulation room was needed.

Patients were transported after applicator removal for intracavitary treatments at all sites. Patients were transported prior to applicator removal for interstitial treatment procedures which required surgical removal of the applicators in a separate applicator removal area. At these sites, when multiple treatment fractions were performed, transportation to the applicator removal area was performed only after the final treatment fraction was delivered.

Task Performance

Practices

Transportation practices varied depending on the mobility of the patients and whether they had been removed from the transport equipment used to bring them to the treatment area. Patients who were mobile and whose applicators were removed in the treatment area were assisted in self-transport. Others required transfer to and from the treatment bed or platform using a transport device. Care was required during transport to prevent movement of the applicators and to monitor and maintain any life support devices.

Task Locating

Procedures

Transportation occurred between workspaces.

Practices

At three sites, the RAB workspaces used by the patients were combined in a single room. No transportation other than transport into and out of the RAB treatment room occurred at these sites.

Task Linkage

Procedures

One site (1/15 = 7%) had a written description related to task linkages in patient transport. The description warned that care should be taken to prevent the movement of applicators between placement and other RAB workstations.

Results

Practices

Patient contact tasks were physically linked by the transportation of patients between the workspaces used for the RAB tasks. At most sites the transportation staff was aware that applicators might move during transport and that care should be taken to avoid movements which might shift the applicator's position. At several sites special transfer devices for moving patients had been obtained that allowed the patients to be transferred between beds while remaining supine on a movable platform.

Transportation was also provided between other departments and the RAB facility, although this task was only rarely performed by the RAB staff. In such cases non-RAB transporters were responsible for initial identification of the patients and participated in the task of identifying the patients upon their arrival in the RAB facility by presenting the patient's chart and person for treatment. Such hospitalized patients were often unable to identify themselves so that the linkage between the transportation and identification tasks became particularly important. No site used non-RAB transporters within the RAB facility.

Verification of Task Performance

Procedures

One site ($1/15 = 7\%$) had an item on a pre-treatment worksheet that asked the user to check applicator position visually before treatment was started.

Practices

Three sites ($3/15 = 20\%$) took occasional post-treatment radiograms to measure applicator movement between simulation and treatment. One of these was a site at which no transportation occurred between these tasks so that the verification would not have been relevant to transportation performance. Applicator movement between placement and simulation was verifiable during simulation, but no data were recorded on whether such a verification was performed regularly.

Verification of Task Linkages

Practices

Patient identity information was transferred along with the patients when the transport occurred between workspaces with different staff. It was the practice at most sites for the patients to be re-identified by checking their identification

and chart when they arrived against the logbook and any written directive regarding the treatment to be performed.

Simulation x-ray negatives were obtained prior to treatment at seven of the nine sites ($7/9 = 78\%$) at which multiple fraction interstitial treatments were performed. At the two other sites ($2/9 = 22\%$) the position of the applicator was regarded as fixed so that no attempt was made to verify that the applicator had not moved during transport between treatment fractions.

3.2.2 Treatment Planning

Treatment Planning is the function in which the dose distribution specified by the radiation prescription is transformed into instructions for positioning the source during treatment. It involves specification of each radiation source to be used, the linear distance to move that source into its treatment position and the amount of time that the source should be allowed to dwell at that position. LDR treatment plans specify a different source at each treatment position. HDR plans specify a single source which is then moved to different positions during treatment.

Treatment planning is often performed using computers with specialized software. The computer is used to reconstruct the positions of the applicator(s) and targets in space from simulation images, and to calculate and plot the dose distributions that would result from sources allowed to dwell at specified positions within the applicator(s). Staff enter information from the treatment directive and select and digitize the simulation images used to identify the expected positions of the targets, applicators, and sources.

3.2.2.1 Simulation with Dummy Sources

The purpose of simulation is to establish the position of the implanted applicator relative to the target. Typical steps in this task involve insertion of radio-opaque dummy source strings into the applicators followed by exposure of two orthogonal x-ray images (usually anterior-posterior and lateral). These images show where the applicator has been placed in the patient's body. The dummy sources identify potential dwell positions within each applicator. Fluoroscopy is often used to position the patient so that the x-ray images will contain the desired information.

Task Allocation

Practices

Simulation was performed by technologists at all sites ($15/15 = 100\%$). Physicians reported that they assisted in some steps at two sites ($2/15 = 13\%$). Physics staff

(physicists or dosimetrists) also performed some of the task steps at two sites ($2/15 = 13\%$).

Task Ordering

Procedures

Simulations were performed for all treatment fractions at 11 sites ($11/15 = 73\%$). Simulations were performed for only the first treatment fraction at three sites ($3/15 = 20\%$).

At the remaining site ($1/15 = 7\%$), simulations were performed only for interstitial treatments.

Practices

Simulations were performed immediately after applicators were placed in most intracavitary treatments. In interstitial treatments the time between placement and simulation varied depending on the time needed to transfer each patient from the workspace in which the needles were implanted to the RAB site.

The time between simulation and treatment depended on the treatment planning method used and whether simulations were performed for each treatment fraction. At sites at which only the first fraction was simulated, days or weeks would elapse between the initial simulation and the last treatment. In most, but not all, of these cases applicators were rigidly mounted to a frame to restrict their range of motion between simulation and treatment. Sites which performed a simulation for each treatment fraction had a simulation-to-treatment interval that was dependent on the length of time that was taken to produce a treatment plan after simulation. This interval ranged from ten minutes (for a plan taken from an atlas) to four hours (for a site which had difficulty getting their equipment to pass a QA check) in treatments observed during this study.

Task Performance

Procedures

Task performance procedures for simulation were found at five sites ($5/15 = 33\%$). One of these used a worksheet that was filled out during task performance.

Practices

Standard practice at the sites visited was to position the patient in the x-ray field and to expose two orthogonal x-ray negatives to show the projected images of the applicators which had been placed in the patient. Strings of

radio-opaque markers were inserted into the applicators prior to exposure of the negatives to simulate the positions at which the radioactive source would dwell within the applicators during treatment. Magnification and viewing angle information was then added to a label on one of the x-ray negatives prior to transmitting the two negatives to the remaining treatment planning tasks.

Variation was observed in the method of coding the magnification information (some sites used magnification rings or positioning frames) and the degree of standardization of the process (some sites always produced orthogonal views). In some cases dummy marker strings (which were coded by spacing to be distinguishable on the negatives) were always placed in multiple applicators according to labels on the applicators that had been attached during placement. In others (sometimes within the same RAB site) no order of placement was observed.

At sites with treatments which used many multiple channels, more than two images were sometimes taken so that some dummy strings could be removed from one set of images to facilitate identification of the individual applicators on the negatives.

The amount of anatomical information visible on the images also varied widely, but was consistent within an individual site for a particular treatment procedure. For gynecological procedures some sites inserted contrast media (e.g., barium) into critical organs to render their projections visible for dosimetric calculations on the x-ray negatives.

Task Locating

Procedures

The workspace allocated for simulations for RAB cases was usually physically determined by the location of the simulation equipment.

Practices

Simulation was performed in the same workspace as treatment at three sites ($3/15 = 20\%$). It was performed in a separate dedicated workspace for simulation at 11 sites ($11/15 = 73\%$) and was not performed for RAB treatments and therefore had no RAB workspace at one site ($1/15 = 7\%$).

Results

Task Linkage

Procedures

Written procedures describing some of the linkages to this task were found at two sites ($2/14 = 13\%$). X-ray negatives containing simulation information were carried between RAB tasks at all sites at which simulations were performed ($14/14 = 100\%$).

Practices

X-ray negatives containing images of the placed applicators were passed from the simulation to the radiation prescription and other treatment planning tasks at all sites in which simulation was used. At most sites the images were marked during simulation with simulated source dwell positions. Information on view angle and magnification of the images was written on the x-rays at 11 sites ($11/14 = 79\%$). The remaining three sites ($3/14 = 21\%$) used standardized orthogonal views and magnifications, and marked the images with view angles and magnifications only when the standards were not followed (e.g., when a good image could not be obtained from orthogonal views).

Verification of Task Performance

Procedures

Written procedures describing verification of the performance of this task were found at one site ($1/14 = 7\%$).

Practices

X-rays from the simulation were approved by a physician or member of the physics staff at nine sites ($9/14 = 64\%$). At the other sites ($5/14 = 36\%$), the technologists were responsible for verification of their own performance. In either case the x-ray negatives that were produced during the simulation were physical evidence that the task had been performed and provided documentation of the quality of the performance.

Verification of Task Linkages

Procedures

Written procedures describing verification of some of the linkages to this task were found at one site ($1/14 = 7\%$).

Practices

Magnifications and view angles were carried in the simulation images by a positioning frame with markings visible on the x-ray negatives at six sites ($6/14 = 43\%$). Magnifications were marked by a magnification ring in the field of view at two other sites ($2/14 = 14\%$). Three other sites ($3/14 = 21\%$) used the spacing between the markers for the dwell positions as an independent check of the magnification of the image. At the remainder of the visited sites ($3/14 = 21\%$) no specific method was used to identify the magnification or view angle at which the simulation images had been made. At those sites, simulation images were commonly made using orthogonal views and a single magnification. Planning staff then assumed that the images they were given conformed to that practice.

3.2.2.2 Target Volume Localization

This task defines the anatomical boundaries of the target volume (tumor) that is to be irradiated. Target volume determinations are usually based on qualitative clinical judgment using several factors: imaging techniques, surgical staging, and knowledge of the biological behavior of various tumors. Typically, heavy reliance is placed on the ability to form accurate three-dimensional mental images. Increasingly, treatment planning computers are being used to construct two or three-dimensional anatomical images for more precise tumor localization.

Task Allocation

Practices

This task was shared between the physician, the physics staff, and the treatment planning equipment at the visited sites. The physician performed part of the task at every site ($15/15 = 100\%$). At four sites physics staff (physicists or dosimetrists) also reported that they participated in localizing the target volume. At all sites in which treatment plans were produced by digitizing x-ray images ($14/14 = 100\%$), the digitization was performed by the physics staff.

Task Ordering

Practices

Target volume localization occurred in one of three distinct periods at the visited sites. The specification of the radiation target was always performed by the physician in conjunction with the radiation prescription. This occurred after placement of the applicator at all sites. Target localization was performed after simulation at all sites in

which simulation was performed prior to treatment. Quantification of the target volume so that dosimetry could be performed for a treatment plan depended upon when the dosimetry was performed in relation to the other RAB tasks. When treatment planning included digitization of the x-ray images, the radiation target was localized by digitization immediately after the specification of the target by the physician. At sites in which x-ray images were not used for treatment planning, but were used for dosimetric calculation after the treatment had taken place, digitization of the images took place after the treatment session had ended. Staff at sites with low dose rate remote afterloaders reported that they often preferred to initiate treatment immediately after receiving the radiation prescription. They would then digitize the x-ray images or template information and produce a treatment plan while treatment was taking place.

Task Performance

Procedures

A worksheet item dealing with target localization was filled out during performance of this task at one site ($1/15 = 7\%$).

Practices

The physician's specification of the desired target consisted of a verbal description combined with a sketch of either the tumor boundaries or a desired radiation isodose drawn on the x-ray images at three sites ($3/15 = 20\%$). At the other sites ($12/15 = 80\%$) the physician specified a target position by prescribing a desired radiation dose at some distance (usually 1 cm.) from the applicator.

Digitization of x-ray images (or in some cases needle templates) was always performed using computerized treatment planning software and a digitization device provided as part of the software-hardware planning package. The user was required to place a graticule over each point to be digitized and press a button to signal that the point was to be measured by the software. Two x-ray negatives were used on which images of the applicators had been projected from different viewing angles so that the spatial orientation of the digitized points could be reconstructed in three dimensions from the digitized data.

At the sites in which simulation was performed for only the first treatment fraction, the specification from the prior simulation was used.

The usual practice at sites using simulation x-rays was for the physician to select the dwell positions for the source during treatment by marking the images on the x-ray negatives of radio-opaque markers that had been inserted

into the applicators during simulation. The radiation dose would then be prescribed to an unspecified target at a fixed distance from those source dwell positions.

Task Locating

Practices

The target was specified by the physician at a light box for viewing x-ray images that was located near or in the simulation workspace at all sites in which simulation x-rays were acquired prior to treatment. At sites in which no simulation was performed, the target was specified in the radiation prescription which was produced in or near the workspace in which the applicator was placed. Digitization of simulation images was always performed in the treatment planning workspace.

Task Linkage

Procedures

Worksheets were used at four sites ($4/15 = 27\%$) to carry data on the desired target from the localization task to the other treatment planning tasks. One site ($1/15 = 7\%$) had a written procedure describing the linkage between localization of the target and other planning tasks.

Target locations to be digitized or included in treatment planning were either marked on simulation x-ray negatives by the radiation prescriber, or highlighted on the x-ray images by radio-opaque markers.

Hard copies of the treatment plan generated from the target localization were produced by all treatment planning systems. Some of these also produced isodose distributions that incorporated information from the digitized images.

Practices

The physician's specification of the desired target was carried to the other planning tasks by verbal description combined with a sketch of either the tumor boundaries or a desired radiation isodose drawn on the x-ray images at three sites ($3/15 = 20\%$). Contrast media (e.g., barium) was used to delineate other critical structures during simulation and was visible as a projection on the simulation x-ray negatives.

No attempt was made to incorporate information from other localization methods (e.g., CAT scans) into the simulation negatives—beyond the effect that knowledge of such information may have had on the physicians as they drew targets on the negatives. No attempt to provide assistance to

Results

them in translating what they had seen while placing the applicators into images projected onto the negatives was observed.

Information digitized during this task was used in dosimetry performed with the same computer equipment used for the digitization. Linkages between these tasks were performed in the hardware and software of the treatment planning systems. Proper linkage between target volume localization and dwell point localization required that coordinate axes be established that allowed the positions of the applicators and target to be reconstructed from the digitized images. Digitized values of the dwell positions and target information (when they differed) were always referred to the same coordinate axes by digitizing both referenced to the coordinate axes of the simulation negatives.

At one site computer aided tomography (CAT) was used instead of simulation x-ray negatives to locate both applicators and the target. At that site, measurements were performed of the distance between the applicator and the target structures directly from the CAT screen using software that measured the distance between user positioned cross-hairs on the screen.

Verification of Task Performance

Procedures

A worksheet item dealing with verification of target localization was found at one site ($1/15 = 7\%$). Software within some of the treatment planning systems performed a check on the consistency of the digitized data entries.

Practices

Points in target structures were digitized, plotted, and compared with the simulation x-ray by a second physician at one site ($1/15 = 7\%$) to verify that the target had been correctly identified and digitized.

Each point was digitized on both simulation views. The X and Y_1 coordinates of the point were digitized from one negative, and the Y_2 and Z from the other. A software check on digitization accuracy was performed by comparing the reconstruction of the point using each Y coordinate.

Verification of Task Linkages

Practices

Isodose plots from dosimetry were measured during plan approval to verify that the distances between the target and the applicator had been properly quantified at five sites ($5/15 = 33\%$). The measured distances were compared with the measured distances between the projected images on the simulation x-ray negatives. Since the isodose curves were usually plotted referenced to orthogonal planes around the applicators, there were differences in perspective between the projections of the images produced by the x-rays on the negatives and the plotted distances from the dosimetry. Software in the planning system allowed the isodose planes to be rotated but was not used to project the digitized applicator images and the associated isodose lines onto a plane that would correspond to that of the actual simulation negatives at any of the sites.

3.2.2.3 Radiation Prescription

Once radiation targets are identified, the dose to be given to each target is prescribed by a physician and incorporated in a treatment directive. The treatment directive specifies the prescribed dose distribution and the method to be used to deliver the dose to the targets. It may include a specification of the source dwell positions to be used or may leave the choice of dwell positions to other treatment planning tasks. The physician may formulate his radiation prescription using the case history of the patient and information about the target and applicator derived from the simulation x-ray.

Task Allocation

Procedures

Radiation prescription is a medical task that is professionally reserved for physicians by licensing requirements.

Practices

At each site, radiation prescription was limited to physicians who had participated or observed applicator placement.

Task Ordering

Practices

At three sites (3/15 = 20%), a single treatment directive was written to cover multiple treatment fractions for some medical procedures. On those occasions the radiation prescription for an individual treatment fraction might precede the treatment by several days. This practice was not consistent between or within sites and appeared to be a characteristic of the individual prescriber.

Task Performance

Procedures

Seven sites (7/15 = 47%) had some form of written procedure for radiation prescription. Three of these (3/15 = 20%) were descriptions of the radiation prescription steps and four (4/15 = 27%) were embodied in worksheets that were filled out during task performance.

Practices

Although radiation prescription in principle involves the specification of a radiation target and a radiation dose distribution to be delivered to that target volume, the actual target was specified in the radiation prescription at only three sites (3/15 = 20%).

At these sites the prescription was accompanied by a sketch, on one x-ray negative, of the area that might represent the image of the intended target had the target been projected on the x-ray negative. In no case was a projection of the target itself visible on the simulation negatives, although contrast media were used to highlight other critical structures such as the bladder. Physiologic reference points visible on the negative and the known placement position of the applicators were used instead of the target image to define the target area. (Note that these sketches provided an estimate of the target *area* rather than its volume since only a single negative was used in the sketch.) The prescription format at these sites consisted of a dose plus an isodose outline.

At the other sites (12/15 = 80%) no attempt was made to describe the target. At those sites the spatial relationship between the applicator and the target was noted during placement of the applicator. A dose distribution was then prescribed to the applicator that was designed to produce the desired (and different) dose distribution at the target's distance from the applicator.

The usual radiation prescription at these sites defined a surface around the applicator to which a specific dose of radiation should be delivered. Variation was seen in the dosage, in the distance of the surface from the applicator, in the reference for measuring the distance (measured into the body starting from either the center or the surface of the applicator), and in the number of fractions to be used to deliver the total prescribed dose. These variations were attributable to the clinical judgment of individual radiation oncologists. Several sites had standard prescriptions (e.g., 500 cGy @ 1 cm.) for the dose and surface distance and varied only the length of the cylinder (by choosing the number of dwell points). The reference distance was standardized at some sites (e.g., always from the surface of the applicator) and varied between prescribers at others. When a surface measurement was used the prescription also specified the size of the applicator. Table 7 shows representative prescription formats from several sites. (Note: These data were collected prior to the effective date for the NRC's Quality Management Rule.)

Task Locating

Practices

Radiation prescriptions were produced in or near the simulation workspace at all sites which performed simulations prior to treatment. At the others, radiation prescriptions were produced either in the applicator placement workspace or were transferred verbally to the planner when the physician met the treatment planner after applicator placement was completed.

Task Linkage

Procedures

No written procedures describing the linkages to this task were found at any site, although worksheets for carrying the radiation prescription between tasks were used at four sites (4/15 = 27%).

Information from applicator placement was needed for radiation prescription at all sites. Information from simulation of dwell positions was used in radiation prescription at 13 sites (13/15 = 87%). The radiation prescription was used to select a treatment plan and to approve the selected treatment plan before it was entered into the afterloader control unit.

Practices

Radiation prescriptions were written on the simulation x-rays at most of the sites at which simulations were

Results

performed prior to treatment. Information on the size of applicator to allow surface doses to be calculated was contained in prescriptions for most gynecological procedures.

Verification of Task Performance

Procedures

No written procedures describing verification of the performance of this task were found at any site. One site had a worksheet that included an item related to verification of the prescription.

Practices

Radiation prescriptions were compared with prior prescriptions for the same patient at two sites ($2/15 = 13\%$). The resulting dose to an estimated volume around the applicator was compared to low dose rate treatment nomograms at two other sites ($2/15 = 13\%$).

Verification of Task Linkages

Practices

The treatment plan resulting from the radiation prescription was approved after the plan was generated by the radiation prescriber at 13 sites ($13/15 = 87\%$).

3.2.2.4 Dwell Position Localization

Dwell position localization involves selecting and specifying positions for sources to occupy along the treatment path defined by the source guide tubes and applicators. In HDR RAB, treatment planning takes far longer than treatment so the dwell times at each position must be calculated prior to positioning the source. In LDR RAB, dwell positions are specified for multiple sources that are placed in applicators and held in place for an extended period of time (up to several days). This permits LDR treatment sessions to begin before the source dwell times have been specified.

Task Allocation

Practices

The radiation prescriber indicated the dwell positions to be used during treatment at most sites. At one site ($1/15 = 7\%$) dwell positions were chosen by the physicist after consultation with the physician on the desired dose

distribution. Technologists at one site helped to choose the number of dwell positions. Digitization of the chosen dwell positions was performed by the physicist or dosimetrist at all sites at which dosimetry was performed.

Task Ordering

Practices

Dwell positions were chosen, either from simulation x-ray images or from information derived from applicator placement just prior to treatment planning at all sites.

Task Performance

Procedures

No written procedures describing the performance of this task were found at any site. Four sites ($4/15 = 27\%$) used worksheets that were filled out during performance of this task.

Practices

Dwell positions were chosen at most sites by having the person who had placed the applicator mark the images of marker sources on simulation x-rays or, in cases in which no simulation was performed, from sets of standard pre-planned dwell positions based on applicator geometry.

Digitization of x-ray images (or in some cases needle templates) was always performed using computerized treatment planning software and a digitization device provided as part of the software-hardware planning package. The user was required to place a graticule over each point to be digitized and press a button to signal that the point was to be measured by the software. Two x-ray negatives were used on which images of the applicators had been projected from different viewing angles so that the spatial orientation of the digitized points could be reconstructed in three dimensions from the digitized data.

Task Locating

Practices

Dwell positions were selected in the simulation or applicator placement workspaces at 13 sites ($13/15 = 87\%$). At the remaining sites ($2/15 = 13\%$) the positions were selected in the treatment planning area.

Table 7. Representative Radiation Prescription Formats

Dose	Distance	Applicator Size Specified	Target Specified	Dwell Points	Format
65 600 cGy	@ 1.2		yes		written on x-ray written on x-ray
550 600 cGy	@ 1 cm		yes	# dwell positions	verbal written
500 cGy X6 700 cGy	@ 2 cm	yes	yes	5 cm length	written written
2100 Rad in 3 fx 500 cGy	@ 0.5 cm from surface				written written
1000 cGy 6 Gy X 4 fx	@ 1.5 cm			region marked	written on x-ray written on x-ray
12 Gy X2 Fx 6 ea 6 Gy X3	@ 2 cm	yes			written on x-ray written on x-ray
750 cGy	@ 1 cm from surface				written on x-ray verbal
	(pointed to where isodose was desired)				

Task Linkage

and view angle of the images on the simulation x-ray negatives.

Procedures

Written procedures describing the method of passing dwell points between the treatment planning and treatment functions were available at eight sites (8/15 = 53%). Worksheets carrying the chosen dwell points were passed between tasks at five sites (5/15 = 33%).

Practices

The physician's specification of the desired dwell positions was carried to the other planning tasks by either marks indicating the treatment region on the simulation x-rays or by worksheets used to bring the prescription to the other planning tasks.

These dwell points from the x-ray negatives were brought to the treatment planning system by the planner and digitized to make them available to the planning system software. Information digitized during this task was used in dosimetry performed with the same computer equipment used for the digitization. Information from the simulation task was entered by the user to indicate the magnification

Verification of Task Performance Procedures**Procedures**

No written procedures describing verification of the performance of this task were found at any site. A worksheet used at one site contained an item related to verification of dwell positions. Software within some of the treatment planning systems performed a check on the consistency of the digitized data entries.

Practices

Each digitized value carried information from two axes: (X,Y₁) from one negative and (Y₂,Z) from the other. The X and Y coordinates were taken from one negative, and the Z from the other, to reconstruct the location (X,Y₁,Z) of each point. A software check on digitization accuracy was performed by comparing the unused Y₂ coordinate measurement with the Y₁ coordinate of the reconstructed point. The actual distance between the markers was known at some sites and could be compared with the reconstructed

Results

distances as a second check on digitization and reconstruction accuracy.

Verification of Task Linkages

Practices

Isodose plots from dosimetry were used during plan approval and could be compared with the simulation x-ray negatives to verify that the reconstruction of the applicators was correct at five sites ($5/15 = 33\%$). Since the applicator positions were reconstructed in space rather than projected to the plane of the x-ray negatives, there were differences in perspective between the projections of the images produced by the x-rays on the negatives and the reconstructed applicators from the dosimetry. Software within the planning system allowed the isodose planes to be rotated, but was not used to project the digitized applicator images and the associated isodose lines onto a plane that would correspond to that of the actual simulation negatives at any of the sites.

3.2.2.5 Dosimetry

Dosimetry is the task that calculates the prescribed dose at specific anatomical or spatial locations due to radiation. Dosimetry can be used to predict the dose distribution produced by a specific treatment plan or to generate a treatment plan by calculating treatment positions and/or dwell times. In RAB, the radiation comes from one or more radioactive sources positioned in the applicator(s) during treatment. Although computer software is used to calculate the dose distributions from these sources, users are required to digitize the placement locations from simulation images (x-rays) so that the distances between the treatment positions and targets can be reconstructed by the computer. Those distances are then used to calculate the dose that would be delivered to the reconstructed targets by placing a known source at the measured position(s).

Task Allocation

Procedures

Calculation and the reconstruction of applicators and isodose plots were performed by planning system hardware and software at all sites.

Practices

Dosimetry for RAB was performed by physics staff (physicists or dosimetrists) at 14 sites ($14/15 = 93\%$). A technologist performed dosimetry at the remaining site.

Physicians also performed dosimetry for some cases at two of the sites.

Task Ordering

Procedures

Undocumented procedures were followed at all sites to constrain this task so that it would be performed prior to the tasks that were dependent on it.

Practices

Dosimetry was performed at one of three times in relation to the other RAB tasks. At seven sites ($7/15 = 47\%$) treatment plans were taken from a dose atlas which had been compiled before the patients arrived for placement of the RAB applicators. In those sites dosimetry was performed prior to all the other RAB tasks. At the other sites ($8/15 = 53\%$), and also for some medical procedures at many of the sites using a dose atlas, dosimetry was performed on simulation x-rays taken of the applicators in the individual patient undergoing treatment. Dosimetry at these sites was performed either during treatment planning or after the treatment had taken place as a verification of the treatment rather than as an aid in selecting a treatment plan.

Task Performance

Procedures

No written procedures describing the performance of this task were found at any site. The use of computer programs to perform calculation and display operations in dosimetry constituted a form of unwritten procedure. These programs consisted of ordered sequences of steps that were performed by the planning system to calculate and display dose distributions. Although the result of these computer procedures was documented and presented to the users, the actual steps performed by the planning systems were usually not accessible to the users. At three sites, staff had written their own planning system software so that the procedures used in the calculations would be accessible and could be changed by the users.

Practices

Dosimetry was always performed using treatment planning systems which performed the calculations along with some form of digitization software to identify the dwell positions of the source to the planning software. At sites that used a dose atlas as a source of generic treatment plans, dosimetry

was based on standard source placement geometries. In this way, the isodose plots for the atlas plans could be used to approve treatment plans. Marked source positions from simulation negatives of the actual patient to be treated were used to identify the dwell positions at the other sites. Post-treatment dosimetry used actual treatment dwell times while pre-treatment dosimetry used the dwell times from a proposed treatment plan to quantify the dose.

Task Locating

Practices

Dosimetry was always performed in the treatment planning workspace.

Task Linkage

Procedures

Written procedures describing the linkages to this task were found at three sites (3/15 = 20%). At two of these, worksheets were used to carry information between tasks.

Practices

Dosimetry results were carried to the treatment plan approval task by isodose plots in all cases in which dosimetry was performed. At four sites (4/15 = 27%) dosimetry was used to determine the dose to critical physiologic structures in addition to measuring the dose distribution.

Verification of Task Performance

Procedures

A worksheet at one site contained an item related to verification of dosimetry results.

Practices

At seven sites (7/15 = 47%) treatment planning software was tested on known treatment plans whenever it was upgraded to verify that the software was operating properly. At one site this verification was performed prior to the generation of each multi-channel treatment plan.

Verification of Task Linkages

Practices

Verification that the isodose plots had been produced for the correct patient and treatment fraction was performed at most sites.

3.2.2.6 Treatment Plan Selection and Approval

The final task in treatment planning consists of selecting and approving a treatment plan and verifying that the plan will deliver the prescribed radiation dose. Plans may be chosen from a dose atlas, generated for an idealized patient using standard treatment geometries, or for individual patients by inserting simulated sources into the patient's applicator(s) and taking x-ray films of the sources and radiation targets. Once a tentative plan is selected, its dose distribution is compared to the dose distribution required by the radiation prescription. Once the distribution is verified, the plan is reviewed and approved by the prescribing physician.

Task Allocation

Practices

The task of selecting and approving a treatment plan was performed by physicians at 13 sites (13/15 = 87%). Physicists at three sites (3/15 = 20%) also approved treatment plans and dosimetrists and technologists each reported that they had performed this task at one site (1/15 = 7%). At two sites (2/15 = 13%) the treatment plan was required to be approved by a physician other than the one who had prescribed the treatment.

Task Ordering

Practices

Treatment plans were approved prior to treatment at 11 sites (11/15 = 73%). Treatment plans were approved after the first treatment fraction was delivered at four sites (4/15 = 27%). Approval was performed during treatment at both sites performing low dose rate afterloading (2/2 = 100%). Treatment plans were approved prior to entry of the plan into the afterloader control unit at all of the sites whenever individual treatment plans were generated for a treatment. The exact moment and format of the approval for sites using a dose atlas was more difficult to measure since the plans in the atlas at several sites had been generated locally and approved prior to their inclusion in the atlas. At these sites each plan was pre-approved and was selected prior to

Results

treatment from the approved plans by the physician's radiation prescription.

Task Performance

Procedures

Written procedures dealing with the approval of treatment plans were found at three sites (3/15 = 20%). Two of these provided worksheets to be filled out during performance of the approval task and the other had a written description of the approval procedure. One site provided both a worksheet and a description of the approval procedure.

Practices

Treatment plan approval and review practices were found to range from simple verification of treatment parameters taken from a planning atlas to careful comparisons of the proposed treatment's dose distribution with both simulation x-ray negatives and the prior treatment history of the patient and the RAB site. The most comprehensive approval process was found at a site which provided a worksheet to the physician consisting of 10 items which included a comparison of the prescribed dose to a clinical protocol, comparison of the isodose plot with the prescribed 100 percent dose distance, comparison of locations and dosages for each critical point specified on the radiation prescription, comparison of the planned total treatment time to a time extrapolated from the patient's previous treatment plan, comparison of the prescribed and planned treatment distances and dwell regions, and a verification that the applicators had not moved since they were placed.

At two sites (2/15 = 13%) the physicians used the planning system to change the plotting axes of the isodose lines to highlight the dose at points that might not have been visible from a single perspective.

Task Locating

Practices

The most commonly observed practice was for the treatment plan to be brought by planners to a physician for approval. Approval occurred at whatever workspaces the physicians happened to occupy at the time they were located by the planners. At two sites the physicians used the isodose displayed on the planning system screen instead of an isodose plot in approving the plan. This practice located the approval task in the treatment planning area.

Task Linkage

Practices

At 13 sites, (13/15 = 87%) dosimetry was used in the selection of a treatment plan. At those sites, planners either carried isodose plots from one or more tentative plans to the physician who had produced the treatment directive for approval, or attached the plots to the treatment directive and left them for later selection and approval. At the other two sites, plans were chosen from a treatment atlas. At those sites, dosimetric information was not utilized when a plan was selected. Instead, the treatment directive specified a particular plan number from the atlas. The treatment parameters corresponding to that plan were then selected and presented to the physician for approval.

Verification of Task Performance

Procedures

No written procedures describing verification of the performance of this task were found at any site. Worksheets on which a signature was required to verify that a treatment plan had been approved were used at six sites (6/15 = 40%). Other forms relating to treatment on which a signature was required were part of the patient record at most sites, but were not tabulated for this study unless they were used during treatment by the RAB team to verify that approval had been given for the treatment.

Practices

Treatment plan approval was itself a verification of the performance of the other treatment planning tasks. Approval was required at each site prior to treatment, but the approval process varied greatly between sites. At sites without a worksheet to indicate approval of a plan, the person initiating the treatment used either the presence of the prescribing physician from whom approval would be required, or a verbal or tacit assurance of approval by the planner who was charged with obtaining that physician's approval.

Verification of Task Linkages

Procedures

No written procedures describing verification of the linkages to this task were found at any site. Worksheets at two sites (2/15 = 13%) required information from other tasks to be evaluated before approval of the treatment plan was given.

Practices

This task is itself a verification of the linkages between other tasks and treatment.

3.2.3 Treatment Delivery

This is the RAB function in which the dose of radiation specified in the treatment directive is delivered to the patient. Tasks in treatment delivery involve connecting the patient to the afterloader, entering a treatment plan into the afterloader control unit, and monitoring and controlling the delivery process.

3.2.3.1 Treatment Set-Up

Treatment set-up is the first task in treatment delivery. During this task the patient is placed and stabilized in a treatment position. The afterloader unit is then adjusted for height and fixed in position and the patient is hooked to the afterloader unit by attaching source guide tubes between the applicators in the patient and the correct afterloader channels. Treatment set-up required information from other tasks on each patient's identity and a map specifying the channel of the afterloader to which each applicator should be connected. Information on the completion of the set-up task was required by the other treatment tasks before the treatment could be delivered.

Task Allocation

Procedures

Site licenses mention the personnel who will be allowed to operate the treatment equipment, but those which were examined by the site visit team did not specify who would make the connections between the equipment and the patient. It was the procedure at two sites (2/15 = 13%) that only persons who were certified to care for patients (technologists, nurses and physicians) would be allowed to operate or connect remote afterloading devices. This procedure was not documented specifically for RAB, but was embodied in a policy statement deemed to cover all staff/patient interactions at the sites.

Hardware in the afterloader and its control unit was used for some of the steps during task performance.

Practices

Treatment set-up was often shared between two individuals with one responsible for arranging the equipment and another for connecting the patient to the remote afterloader.

Set-up was performed by technologists at nine sites (9/15 = 60%), by physicists at five sites (5/15 = 33%), by physicians (some steps) at six sites (6/15 = 40%), by nurses at three sites (3/15 = 20%), and by dosimetrists at two sites (2/15 = 13%). Connections were made solely by the prescribing physician at five of these sites (5/15 = 33%), only by technologists at three sites (3/15 = 20%), only by physics staff (physicists or dosimetrists) at three sites (3/15 = 20%) and only by the nurse at one site. At one of the three remaining sites, the prescribing physician connected all multiple channel cases. At the other two sites (2/15 = 13%), connection was performed by either a physician, a physicist, or a technologist.

Task Ordering

Practices

Channel connection was physically constrained to take place after the patients' applicators had been placed and the patients had been transported to the treatment workstation.

Task Performance

Procedures

Four sites (4/15 = 27%) had written procedures or worksheets for setting up a treatment session.

Practices

At all sites, pre-treatment QA checks were performed before an RAB treatment was performed. At most sites the time for the QA check was standardized so that the QA check was performed before patients entered the room to be connected to the afterloader. At others, some of the QA checks of the treatment control and monitoring equipment were performed while the patients were in the treatment room.

At sites at which the treatment planner performed the connection to the afterloader, the patients would wait in the treatment room for the plan to be completed before the connections were made. At some other sites, the patients would be connected whenever they entered the treatment room and would remain connected during the interval between set-up and the start of treatment.

Results

Task Locating

Procedures

Site license agreements or radiation shielding plans were reportedly available at all sites that specifically designated the workspace to be used for treatment delivery. Physical constraints required set-up and connection to be performed close to the remote afterloader.

Practices

Treatment set-up was always performed in the treatment delivery workspace.

Task Linkage

Practices

The usual mapping convention was to label the applicators in order of placement (1,2,3, ...). An alternative (and sometimes complementary convention) was to label the applicators by placing numbered radio-opaque marker strings into them during simulation that would be visible on x-rays used by the planner.

Verification of Task Performance

Procedures

One site had a written description of a verification procedure to follow after setting up an RAB treatment. Another site had a checklist item related to verification of this task. Manufacturer's suggestions for verification procedures that might be followed were provided in the equipment instruction manuals.

Some verification procedures were standardized in the afterloader hardware. Manufacturer's instruction manuals provided written descriptions of these hardware verification procedures which occurred at the start of treatment (see 3.3.3.6 Treatment Session Monitoring and Control: Verification of Task Performance).

Practices

Verbal communication along with the exit of the set-up staff from the treatment room was used to signal completion of the set-up task.

Channel connections were checked by the users by rotating a locking collar that was designed so that it would not close

if the connectors were not fully seated in the treatment channels.

Check cable runs through the connected applicators were used to verify some steps in the set-up. These hardware checks were automatic and occurred just prior to initiating treatment (see 3.3.3.7 - Treatment Session Monitoring and Control: Verification of Task Linkages).

Verification of Task Linkages

Procedures

No locally written procedures describing the verification of the linkages to other tasks were found at any site. No documented procedure for checking the map between planned treatment channels and channel connections was found at any site.

Linkages to the Treatment Plan Entry task were partially checked by hardware (see below). Written descriptions of the procedures carried out in these hardware checks were provided in the manufacturer's instruction manuals.

Practices

At some sites the planner reported checking the applicator-channel connections to determine that they agreed with the treatment plan prior to the start of treatment. The practice was not uniform across the sites and differed within the sites between individuals.

Informal verbal communication was used at most sites to signal the completion of the set-up task so that the treatment could proceed.

Some hardware checks were automatic and were always performed by the afterloader control unit prior to treatment.

3.2.3.2 Treatment Plan Entry

Treatment plan parameters can be entered into the afterloader control unit either manually or by one of several automated or partially automated means:

- using the keyboard at the control console
- using a memory card
- recalling a treatment plan stored in the control unit memory
- direct transfer between the treatment planning system and the treatment delivery system

Task Allocation

Practices

The treatment plan was entered into the afterloader control unit by the planner (physicist or dosimetrist) at ten sites ($10/15 = 66\%$) and by a technologist at five sites ($5/15 = 33\%$). At two sites ($2/15 = 13\%$) a physician also entered plans on occasions when the technologist or physicist assigned to RAB was unable to do so. At both sites at which physicians entered treatment plans, the plans were taken from an atlas so that a separate planner did not need to participate in the treatment.

Part of the treatment plan entry task was performed by hardware at ten sites ($10/15 = 67\%$) in which magnetic cards or disks were used to perform some steps in the entry process.

Task Ordering

Procedures

No written procedures describing when a treatment plan should be entered were found at any site. At one site standard plans were entered and stored prior to treatment and recalled at treatment time.

Practices

Treatment parameters were entered either immediately after the planning and verification tasks or after the parameters had been read from an atlas following prescription of the treatment dose. Treatment plan entry took place independently of treatment set-up at most sites so that patients were connected to the afterloader prior to plan entry and waited for the plan to be entered. Hardware checks of the treatment set-up task required a treatment plan to be entered and therefore took place after entry of the treatment plan.

Task Performance

Procedures

Written procedures for entering a treatment plan were found at six sites ($6/15 = 40\%$). Descriptions of steps used in treatment plan entry were available from manufacturer's instruction manuals.

Magnetic cards or disks standardized some of the entry steps at ten sites ($10/15 = 67\%$).

Practices

Task performance varied depending on the entry mode selected and equipment available for performing this task. Three methods were available at the sites that were visited: manual entry of each plan parameter; card or disk entry of an entire treatment plan; and recall of a treatment plan that had been previously entered and stored in the afterloader control unit.

Entry using magnetic media (a card or disk) was available at 11 of the sites ($11/15 = 73\%$) in which matched planning and treatment delivery equipment had been acquired. Eight of these ($8/15 = 53\%$) used planning systems to generate a new plan for each treatment fraction and used the magnetic media to enter each plan into the afterloader control unit. Two of the remaining three sites with card or disk entry equipment did not make use of magnetic media. Staff at those sites selected plans from a planning atlas and entered the atlas plans manually. In no case was an atlas plan stored on a card. The final site with card entry capability did not generate a new card for each treatment fraction. At that site one card was generated by the planning system for the first treatment fraction and then stored in the patient's chart. The card was removed from the chart and used to re-enter the original plan for each subsequent treatment fraction.

Three sites without matched planning and treatment systems entered all plans by hand ($3/15 = 20\%$). Staff at one of these sites had entered atlas plans into the memory of the afterloader control unit and recalled one of them for each treatment. At another site the control unit memory was used to store an individual treatment plan during the treatment session. At that site the set-up procedure required that the afterloader control unit be turned off to allow access to motion controls for the patient's bed. The plan was entered by hand, then stored in the afterloader control unit's memory, and finally recalled from memory after the power to the control unit had been restored.

Task Locating

Procedures

The need to physically enter the plan into the afterloader control unit restricted this activity to the treatment control workstation.

Practices

All plans were entered into the control unit while it was in the treatment control workstation.

Results

Task Linkage

Procedures

Written task linkage procedures for treatment plan entry were found at eight sites ($8/15 = 53\%$). Five ($5/15 = 33\%$) of the sites used worksheets to transfer the information from planning to the treatment plan entry task.

Magnetic cards or disks were used at ten sites ($10/15 = 67\%$) to carry the plan parameters from the treatment task to the treatment plan entry task.

Practices

At all sites in which magnetic cards were used, a single treatment plan was stored on a single card at the planning station and transferred on the card to the treatment control workstation. At the one site using a computer disk for transferring the plan to the afterloader control unit, the disk contained all the plans which had been generated by the planning system that year, indexed by patient name. All of these plans were entered into the afterloader control unit and the desired plan was selected from a menu of patient names that appeared on the screen of the control unit.

At some units requiring hand entry, information was entered into the afterloader control unit that was not on the treatment plan. These required entry of the date so that the afterloader control unit could calculate an estimate of the current source activity by estimating the decay of the stored activity between the calibration and the current dates. This entry was particularly difficult for users since the unit required that the date be entered in a different order (day-month-year) from the usual order (month-day-year) in the United States.

Verification of Task Performance

Procedures

Written performance verification procedures for treatment plan entry were found at six sites ($6/15 = 40\%$).

Practices

All sites ($15/15 = 100\%$) required that the afterloader control unit display the entered planning parameters. These parameters were then checked against a printout of the plan before the treatment was started. Some of the sites ($6/15 = 40\%$) required this check to be performed by someone other than the person who had entered the plan.

Sites at which the date was entered in addition to the treatment plan included the date and the format of the date in the verification procedure. No hardware steps were available for assistance in this date verification process.

Verification of Task Linkages

Procedures

Written procedures that described the verification of the linkage between treatment plan entry into the afterloader control unit and the RAB tasks that generated the treatment plan values were found at six sites ($6/15 = 40\%$).

Practices

In addition to written procedures, cross-checking methods were used at several of the six sites to verify that the correct treatment plan data had been entered into the afterloader control unit.

At six sites ($6/15 = 40\%$) tables of source activity were compared with the displayed values for source activity after the plan had been entered into the afterloader control unit. Because the source activity values displayed by the afterloader depend on the treatment plan values, this technique provides a check that the correct treatment plan values had been entered. It also provided independent verification for the entry of the date of treatment at two of the three sites that used an afterloader which required the date to be entered manually prior to each treatment session.

At the third site in which the date was entered manually and at five other sites ($6/15 = 40\%$), the total dwell time reported by the afterloader control unit was compared to an independent calculation based on the treatment plan parameters that had been entered into the afterloader control unit and the source activity. An error in either treatment plan entry or in the source activity calculations would produce a discrepancy between the calculated values and the displayed values for the treatment plan parameters.

Three sites ($3/15 = 20\%$) calculated an expected target volume from the simulation data and determined the time needed to deliver the prescribed dose to that volume from a nomogram. That treatment time was compared to the treatment time displayed by the afterloader control unit. This practice provided an independent check that the plan values that had been entered into the afterloader control unit would deliver the prescribed dose. Additionally, this practice tested the links between the radiation prescription and the treatment plan, and the treatment plan and the values that had been entered into the afterloader control unit.

3.2.3.3 Treatment Session Monitoring and Control

Monitoring a treatment session involves monitoring both the patient and the hardware in the treatment delivery system. Patients are monitored via closed-circuit television and intercom. The afterloader device monitors its own performance during treatment and provides a running account of system status on the operator's console. Indicator lights alert system operators of conditions that require attention. The printer provides a hard copy record of each source movement and status change during treatment.

A treatment session is normally controlled by the afterloading equipment, which determines the position of the sources during treatment. The sources are automatically retracted into shielded parts of the afterloader when treatment is completed. Should the sources fail to retract automatically, the operator can retract them either by alternative automated means or by manual intervention. Sessions are aborted automatically or by the operator when an anomalous condition arises that requires treatment to be stopped immediately.

Task Allocation

Procedures

Site licenses at some sites listed the personnel who were allowed to operate the treatment equipment. At two sites ($2/15 = 13\%$), only persons who were certified to care for patients (technologists, nurses, and physicians) were allowed to operate or connect remote afterloading devices. This procedure was not documented specifically for RAB, but was embodied in a policy statement designed to cover all staff interactions with patients at the sites.

Most of the steps in starting and continuing treatment were performed by the remote afterloader hardware. Hardware also performed some of the monitoring tasks at all sites.

Practices

In practice, both the person who started the treatment and the person responsible for caring for the patient were present during HDR treatments to monitor and help control the treatment session. Others who were present during the treatment also shared the monitoring duties. Physicians monitored the course of the treatment and helped to control the treatment session at four sites ($4/15 = 27\%$). Nurses monitored the clinical state of the patient during treatment at two of these sites and at two others where physicians did not participate in the treatment session ($4/15 = 27\%$).

At three sites ($3/15 = 20\%$) only physicists were permitted to operate the afterloader control units. At three other sites only technologists were allowed to operate the afterloaders and their controls. At the remaining sites, treatment was usually initiated by the technologist responsible for the treatment room, but the treatment session was also monitored or controlled by a physicist and/or a physician.

Physics staff at nine sites ($9/15 = 60\%$) and technologists at seven sites ($7/15 = 47\%$) reported that they would be responsible for deciding whether to interrupt the treatment. Nurses did not report that they would be involved in controlling the treatment. On two occasions, however, nurses were observed to interrupt the treatment session by entering the treatment room to care for patients requiring their attention.

Afterloader hardware and software was used to monitor the performance of the afterloading equipment during treatment. The software was designed to abort the treatment when either an obstruction or a power failure was detected.

Task Ordering

Procedures

Hardware constraints limit the treatment to the period between connection and disconnection of the patient to the afterloader.

Practices

In practice treatment was always started after connecting the patient and entering the treatment plan. In cases in which dosimetry was not part of the planning procedure, treatment could precede dosimetric evaluation of the treatment plan.

Task Performance

Procedures

No written procedures describing the monitoring required during RAB were found at any site. Written descriptions of steps to be followed in controlling a treatment session were found at three sites ($3/15 = 20\%$).

Manufacturer's procedures for controlling afterloader equipment were listed in the equipment control manuals. Descriptions of the procedures followed by the hardware were provided in some of the manufacturer's instruction manuals.

Results

Practices

At all sites the practice when starting a treatment session was to check that the room had been cleared, check that the treatment plan had been entered and verified, and then to follow the (memorized) manufacturer's procedure for starting the afterloader.

Staff watched the patients on TV monitors and listened to their voices during treatment at 14 of the sites (14/15 = 73%). The TV monitor was damaged at one site (1/15 = 7%), but treatment was continued by visual observation through a leaded glass window from the treatment control station into the treatment room. Staff at all sites reported that they monitored the course of treatment on the afterloader control unit displays during each treatment session. They were observed to do so during treatment at seven sites (7/15 = 47%). The level of monitoring at these seven sites was highly variable and ranged from casual glances at the displays during treatment to prediction and documentation of each reported dwell position and dwell time during the course of the treatment. At four sites monitoring consisted of being within range of the treatment control hardware so that alarms from either the hardware or verbal communications from the patient could be recognized.

The afterloader control units monitored and controlled the course of treatment and provided a printed record of the dwell time at each source position. The afterloader units also checked channel connections prior to entering each channel and monitored the resistance to the movement of the source cable during treatment and the presence of power to the unit. If either an obstruction or a power failure was detected during treatment, the afterloader units would abort the treatment session. Power failures were not experienced during any site visit, but obstructions and faulty connections were encountered. In these cases the hardware monitoring equipment functioned as specified in the manufacturer's procedures.

Task Locating

Procedures

Site licenses and plans described the workspace that would be used for treating patients and the workstations that would be used for controlling the treatment.

Site licenses and descriptions of the equipment to be used in setting up the RAB treatment room usually mentioned the equipment that should be used for monitoring, but did not specify the exact nature of the workstation at which monitoring would take place.

Practices

Treatment and treatment control workspaces were often shared with other treatment units. Four sites (4/15 = 27%) had dedicated workspaces for HDR treatment and treatment control. Three of these were also used for simulation.

Monitoring always occurred from the treatment control workstation. The treatment itself took place in the treatment area which was connected to the treatment control workstation by TV cameras and intercoms at all sites. Two sites (2/15 = 13%) had windows from the treatment control workstation into the treatment workstation through which it was possible to observe the patients and any physiological monitoring devices which might have been attached to them. At all sites, the workspace for concluding a treatment session was the same as for monitoring and controlling a treatment session.

Task Linkage

Information that the QA checks have been performed is needed to ensure that the equipment is in working order. Proper set-up and patient connection is required prior to starting the treatment. Information that the treatment room has been cleared and that the patient is ready for treatment is needed before starting treatment.

Monitoring and controlling a treatment session requires knowledge of the expected duration and course of treatment from the plan entry task. Knowledge of any special needs of a patient is needed to enable appropriate actions to be taken upon the conclusion of a treatment session.

Monitoring produces information on the conclusion of the treatment for the tasks requiring entry into the treatment room. It also produces information on the treatment itself for record-keeping and post-treatment dosimetry.

Procedures

Written worksheets were used to transmit monitoring data to other tasks at two sites. Written procedures for linking the start of treatment to other RAB tasks were found at four sites (4/15 = 27%).

Practices

QA checklists were present at ten sites (10/15 = 67%) to indicate that the QA had been performed.

Verbal confirmation that the room was clear and the patient connected was used at all sites to verify that the set-up task had ended and the treatment task could proceed. Some sites

were also observed to check the video monitors to verify that the room was clear and the patient stable before treatment was started. In most cases the entire room could not be viewed on the TV monitors so a system was used in which the last person out of the room would close the door to indicate that the room was empty.

The staff monitoring the treatment session had also often performed the tasks immediately prior to treatment minimizing the need for information transfer.

Two sites required the person monitoring the treatment to record and compare the actual treatment dwell times at each position to the dwell times specified in the treatment plan that had been entered into the afterloader control unit. These numbers were transferred to a post-treatment dosimetry task and post-treatment approval tasks and would have been used by one of these individuals to conclude the treatment session if major discrepancies (of more than a few seconds) were noted between the expected and reported treatment dwell times.

The printouts from the afterloader control unit console were transmitted to the record-keeping task at the conclusion of the treatment session.

At no site were any personnel observed to watch the radiation warning lights outside the treatment room to determine whether to enter the room. Verification that the treatment was over and the room safe to enter was instead passed either verbally between task performers or visually as the performer about to enter the room observed the operator of the afterloader control unit turn the key that disabled the unit.

Hardware printouts of the treatment parameters were collected at all sites and either placed in the patient record or routed to other tasks.

Verification of Task Performance

Procedures

Written procedures for verification of the start of treatment were found at four sites ($4/15 = 27\%$). Three of these were worksheets on which information regarding the start of treatment was entered.

At one sites ($1/15 = 7\%$) a worksheet was filled out during monitoring that could be used later to verify that monitoring had taken place. Documentation by technologists explaining unexpected or emergency interruptions of treatment was required at two sites ($2/15 = 13\%$).

The afterloading hardware provided printouts of the actual dwell times and positions used in each treatment. These could be compared with the treatment plan and provided a means of verifying that the planned treatment had been delivered.

Practices

Worksheets filled out at the two sites in which they were used were reviewed after treatment at each site. Hardware printouts from the treatment session were completed at the end of the session and retained at each site. Hardware printouts were reviewed for post-treatment dosimetry at three sites ($3/15 = 20\%$).

Verification of Task Linkages

Procedures

A written procedure advising that the applicator position be checked prior to treatment was found at one site ($1/15 = 7\%$).

Hardware in the afterloader checked that the source guide tubes had been connected to the afterloader channels prior to the start of treatment. Documentation of these verification procedures was provided in the manufacturer's instruction manuals.

No written procedures describing the verification of other linkages to the treatment control and monitoring task were found at any site.

Practices

Applicator position was checked for lung treatments at several sites by placing an ink mark on each applicator at the point at which it entered the nares. Divergence of this mark from the entry site was taken as evidence that the applicator had changed position.

Applicator position was checked by the physician prior to gynecological treatments at one site.

The hardware checked that the connecting tubes between the applicators and the afterloader had been properly inserted into the afterloader by passing a check cable through each programmed channel. Channel connectors were designed so that unconnected or poorly connected channels would obstruct the passage of the check cable and produce an error condition that could not be bypassed until the channels were properly connected.

Results

In one brand of afterloader a check cable was extended into each channel prior to treatment until it reached and was obstructed by the end of the applicator. In this afterloader, treatment positions were referenced to the end of the applicator and an error would be reported if an obstruction (the end of the applicator) was not reached within a few millimeters after the cable had been extended beyond the most distal treatment position. Check cables in the other afterloaders were also extended into the applicators, but did not reach the end of the applicator and checked only that there was an unobstructed path to the specified treatment distance.

Verification of patient needs during treatment was performed by verbal interrogation and discussion between team members. Most sites were careful to annotate the printed record of treatment from the afterloader control unit and to add it to the appropriate worksheet or patient chart.

Verbal and physical cues (e.g., moving toward the door of the treatment room) were exchanged between task performers to corroborate the transmission and receipt of the information that the treatment had been completed.

Documentation produced at each site was annotated with the patient's name and either routed to another task or placed in the patient's chart.

3.2.4 Post-Treatment

This is the function in which the RAB patient is prepared for release or resumption of routine nursing care after the treatment session has been completed. Tasks in this function involve disconnecting the patient from the afterloader source guide tubes, removing the applicators from the patient, transporting the patient from the treatment delivery area, verifying treatment delivery, and record-keeping.

3.2.4.1 Source Guide Tube Disconnection

In this task, the source guide tubes are disconnected from the applicators and (usually) from the source head of the remote afterloader. They are then placed in storage locations and used in later treatments.

Task Allocation

Practices

Source guide tubes were usually disconnected by a technologist at seven sites (7/15 = 47%), by nurses at four sites (4/15 = 27%), by a physician at three sites (3/15 = 20%) and by a physicist at two sites (2/15 = 13%). There

was some overlap in staffing between nurses and technologists in performing this task.

Task Ordering

Practices

Source guide tubes were disconnected immediately after the end of the treatment at all sites.

Task Performance

Procedures

Written procedures describing the performance of this task were found at two sites (2/15 = 13%).

Practices

Source guide tubes were not disconnected from the indexer head at one site (1/15 = 7%). At that site the tubes remained permanently connected to the indexer head of the afterloader. The source guide tubes were disconnected from the patient's applicators at all sites. No other deviations from the steps expected for this task from the function and task analysis were observed.

Task Locating

Practices

Source guide tubes were disconnected from the patient in the treatment workspace at all sites.

Task Linkage

Practices

Source guide tubes were sorted by length and hung in racks to make them accessible for setting up and connecting to the next patient at nine sites (9/15 = 60%). They remained connected to the afterloader after treatment at one site (1/15 = 7%). A single guide tube whose length had been previously measured was used for all treatments at one site (1/15 = 7%).

Verification of Task Performance

Procedures

A checklist was used in verification of performance of this task at one site ($1/15 = 7\%$).

Practices

Since each patient was physically attached to the afterloader until this task was performed, most sites verified that the source guide tubes had been disconnected by noting that the patient had been removed from the treatment area.

Verification of Task Linkages

Practices

It was the practice at three sites ($3/15 = 20\%$) to measure and match source guide tube lengths to applicator lengths as a quality assurance function. At these sites periodic verifications of the length of the source guide tubes were also performed. Two sites ($2/15 = 13\%$) reported that their QA had shown that the tubes were likely to change length when hung on racks and were for that reason stored in drawers instead of hanging from racks.

3.2.4.2 Applicator Removal

Applicators are usually removed by the staff who placed them, although removal procedures can be simpler than placement procedures since position information is often not collected during removal. Removed applicators are either discarded or sterilized for reuse.

Task Allocation

Practices

Applicators were removed by physicians at 13 sites ($13/15 = 87\%$), by nurses at seven sites ($7/15 = 47\%$), by technologists at three sites ($3/15 = 20\%$), by physicists at three sites ($3/15 = 20\%$), and by the dosimetrist at one site ($1/15 = 7\%$). Most of the non-physician task performers were involved with endobronchial treatments. Allocation of the removal task to the person who had placed the applicators was a common practice. This allocation, when it was followed, provided an internal communication path between placement and removal tasks.

Task Ordering

Practices

Applicators were removed after each treatment fraction for intracavitary treatments at 14 sites ($14/15 = 93\%$). At one site endobronchial applicators were used which remained in place for multiple treatment fractions ($1/15 = 7\%$). Interstitial applicators were also removed in the treatment area for some cases, but were removed following transport to separate applicator removal areas for all surgically implanted applicators.

Task Performance

Practices

Applicator removal practices varied depending on the type of applicator and the methods used at each site for inserting and stabilizing the applicators during placement. Sites at which applicators were re-used often performed visual inspection of the removed applicators for defects or wear as part of this task. Staff at some sites reported that they performed an inventory of removed items. The lack of written procedures or documentation for such inventories suggests that these practices might differ depending on who performed the applicator removal task.

Task Locating

Practices

Applicators were removed in either the treatment room (intracavitary treatments) or in separate applicator removal areas for surgically implanted applicators.

Task Linkage

Practices

Applicator removal is linked to the applicator placement task for information on the number, location, and characteristics of the applicators to be removed. Information can be provided to the QA task to produce a log of placed and removed applicators and to log any changes in their condition or position since they were placed.

Endobronchial applicators were checked for movement at the time they were removed at three sites ($3/15 = 20\%$). At these sites marks made on the applicators and on tape holding them to the nares were compared just prior to

Results

removal to gauge the amount of movement that had occurred since the applicator was placed. X-ray negatives were made of applicator position prior to removing applicators at two sites (2/15 = 13%) to measure movement of the applicators during treatment.

Verification of Task Performance

Practices

Visual verification that applicator removal had been completed was performed at all sites.

Verification of Task Linkages

Practices

No verification practices were observed regarding the linkages to this task. Since surgical placement and removal of implanted applicators was not directly observed during treatment sessions at these 15 sites, data on any accounting practices that might have verified the linkages to the surgical placement regarding the number and type of applicators placed and the number and type removed were not collected.

3.2.4.3 Patient Transportation

Patient transportation at the conclusion of a treatment session does not differ appreciably from patient transportation that occurs at other stages of the RAB process. Refer to section 3.1.5 for a discussion of the procedures and practices involved in patient transportation.

3.2.4.4 Record-keeping

Patient and brachytherapy record-keeping involves gathering and collating all treatment planning and treatment delivery data. These data are placed in patient records, departmental records, and hospital records for storage and future access.

Task Allocation

Practices

Record-keeping tasks were shared between personnel at most sites. Technologists at 10 sites (10/15 = 67%) reported that they had some record-keeping duties while physicists reported record-keeping duties at seven sites (7/15 = 47%). Nurses reported post-treatment record-keeping duties at four sites (4/15 = 27%) while physicians and dosimetrists

each reported post-treatment record-keeping duties at two sites (2/15 = 13%).

Task Ordering

Practices

Records were collected as they were produced during all of the RAB tasks performed during a treatment session and were stored after the treatment was completed. Since summaries were required at some sites, and documentation and billing information was processed after treatment, the record-keeping task extended beyond the treatment session at most sites.

Task Performance

Procedures

Written procedures describing post-treatment record-keeping were found at two sites (2/15 = 13%). Two other sites (2/15 = 13%) had worksheets used during post-treatment record-keeping that structured the performance of this task.

Practices

Treatment printouts, treatment plans, and simulation x-rays were retained at all RAB sites. Individual patient charts were retained for the duration of the patient's treatment at the site.

Worksheets filled out at some sites were entered into each patient's chart. A written summary of the treatment was required of the physics staff after treatment at two sites (2/15 = 13%). Videotaped records of bronchoscopy were retained and used to gauge response to treatment at four sites (4/15 = 27%).

Task Locating

Practices

Part of the performance of this task always occurred in the treatment control area. Other portions were likely to be spread to record storage areas or to be performed in offices or dictation areas at the site.

Task Linkage

Procedures

Post-treatment record-keeping was linked to QA functions, to post-treatment dosimetry and treatment plan approval, and to treatment planning functions for multiple treatment fractions on a single patient.

A worksheet was used for multiple treatment fractions at three sites (3/15 = 20%) which carried information from prior treatment fractions. Another site had a written procedure for using the results of the last treatment fraction to verify treatment planning for the current treatment fraction.

Practices

Records of previous treatment fractions were used in subsequent treatments at most sites. At two sites (2/15 = 13%) treatment times and doses from previous treatment fractions were compared with those proposed for the current fraction as part of the task of approving a treatment plan. It was the practice to adjust dosages for multiple treatment fractions based on previous treatment fraction dosages at all sites, which produced an individual radiation prescription for each treatment fraction (incidence varied with treatment procedure). At sites at which a single prescription was used for multiple fractions, the record of the prior fraction's dosage was used to indicate that the prior fraction had been given.

Verification of Task Performance

Procedures

No written procedures describing verification of the performance of this task were found at any site. One site had a checklist item dealing with record-keeping. Signatures and written entries provided physical evidence of the performance of this task at all sites.

Practices

The records themselves provided verification of the performance of this task. Individuals tended to keep track of their own performance. At three sites (3/15 = 20%) chart rounds were used to insure that records were made and kept in a timely manner.

Verification of Task Linkages

Practices

Recorded information was identified by its location in the particular patient's chart and by the name and scheduled treatment of the patient at all sites.

3.2.5 Quality Assurance and Maintenance

This function consists of five tasks that are performed to ensure that the RAB system is operating reliably, safely, and effectively. These tasks include exchanging the source, calibrating a newly installed source, performing equipment and software updates, troubleshooting problems in RAB equipment or process, and conducting routine quality assurance tests of the RAB system.

3.2.5.1 Source Exchange

Source exchange involves the ordering, receipt, storage and maintenance of new radioactive sources and the storage and disposal of old ones. Source exchange is performed frequently for the short life LDR sources, never for long life LDR sources, and three to five times a year for HDR sources.

Task Allocation

Procedures

Site licenses were reported to define the people who were to perform this task at all sites.

Practices

High dose-rate source exchanges were performed by a physicist at three sites (3/15 = 20%) and by a representative of the distributor of the remote afterloading equipment at the remaining 12 sites (12/15 = 80%). The low dose rate cesium-137 source pellets used by the Selectron LDR afterloader are changed very infrequently due to the long half-life of cesium-137 (37 years); a representative of the distributor would perform these source exchanges. The sources used by the microSelectron LDR afterloader (either iridium-192 ribbons or wires or cesium-137 ribbons) are returned to the source storage container after each treatment session by a physicist. These sources are usually exchanged by a representative of the distributor although a physicist might also perform the iridium-192 ribbon or wire exchanges.

Results

Task Ordering

Practices

The intervals reported between high dose rate source exchanges varied from three to six months at the visited sites with most sites attempting to adhere to a three month replacement interval. Source exchange pre-empted most of the other RAB tasks with the exception that source exchanges could occur between multiple treatment fractions or between planning and treatment delivery at some sites. Special procedures were needed to prevent misadministrations when these situations occurred.

Low dose rate source exchanges occur very infrequently due to the 37-year half-life of cesium-137. Indeed, none of the visited sites had ever required the exchange of the cesium-137 sources from their low dose rate afterloaders.

Task Performance

Procedures

Locally written procedures for dealing with source exchanges were found at two of the three sites which performed their own source exchanges (2/3 = 67%). Both sites had step-by-step checklists to be used during task performance and one also had a worksheet to be filled out during task performance. Written procedures were contained in the manufacturer's instruction manuals and were followed by the manufacturer's representatives when they performed source exchanges.

Practices

Source exchange practices differed by manufacturer and by the type of equipment (low or high dose rate) used at the site. All three sites that performed their own high-dose source exchanges used equipment from a single manufacturer. Licensing agreements at all other sites and agreements with manufacturers limited source exchange to the manufacturer's representatives. Radiation surveys were performed after the source exchange at all sites and were also performed prior to the exchange at most of the sites.

Some variation was observed in the practice of source exchange at sites where physicists performed their own exchanges. Two of the sites reported that engineering personnel were also licensed to participate in the source exchange and one reported that the usual task performer preferred to use a hand crank to transfer the source instead of the afterloader control unit.

Task Locating

Procedures

Licensing requirements were reported to constrain source exchange to the shielded treatment room at the visited sites.

Practices

High dose rate source exchange was reported to always be performed in a shielded room at the visited sites, although several sites had essentially similar rooms in which the exchange could be performed rather than a single dedicated room for the purpose. Most were always performed in the single treatment room dedicated to RAB at the site.

Low dose rate sources were prepared and loaded in a closed room separate from the treatment rooms in which the treatments were delivered for one type of remote afterloader (microSelectron-LDR).

Task Linkage

Source exchange is linked to the calibration, treatment planning and treatment delivery tasks because it changes the radiation source used to plan and deliver treatments. It is also linked to equipment updates and QA because some of the equipment (source and cables) that is tested during QA and used during treatment delivery may be modified when a source is exchanged.

Procedures

Calibration was required to be performed immediately after source exchange and before treatment at all 15 sites (15/15 = 100%). The procedures examined at two of the three HDR sites which performed their own source exchanges required routine QA checks to be performed and source positioning and dwell times be checked after a source was exchanged. Manufacturer's manuals specified extensive QA and maintenance to be performed following a source exchange.

Practices

QA procedures on the afterloading equipment were performed at all sites after source exchange. Linkages to the calibration task were satisfied by performing the calibration immediately after the source was exchanged.

Verification of Task Performance

Procedures

Signed documentation of the source exchange was required at all sites. QA following HDR source exchanges was used to verify that the equipment remained operative after the exchange. One site had a procedural description of some of the QA steps that RAB staff members were expected to follow after the manufacturer had performed a source exchange. Calibration following the exchange was used to verify that the exchanged source was of the appropriate activity.

Practices

Two sites checked the source calibration at intervals after the initial exchange to verify that the exchanged source contained the specified radioactive isotope.

Verification of Task Linkages

Practices

One site used colored binders for records of patients whose multiple treatment sessions spanned a source exchange. In this way, staff were alerted that it was necessary to re-compute plan parameters that were originally based on the activity of the previous source.

3.2.5.2 Source Calibration

This task involves measurement of the activity of a radiation source and the transfer of that measurement to the devices and into the activity units used for planning and delivering RAB treatments.

Task Allocation

Procedures

Licensing agreements were reported to limit the personnel who were authorized to calibrate the source at most sites.

Practices

Source calibration was performed by a physicist at all of the visited sites (15/15 = 100%). The allocation between humans and equipment varied. All sites used equipment to measure the activity of the source, but calculations were performed by hand at some sites, by interaction with simple

hand calculators at others and by computer programs or programmable calculators at many sites.

Task Ordering

Practices

Source calibration was performed immediately after source exchange at all of the visited sites (15/15 = 100%). At one site the calibration was repeated at monthly intervals and at another the calibration was checked daily.

Task Performance

Procedures

Some form of local written procedure for calibration of the source was found at nine sites (9/15 = 60%). Checklists were used at four of these (4/15 = 27%), and worksheets were used at the other five (5/15 = 33%). Descriptions of the procedures to be used were also found at seven of these sites (7/15 = 47%). Manufacturer's instructions and professional journals that contained suggested calibration procedures were also found at most sites.

The use of programmable calculators or computer programs to perform some of the calculations during source calibration provided a form of procedure which was used at several sites to direct task performance. These programs allowed a sequence of calculation steps to be stored and repeated for each calibration.

Practices

High dose rate calibration was always performed in air at the visited sites although some had experimented with other methods (e.g. various phantoms). Most sites reported using a Farmer chamber to measure the source activity although three sites used other chambers: (PTW, Thimble, and parallel-plates). Two sites (2/15 = 13%) used a cobalt reference for calculation of the source activity from the chamber measurements while the remainder (13/15 = 87%) interpolated values from copper, cesium and other references. All sites made multiple measurements of activity at different dwell times to check the transit time to the measurement position of the source as well as its activity.

Results

Task Locating

Practices

Calibration was always performed in the treatment area at these sites (15/15 = 100%).

Task Linkage

Practices

Source calibration is linked to treatment planning and treatment tasks since it provides the activity of the radiation source used to plan and deliver treatments. Source calibration is linked to the source exchange task since the type and activity of the source that was exchanged is specified upon receipt of the source in that task.

Source activity from the calibration task was entered into the treatment control equipment immediately after calibration was performed at all sites (15/15 = 100%). Source activity was entered into the planning systems at a later, unspecified time at each site.

Verification of Task Performance

Procedures

One site had a procedural description of steps to follow in verifying calibration of a source. Calibration worksheets were saved to verify that the source had been calibrated at all sites.

Practices

Calibration calculations were repeated at most sites before the results of the calculations were used. At all sites, before the calculated value was accepted, the result of the calibration was compared against the estimated activity of the source calculated from the supplier's description of the source activity when shipped. Physicists at 14 sites (14/15 = 93%) reported that they would accept and use their own calibration if the activity they measured was within 10 percent of the supplier's value (after allowance for decay in the interval since the source was measured by the manufacturer). Larger discrepancies were reported to require recalibration and resolution with the supplier before they could be used. At the remaining site a 10 percent difference would also be accepted, but the supplier's source activity would then be entered into the treatment and planning equipment instead of the locally calculated value.

Several sites reported that the performance of calibration equipment was verified on known sources prior to each new calibration.

At two sites calculations made by programmable calculators or computers were verified by a different program or calculator before the calculations were accepted.

At one site (1/15 = 7%) re-calibration and re-entry into the treatment and planning units was practiced at monthly intervals.

Verification of Task Linkages

Practices

At two sites (2/15 = 13%) equipment was used to check the source activity on a daily basis without a complete recalibration. Worksheets at four sites (4/15 = 27%) were used to verify that the same source activity was used in the planning and treatment equipment.

3.2.5.3 Equipment and Software Updates

This task involves changes to the devices or programs used to perform RAB tasks. These include installation of software and hardware updates and any other changes to hardware or software that might change the interface with the equipment or the way in which the equipment or software operates.

Task Allocation

Practices

Updates to the planning programs were performed by a physicist at 12 sites (12/15 = 80%) and by personnel not connected with the RAB team (either the manufacturer's representative or a departmental computer manager) at the other three sites (3/15 = 20%).

Task Ordering

Practices

Updates were performed at the discretion of the planners at several sites. Some of these (4/15 = 27%) kept a previous version of the software running until the users had sufficient time to accommodate to and test the newer version. At two sites (2/15 = 13%) updates were regularly performed without warning to the planners so that new

versions with different interface requirements were a continuing source of confusion.

Task Performance

Procedures

A written procedure describing software updates was found at one site (1/15 = 7%). Manuals describing update procedures were present at some sites.

Practices

No consistent practice for upgrading software was found. At four sites more than one version of the planning software was kept and used for different treatment procedures. At others, planning software had not been upgraded because the upgrade was not perceived to offer any advantages over the old system.

Task Locating

Practices

Software upgrades were either performed at the planning workstation for dedicated planning systems or at a central processing unit for planning units that had multiple workstations.

Task Linkage

Practices

Planning software upgrades are linked to the treatment plans produced by the planning systems and, in some cases, to the data that are brought to those systems from other tasks.

Planning software was tested on known treatment plans after each upgrade at six sites (6/15 = 40%). At one site the software was tested prior to each multi-channel treatment plan.

Verification of Task Performance

Procedures

A description of upgrade performance verification procedures was found at one site (1/15 = 7%).

Practices

Tests performed on the software after each upgrade at six sites (6/15 = 40%) were filed to verify that the testing procedure had been performed. Information on the version of the treatment planning system in use was available to the user during planning, but the date of the upgrade was not displayed.

Verification of Task Linkages

Practices

Tests performed on the software after each upgrade at six sites (6/15 = 40%) were used to verify that with the same data, the new software would produce a treatment plan similar to that produced before the upgrade was installed.

3.2.5.4 Troubleshooting

This task involves the recognition and resolution of problems or difficulties in the RAB equipment or process. It includes dealing with problems detected during QA or maintenance activities as well as problems related to the support of the patient and staff during emergencies or other unexpected occurrences.

Task Allocation

Practices

Although problems and emergencies are likely to confront any task performer, all of the respondents in this study reported that the task of troubleshooting non-medical problems dealing with remote afterloading would be performed by the physicists at their site (15/15 = 100%). At two sites (2/15 = 13%) engineers were on call to assist with equipment problems. At seven sites (7/15 = 47%), technologists who performed routine QA also participated in the troubleshooting process.

Task Ordering

Practices

Emergencies and delivery system problems were, of necessity, dealt with as they occurred at all sites. Although not formalized by a procedure, physicists at many sites (data not formally collected at any site) reported that they formulated a conceptual model of RAB system performance that they used to anticipate potential problems and test system performance during emergencies. This

Results

practice extended troubleshooting task performance to intervals before, as well as after, the occurrence of problems.

Task Performance

Practices

Physicists were "on-call" twenty four hours a day to deal with emergencies and to isolate problems at all of the visited sites. Troubleshooting practices were observed during walk-through demonstrations or observation of treatments visits at six sites ($6/15 = 40\%$).

Two primary methods for dealing with problems were observed. In the first, experimental verification of the elimination of problems was required. At a site using this method all treatment procedures would be suspended until an identified problem had been diagnosed, corrected, and, in the case of a failed QA check, the check had been successfully passed. An interval of four hours was observed during which treatment was suspended due to a failure to pass a positioning accuracy check at one site. At that site the equipment used to measure the accuracy of the remote afterloader during QA had broken so that, although there was no reason to believe that the remote afterloader itself had positioning problems, the accuracy of that positioning could not be tested until the QA equipment was repaired.

In the second method, compensating adjustments were made to compensate for problems or errors after they had occurred. At one site an error in positioning the patient during simulation was detected by the digitization software and adjusted by moving the measurement axes on one negative without requiring that the simulation be repeated.

Task Locating

Practices

Two troubleshooting practices were observed during these visits. The first was to obtain an explanation or advice concerning a problem via telephone and the second was to travel to the problem site itself. Telephone consultation was often followed by extensive experimentation at the problem site.

Task Linkage

Practices

Troubleshooting was initiated by problems in a single task, but often required that the troubleshooter recognize that the

source of the trouble was from the linkage to a prior task. These linkages were obviously tested by the troubleshooters on several occasions during the site visits, but were not measured since the mental models used by the troubleshooters were not tested in this study.

Verification of Task Performance

Practices

The physicists at all the visited sites were expected to verify their own performance on troubleshooting tasks.

Verification of Task Linkages

Practices

When a problem was recognized by failure of equipment to pass a QA check, the troubleshooting task performance was verified by either the successful subsequent passage of the equipment through the QA check after isolation and resolution of the reason for the failure, or by isolation of the defect to the level that the faulty equipment could be replaced.

3.2.5.5 Routine Quality Assurance

Routine quality assurance involves tests conducted to determine whether the RAB system is operating properly, procedures have been followed, and whether those procedures have produced the intended results. Routine QA verifies that the patient is ready for treatment, that the RAB treatment process is being used within its designed capacity, and that the system is meeting its operational and performance goals. Routine QA tasks include verifying the identity of the patient, testing the operation of the equipment, and verifying and monitoring the performance of the RAB system. Less routine QA tasks involve certification of performance of new or modified equipment, software, and procedures.

Task Allocation

Practices

Routine quality assurance and pre-treatment equipment checks were performed exclusively by physicists at eight sites ($8/15 = 53\%$). Routine QA was performed only by technologists at four sites ($4/15 = 27\%$), and by either physicists or technologists at three sites ($3/15 = 20\%$). The afterloader treatment and control unit hardware also performed part of this task.

Task Ordering

Procedures

Nine sites (9/15 = 60%) had written procedures directing that routine QA be performed daily prior to performing a treatment on that day. At many of these sites QA was required prior to each RAB treatment.

Practices

The usual practice at the visited sites was to perform QA on the afterloader equipment early in the morning before the equipment would be used and before any patients arrived for treatment on any shared equipment in the treatment room. Most sites also performed visual and emergency equipment checks on the afterloader control unit prior to treating each patient. Sites with more than a single RAB treatment per day often split the QA procedures so that source positioning checks would be performed once early in the day and visual checks would be performed immediately before treatment for each patient. Independent QA checks were performed by the afterloader hardware prior to each treatment. Table 8 shows the observed QA intervals for different RAB tasks.

Task Performance

Procedures

Written procedures describing or dealing with routine QA were found at 10 sites (10/15 = 67%). Eight of these (8/15 = 53%) had step-by-step checklists for use during task performance and four had worksheets that were filled out by users during performance of the task.

Practices

Routine QA checks on afterloading equipment were performed daily prior to treatments at all sites. At most sites simulator alignment, view angle and magnification were tested on a regular schedule by non-RAB personnel who used the simulator for other treatments. Two of the sites tested simulator equipment as part of their RAB QA procedures.

Table 8 shows the intervals at which different types of equipment were tested. Most sites performed routine QA on a daily basis. RAB staff at many sites, including those sites without checklists for the performance of routine QA, also ran through a routine set of QA checks before each treatment. Console displays were checked weekly rather than daily at one site. Emergency stop controls for the

remote afterloader were checked weekly at one site, and only after a source exchange at another. At six sites (6/15 = 40%) planning equipment software was checked after each software update. At another site, planning software was checked prior to planning each multi-channel treatment.

Staff at another site checked the length of all newly acquired applicators and guide tubes. At one site, staff re-checked the length of applicators and guide tubes whenever the source was exchanged. A radiation survey was performed by RAB staff after source exchange at all three HDR sites at which the staff performed the source exchanges. The source activity was calibrated after a source exchange at all sites.

Task Locating

Procedures

Locally written descriptions of the pre-treatment QA procedures at eight sites (8/15 = 53%) specified the hardware to be tested. Since the hardware was located in specific work areas at all sites this constrained the performance of the QA procedures to those work areas.

Practices

Routine QA was performed at the treatment control workspace and in the treatment area at all sites. A few sites also performed QA for treatment planning equipment located in the treatment planning workspace. QA for simulation equipment was performed in the simulation equipment's workspace which varied depending on whether the simulation equipment was shared or dedicated to RAB. QA operations on highly portable equipment (applicators, source guide tubes and measuring equipment) were performed in labs or offices outside the treatment workspaces at most sites.

Sites which re-used endobronchial applicators and applicator needles all practiced visual inspection of the applicators for damage following each treatment in which they were used.

Task Linkage

Procedures

Written procedures dealing with the linkage between QA and other tasks were found at five sites (5/15 = 33%). All of these specified independent procedures for testing the accuracy of the estimation of the activity of the radiation source prior to treatment. Procedures for measuring the length of source guide tubes were also found at two sites (2/15 = 13%).

Table 8. QA Check Intervals (15 Sites)

QA Item	Daily	Weekly	Monthly	At Source Exchange	When Purchased
Applicators					
Condition	♦				
Length/size	♦			♦	♦
Simulator					
Alignment			♦		
View angle			♦		
Magnification			♦		
Treatment Planning					
Software integrity	♦				♦
Measurement accuracy	♦				
Plotting accuracy	♦				
Source decay calculation	♦				
Afterloader Control Unit					
Console displays	♦	♦			
Operates treatment unit	♦	♦			
Interrupts treatment	♦				
Dwell time	♦	♦		♦	
Source decay calculation	♦				
Afterloader					
Plugged in	♦				
Source extension distance	♦			♦	
Source position accuracy	♦	♦	♦	♦	
Source activity	♦	♦		♦	
Radiation survey	♦			♦	
Monitors/Emergency					
TV	♦				
Intercom	♦				
Radiation detector	♦				
Emergency stop	♦	♦		♦	
Door interlock	♦	♦			

Practices

QA was directed at the identification of faulty equipment at most sites rather than at the detection of faulty links between tasks.

Verification of Task Performance*Procedures*

No written procedures describing verification of the performance of this task were found at any site. The description of the daily QA tasks performed at most sites required that the checklist used in QA be signed by the person performing the QA prior to treatment each day.

Practices

Performance of the routine daily QA procedures was documented by a signed and completed checklist at most sites.

Verification of Task Linkages*Practices*

The person starting treatment verified that the QA had been performed that day by either visual inspection of the completed checklist or by verbal interrogation of the person responsible for the QA.

4 Discussion

The study of RAB procedures and practices has shown that RAB sites have developed and implemented a wide variety of practices in order to accomplish RAB functions and tasks. The objective of these procedures and practices is to facilitate the administration of a prescribed radiation dose to a patient while minimizing staff radiation exposure.

Methods used to link RAB tasks together and the communications procedures used to pass information and material between tasks have been identified. These linkages are a crucial but often overlooked aspect of RAB task performance. Without a well-established system of linking tasks, information that is critical to error-free RAB task performance can be lost. Similarly, verifications can confirm that certain actions occurred at the appropriate time and place in the RAB process. However, verification procedures were absent, poorly structured, or inconsistently followed at many facilities.

One of the more salient findings of Phase 3 was the overall lack of documentation for performing RAB tasks. Although RAB staff and equipment had been acquired and assigned tasks, only a few sites had formally defined those tasks or produced written procedures to guide staff in performing them. The reasons for this lack of documentation include the fact that most training is of the apprenticeship or on-the-job variety; little formal training occurs in RAB.

As a consequence of not having formal procedures, all sites had developed an extensive array of local practices that enabled RAB to be conducted reliably and safely most of the time. These local practices invariably featured verbal communication among RAB staff during task performance to pass important information along the chain of RAB tasks. Unfortunately, these communication linkages were particularly error-prone. Quality assurance procedures designed to identify RAB errors and address their consequences were incomplete and often failed to pass the information needed by staff to verify that the RAB process had been performed correctly.

The only tasks that were performed in exactly the same way at different facilities were those involving the actual operation of the RAB treatment delivery equipment. The constraints imposed by equipment hardware and software required an unvarying sequence of operational steps in order to perform certain tasks. These constraints helped to mitigate the effect of imperfect communication linkages among RAB staff. Of course, not all RAB tasks impose behavioral limitations on system operators, thus increasing reliance on communication linkages and increasing the likelihood of human error.

Error detection and error correction are two major aspects of quality assurance that can mitigate the consequences of human error in RAB. As the Phase 3 findings demonstrate,

many potential problems in RAB stem from the failure to transmit information that is needed to detect and correct errors. In order to prevent misadministrations, RAB system status should be assessed immediately before starting treatment delivery for the occurrence of errors in prior tasks. However, because of shortcomings in the propagation of information through the RAB system, all the information needed to assess system status may not be available to RAB staff during treatment delivery. An important undertaking for improving RAB systems is to develop a way to funnel information to RAB staff at the time and place when they must decide whether or not to initiate treatment delivery.

4.1 Error Detection

Error detection requires that redundant information be collected and compared with an intermediate or final task product. Redundant information is usually not produced by the task that is being checked for errors, but is instead obtained from some preceding task. In many RAB treatment delivery systems, redundant information was not propagated forward through the system from the point at which it was generated to subsequent tasks. In these cases, task performance errors become difficult if not impossible to detect after completion of the task. Some of these hidden errors would be unlikely ever to be detected or reported.

Examples of these hidden errors include

- improper applicator positioning when no simulation is performed
- movement of applicators between simulation and treatment
- errors in treatment planning software
- connection of applicators to the wrong treatment channels

In many other cases, although information might be available to detect errors or their consequences, they were unlikely to be detected prior to starting treatment because of inconsistent verification procedures.

Examples of these potentially undetected errors include

- applicator size mismatches between placement and planning
- treatment distance errors
- source dwell position errors due to improper placement of simulation markers
- selection of an inappropriate treatment plan

4.2 Error Correction

A good case can be made that the human function in any system is to make and then diligently correct task performance errors. Many human activities are better described as a series of error corrections rather than as a sequence of error-free actions. A system can be considered robust with respect to human error if either: (1) no error can modify its outcome or (2) the error will be detected and corrected before it can have an adverse effect on that outcome.

The RAB delivery systems studied in this report are certainly not robust in the first sense. A single error in applicator positioning or dwell time, if uncorrected, could have quite significant long term effects. To achieve robustness in the second sense requires that errors be identified and then corrected by the human-machine system. Errors which are not detected are unlikely to be corrected. Errors which are detected after treatment, e.g., those discovered by post-treatment dosimetry, are also difficult to correct. Since radiation effects tend to be cumulative, some small errors in the dosage delivered to the patient can be corrected if they occur before the delivery of the final treatment fraction.

Correction of an error requires that even more information be carried forward through the RAB system than does the detection of that error. A difference in two values which should agree may indicate that an error has occurred, but does not indicate which value is correct. This extra information requirement to correct errors was only rarely provided at the RAB sites visited during Phase 3. Because of this shortcoming, only a few RAB errors are presently correctable. Notable among these potentially correctable errors were

- (1) simulation errors which could be detected by measuring known distances between simulated objects and then corrected by repeating the simulation, and
- (2) errors in entering the treatment plan into the afterloader control unit

Since a printout of the original treatment plan was preserved after the plan was entered, entry errors could be identified and corrected at any time before treatment started. Notably absent from RAB was any index of the position of the source in relation to the target or the dose that the target was receiving that could be checked during treatment to verify that the prescribed dose was actually hitting its designated target.

Appendix A: Figures

Table of Contents

Figure		Page
1	RAB conceptual model of information and material flow in major tasks and task linkages	144
2	Tasks performed by physicians	145
3	Tasks performed by physicists	145
4	Tasks performed by dosimetrists	146
5	Tasks performed by technologists	146
6	Tasks performed by nurses	147
7	Tasks performed by clerical staff	147
8	Flow of information and objects through the RAB system to generate a treatment plan	148
9	Treatment plan selection	149
10	Steps involved in producing a treatment plan atlas	150
11	Treatment plan for RAB treatment delivery	151
12	Written descriptions of task performance procedures	152
13	Checklist usage.....	152
14	Worksheet usage	153
15	Procedural documents usage (all types)	153
16	Workspace allocation for patient contact tasks—cervical and endometrial treatments	154
17	Workspace allocation for patient contact tasks—endobronchial treatments	155
18	Written descriptions of the linkage procedure.....	156
19	Checklists used in task linkage.....	156
20	Worksheets used in task linkage	157
21	Sites with any linkage documents	157
22	Written descriptions of procedures for verifying task performance.....	158
23	Checklists used in verifying task performance	158
24	Worksheets used in verifying task performance	159
25	Any form of documentation related to verifying task performance	159

Figure 1. RAB conceptual model of information and material flow in major tasks and task linkages

Figure 2. Tasks performed by physicians

Figure 3. Tasks performed by physicists

Figure 4. Tasks performed by dosimetrists

Figure 5. Tasks performed by technologists

Figure 6. Tasks performed by nurses

Figure 7. Tasks performed by clerical staff

Figure 8. Flow of information and objects through the RAB system to generate a treatment plan

Figure 9. Treatment plan selection

Figure 10. Steps involved in producing a treatment plan atlas

Figure 11. Treatment plan for RAB treatment delivery

Figure 12. Written descriptions of task performance procedures

Figure 13. Checklist usage

Figure 14. Worksheet usage

Figure 15. Procedural document usage (all types)

Workspace allocation for patient contact tasks

Cervical and Endometrial TREATMENTS (10 sites)

Figure 16. Workspace allocation for patient contact tasks—cervical and endometrial treatments

Figure 17. Workspace allocation for patient contact tasks—endobronchial treatments

Figure 18. Written descriptions of the linkage procedure

Figure 19. Checklists used in task linkage

Figure 20. Worksheets used in task linkage

Figure 21. Sites with any linkage documents

Figure 22. Written descriptions of procedures for verifying task performance

Figure 23. Checklists used in verifying task performance

Figure 24. Worksheets used in verifying task performance

Figure 25. Any form of documentation related to verifying task performance

This page intentionally left blank

Section C

Training and Organizational Practices and Policies

CONTENTS

	Page
1 INTRODUCTION	167
1.1 Organization of Section C	167
1.2 Objectives of Phases 4 and 5	167
2 METHOD	169
2.1 Training Data Collection	169
2.1.1 Training Materials	169
2.1.2 Training Interviews	169
2.2 Training and Qualification Data Analysis	170
2.3 Organizational Data Collection	170
2.3.1 Organizational Interviews	171
2.4 Organizational Practices and Policies Data Analysis	172
3 RESULTS	173
3.1 RAB Training and Qualifications	173
3.1.1 RAB Staff Training Characteristics	173
3.1.2 Training Organized by Job Category	177
3.1.3 RAB Training Resources	179
3.1.4 Skills Transfer	182
3.1.5 Testing and Qualification	182
3.1.6 Refresher Training	183
3.1.7 Supplemental Training	183
3.2 Organizational Functions and Tasks	184
3.2.1 Establish Goals	184
3.2.2 Determine Tasks	184
3.2.3 Acquire Resources	184
3.2.4 Design Procedures	184
3.2.5 Allocate Tasks and Resources	184
3.2.6 Communicate Goals, Procedures, and Information	186
3.2.7 Monitor Progress Toward Goals	186
3.2.8 Direct Progress Toward Goals	186
3.3 On-Site Evaluation of Organizational Functions	186
3.3.1 Establish Goals	186
3.3.2 Determine Tasks	187
3.3.3 Acquire Resources	188
3.4 Design of Procedures	193
3.4.1 Administrative Procedures	193
3.4.2 RAB Procedures	196
3.5 Allocate Tasks and Resources	196
3.5.1 Allocate Personnel and Equipment	196
3.5.2 Allocate Workspaces	198
3.5.3 Allocate Supplies	198
3.6 Communicate Goals, Procedures, and Information	200
3.6.1 Communicate Goals	200
3.6.2 Communicate Procedures	200
3.6.3 Communicate Information	200

	Page
3.7 Monitor Progress Toward Goals.....	201
3.7.1 Evaluate Personnel Performance.....	202
3.7.2 Evaluate Equipment	203
3.7.3 Evaluate Procedures	203
3.7.4 Evaluate Workspaces	203
3.7.5 Evaluate Materials and Supplies	203
3.8 Direct Progress Toward Goals.....	203
3.8.1 Participate in Policy Decision Making.....	204
3.8.2 RAB Staff Motivation and Job Satisfaction.....	204
3.8.3 Modify Equipment and Materials	206
3.8.4 Modify Workspaces	207
3.8.5 Modify Procedures	207
4 DISCUSSION	209
4.1 Training and Qualification	209
4.1.1 Current RAB Training Programs	209
4.1.2 Available Training Courses and Materials.....	209
4.1.3 Refresher (Follow-On) Training	210
4.1.4 RAB Qualification	210
4.2 Organizational Practices and Policies.....	210
4.2.1 Establish Goals	210
4.2.2 Determine Tasks.....	210
4.2.3 Acquire Resources	211
4.2.4 Design Procedures.....	211
4.2.5 Allocate Tasks and Resources.....	211
4.2.6 Communicate Goals, Procedures, and Information	211
4.2.7 Monitor Progress Toward Goals	211
4.2.8 Direct Progress Toward Goals	211
4.3 Conclusions.....	211
5 REFERENCES	213

LIST OF FIGURES

Figure	Page
1 Summary of RAB training for oncologists	178
2 Summary of RAB training for physicists	178
3 Summary of RAB training for technologists	178
4 Summary of RAB training for dosimetrists	179
5 Summary of RAB training for nurses	179
6 Summary of interview data according to job category	180
7 Defining RAB treatment planning tasks	185
8 Defining RAB treatment delivery tasks	185
9 Acquisition of resources	189
10 Workspace allocation for gynecological treatments	191
11 Workspace allocation for lung treatments	192
12 Typical radiation oncology organizational structures	194
13 A work group organizational chart for a large hospital (RAB work group shown in shaded area)	195
14 Allocation of tasks, workspaces, and resources	197
15 A typical flow diagram for administrative information	201
16 A systems approach to training (based on Gagne, Briggs, and Wager, 1988; Kaufman, Corrigan, and Nunnally, 1966)	212

LIST OF TABLES

Table		Page
1	Staffing Distribution	169
2	Years of RAB Experience	173
3	Pre-Service RAB Training	174
4	In-Service RAB Training	175
5	Adequacy of Training Received	175
6	Formal Skills Testing	176
7	Performance Feedback	176
8	Additional Training Desired	176
9	Manual Afterloading Brachytherapy Experience	177
10	Other Radiation Therapy Experience	177
11	Sites with Locally Produced Training Materials	181
12	Summary of Locally Produced Training Materials	183
13	RAB Site Descriptors	188
14	RAB Functions and Tasks	196
15	RAB Task Performance According to Job Category at 16 Sites	199
16	"Who Would Notice If You Did a Better Job"	202

This page intentionally left blank

1 Introduction

Section C reports on Phases 4 and 5 of the project, Training and Organizational Practices and Policies. In Phase 4, the training provided for RAB personnel was evaluated. The evaluation addressed the actual training received, the training materials available to support task performance, and the qualifications of RAB personnel. In Phase 5, the organizational factors that are required to design, support, monitor, and direct the operation of a RAB delivery system were examined.

1.1 Organization of Section C

The introduction describes the objectives of Phases 4 and 5.

The methods section describes how data were collected at the sites using traditional training and organizational assessment tools and by observation of training and organizational activities that were being performed related to RAB at each site. The data collection methods were designed to identify training and organizational factors needed for RAB. The data provide a description of training and organizational approaches to RAB taken by the eight facilities examined in Phases 4 and 5 with additional information collected during visits to the other 15 facilities.

The results section presents an analysis of the data from the assessments of training and organizational attributes along with data relating to the specific RAB functions identified in Phase 1.

The discussion section considers how the results of the training and organizational assessments are related to the overall reliability and level of performance of RAB systems.

1.2 Objectives of Phases 4 and 5

The purpose of Phase 4 was to evaluate the training and qualifications of radiation therapy staff in terms of RAB task demands. The evaluation was based mainly on the results of the function and task analysis reported in Volume 2. Additionally, Phase 4 examined strengths and weaknesses of training and qualification of RAB personnel based on human factors guidelines for training and instructional techniques, and professional qualification.

The purpose of Phase 5 was to evaluate the organizational practices and policies of medical facilities as they related to the performance of RAB. This evaluation was based on the results of the function and task analysis (Volume 2) as well as on eight organizational factors that affect human

performance. These eight factors guided collection and subsequent analysis of RAB organizational data:

- organizational structure
- staff selection criteria
- staff motivation methods
- training policies
- job satisfaction
- performance appraisal methods
- decision making methods
- decision communication methods

This page intentionally left blank

2 Method

The methods used to gather information on training and organizational practices and policies are presented below. These methods, widely used to assess training (e.g., Phillips, 1983) and organizational factors (e.g., Goldstein, 1989; Harrison, 1987) provided a procedure for collecting data that could be used to increase our understanding of how training and organizational factors influence the likelihood of human error in RAB.

2.1 Training Data Collection

Training practices and policies were investigated as part of Phase 4 of the project. Data from all 23 sites visited during this project were used for the training evaluation; however, eight of the 23 sites were evaluated specifically for training and qualification practices and policies.

2.1.1 Training Materials

To evaluate training materials and programs available to RAB staff, the following items were collected from each equipment manufacturer and all 23 RAB sites:

- (1) technical documentation provided by RAB equipment distributors
- (2) training course materials provided at the Nucletron training facility
- (3) training and marketing video tapes produced by the RAB equipment manufacturers
- (4) training material produced locally at each RAB site including
 - written RAB related policies and procedures
 - written evidence of a training course
 - written testing material
 - written qualifications standards
 - performance checklists
 - miscellaneous training materials, including background reading material, reports and protocols developed by other RAB sites, and general information that may be of value as supplementary training material

2.1.2 Training Interviews

Detailed, structured interviews were developed for the professional specialties represented in RAB, including medical physics, radiation oncology, oncology nursing, administration, housekeeping, dosimetry, and radiological therapy. The structured interviews were conducted with all available staff members involved in RAB at each of the eight RAB sites visited during Phases 4 and 5. RAB

functions and tasks identified in Phase 1 served as a basis for the development of specific training and qualifications related questions used in the interviews.

Individual interviews covering RAB training and organization were conducted with a total of 124 RAB staff members at the 23 sites visited during the project. Table 1 shows the job category distribution of these personnel.

Table 1. Staffing Distribution

Job Category	Number of Respondents
Oncologists	18
Physicists	43
Dosimetrists	10
Technologists	36
Nurses	17
Total	124

Interviews were conducted individually in a private location. Questions asked during these interviews were sufficiently open-ended to permit discussions of training and qualifications issues peculiar to the various RAB sites, thus permitting more complete data collection.

Questionnaire responses varied among job categories and among visited sites; respondents were asked questions pertaining only to their RAB site, personal experience, and job responsibility. Also, occasional interruptions were experienced because of clinical commitments. Interviews were conducted so as not to interfere with ongoing activities.

Questions and discussion focused on determining the type and extent of training related to the accomplishment of RAB and covered the following topics:

- type of formal (college) education received and degrees held
- medical certification training
- type and length of RAB training received in a formal setting (e.g., classroom instruction with qualified instructor and standardized course of instruction)
- perceived adequacy of the formal training
- instructional material used during the course of formal instruction

Method

- type and length of RAB training received in an informal setting (e.g., on-the-job training), apprenticeships, seminars, working groups, newsletters, videotapes, etc.)
- length of directly related RAB experience
- length of indirectly related manual afterloading brachytherapy experience
- length of indirectly related experience in other forms of radiation oncology treatments
- form and frequency of re-training received
- testing required and qualification procedures conducted prior to performing RAB
- form and frequency of performance feedback received
- perceived transfer of training that occurred between RAB tasks, and other tasks performed by an RAB staff member
- additional training desired

With respect to the RAB functions and tasks identified in Phase 1, members of the RAB staff were asked

- how they had learned to perform the task and task linkages
- whether there was a training program for that task at the site
- whether they had learned to perform, link, and verify the task from that training program

2.2 Training and Qualification Data Analysis

The content of RAB training programs was evaluated by comparing each instructional system to a model training system specified by the systems approach to training. This model requires that training needs be defined, that training objectives be stated, that specific knowledge, skills, and abilities be identified, and that those requirements be addressed with training material and testing methods designed to meet specific learning objectives.

To facilitate evaluation against the model system, the interview data were entered into a computer based training and qualification matrix, and organized according to five staff positions: Oncologist, Physicist, Dosimetrist, Technologist, and Nurse. RAB site, type of RAB equipment used, and site licensing agency (whether the sites were licensed by the NRC or by the State) also were included in the matrix. This additional information allowed factors that might affect local training and qualification requirements to be considered.

The matrix was then used to compare the training and qualifications of individuals within a staff position group; and also to consider the differences in training and qualification requirements across staff positions. The training requirements for each staff position were determined by using a structured protocol, the Job Comparison and Analysis Tool (JCAT; Seven, Akman, Muckler, Knapp, and Bernstein, 1991) to identify critical skills and abilities required for each RAB task. Skills and abilities required for RAB tasks performed by individuals in each staff position were then compared to the training provided to individuals in those positions.

To obtain a rough estimate of the prevalence of RAB training materials at each site, a simple count was made of the types of training material collected. Training materials were then categorized according to type, and evaluated on their availability, their content and their suitability for training purposes. Due to the brevity of many of the collected training materials, only a few items were selected for a full content and format evaluation.

The format of the selected training material was first evaluated against human factors guidelines. The evaluation focused on

- highlighting
- graphics
- information organization
- language and readability
- legibility
- physical media properties

The material's suitability for training was then evaluated by comparing the strengths and weaknesses of the material in each category with RAB training objectives.

2.3 Organizational Data Collection

Basic organizational information regarding site composition, site licensing, number of treatments, types of treatments, staff educational background and staff composition, were collected from staff at all 23 sites. Data collected at all sites also included

- the site's hospital affiliations: government, community, private, and university
- area and population served by the site
- hospitals affiliated with the RAB site
- RAB case load
- RAB equipment installed

- size and composition of the departments performing RAB
- size and composition of the RAB teams
- organizational relationships and diagrams related to RAB
- perceived organizational problems and suggested solutions
- selection criteria for job candidates in radiation oncology, medical physics, dosimetry, radiation therapy, and nursing
- training offered on-site for RAB staff
- training supported off-site for RAB staff
- training and certification requirements for RAB staff
- maintenance policies for RAB equipment
- radiation safety policies for RAB

During Phases 4 and 5, the same eight sites were used for detailed examination of RAB organizational practices and policies as for collection of training and qualification data. Interviews were conducted with the people who had defined the goals and objectives of the RAB facility, designed the system for delivering treatments, selected the equipment, and selected and trained the RAB staff. Interviews also were conducted with personnel who were responsible for defining and communicating procedures for RAB task performance and with those responsible for monitoring and directing progress toward departmental goals.

Because interlocking organizational structures were found for the various RAB disciplines (e.g., physics, oncology, nursing, housekeeping, and radiology) care was taken to record the perspectives of representatives of all groups at each site. Whenever they were available, the personnel who held administrative positions related to RAB organizational functions at each site were interviewed. Data were collected from RAB staff at the sites regarding their participation in the organizational functions and the effect those functions had on their job performance.

Additional data on organizational practices, e.g., motivation, supervision, and communications, were collected during interviews with RAB staff at all sites.

2.3.1 Organizational Interviews

Detailed interviews were conducted with all available staff members involved in RAB at each of the eight RAB sites visited during Phases 4 and 5. RAB functions and tasks identified in Phase 1 served as a basis for the development of specific interview questions about training and organizational practices and policies. The following topics

were included in the questionnaires that guided the interviews with RAB staff at each site:

Medical and Administrative Structures

- organizational structure established at the site for RAB
- RAB problems anticipated and protection mechanisms designed against them
- adjustments made to the structure after implementation at the site

Communications Procedures

- procedures established
- problems anticipated and protection mechanisms designed for them
- adjustments made since implementation of the procedures

Performance Appraisal Methods

- procedures established
- problems anticipated and protection mechanisms designed against them
- adjustments made since implementation of the procedures

Workplace Safety Procedures and Policy

- procedures established
- problems anticipated and protection mechanisms designed against them
- adjustments made since implementation of the procedures

Employee Motivation

- procedures established to address employee motivation
- problems anticipated and protection mechanisms designed to address them

Task Performance Procedures

- methods used at the site to allocate RAB staff to each RAB task
- performance evaluation procedures used at the site
- task performance procedures that were being used for each task
- monitoring methods used to determine if task performance procedures were adequate and being used by the RAB staff
- problems that had been considered in designing task performance procedures

Method

- linkage and verification procedures designed for the RAB tasks

Organizational Performance

- job responsibilities
 - percent of time spent on RAB
 - RAB tasks performed
 - other duties performed
 - people supervised
 - perceived organizational relationships
- work schedule
 - work hours and shifts
 - participation in setting up the work schedule
 - method by which the work schedule was communicated
- communication procedures
 - communication with subordinates
 - communication with supervisors one level above
 - communication with supervisors two levels above
 - communication with coworkers
 - participation in setting up communications procedures
 - method by which changes in procedures are communicated
- feedback from others on job performance
 - who would notice if they did a better job
 - the frequency and form of feedback from supervisors and co-workers
- job satisfaction
 - perceived opportunity for growth and development
 - effect of departmental rules on job performance
 - expectation of rewards for better performance
 - changes that might make the job easier
 - how difficult it might be to make those changes
- working conditions
 - most stressful part of the job
 - part of the job taking the most mental effort
 - part of the job with the most time pressure

- what could be changed to improve working conditions
- procedures for dealing with safety hazards
- problems which would be difficult to deal with
- perception of the organization's attitude toward safety

2.4 Organizational Practices and Policies Data Analysis

Data collected on organizational factors from all sites were evaluated to identify RAB organizational functions and tasks that described

- organizational functions related to RAB facility operation
- how those organizational functions were performed at each site
- practices and policies needed to perform those functions
- how the organization supported and directed performance of RAB functions and tasks

3 Results

This section presents the results of analyses of the data that were collected to evaluate RAB training and organizational practices and policies. The results of the training evaluation are discussed first. They include the extent and type of training that staff in each RAB job category have undergone, along with related training issues such as skills transfer, testing and qualification, and supplemental training. Organizational practices and policies are then presented in terms of eight functions (establish goals; determine tasks; acquire resources; design procedures; allocate tasks and resources; communicate goals, procedures, and information; monitor progress toward goals; and direct progress toward goals) that influence the organizational dynamics of an RAB treatment facility which, in turn, influence the likelihood of human error in RAB.

3.1 RAB Training and Qualifications

The interviews yielded a large volume of information concerning RAB training. They revealed many paths for training, often unique to the RAB site and job category concerned. Some RAB staff attended manufacturer-sponsored training courses to learn RAB treatment planning and treatment delivery before they performed RAB. Others obtained manufacturer training as a refresher course after receiving on-site training.

Some RAB staff received the majority of their training from equipment manufacturers' field personnel during equipment installation or maintenance, or at seminars or working group meetings. Still others relied on operators manuals or on-the-job (OJT) training. For the purposes of this report, data collected on RAB training were divided into two categories; training provided before the respondent performed RAB (pre-service training), and training received on-the-job (in-service training, or locally developed training, both on and off site).

3.1.1 RAB Staff Training Characteristics

Nine characteristics of RAB staff training were evaluated:

- years of RAB experience
- formal education
- pre-service RAB training
- in-service RAB training
- adequacy of training
- formal skills testing
- performance feedback
- additional training requested
- previous radiation therapy experience

3.1.1.1 Years of RAB Experience

Table 2 shows the average years of RAB experience for each RAB job category. Low values reflect the relatively recent introduction of RAB into the U.S.. Nearly all RAB staff acquired their RAB experience at the medical facility where they currently work.

Table 2. Years of RAB Experience

Job Category	Number of Respondents	Average RAB Experience (yrs)
Oncologists	15	2.6
Physicists	41	3.2
Dosimetrists	9	3.2
Technologists	34	3.3
Nurses	17	3.6
Total / Average	116	3.2

3.1.1.2 Formal Education

Formal education received by RAB staff at almost all sites did not explicitly include RAB. Nevertheless, all respondents considered their formal education to be valuable in providing a general foundation in basic skills and knowledge required for their positions. Although RAB staff acknowledged the importance of these basic skills and knowledge, they emphasized that their formal education alone would have been insufficient preparation for performing RAB. They felt that additional specialized RAB training was essential before they could perform RAB effectively.

Most of the RAB job categories had well established and unique educational backgrounds. Oncologists, for example, held MD degrees and appropriate board certifications as a prerequisite to RAB. Several of the oncologists interviewed also had graduate degrees in physics, which gave them additional competence in the technical aspects of RAB. Most physicists had graduate degrees in medical physics or nuclear physics. Most held a Ph.D. (40%) or an M.S. (43%). One major distinction between the duties of the Ph.D. and the M.S. physicists concerned their research responsibilities. The Ph.D.-level physicists were often expected to conduct and publish research in addition to

Results

their clinical duties. Consequently, they were most often found at university-based RAB sites. Those with a bachelor's degree usually worked as junior physicists under the supervision of a more senior physicist. Only about half of the physicists were board certified. Many reported that board certification was not relevant for RAB and that it was not necessarily career enhancing within their organizations.

At many sites, dosimetrists were a separate and distinct RAB job category. Unlike other RAB job categories, there was no unique educational background for dosimetrists. The dosimetrist position was either an entry-level job for a bachelor's degree physicist (20%) or, more commonly, an opportunity for advancement for a technologist (80%). In this sense, the dosimetrist position represented a career path for RAB staff. The other RAB job categories required unique educational prerequisites so that no career movement between positions was likely. The dosimetrist position requires knowledge of physics and radiation therapy. It also may require incumbents to visualize abstract three-dimensional structures and to deal with patients in a clinical setting. Since there is no single formal educational background that provides these diverse requirements, dosimetrists were typically trained on-the-job by the senior physicists. It was reported, however, that only one component of the specialized skills and knowledge could be trained effectively. That is, either a bachelor's-level physicist could be trained in radiation therapy or a radiation therapist could be trained in basic nuclear physics. Either candidate would be required to learn the details of the computerized treatment planning process.

Technologists, or radiation therapists, constitute another RAB job category. While the tasks performed by technologists differed markedly among sites, they had similar educational backgrounds. The majority (73%) were graduates of technical training programs in radiation therapy. Due to labor shortages of technologists, several sites had established their own training programs, which often included a rotating internship experience. Other technologists held A.S. (21%) or BS (6%) degrees. Most (61%) held radiation therapy technologist (RTT) certifications.

Nurses who are part of the RAB team at many sites were usually registered nurses (93%) who were graduates of a 2-year or 4-year nursing program. Most had other types of nursing experience before becoming involved with radiation therapy. One of the more common types of prior nursing experience was in emergency rooms, where they developed skills in anesthesia, attaching life support apparatus, and in instructing patients.

3.1.1.3 Pre-Service RAB Training

Pre-service training includes classroom instruction at the equipment manufacturer's facility, training programs offered on-site prior to performance of RAB, RAB training during formal education, and training provided by the equipment manufacturer during initial equipment installation. Table 3 shows the amount of pre-service RAB training that staff members received. Considering the highly specialized nature of RAB, it seems surprising that only 68 percent of the respondents received pre-service training. Detailed analysis of the pre-service training curriculum, however, revealed that it emphasized operation of computer-driven treatment planning systems. Other pre-service training topics included radioactive source exchange and calibration. For the most part, these topics are of greatest relevance to physicists and dosimetrists, and the vast majority of those (85%) reported receiving pre-service training.

Table 3. Pre-Service RAB Training

Job Category	Number Responding	% of Respondents Who Received Pre-service Training
Oncologists	7	57%
Physicists	26	85%
Dosimetrists	7	86%
Technologists	25	56%
Nurses	12	50%
Total / Average	77	68%

Physicists and dosimetrists who had received the pre-service training concluded that it was too concentrated. Too much information was delivered over a brief time period for effective training to take place. Nevertheless, the "hands-on" nature of the training helped to teach them about the equipment and basic procedures.

3.1.1.4 In-Service RAB Training

The most common form of in-service training received by RAB staff was on-the-job training (OJT). Other types of in-service training included seminars, discussions with RAB staff at other sites, training by equipment manufacturers,

videotapes, medical journals and newsletters. Table 4 shows the number of RAB staff who received some form of in-service training. In one sense, all RAB staff receive OJT in that they all learn certain skills "on-the-job." Table 4, however, represents those RAB staff who felt they had received systematic, structured in-service training. It suggests that at many sites, RAB staff did not receive any in-service training. The substitute for systematic in-service training was word-of-mouth training received from other RAB staff members on-site, self-instruction by RAB staff, or, as was often the case, informal situations where staff members learned together using a trial-and-error approach. It is important to note that many RAB staff, particularly physicists, reported that they learned many of their skills individually, on their own time. This was particularly true for the computer-assisted treatment planning systems. One such informally developed procedure found at many sites involved error-checking. RAB staff observed and double-checked each other during treatment sessions to watch for various types of errors. The fact that RAB staff operate as a team reflects the need for team-oriented training in RAB in addition to training of individual RAB team members.

Table 4. In-Service RAB Training

Job Category	Number Responding	% of Respondents Who Received In-Service Training
Oncologists	7	43%
Physicists	23	61%
Dosimetrists	6	67%
Technologists	26	61%
Nurses	13	81%
Total / Average	75	63%

3.1.1.5 Adequacy of Training

Regardless of how RAB staff were trained, it is important to determine whether the training was adequate for the requirements of the job. One way of judging adequacy of training is to ask experienced RAB staff how well their RAB training had prepared them for their jobs. Table 5 shows the percentage of respondents who judged their training as adequate.

Table 5. Adequacy of Training Received

Job Category	Number Responding	% of Respondents Who Felt Training Was Adequate
Oncologists	5	100%
Physicists	11	91%
Dosimetrists	3	67%
Technologists	7	43%
Nurses	16	69%
Total / Average	42	74%

Overall, most respondents (74%) felt that their training had been adequate; however, respondents in every RAB job category stated in interviews that they would like to receive additional training of some kind. Note that most senior RAB staff (oncologists and physicists) were relatively satisfied with their training, while a smaller percentage of technologists reported that their training was adequate. This finding is consistent with the fact that most training is provided for senior staff rather than technologists.

3.1.1.6 Formal Skills Testing

Another way of judging adequacy of training is by formal skills testing. Formal skills tests can be established for each job category. Passing a skills test would be one way of demonstrating proficiency for job performance. Table 6 shows that formal skills testing is seldom used at RAB sites; few RAB staff are required to test or qualify for their positions using a formal skills test.

3.1.1.7 Performance Feedback

Performance feedback is an important factor in determining the extent to which organizational goals are met which, in turn, influences staff motivation and job satisfaction (Erez, 1977; Ivancevich, 1976; Latham, Mitchell, and Dossett, 1978, Steers and Porter, 1987). The lack of formal skills testing does not mean that RAB staff members do not receive some form of performance feedback and appraisal. Table 7 shows that the overwhelming majority of respondents (91%) received performance appraisals or feedback. The periodicity (daily, weekly, monthly, annually, etc.) of administrative feedback was not consistent across sites. Nevertheless, almost all

Results

Table 6. Formal Skills Testing

Job Category	Number Responding	% of Respondents Who Received Skill Testing
Oncologists	2	0%
Physicists	10	0%
Dosimetrists	8	50%
Technologists	4	25%
Nurses	4	25%
Total / Average	28	21%

RAB team members were being observed continuously by other members of the RAB team, and immediate verbal performance feedback usually was provided. Some feedback was formal and structured although most was informal and unstructured.

Table 7. Performance Feedback

Job Category	Number Responding	% of Respondents Who Received Feedback
Oncologists	3	100%
Physicists	19	84%
Dosimetrists	6	100%
Technologists	23	96%
Nurses	14	86%
Total / Average	65	91%

3.1.1.8 Additional Training Desired

During interviews, RAB staff were asked about specific additional training they felt would be useful to them. Additional training was desired in almost every area by someone in a given job category. Responses were grouped according to the RAB tasks defined in Volume 2. Table 8 lists the tasks for which at least half of the members in a job category expressed a desire for additional training.

The perceived need for additional training varies with job category. Oncologists identified no additional training and felt that they had received sufficient training. Dosimetrists and technologists desired more training on various aspects of treatment planning and quality assurance. Nurses expressed a need for additional training in tasks that concern treatment simulation and the treatment process itself.

Table 8. Additional Training Desired

Job Category	Additional Training Area Desired
Oncologists	• Areas Not Specified
Physicists	• Dosimetry
Dosimetrists	• Life Support Monitoring • Applicator Placement • Target Volume Localization • Dosimetry • Treatment Plan Selection & Approval • Source Calibration
Technologists	• Target Volume Localization • Dosimetry • Treatment Plan Entry • Troubleshooting • Routine QA: Source Position and Time • Routine QA: Systems, Alarms, and Interrupts
Nurses	• Patient Instruction • Life Support Monitoring • Applicator Placement • Simulation x-ray • Dosimetry

In general, areas of desired additional training were related to, but fell outside of, the job requirements for the RAB staff who identified them. For example, many nurses would like to gain increased familiarity with simulation and dosimetry which are performed by other job categories. This finding may indicate the value of increased cross-training among RAB team members so each is familiar with the duties of others. In this way, team members would be better able to perform quality assurance (QA), check

each others work product and thereby facilitate work flow and function and task transition.

3.1.1.9 Previous Radiation Therapy Experience

A final characteristic about training and qualifications concerns the general experience levels of RAB staff in other forms of radiation therapy. Tables 9 and 10 give the average self-reported years of general radiation therapy and specific manual afterloading brachytherapy experience. Tables 9 and 10, respectively, show that many RAB staff members had extensive manual brachytherapy and other radiation therapy experience. Although many of the specific skills required by these areas are not directly transferable to RAB, some general relationships exist between them and RAB.

Only a subset of the respondents with general radiation therapy experience also had experience with manual afterloading brachytherapy. Also, at many sites, RAB workload was small enough that staff performed non-RAB duties as well. Thus, while a person may have conducted RAB treatments several times over the past five years (giving that person five years of RAB experience) their primary duties were related to other forms of radiation therapy.

3.1.2 Training Organized by Job Category

Data on RAB training characteristics presented in the preceding section can also be organized according to each RAB job category. This method of organization provides a summary of training characteristics by job category. Although the total number of respondents is indicated for each job category, this number may vary within a category for individual questions. The following descriptive statements are based upon the number of respondents for each question.

3.1.2.1 Oncologists

Eighteen oncologists were interviewed for training and qualifications data from 11 sites. The majority of them (57%) had received pre-service training on RAB and 43 percent had received in-service training on RAB. All of them judged their RAB training to be adequate. This training ranged from classroom training by RAB equipment manufacturers, seminars, observation of and instruction from other staff, and OJT from the equipment manufacturer. The most common form of training for both pre-service and in-service training was OJT. The average length of experience in RAB was 2.6 years. None of the oncologists were formally tested on their RAB skills. All the oncologists received performance feedback in some

form. Most of them (67%) requested additional training of some kind, although less than half of them requested more training in RAB. Figure 1 summarizes these findings.

Table 9. Manual Afterloading Brachytherapy Experience

Job Category	Number of Respondents	Manual Afterloading Experience (years)
Oncologists	4	8.8
Physicists	24	9.6
Dosimetrists	5	7.0
Technologists	7	6.5
Nurses	10	12.0
Total / Average	50	9.3

Table 10. Other Radiation Therapy Experience

Job Category	Number of Respondents	Other Radiation Therapy Experience (years)
Oncologists	9	15.2
Physicists	26	11.5
Dosimetrists	7	12.2
Technologists	26	11.8
Nurses	16	7.8
Total / Average	84	11.3

Results

Figure 1. Summary of RAB training for oncologists

3.1.2.2 Physicists

Forty-three physicists from 23 sites were interviewed regarding training and qualifications. The majority of them (85%) had received pre-service training on RAB, and 61 percent received in-service training on RAB. The large majority (91%) judged their RAB training to be adequate. Types of training they had received included classroom training by RAB equipment manufacturers, seminars, apprenticeships under qualified staff, personal observation of other staff, general OJT, OJT from equipment manufacturers, and OJT from other staff members. The most common form of training for both pre-service and in-service training was OJT. The average length of experience in RAB was 3.2 years. None of the physicists received formal skills testing in RAB. Eighty-four percent of them received performance feedback in some form, and 70 percent requested additional training, especially in dosimetry. Figure 2 summarizes these findings.

Figure 2. Summary of RAB training for physicists

3.1.2.3 Technologists

Thirty-six RAB technologists from 20 sites were interviewed regarding their qualifications and training. Most of them (56%) had received pre-service RAB training, and 61 percent had received in-service RAB training. Less than half (43%), however, judged their training to have been adequate. Training they had received included classroom instruction by RAB equipment manufacturers, seminars, apprenticeships under qualified staff, personal observation of other staff, general OJT, OJT from the equipment manufacturer, and OJT from other staff members. The most common form of training for both pre-service and in-service training was OJT. The average length of experience in RAB was 3.3 years. Only 25% of the technologists were formally tested for qualification in RAB. Virtually all of them (96%) received feedback on their performance. Sixty percent of them stated that transfer of training took place with respect to other types of radiation therapy skills, most notably making x-rays and performing dosimetry. A large majority (91%) desired additional training, especially in target volume localization, dosimetry, treatment plan entry, troubleshooting, and routine QA. Figure 3 summarizes these findings.

Figure 3. Summary of RAB training for technologists

3.1.2.4 Dosimetrists

Ten dosimetrists from 10 sites were interviewed concerning their qualifications and training. Eighty-six percent of them had received pre-service training on RAB, and 67 percent had received in-service training on RAB. Two-thirds judged their RAB training to be adequate. Types of training they had received included classroom instruction by RAB equipment manufacturers, seminars,

general OJT, OJT from the equipment manufacturer, and OJT from other staff members. The most common form of training for both pre-service and in-service training was OJT. The average length of experience in RAB was 3.2 years. Fifty percent of the dosimetrists were tested on their RAB skills or required to qualify for their positions. All of them (100%) received performance feedback in some form and all of them expressed a desire for additional training, especially in life support monitoring, applicator attachment, target volume localization, dosimetry, monitoring the treatment session, and source calibration. Figure 4 summarizes these findings.

Figure 4. Summary of RAB training for dosimetrists

3.1.2.5 Nurses

Seventeen nurses from 14 sites were interviewed concerning their qualifications and training. Half of them had received pre-service RAB training, and 77 percent had received in-service RAB training. Types of training they had received included seminars, apprenticeships under qualified staff, general OJT, OJT from the equipment manufacturer, and OJT from other staff members. The most common form of training for both pre-service and in-service training was OJT. The average length of experience in RAB was 3.6 years. Although only 25 percent of the nurses were tested on their RAB skills, 86 percent of them received performance feedback. One nurse stated that there was transfer of training with skills associated with other nursing duties, and another nurse judged there to be a transfer of training with skills used in the ICU. Every nurse requested additional training of some kind, especially in patient instruction, life support monitoring, applicator placement, simulation x-ray with dummy sources, and dosimetry. Figure 5 summarizes these findings.

Figure 5. Summary of RAB training for nurses

3.1.2.6 Summary of RAB Training by Job Category

Figure 6 summarizes the findings for each job category according to each of the characteristics discussed in the preceding section.

3.1.3 RAB Training Resources

The resources that contribute to RAB staff training have been reviewed and are classified in four sections: Academic Training, In-House Training, Vendor Training, and Training Materials.

3.1.3.1 Academic Training

Although formal academic training in their specialties was required of physicians, nurses, and physicists, only one staff member reported that academic training had dealt with RAB. In that instance, a physicist had learned about RAB during a clinical apprenticeship at an RAB site rather than as a formal part of the medical physics curriculum. Pre-employment certification examinations for RAB job categories were required only for radiation therapy technologists at most sites. That certification usually did not address any special requirements for RAB.

Several sites were affiliated with universities that provided general medical training in radiation therapy procedures and concepts for physicians, physicists, technologists, and nurses. A few also provided some training in dosimetry. None included training in RAB procedures for their students, although several required a rotation through the RAB facility for physicists and oncologists.

Results

Figure 6. Summary of interview data according to job category

3.1.3.2 In-House Training

Most sites visited during Phase 4 had no formalized training programs and little or no written training material. Only two sites had any sort of formal training and certification for RAB task positions. One site had developed a training program to teach methods used to verify an RAB treatment plan. However, training and certification were scheduled only once every two years. As a result, new employees could be on the job for as long as two years before they were certified as trained to perform

RAB tasks for their position. The second site had developed a formal training program for the RAB radiation therapy technologist position. That program included a description of position qualifications and demands in relation to the major goals and objectives of the radiation therapy department and provided lectures and training material designed to meet those objectives. At that site, formal certification of proficiency was required before a trainee was permitted to operate RAB equipment.

There was no correlation between the number of RAB staff requesting additional training and the type of locally produced training material or programs available at each site. This may indicate that having written policies and procedures, and a large amount of locally produced training material, does not necessarily indicate that adequate training is being conducted at a given site. Conversely, the lack of written policies and procedures, and locally produced training material does not necessarily indicate the lack of adequate training at a given site.

Training often consisted solely of watching other staff members perform their duties. Apprenticeship training methods were common. In RAB apprenticeship training, an experienced task performer directs new staff members in RAB task performance until the new members demonstrate that they are qualified to perform independently. The employee's task performance was monitored by a supervisor or co-worker for a few cases before the new employee was allowed to perform RAB tasks without supervision. Other sites required their RAB staff to "self-train" by using available documentation and observing other staff. One site reported sending physicians to another hospital which performed RAB for forty hours of training. No formal testing was performed in conjunction with any of these training methods.

Despite the lack of formal training for RAB, the large majority of RAB staffs at visited sites reported that they had received adequate training for the RAB tasks that they performed. Many staff also indicated that they would welcome additional training in tasks which they did not perform regularly. The following sections identify the training that was available to RAB staff and evaluate training issues that might influence human error in RAB

3.1.3.3 Vendor Training

Only one regularly scheduled RAB training course was identified during this project. That course was provided by one RAB equipment distributor to RAB sites that purchased their treatment planning systems. It was organized as a one-week, hands-on, classroom training session to orient new users to the treatment planning system. Both distributors provided on-site instruction during initial installation of the RAB equipment.

Most sites had made use of vendor training programs or vendor provided on-site training sessions to teach afterloader and treatment planning system operating procedures to some staff at the time the equipment was installed. Source exchange procedures were taught by one vendor using similar on-site demonstrations.

These vendor courses involved lectures and hands-on equipment usage to familiarize students with the vendor's equipment and planning software. They also provided an opportunity for students to ask questions of system designers and meet other equipment users. Neither constituted a complete training program since students attending courses were not tested on their understanding and comprehension of the course material. Classes, however, were reported to be small and personal, providing the opportunity for dedicated students to pursue their own learning objectives. Experienced users were able to ask questions and to request clarification of material that had not been covered to their satisfaction in the user's manuals.

3.1.3.4 Training Materials

RAB staff reported that professionally developed RAB training and testing material did not exist. Much of the material used to train RAB staff was not training material, per se, but rather a collection of technical manuals, journal articles, checklists, forms, manufacturer's literature and advertisements. In most cases, the material had not been organized for either specific job categories or for particular RAB functions and tasks. RAB staff had to review both general references on RAB and documents on specific types of RAB equipment in order to discover information that applied to their jobs.

Locally produced training materials and programs varied considerably in both quantity and quality from site to site. A few sites (22%) had some locally produced information, including well-documented policies and procedures addressing RAB. Table 11 summarizes these materials.

Table 11. Sites with Locally Produced Training Materials

Training Material	Percent of Sites (n = 16)
Written procedures for some tasks	69
Training course material for some tasks	25
Written testing material	12
Written qualification standards for some positions	6
Performance checklists for some tasks	62
Miscellaneous training material	81

Results

Much of the information found useful in these documents was too general to be classified as training material. Few materials stated training objectives, specified performance requirements, or addressed other features expected in a systematic training program. Some sites had well-documented RAB policies and procedures, but few made those procedures available to the RAB staff as training aids. Most of these local training materials were found in storage areas that were inaccessible to trainees. Table 12 summarizes the number of locally produced training materials found at the sites visited.

Vendor Training Materials

Training materials provided by RAB manufacturers included user manuals, written instructional materials, and video tapes. Because of the limited opportunities for RAB staff to receive organized training courses, user manuals for the RAB systems were de facto training materials. Physicists and dosimetrists commonly relied on user manuals to provide information on a new system or on new system features. They also referred to the manuals when troubleshooting RAB system problems. Thus, user manuals were used for both initial and refresher training.

The commercially available documents written for specific models of RAB equipment varied in quality and format. Seven RAB user manuals were evaluated in Phase 2 against document design standards and guidelines. They were designed as equipment or software reference manuals rather than training manuals; none followed systematic training objectives. Almost without exception, the manuals lacked useful presentation and format features. Deficiencies were noted in the areas of information organization, language and readability, illustrations, highlighting, and typography. Color was used in only one manual; white space and typographic cueing were used inconsistently; tables of contents lacked detail; and illustrations were rarely used. Some procedural descriptions were incomprehensible even to RAB personnel familiar with the procedures being described.

The content and format of written instructional material provided by the manufacturers were also evaluated. Although the material constituted a source of information on RAB, it was poorly organized for training purposes. Much of the material was dated, and required the student to refer to separate handouts or equipment manuals for current information.

Other Types of RAB Training Materials

Video tapes provided by one of the RAB distributors supplemented other forms of training. They are readily available to RAB staff who use that distributor's

equipment. They are general in nature and are probably only valuable for basic or familiarization training. Users of other brands of RAB equipment do not have access to this form of training.

Another source of training information includes personal discussions with professional colleagues and with the RAB system manufacturer's field service representative. These discussions are generally informal and unstructured, but are widely cited as of great value in learning new techniques and procedures.

Seminars and workshops held in conjunction with professional meetings for oncologists and physicists were reported as valuable sources of new RAB information. They should be viewed as training opportunities, particularly for those who are actively involved with RAB.

3.1.4 Skills Transfer

Many RAB staff performed RAB tasks after gaining extensive experience in teletherapy or manual afterloading brachytherapy. Some transfer of skills appropriate to RAB was expected since these other treatment modalities also involve therapeutic application of radiation to tissue. This expectation was not well supported by team interviews with RAB staff. Many staff reported that there had been only slight positive transfer of skills (i.e., transfer facilitating task performance) from teletherapy or manual brachytherapy to RAB. Tasks in which there had been some positive transfer included scheduling and simulation. Both of these tasks use equipment and techniques that are often shared with other modes of radiation therapy treatment (e.g., teletherapy) used at a treatment facility. Most respondents stated there was no negative transfer of skills (i.e., transfer interfering with task performance) between other radiation therapy and RAB.

3.1.5 Testing and Qualification

Testing determines whether facts, procedures, and relationships have been learned. Qualification ensures that persons in a specific job category have acquired the skills and knowledge needed to perform tasks assigned to that position.

Only 15 percent of the RAB staff reported that they had been tested or formally evaluated to qualify for their RAB positions. Most of these were at the one site with a formal training program for radiation therapy technologists. Three brief examinations were required for certification of technologists at that site:

Table 12. Summary of Locally Produced Training Materials

Sites	Written Policies	Training Course Materials	Written Testing Material	Written Qualification Standards	Performance Checklists	Misc. Training Material
1						
2						
3	29				13	2
7	17				8	6
8	4				6	3
9	1					3
10	7				5	2
11	13	very little			4	4
12	6	very little			5	3
13	1					9
14	2	very little			12	3
15						
18	4	extensive	3	1	2	8
19			2		1	3
20						1
23	3				9	1

Note: Shaded areas indicate that no locally-produced training material was found. While relatively extensive evidence was found of a structured training course at one site (18), it was exclusively for technologists. There was no training course for other RAB job categories.

(1) an operator's certification exam

(2) a general procedures checklist exam

(3) an emergency procedures checklist exam

Treatment planners at that site had also completed the training program and taken the certification examinations.

Most other RAB staff interviewed in this study had never been tested or otherwise formally evaluated on their RAB skills and knowledge.

3.1.6 Refresher Training

Refresher training is received by experienced workers in order to limit the degradation of job-relevant skills. Because RAB is performed infrequently at many sites, RAB staff usually spend more time working in other radiation oncology activities than they do in RAB. Given

3.1.7 Supplemental Training

Desire for additional training in RAB procedures was expressed by personnel in most all job categories. Many

The two sites with formal training and certification programs included provisions for annual refresher training; however, those programs had not been in place long enough for any refresher training to have been provided.

Few RAB staff reported that they had received refresher training in RAB. One exception was emergency procedures. Staff at several sites reported that they had undergone periodic retraining to handle fire drills and fire-related emergencies.

These circumstances, some skill degradation is likely to occur, and refresher training is therefore an important part of a complete RAB training program.

Results

dosimetrists, technologists, and nurses stated that they would welcome additional training in the RAB tasks that they performed regularly. They also expressed a desire to become more familiar with RAB tasks that they typically did not perform. For example, several nurses expressed an interest in learning simulation procedures and some technologists were interested in learning dosimetry.

Since most training in RAB occurred on the job, there was only limited opportunity for staff to cross-train on skills outside their job classifications. Within job classifications, several informal sources of supplementary training information were available to RAB personnel. Discussions with professional colleagues and with RAB manufacturer's representatives were often used to identify and evaluate new techniques and procedures. Seminars and workshops conducted at professional meetings were also mentioned as potentially valuable training opportunities. Some dosimetrists, physicists, and physicians reported augmenting their training by visiting other RAB sites to observe unfamiliar procedures and by viewing video tapes and reading commercially available literature on RAB.

3.2 Organizational Functions and Tasks

Eight organizational functions were identified by the organizational analysis conducted during Phase 5 of the project:

- Establish Goals
- Determine Tasks
- Acquire Resources
- Design Procedures
- Allocate Tasks and Resources
- Communicate Goals, Procedures, and Information
- Monitor Progress Toward Goals
- Direct Progress Toward Goals

Each function is composed of tasks that are performed to accomplish that function. The following sections address the eight organizational functions.

3.2.1 Establish Goals

It is an organizational function to identify the goals for each organizational unit (e.g., department or division) involved in RAB. Someone of authority must define what the RAB system is expected to accomplish so that equipment and personnel can be acquired and procedures can be designed to meet those goals. Tasks in this function include establishment of specific goals related to training, service, safety, and planning and delivery of RAB treatments.

Figure 7 illustrates the process of establishing system goals and defining tasks for RAB treatment planning. Figure 8 illustrates the same process for RAB treatment delivery.

3.2.2 Determine Tasks

Once goals are established, tasks that must be performed in order to meet those goals can be determined. Both administrative tasks, required to perform organizational functions, and RAB tasks required to plan and deliver therapy, must be defined before equipment can be acquired and procedures designed to perform those tasks.

3.2.3 Acquire Resources

Once RAB tasks have been defined, the resources needed to perform those tasks can be identified and acquired. Organizational tasks within this function include acquisition of the personnel, equipment, supplies, and workspaces needed to conduct RAB. The tasks performed under this function include

- selection of personnel
- selection of equipment
- selection of workspaces
- selection of materials and supplies

3.2.4 Design Procedures

Procedures for performing both RAB and administrative tasks must be designed so that workspaces, personnel, tasks, and resources can be combined into a system capable of meeting system goals. In RAB, this function includes design of procedures for performing each RAB task, design of transport and linkage procedures, design of verification and emergency procedures, and design of administrative support and communication procedures. Procedural design tasks performed under this function include

- RAB task performance procedures
- RAB task linkage procedures
- Verification procedures
- Control procedures
- Communication procedures
- Emergency procedures

3.2.5 Allocate Tasks and Resources

Personnel, equipment, workspaces, and other resources must be brought together at specific times and places so that RAB can be performed. Management determines who

Figure 7. Defining RAB treatment planning tasks

Figure 8. Defining RAB treatment delivery tasks

Results

will perform each task, specifies where and when it will be performed, and distributes the resources needed. Allocation decisions must be made both for RAB task and organizational task performance. These decisions involve allocating tasks and resources in terms of three aspects of the RAB system:

- allocation of tasks to personnel and equipment
- allocation of workspaces
- allocation of supplies

3.2.6 Communicate Goals, Procedures, and Information

Performance goals, procedures, and information must be communicated to staff to guide them in using the equipment and other resources effectively. Training programs can communicate procedures and some information. Changes to goals or procedures that are made after training is completed must also be communicated and explained.

3.2.7 Monitor Progress Toward Goals

The performance of personnel, procedures, equipment, and resources must be monitored to determine whether progress is being made in meeting the system's goals. Tasks performed in this organizational function collect and organize the information on system performance needed to evaluate whether goals are being met, and determine whether staff, equipment or their support structures require modification. Monitoring tasks involve evaluation of the following system components:

- personnel
- equipment, materials, and supplies
- workspaces
- procedures

3.2.8 Direct Progress Toward Goals

Based on information collected during monitoring, progress toward goals can be directed by making changes in existing policies and procedures. Alternatively, goals can be modified to respond to perceived changes in mission, focus, or capability. This function includes the specification and implementation of modifications to either goals or to tasks, workspaces, equipment, personnel, procedures, training, and resources that are being used to achieve those goals.

3.3 On-Site Evaluation of Organizational Functions

Once RAB organizational functions and tasks had been determined, an analysis was conducted to determine the range of organizational practice in performing those functions at eight RAB facilities.

3.3.1 Establish Goals

Because all sites in this project were visited after RAB became operational, the goals which had led to the establishment of RAB at each site were not always apparent. Some general comments, however, can be made regarding system goals. All sites appeared to have considered safety, service, and production goals for RAB and to have organized the local RAB process to balance those goals with other complementary or conflicting organizational requirements (e.g., space, cost, licensing regulations). The main reasons given for the introduction of RAB involved reducing radiation exposure to staff (a safety goal), performing brachytherapy on an outpatient basis (HDR) (a production goal), and decreasing time spent as an inpatient (a production goal).

In several cases, the impetus for introducing RAB had come from outside the radiation oncology department. Several administrative staff involved in starting an RAB program suggested that RAB had been instituted at their site in order to provide a service that had been requested by referring physicians (a service goal). Some mentioned that RAB allowed them to provide faster and more convenient treatments for patients, while reducing staff exposure to radiation (combined service and safety goals).

3.3.1.1 Production Goals

The number of RAB treatments delivered to patients differed markedly among the sites, representing differences in production goals at the sites. For purposes of this report, a treatment is defined as the delivery of a single prescribed dose to a patient during one visit to the clinic. A single treatment might be only a fraction of the total dose prescribed and delivered during several patient visits to the clinic over a period of days or weeks. One might expect the number of treatments to be correlated with the size of the parent institution, the size of the RAB staff or the size of the geographic area from which the site could draw patients. No consistent relationship between these variables was found, although the largest RAB staff was at the largest hospital and also had the greatest number of treatments delivered.

Private facilities that specialized in RAB tended to be slightly more production and service oriented than public or university-based facilities which incorporated education and research programs into their goals. Table 13 shows features of 19 RAB sites rank-ordered by the number of beds in their parent institutions. The table also shows the affiliation of the site (hospital, university or private clinic), licensing agency for the site, total number of oncologists, physicists, dosimetrists, technologists, and nurses involved in RAB at the site, and the number of RAB treatments performed per year at each site as of the time of the site visit.

The number of beds at the parent institutions ranged from zero (private referral clinics) to 950. Three sites were private clinics, seven were affiliated with universities, and the remaining nine were private or community hospitals with no university affiliation. Nine facilities were licensed by the NRC and ten were located in agreement states.

Treatments per year ranged from a minimum of 11 to a maximum of 418. Lung cancer treatments were the predominant RAB performed at six of the sites (6/19 = 32%). Gynecological treatments were the predominant RAB performed at eight sites (8/19 = 42%). Nine sites (9/19 = 47%) performed a substantial proportion of both lung and gynecological procedures. Interstitial procedures were performed at 10 sites (10/19 = 53%). One of these sites had performed 160 interstitial treatments during the previous year.

3.3.1.2 Service Goals

Many sites provided RAB as either a service that was offered to referring physicians, or as a service that was offered to patients. Most sites received a significant proportion of their patients on referral and offered RAB as a service to referring physicians in conjunction with other forms of radiation therapy. In community hospitals, RAB tended to be organized to accommodate the schedules of referring physicians. Patients were scheduled for treatment when the referring physician would be available, and often waited between treatment stages until the physicians and staff were available. Private facilities were also service oriented, but often tended to provide service to the patient at the expense of the physicians and staff who adjusted their activities to accommodate the patients' schedules and needs.

3.3.1.3 Teaching and Research Goals

Goals at some facilities involved training and research in addition to service, safety, and production goals. The way in which these goals were balanced influenced the way in which RAB was conducted. Sites with training goals were likely to allow extra time for staff to perform the tasks and verify task performance. Sites with more dominant service and production goals were more likely to employ only experienced staff. Those organizations often required their staffs to perform RAB under extreme time pressure. University hospitals, for example, included teaching and research in their organizational goals.

3.3.2 Determine Tasks

Tasks that are involved in performing and maintaining RAB activities must be determined. These tasks can be divided into two categories: those related to actual performance of RAB and those related to administrative support of RAB.

3.3.2.1 RAB Tasks

All sites performed the RAB functions described in Volume 2 for at least some of their cases. Differences among sites were observed that represented organizational decisions to omit certain tasks (e.g., simulation with dummy sources) for selected medical procedures. Section B of this volume describes the procedures followed in performing RAB tasks at those sites. Documentation of tasks to be performed and approved procedures for performing them had been designed at fewer than half of the sites.

3.3.2.2 Administrative Tasks

Although administrative tasks were performed to carry out some organizational functions at all sites, only a few of these tasks had been explicitly defined. In addition to failing to document organizational tasks, many sites failed to perform all of the organizational functions. Written procedures were identified at less than half the sites and training evaluation programs were identified at only three sites.

Administrative responsibility for RAB was often assigned to individuals who were expected to perform organizational functions without explicit specification of those functions or their associated tasks.

Table 13. RAB Site Descriptors

Rank	Size (# beds)	Affiliation	License	Number of RAB Staff	Treatments Performed per Year
1	950	hosp	NRC	34	418
2	925	univ	NRC	19	16
3	900	univ	NRC	13	206
4	900	univ	state	29	125
5	586	hosp	state	9	27
6	565	hosp	state	12	136
7	550	univ	state	23	228
8	510	hosp	state	10	144
9	500	univ	NRC	21	380
10	480	hosp	NRC	14	98
11	388	hosp	NRC	5	106
12	380	hosp	NRC	17	360
13	370	univ	NRC	11	116
14	370	hosp	state	14	180
15	300	hosp	state	6	133
16	60	univ	state	12	11
17	0	private	state	6	98
18	0	private	NRC	12	252
19	0	private	state	9	301
Total				278	3335
Average				15	176

3.3.3 Acquire Resources

The people, facilities, equipment, supplies, and materials that must be acquired for RAB are derived through a determination of task performance needs. Figure 9 illustrates this process. No site was found in which human and physical resources had been acquired solely to perform RAB treatments. In all cases, the radiation oncology department in which RAB was performed predated RAB installation. RAB treatment delivery systems had therefore been designed to fit into the existing organizations. Facilities often added RAB afterloaders, afterloader control units, source guide tubes, and applicators to the equipment, people, and workspaces already in use at those sites for other forms of radiation treatment. Occasionally, workspaces designed especially for RAB were added.

3.3.3.1 Acquisition of Staff

Staff were already in place at the visited sites so that information about the personnel selection process could be

investigated in terms of its results (composition of the staff) as well as from answers provided to directed interview questions on selection methods. Size of the radiation oncology staff at the sites ranged from 8 to 56. The greatest variation was in the positions of oncologist (1 to 16 per site), physicist (1 to 12 per site), and technologist (2 to 14 per site). A typical RAB team was composed of several oncologists, one or two physicists, one dosimetrist, several technologists and one or two nurses. Five sites had no dosimetrists, and two sites had no nurses. Several sites had a dedicated RAB nurse, but most nurses had other duties in addition to RAB.

Acquisition of Staff from Outside

Several methods were used to solicit personnel, including personal interviews, word of mouth advertising, and

Figure 9. Acquisition of resources

professional newsletters. A few sites indicated that their reputations attracted sufficient applicants so that formal recruitment was unnecessary.

Since RAB groups had overlapping organizational structures, some sites divided their recruitment and selection efforts between overlapping professional organizations. A "typical" example might be a site at which oncologists were recruited and hired by an oncology group that was separate from the hospital organization. In that case, the physicist might be hired by either the hospital or the oncology group. Six of nine sites reported that one person, usually the chief oncologist, was responsible for hiring of all new employees. The chief would often involve other staff members in the selection process, but would make the final decision himself.

Locating qualified employees who were already trained and experienced in RAB was often reported to be difficult. As a result, recruiting was often based on other criteria, such as teletherapy experience, personal attitude, and interpersonal skills. Some sites had instituted training programs for radiation therapy technologists, while other sites provided support for technologist training programs in local community colleges.

Sites reported that experienced RAB physicists were difficult to find. A few sites preferred medical physicists with both academic and research experience and two sites indicated a preference for less highly trained physicists (e.g., M.S. rather than Ph.D.) based on the belief that such individuals would be more likely to conform to local practices.

Acquisition of Staff from Within

Oncologists and physicists whose positions typically require more formal education were usually not hired from within an organization, although there were exceptions. RAB was considered to be a desirable specialty by both nurses and technologists due to the lack of night work and the limited radiation risk to the staff. This allowed some of the larger institutions to select their RAB personnel from the ranks of technologists and nurses that were already performing similar functions in other areas of the hospital. Many sites selected dosimetrist candidates from the ranks of their technologists because dosimetrists were in short supply.

Results

3.3.3.2 Acquisition of Workspaces

Appropriate workspaces must be acquired before RAB can be conducted. As with personnel, RAB workspaces should possess certain characteristics that facilitate effective RAB.

Figures 10 and 11 show how several sites allocated workspaces for several tasks of two major RAB medical procedures: gynecological and endobronchial (lung) procedures. Planning workspaces were shared with planning systems for other types of radiation therapy at 29 percent of the sites. Treatment workspaces were shared with other radiation treatment units (e.g., teletherapy) at most of the high dose sites ($17/21 = 81\%$).

Most sites had met shielding requirements for RAB treatment areas by either converting areas previously used for other radiation therapy treatments or by sharing areas that were still used for other types of treatment. Shared workspaces often presented a scheduling problem and markedly increased the time pressure during treatment planning for RAB staff at some facilities.

3.3.3.3 Acquisition of Equipment

RAB requires afterloading equipment for positioning the source and controlling that position during treatment. All sites had supplemented their afterloaders with additional equipment designed to aid staff in planning and monitoring RAB treatments. Policies on what equipment to acquire varied depending on the administrative structure at the sites and the degree of participation of administrators in RAB. At some sites, the afterloading equipment was owned and maintained by the RAB staff under contract to the facility. At other sites, the equipment was owned by the facility which then hired staff to operate it. Prior clinical experience was the main determining factor in the type of RAB equipment selected: administrators who had used one type of equipment usually acquired similar equipment for subsequent installations. Only three sites had RAB equipment from more than one manufacturer.

External beam treatments were performed in addition to RAB at all sites. Most sites used common scheduling, record-keeping, and simulation equipment for their RAB and external beam treatments. Shared equipment reduced the number of human-system interfaces staff needed to learn. Thus, in addition to being cost-effective, shared equipment also had some advantage from a human factors point of view.

The sharing of equipment among different types of radiation therapy is not without its shortcomings, however.

For example, shared simulation equipment usually required transport of the patient from the simulation workspace to the RAB treatment workspace. This increased the potential for applicators to shift position between simulation and treatment. At some sites, problems in scheduling shared equipment had been addressed by acquiring additional treatment planning and simulation equipment. Often, this equipment had different interfaces and usage requirements. These differences required additional training and verification procedures to be designed to ensure that simulation results were correctly transmitted to RAB treatment planners.

Afterloaders

MicroSelectron high dose rate afterloaders were used by 16 sites ($16/23 = 70\%$), GammaMed high dose rate afterloaders were used by five sites ($5/23 = 22\%$) and MicroSelectron or Selectron low dose rate afterloaders were used by four sites ($4/23 = 17\%$). Although those devices were not included in this evaluation, two sites ($2/23 = 9\%$) had Omnitron high dose rate afterloaders. Three sites had both low and high dose afterloaders ($3/23 = 13\%$). Two sites had afterloaders from more than one manufacturer.

Treatment Planning Systems

Sites with teletherapy programs often used their teletherapy planning systems to produce RAB treatment plans. Some of these systems could not optimize dose distributions for target volume geometries that are common in RAB. This required additional planning procedures to be designed to adapt these treatment plans to RAB.

Planning systems were selected from the same manufacturer that provided the afterloaders at 17 sites ($17/23 = 74\%$). Other sites used shared planning systems that were already in place for other teletherapy or brachytherapy programs and adapted the output from these systems for RAB.

Simulators

All sites used simulation x-ray equipment for some RAB treatments. Simulators were usually shared with other brachytherapy and teletherapy treatment programs and most had been initially selected for use in those other programs. Three sites had simulation equipment dedicated to RAB, and one site had constructed a simulator specifically for RAB. One site used CAT scans in place of simulation x-rays for some treatments.

Gynecological Treatments (10 sites)

Placement and simulation workspaces are combined during the patient's first treatment.

Figure 10. Workspace allocation for gynecological treatments

Figure 11. Workspace allocation for lung treatments

Applicators

All sites used applicators provided by the manufacturers of RAB equipment. Four sites ($4/23 = 17\%$) had manufactured their own specialized applicators and staff at two sites had constructed frames for positioning the applicators during placement and treatment.

Monitoring Equipment

All sites had TV cameras and intercoms to monitor patient status during treatment delivery. Two sites had windows between treatment delivery and treatment control areas so that staff could visually inspect readouts on any monitoring equipment that was attached to the patient.

Emergency and Safety Equipment

All sites had door interlocks that would initiate source retraction if the door was opened during treatment. All sites had emergency stop buttons to retract the source in an emergency and radiation warning lights in the treatment room that operated independently of the remote afterloader warning system. All sites had a lead pig for disposal of loose source material in the event of an emergency, and five sites had tongs to aid in its retrieval.

3.3.3.4 Acquisition of Materials and Supplies

All sites had treatment programs in addition to RAB with which they shared supplies and materials for x-ray, simulation, and planning. Supplies specific to RAB were usually acquired from the afterloader vendors. Two sites had experimented with applicators from sources other than the RAB equipment manufacturer. Inventory maintenance and control practices for RAB supplies varied. Some sites re-ordered supplies as they were needed and others kept a large local stock of disposable or reusable items. Disposable applicators were commonly used for lung treatments, although several sites sterilized and re-used the same lung applicator for each treatment fraction on a single patient. This practice was accompanied by evaluating the used applicator for wear or damage at most sites. Staff at a few sites inventoried and tested each newly purchased applicator, guide tube, or software update before it was used. Although these practices were often adhered to rigidly by staff, no formal procedure linking purchases to pre-treatment quality assurance was identified.

3.4 Design of Procedures

For the purposes of this project, procedures were defined as an ordered sequence of tasks or steps that have been designed, approved, and documented for some purpose.

Steps in a procedure must be documented in a form that permits its use as a reference for task performers and allows deviations from the approved sequence to be detected. Approval of such a procedure may be informal, and there may be more than a single procedure approved for a particular purpose. Procedures are distinguished from practices which were defined as any ordered sequence of tasks or steps used repeatedly for some purpose. Practices may differ between individuals and may or may not conform to the approved sequence set out in a procedure. Thus procedures and practices both govern performance of tasks, but procedures had to be documented while practices did not.

Once RAB tasks have been determined and RAB staff, workspaces, and equipment have been acquired, procedures must be designed to perform RAB tasks and communication and transport activities that link the tasks together. Procedures can be designed both for RAB tasks and for tasks related to administrative functions. A complete procedure design undertaking includes the initial requirements specification, initial design, testing against requirements, modification, and approval of the procedure for performing a particular task or task linkage.

All sites had designed procedures for some tasks, although the procedure design function was informal and undocumented at most sites. Only two sites included procedure design as a formal job function. Staff at all sites indicated that medical and nursing procedures could be changed by physicians or nurses without consultation with other staff. Most staff also felt that physicists would be responsible for deciding whether non-medical procedures needed to be changed and would also be responsible for implementing any changes. No site provided resources to assist in the design and documentation of RAB procedures.

3.4.1 Administrative Procedures

Administrative procedures govern the way in which organizational functions are performed. Administrative procedures were formalized by organizational charts showing the relationship between different job categories at most sites. These organizational charts had from two to seven vertical levels with an average of between four and five levels. Figure 12 shows some of the most common organizational arrangements found during site visits. Most sites had separate organizations for physics and radiation oncology staff. Some large sites had separate organizational structures for technologists and nurses as well.

One interesting deviation from this common arrangement was found in hospitals that contracted for oncology services. At those facilities, tasks performed by oncologists and physicists were allocated to contractors rather than to

12a Single level radiation oncology structure found in small, private clinics

12b. Three-level organizational structure for small clinics and hospitals

12c. Seven-level organizational structure found in large hospitals

Figure 12. Typical radiation oncology organizational structures

Figure 12. Typical radiation oncology organizational structures (continued)

Figure 13. A work group organizational chart for a large hospital (RAB work group shown in shaded area)

hospital employees. Figure 12d shows a model organizational chart for a facility with different contracted groups for physics and oncology.

The functional organization for RAB differed from the formal organizational chart at most sites. RAB task performers were often members of an RAB team that had been assembled from different administrative hierarchies or departments. Figure 13 shows the relation of such a team (shown shaded) to a typical departmental structure. In this figure, teams that overlap the formal structure have

been formed to accomplish different tasks. The RAB work group is drawn from members of physics, oncology, pulmonology, and nursing staffs. In this type of structure, the person evaluating a staff member might be an administrative supervisor who was not directly involved with RAB treatment delivery.

Although most sites had one or more individuals in charge of monitoring progress and directing progress toward goals, those goals seldom involved RAB directly. They were more likely to involve overall safety, production, and

Results

service for the entire department or facility without specifying or considering the contribution of individual treatment modalities such as RAB.

3.4.2 RAB Procedures

RAB procedures are ordered sequences of tasks and steps that have been designed, approved, and documented for performing RAB functions, tasks, and task linkages. RAB functions and tasks presented in Volume 2 are shown in Table 14.

While all sites had developed procedures for some RAB tasks and linkages, no sites had developed or promulgated a formal procedure design and review process.

Table 14. RAB Functions and Tasks

I.	Patient Preparation
1.	Patient scheduling, identification and tracking
2.	Patient instruction
3.	Life support monitoring
4.	Applicator placement & stabilization
5.	Patient transportation
II.	Treatment Planning
1.	Simulation with dummy sources
2.	Target volume localization
3.	Radiation prescription
4.	Dwell position localization
5.	Dosimetry
6.	Treatment plan selection and approval
III.	Treatment Delivery
1.	Treatment set-up
2.	Treatment plan entry
3.	Verify treatment data
4.	Treatment session monitoring
5.	Treatment session Control
IV.	Post-Treatment
1.	Source guide tube disconnection
2.	Applicator removal
3.	Treatment verification
4.	Record-keeping
V.	Quality Assurance and Maintenance
1.	Source exchange
2.	Source calibration
3.	Equipment and software updates
4.	Troubleshooting
5.	Routine quality assurance

3.5 Allocate Tasks and Resources

State and NRC licensing guidelines provide considerable leeway in the implementation of this function. That leeway was reflected in considerable variation in the way tasks, workspaces, and staff had been allocated. Some sites had dedicated RAB treatment planning work areas for different types of radiation therapies, while treatment planning work areas at other sites were used by all types of radiation treatments. Most sites delivered high dose rate RAB treatments in the same shielded workspaces that were used for teletherapy treatments. Figure 14 illustrates the means by which tasks, workspaces, and resources were often allocated for RAB.

Staff at all sites performed these allocations prior to starting RAB and had documented some of them in their applications for site license or accreditation. Licensing and accreditation guidelines had been followed for these initial allocations and were adhered to in changes introduced after the RAB system was operational (e.g., tasks specified for a certain job category in the licensing agreement continued to be allocated to individuals in that job category).

All sites had an administrator who was responsible for ensuring that the RAB job categories were filled and that supplies were available for performing RAB. In many cases, this was a member of the RAB team. Administrative employees without RAB duties filled these roles in some larger organizations.

3.5.1 Allocate Personnel and Equipment

In RAB, the critical task of placing radioactive sources in the patient's body is performed by hardware and software with human supervision and oversight. In contrast, while a few performance verification tasks and task linkages are performed by equipment and software, most are performed by humans. For example, RAB staff performed tasks that required data collection, manipulation, pattern recognition, medical experience and judgment. RAB staff also transported the patient, information, and materials among workspaces, and verified that the linkages between tasks and equipment were performed correctly. As shown by these illustrations, human-machine task allocation has been determined largely by the design of the equipment and degree of automation achieved by the equipment and software.

3.5.1.1 Allocation Among Job Categories

With the exception of specifications contained in site and individual licenses and certifications, only two sites had promulgated procedural guidelines to establish which job categories would perform which specific RAB tasks. Most

Figure 14. Allocation of tasks, workspaces, and resources

Results

task allocation was made informally based on individual motivation, training, skill, and accomplishment, in addition to job category.

RAB is usually performed by small specialized teams within the larger Radiation Therapy department. Most sites had only moderate crossover in task performance among job categories. Table 15 shows a breakdown of RAB tasks performed by physicians, physicists, dosimetrists, technologists, nurses and clerical staff.

At all sites, applicator placement, target volume localization, and dose prescription were performed by physicians. At most sites, physicists or dosimetrists performed tasks involving treatment planning software, and technologists performed daily QA, simulation, linkage, treatment delivery, and monitoring tasks. Source exchanges for one brand of HDR afterloader were always performed by manufacturer's representatives. Source exchanges for other types of afterloaders were usually performed by a physicist on the RAB staff.

Overall, there was great variability among sites in tasks assigned to physicists. Physicists at a few sites performed all non-physician RAB tasks. At other sites, physicists performed only administrative, quality assurance, and troubleshooting tasks, taking little part in day-to-day clinical RAB.

3.5.1.2 Allocation of Organizational Functions

RAB organizational functions were performed by management and administrative staff at three sites and by members of the RAB treatment delivery team at the other sites. These organizational tasks were reported to have been performed solely by oncologists at four sites and by cooperation between oncologists and physicists at the other sites. Organizational responsibility for allocation of tasks, workspaces, and resources was usually assumed by each task performer. For example, nurses were responsible for allocating patient care materials and physicists for allocating QA and test equipment.

Responsibility for communication procedures was highly variable, but responsibility for the content of worksheets and checklists usually was given to the RAB physicist or, at a few sites, to the RAB oncologist.

The senior RTT, senior physicist, and senior oncologist monitored and directed progress toward goals at most sites. Goal direction usually was divided so that medical goals were the function of the chief oncologist while administrative goals were the responsibility of the senior RTT or senior physicist.

3.5.2 Allocate Workspaces

Workspaces for RAB can either be allocated from space dedicated to RAB or overlaid on existing allocations made for other purposes. Administrators at many sites had elected to add RAB to their existing workspaces rather than to allocate dedicated space for RAB. Treatment planning workspaces for RAB were shared with planning systems for other types of radiation therapy treatment at 29 percent of the sites. Treatment delivery workspaces for RAB were shared with other treatment units (teletherapy, hyperthermia, etc.) at all but four of the HDR sites.

Simulation and treatment were performed in different workspaces at 20 percent of the sites. This allowed simulation equipment and resources primarily used for other types of radiation therapy also to be used for RAB, but required transportation of the patient between workspaces. A single workspace was provided for applicator placement, simulation, and treatment at 20 percent of the sites. This allocation of space eliminated transportation of the patient and reduced the opportunity for applicator movement. At the remaining sites, workspaces for placement, treatment, and simulation tasks were combined for some RAB treatments and separated for others.

Allocation of the same workspace for RAB and other forms of radiation therapy presented some scheduling problems for other types of treatment due to the variable length of RAB treatment planning sessions. Some administrators had addressed this problem by allocating space for RAB patients outside the treatment area between simulation and treatment. This allowed teletherapy to continue during RAB treatment planning sessions, but increased the chance that RAB applicators might shift position as the patient was transported between the different areas.

3.5.3 Allocate Supplies

RAB supplies usually were allocated by those who had responsibility for other radiation oncology procedures. Paper and ink for printers, x-ray film and developing supplies, RAB applicators, and record-keeping materials were provided at all visited sites. Applicators were usually ordered and distributed by the physics staff and clinical supplies by the nurse. Responsibility and procedures for performing this function varied widely at the visited sites, with the only consistent similarity being that individual task performers were expected to replenish supplies and materials (other than applicators) themselves from a central supply at most sites.

Table 15. RAB Task Performance According to Job Category at 16 Sites

Function/Task	MD	Job Category (percent of sites*)					Clerical
		Physicist	Dosimetrist	Tech	Nurse		
Patient Preparation							
Patient scheduling, identification, tracking	7	7	—	47	60	33	
Patient instruction	40	7	—	27	67	—	
Life support monitoring	20	—	—	13	53	—	
Applicator placement & stabilization	100	—	—	7	13	—	
Patient transportation	—	7	—	47	47	7	
Treatment Planning							
Simulation x-ray	13	7	7	100	—	—	
Target volume localization	100	20	7	—	—	—	
Dose prescription	100	—	—	—	—	—	
Dwell position localization	33	7	—	7	—	—	
Dosimetry	13	67	27	7	—	—	
Treatment plan selection/approval	87	20	7	7	—	—	
Treatment Delivery							
Treatment set-up	13	33	13	60	20	—	
Treatment plan entry	13	53	13	33	—	—	
Verify treatment data	27	53	13	33	—	—	
Treatment session monitoring	27	60	7	60	27	—	
Treatment session control	20	53	7	47	—	—	
Post-Treatment							
Source guide tube removal	20	13	7	47	27	—	
Applicator removal	87	20	7	20	40	—	
Treatment verification	—	—	—	—	—	—	
Record-keeping	13	47	13	67	20	—	
Quality Assurance and Maintenance							
Source exchange	—	20	—	—	—	—	
Source calibration	—	100	—	—	—	—	
Equipment and software updates	—	80	—	—	—	—	
Troubleshooting	—	100	—	—	—	—	
Routine quality assurance	—	73	—	47	—	—	

* Row sums can be greater than 100 since a task can be performed by more than one job category at some sites.

3.6 Communicate Goals, Procedures, and Information

Once RAB goals are determined, tasks defined, procedures designed, and staff and resources allocated to perform RAB tasks, this information must be communicated to RAB staff along with task performance and linkage procedures. Training sessions and meetings are the primary means for communicating this information. Other methods include bulletin boards, handbooks, instruction manuals, handouts, and private conversations with supervisors (word-of-mouth).

Training sessions and meetings must be designed, maintained, and monitored to ensure that staff understand the goals of the system, have learned procedures, and are given the information they need to carry out their duties.

3.6.1 Communicate Goals

RAB staff meetings were used at all sites to communicate administrative goals and to discuss the implication of those goals for each job category. These meetings were particularly effective when adjustments of work schedules were made since RAB is practiced as a team effort and requires coordination between team members. Individual goals for staff were usually communicated during private conversations with supervisors rather than in meetings.

3.6.2 Communicate Procedures

Procedures usually are communicated through handbooks, instruction manuals, and training. Training usually is used to communicate procedures by teaching compliance with approved task performance procedures.

3.6.2.1 Administrative Procedures

Several of the larger facilities had employee handbooks and instruction manuals describing administrative procedures at the site. Direct personal contact was the usual form of administrative communications between people in adjacent organizational levels in all organizations. Smaller facilities expected supervisors and co-workers to communicate procedures and procedure changes and relied less on written documentation.

Scheduled meetings were the most common form of communication between people in non-adjacent administrative levels. Staff meetings were used at all sites to communicate information on scheduling and to discuss and resolve departmental difficulties. Meeting frequency

varied from weekly to as-needed with the longest interval reported between meetings being three months.

3.6.2.2 RAB Procedures

At many sites, some of the performance procedures for treatment planning tasks and many of the linkage procedures between those tasks were tailored to the requirements of individual oncologists or particular medical treatments. These special procedures were usually communicated verbally from the oncologists to the task performers. Since many of these procedures were undocumented, they provided an additional opportunity for substitution errors that can occur when procedures appropriate for one task or linkage can be used inappropriately in another.

A handout card illustrating emergency procedures was supplied by an RAB equipment vendor. It described how to deal with afterloader problems during treatment and was posted prominently in the treatment control area at many sites. At a few sites, however, the card was placed behind equipment or stored in a notebook that was not stored in the treatment control area.

3.6.3 Communicate Information

Most communication among RAB staff was verbal and informal, although formal communication procedures existed at a few sites. At those sites, staff reported that instead of initiating contact directly with individuals at different organizational levels or in different job categories, they would communicate with an immediate supervisor, who would then relay their information or inquiries. The communication paths among the staff at a typical hospital are shown in Figure 15. Verbal communications are shown between RAB task performers. Memos were often used to transfer administrative information.

Individual verbal communication of time-sensitive information was encouraged within the RAB team at all sites. However, wide variance was noted in routine communication practices. Staff members at some sites were eager to initiate discussions on RAB issues with other team members; at other sites, personnel were reluctant to initiate conversations about problems and preferred to limit their communications to intimate associates or to specific situations in which verbal communication was required. Reasons for reluctance to communicate included intimidation and fear of interrupting ongoing clinical processes.

Staff meetings were used at most sites (11/19 = 58%) to transfer and discuss information between staff on both administrative and RAB issues. Meeting size and regularity

Figure 15. A typical flow diagram for administrative information

varied from one site to another. Several sites (4/19 = 21%) reported holding separate meetings for each job category (physicians, technologists, physicists, nurses, etc.) to discuss procedural changes. The remainder of the sites (7/19 = 37%) held general departmental meetings for all staff members. Some sites usually did not discuss procedural changes during meetings. These sites tended to have small RAB staffs who would inform each other of procedural changes as they were made. At some sites, most RAB tasks were performed by the same person who would unilaterally modify them.

3.6.7.1 Written Notifications

The only written communication reported or observed among RAB staff separated by one organizational level were worksheets that were passed among treatment planning staff while generating a treatment plan. Only two sites reported that written memos were exchanged between RAB staff who were separated by two or three organizational levels. Written communication between levels of RAB administration were found only in certain unusual circumstances in which documentation was necessary to show compliance or disagreement with written directives.

Most sites used worksheets or checklists to carry information between prescription, treatment planning and treatment delivery tasks. The worksheets served, along with an explanation at staff meetings, as the means of notifying staff about modified procedures. At two sites, different revisions of task performance procedure worksheets were being used by staff performing the same task. Obviously,

inadequate measures had been taken to notify all staff of changes in that task and to ensure that all staff were using the same worksheet.

3.6.7.2 Bulletin Boards

Six of fourteen sites used bulletin boards to post information. At least two of these (2/19 = 11%) posted current procedures for RAB task performance, current versions of worksheets or examples of properly completed worksheets or checklists.

At one site, the daily QA checklist was posted on a bulletin board in the treatment control workspace. This checklist was two revisions older than the version that the RAB manager had placed in the procedures manual. As a result, several recently instituted QA checks were not being performed. A master copy of the posted checklist was kept in a separate storage area so that it could be photocopied whenever the check-boxes on the posted list were filled (usually once per week). At some point, a filled checklist had been replaced by a copy of an earlier master list instead of the current master list.

3.7 Monitor Progress Toward Goals

This function involves appraising the overall performance of the components of the RAB system. These components include: personnel, equipment, procedures, workspaces, and materials and supplies. Each appraisal determines whether a given component is contributing in the intended manner to the reliable and safe functioning of the RAB

Results

system. A deficiency in even one component can compromise the integrity of the entire RAB system.

At the visited sites, RAB goals were rarely explicitly described. Not surprisingly, no formal system for comparing progress with RAB goals was found. Many sites monitored service and treatment goals by tracking the number of treatments performed for different physicians or for different medical conditions. Immediate feedback was provided to most RAB staff when short-term goals were not met. Monitoring the efficiency of service and staff performance was usually done informally and continuously.

3.7.1 Evaluate Personnel Performance

Formal evaluations of staff were required at many sites, but the relevance of these evaluations may be questionable. Formal evaluations were conducted by supervisors in the department in which the evaluatee was employed regardless of whether that department was active in RAB. Several staff reported that they were evaluated by administrators whom they met only for the purpose of performance evaluations. This raises the possibility that the evaluator lacked the necessary expertise to assess RAB staff. Often, neither administrators nor staff had a clear idea of the evaluation criteria.

3.7.1.1 Conduct of Personnel Evaluations

All sites conducted some form of performance appraisal. In addition to the formal appraisal, informal personal evaluations were often performed by immediate supervisors and other RAB team members. The administrator at one site performed an initial appraisal after the first three months of employment and continued with annual appraisal updates after that.

An important aspect of performance appraisal is how it is viewed by the person being evaluated. This issue was examined by asking RAB staff to respond to the question: "who would notice if you did a better job?" Sixteen percent (8/51) of the respondents replied: "no one." Fifty-one percent (26/51) reported that their supervisors would notice, and 29 percent (15/51) reported that their co-workers would notice. Four percent (2/51) felt that "everyone" would notice if they did a better job. Eighty percent (41/51) of the interviewees expected immediate feedback from someone in the RAB team should they perform poorly. Table 16 summarizes these findings.

Table 16. Who Would Notice if You Did a Better Job

	Responses	Percent
No one	8	16%
Supervisor	26	51%
Co-workers	15	29%
Everyone	2	4%
Total	51	100%

3.7.1.2 Personnel Evaluation Criteria

Formal appraisals were conducted by supervisors at most sites. They tended to cover overall work performance and organizational goals, with few references to RAB task performance. Some universities included teaching performance and publications in their annual evaluation of senior staff—usually oncologists and physicists. A few sites compared job performance to formal job descriptions. None of these descriptions covered RAB task performance.

Evaluation criteria for informal appraisals appeared to include teamwork, personality traits, and a willingness to deal with patients and other staff in a positive way. Competent RAB task performance and a willingness to learn new procedures were considered minimum requirements for RAB task performers at most sites. Performance evaluations would note deficiencies in RAB task performance skills, but were not designed to evaluate those skills if no problems were encountered. No attempt to rank users on the basis of their task performance skills was observed although obvious attempts had been made to allocate RAB tasks to personnel who had already demonstrated an aptitude for performing those tasks.

3.7.1.3 Personnel Evaluators

Formal evaluations were often carried out by department administrators who were not involved in RAB task performance. Formal evaluations were always carried out by supervisors in the department in which the evaluatee was employed regardless of whether that department was active in RAB. Several nurses reported that they were evaluated by the head nurse who they met with only for the purpose of performance evaluation.

Informal evaluations were usually carried out by the person at the site who was responsible for each RAB function. Oncologists would be expected to evaluate staff in those areas of RAB in which they were experienced, and physicists were expected to evaluate technologists and dosimetrists on the tasks they performed within the physicists' scope of expertise. A marked difference was encountered at sites in which the physicists and oncologists were contracted agents rather than employees. At most of these sites, the role of the physicists and oncologists in performance evaluation was purely advisory; indeed, at one site, no input from the physicist on the performance of technologists was either solicited or welcomed.

3.7.2 Evaluate Equipment

QA procedures were used at all sites to assess equipment performance and to identify operational problems. QA procedures were used daily at most sites to test patient monitoring equipment, safety devices, and source positioning equipment. Wide variation was found in the procedures for testing treatment planning equipment and x-ray equipment. The following equipment components were regularly evaluated at some of the visited sites:

- Patient preparation equipment
 - Life support and monitoring equipment
 - Applicators
 - Fluoroscopy devices
- Treatment planning equipment
 - Digitizers
 - Treatment planning software
 - X-ray magnification measuring devices
 - X-ray view angle measurements
- Treatment delivery equipment
 - Treatment control unit hardware
 - Treatment plan entry devices
 - Radiation source positioning devices
 - Dwell time calculation equipment
- Emergency equipment
- Treatment monitoring equipment
 - TV monitors
 - Intercoms
 - Radiation warning devices
 - Treatment control unit displays
- QA equipment
 - Radiation detectors
 - Source calibration devices

3.7.3 Evaluate Procedures

No site reported having a program to regularly evaluate and update procedures, although three sites showed evidence (revision dates and copies of old versions) of having done so for some procedures on a regular basis. The two sites that provided formal training programs for staff also showed evidence of having an ongoing procedure evaluation program. Many senior task performers, including most physicists, evaluated the procedures they performed in the absence of a formal evaluation program.

3.7.4 Evaluate Workspaces

Most sites had administrators who also performed some RAB functions. Consequently, they were familiar with the strengths and limitations of RAB workspaces. At five sites, these individuals had redesigned RAB workspaces to minimize patient transportation problems from simulation to treatment delivery. No site had a formal program to evaluate workspace performance, but workspace limitations were frequently mentioned by administrators, indicating that workspace evaluation was performed informally at those sites.

3.7.5 Evaluate Materials and Supplies

Sites which re-used applicators had procedures for monitoring the condition of the applicators between treatments. These procedures consisted of visual inspection as well as measurement of changes in length and condition due to repeated sterilization and handling. Other materials and supplies such as writing implements, printer paper, x-ray film and developer, and clinical supplies were used from stock maintained by the department for purposes other than RAB. Performance requirements of these items were determined, in most cases, by the other uses for which the supplies had been purchased rather than in terms of their RAB-specific performance. It was expected that inadequate RAB performance of these items would be reported by the task performers, but no procedures were found to optimize their performance for RAB. Writing implements had been evaluated for their ability to mark x-ray negatives and applicators at several sites.

3.8 Direct Progress Toward Goals

Personnel at several sites reported that they had redefined the treatment goals that had led them to set up an RAB treatment facility. In many cases, modifications were related to changes in the clinical practice of the referring physicians: treatments that had been anticipated had either

Results

not been presented or had occurred in greater numbers than anticipated. For example, adjustments had been made when the number of patients had changed. A few sites reported that the HDR afterloader had originally been intended for only one type of medical treatment (e.g., lung), but had been subsequently used for other types of treatment. Several sites reported that RAB was under evaluation as a potential replacement for manual brachytherapy treatments.

Two sites reported that the expected cost/benefit advantage of RAB had not been achieved due to the number of staff that were required to perform verifications to detect potential human errors in RAB. Since most patients at those sites were referred for treatment, production goals required to justify the cost of the RAB process could not be met. Administrators at both sites were in the process of modifying their RAB goals to include service as well as production.

Service goals had only rarely been redefined, perhaps due to the original general specifications of these goals. For example, the chief oncologist at one site reported that the primary goal of the facility was to provide radiation treatment services to patients. Although the goals had not changed, the methods used to attain it had been markedly modified since the initial installation of the RAB equipment.

3.8.1 Participate in Policy Decision Making

One site had established a quality of working life committee to investigate the decision making process. The committee's recommendations included establishing special wide-participation meetings for controversial issues and an increased use of bulletin boards.

Sites that incorporated a high level of participation generally held meetings at which administrators requested input from RAB staff, and then used that information to make a final decision. Although input was solicited from many employees, the final decision usually rested with one individual.

Many sites welcomed employee participation in decision making regarding general (e.g., division of labor) as well as specific (e.g., selection of equipment) decisions affecting RAB. This form of participatory decision making was less frequent at large institutions, particularly the large universities, than at small clinics.

In RAB, rapid decisions without prior approval can be crucial in emergency situations. One site indicated that in the case of an emergency, anyone involved with treatment could terminate the treatment. Other sites made the cancellation of treatment the responsibility of one job

category and specified that someone from that category was required to be in attendance during each treatment session.

A few sites ($3/14 = 21\%$) deferred all decisions regarding treatment to one physician, usually the chief oncologist. When a site had a small number of RAB staff so that there was effectively a single RAB team at the site, the degree of participation among all members of the team was usually greater than when there was more than one RAB team at the site.

3.8.2 RAB Staff Motivation and Job Satisfaction

Motivation and job satisfaction were measured at each site to assess the effect of organizational practices and policies on RAB staff. High motivation based on personal responsibility for patients was found at most sites. Job satisfaction levels were also high, although organizational policies contributed to a feeling of isolation for some staff.

3.8.2.1 Motivation

Motivation to perform well at RAB tasks was found to be high even at sites in which staff reported little or no feedback from supervisors. High motivation at sites where staff reported communication and personnel problems indicates that at least some job motivation of RAB staff is independent of these variables.

The primary motivational factor for most individuals was a feeling of personal responsibility for the patients under their care. Consequences of poor task performance were explained in terms of its perceived effect on the patient rather than its consequences for the staff member.

Although RAB employees were found to be highly self-motivated at most sites, there were few consistent motivational practices across the sites. Some sites mentioned high salaries or attractive locations as the primary method of motivating (hence, more easily acquiring and retaining) staff. Several sites had total quality management systems or quality groups, and many sites had instituted special positions for RAB staff (e.g., RAB nurse) to add to the prestige of the RAB position. Since RAB teams were usually small, there was daily feedback between team members on RAB task performance. One site responded to employees' requests for more organizational information by posting the minutes of relevant meetings on bulletin boards.

Observation of Effects

Reported Motivators

When reporting motivational factors for their jobs, RAB personnel usually focused on the motivators that were most meaningful to their job category. For example, many physicists enjoyed solving interesting problems, several department chiefs mentioned overseeing the overall RAB system, and technologists were motivated by successful accomplishment of challenging individual tasks.

The team nature of RAB and the consequent levels of participatory decision making and daily feedback from supervisors were reported to be successful motivators at most sites. Staff at four sites mentioned a teamwork orientation as the primary motivating factor.

Technologists and nurses at seven of eight sites (87%) reported that the opportunity to care for and interact with patients was their primary motivation. Staff at three sites reported that the opportunity to conduct HDR treatments was the main reason for their involvement in RAB. Other motivating factors included the location of the institution, cross training, job rotation, and professional respect accorded RAB qualified personnel.

3.8.2.2 Job Satisfaction

Job satisfaction is tied closely to motivation. Job satisfaction can be defined as a set of attitudes that employees have about their jobs. Recent research suggests that job satisfaction may be a stable, enduring, individual characteristic, independent of the features of any particular job (Schultz and Schultz, 1986).

The most frequently mentioned factor leading to job satisfaction was the opportunity to work as a part of a team that aids people who need help. RAB staff reported that working with patients was a primary source of motivation at six of eleven sites.

Employees were highly satisfied with their work schedules. HDR work was generally done Monday through Friday, 7:00 a.m. to 5:00 p.m. with some variation in shifts for technologists (early, middle, late). One site reported a four-day, ten-hour work week with which the employees were extremely satisfied.

Job satisfaction levels varied across sites, although staff at only two sites reported low overall job satisfaction. Most dissatisfaction appeared to be due to either personality conflicts between the staff or to perceived isolation from

control and decision processes. Five primary issues were mentioned by RAB staff as sources of job dissatisfaction:

- (1) **Isolation:** Eight of twelve sites (75%) reported that nurses felt administratively isolated from the RAB treatment team. The floor nurses often worked for a different chain of command from the rest of the RAB team and reported a desire for more information on RAB.
- (2) **Time Pressure:** Technologists and physicists reported excessive time pressure, particularly during treatment planning.
- (3) **Personality Conflict:** A few staff reported that extended personality conflicts created significant job dissatisfaction.
- (4) **Workspace Limitation:** Lack of sufficient workspace and workspace crowding were frequently cited as sources of job dissatisfaction.
- (5) **Staff Shortage:** Complaints about working conditions were most common at sites that had a shortage of technologists.

Large university-based sites tended to have less satisfied employees than small, private institutions. Large universities were regarded by some staff as intractable bureaucracies that were particularly unresponsive to their needs. As a result, personnel were dissatisfied with both the methods available for making procedural changes and the decision making process.

3.8.2.3 Stress Levels

Sixty percent of physicists, dosimetrists, and technologists reported that their positions involved high stress levels. Twenty percent of physicists reported moderate stress and twenty percent reported low stress levels. No technologists or dosimetrists reported low stress levels. The most stressful areas reported for physicists were treatment planning and equipment QA. Lower stress levels were reported by physicists holding a position with a large proportion of administrative work or who did not take part in treatment planning. Mental effort and time pressure were also reported to be high for treatment planning by 60 percent of the physicists.

The main reasons given for stress by dosimetrists and technologists involved time pressure for either treatment planning (dosimetrists) or for patient scheduling (both dosimetrists and technologists). One technologist reported stress due to lack of performance feedback.

Administrators reported the same high stress levels as found in the RAB task performers. Sixty percent reported high stress levels, twenty percent reported moderate stress

Results

levels and twenty percent reported low stress levels. The reasons given for administrator stress were different, however, and tended to be associated with the resolution of personality conflicts among the staff, budget requirements, and report deadlines.

Nurses reported the lowest stress levels with only twenty-five percent reporting high levels of stress, fifty percent reporting moderate stress levels and twenty-five percent reporting low stress levels. Nurses' stress was usually reported to involve problems coordinating treatment with physicians, physicists, and technologists.

3.8.2.4 Refresher Training and Professional Development of Personnel

Refresher Training Methods

New procedures were communicated and discussed at meetings or in on-the-job training sessions at most sites, but only two sites reported a refresher training and certification program for RAB staff.

Professional Development

Five of sixteen sites (31%) reported a policy of sending staff (usually physicists or dosimetrists) to professional meetings such as the American Association of Physicists in Medicine (AAPM) and the American Society for Therapeutic Radiology and Oncology (ASTRO). Two sites had sponsored professional workshops in RAB at which their staffs had presented and exchanged information on task performance procedures. One site had required staff members to visit other facilities to learn new procedures before they were adopted at the home site.

Opportunities for Advancement

None of the RAB sites visited had provisions for career movement between job categories with the exception of RTT to dosimetrist. Most RAB staff members bring professional skills and certifications to their jobs that have been earned through advanced degrees and specialized training. The one exception to this lack of mobility was that a technologist could become a dosimetrist by taking advantage of training offered by the physics staff.

The overlapping medical and administrative structures at most sites presented possible, albeit limited, opportunities for advancement. At those sites, RAB team members might hold an administrative or management position that was not directly related to their RAB clinical duties, but which allowed an independent career path within the organization. For example, senior administrative and management

positions (e.g., directors) within radiation oncology frequently were held by RTTs whose broad experience in various radiology positions made them valuable to the department overall.

Some structure was provided at large institutions for technologists who might advance from the position of junior technologist through staff technologist and lead technologist to chief technologist. Many sites had attempted to reduce the administrative isolation of the RAB team by establishing a position of RAB nurse or RAB technologist.

Most RAB staff were satisfied with the advancement opportunities that were presented. The only reported objection to the advancement system came from a few nurses who stated that there was insufficient opportunity for advancement from the position of radiation oncology nurse because radiation therapy was so isolated from general nursing where most of the advancement opportunities existed.

RAB staff members were well aware of the career opportunities within their profession and concentrated their efforts on improving RAB skills and achieving professional certification and qualification.

Job Rotation

Most RAB treatments are initiated and terminated during the 8 a.m. to 5 p.m. working day. This fact was identified as one of the most desirable features of a radiation therapy job in contrast to diagnostic radiation duties. Some RAB employees are on rotating schedules to oversee LDR patients who are under treatment for extended time periods, for example. One site indicated that all technologists rotated to include work on Saturdays. Another site had an extensive rotation schedule for technologists who were on call for emergencies every six weeks and rotated between teletherapy, RAB, and simulation.

3.8.3 Modify Equipment and Materials

Modification of RAB equipment, source calibration equipment, and other QA equipment is an important, ongoing form of monitoring progress toward goals. Programs of calibration and equipment testing were in effect and active at all sites visited (n=23). Equipment QA programs in radiation therapy usually are under the supervision of the physics staff.

At a few, large sites, special equipment design and modification programs were actively pursued. For example, one site had modified an RAB treatment simulator to reduce the time between simulation and treatment and to

minimize patient movement between simulation views. At others special equipment was designed to pursue research programs. No RAB treatment delivery units had been modified at any of the visited sites, although preventive repairs had been made by the afterloader manufacturers on most of the units.

Six sites had modified applicators to improve their performance. At one site, special endobronchial applicators had been designed to prevent applicator movement between placement and treatment. At three other sites, shielded applicators had been developed for certain treatment procedures. At two sites, special endobronchial applicators had been designed to reduce the radiation dose to tissue at the periphery of the applicator. Two sites had developed special frames for positioning applicators.

3.8.4 Modify Workspaces

The visit team observed many RAB workspace modifications that were undertaken or ongoing as a part of monitoring progress toward goals. The following are examples of workspace modifications that were observed:

- Simulation and treatment delivery workspaces were combined.
- Regular measurement of radiation exposure were made through shielded partitions.
- Clearances between equipment were modified to aid in emergency procedures.
- Treatment planning areas were redesigned to improve isolation and sound proofing.
- Special storage areas for RAB equipment were constructed.
- Patient waiting areas and treatment areas were redesigned with artwork to help the patient relax during treatment and to avoid the sterile look of a clinic.
- X-ray and fluoroscopic equipment in the simulation workspace were relocated to increase speed and efficiency of patient transfer.
- Special viewing arrangements were installed for nurses and others who need to monitor patients during treatment and post-treatment.
- Job performance aids and job decision aids were added to the equipment at the planning and control workstations to assist the staff in ensuring accuracy and proper system alignment.

3.8.5 Modify Procedures

Monitoring progress toward goals includes regular review (and modification if necessary) of procedures and practices. Sites with written procedures (10/15 = 67%) reported that they had modified procedures one or more times although records of the extent and date of modification usually were unavailable. Sites using worksheets or checklists also reported and showed evidence that their format and content had been revised several times.

This page intentionally left blank

4 Discussion

4.1 Training and Qualification

Effective training programs should be designed according to established principles of human learning and performance and be tailored to the specific situation in which they are applied (Fleishman and Mountford, 1989; Holding, 1987). This will help to ensure that task-relevant knowledge and necessary skills are imparted to RAB staff on a regular basis to promote effective, safe, error-free RAB performance.

4.1.1 Current RAB Training Programs

For the most part, RAB training was performed on-the-job (OJT), informally, and irregularly either by more experienced staff members or by the trainees themselves. Training usually consisted of observing other staff members perform RAB tasks. This type of training often arises in medical settings due to a combination of staffing, funding, and time considerations.

A strength of OJT is that it provides a means by which staff performance can be standardized and tailored to the characteristics of individual RAB systems. OJT can be effective when the instructor understands the material and presents it effectively. However, if the instructor is deficient in these respects, or if sufficient training opportunities are not available, then OJT loses much of its effectiveness.

RAB expertise often was seen as a natural progression from diagnostic radiography, external beam teletherapy, and manual afterloading brachytherapy. Currently, highly skilled and well educated personnel acquire RAB skills on a foundation of skills they have already acquired in other areas of radiation therapy. RAB has not yet benefited from new, unique systems, procedures, or materials for training and qualification. Many staff members felt that the current situation was adequate, although many also acknowledged a need for additional, specialized training in a number of areas, particularly treatment planning and dosimetry.

The extent to which an unstructured and non-institutionalized OJT approach to RAB training and qualifications can be sufficient is partially a function of the number of treatments performed. At the 23 sites visited during this project, treatment frequency varied from one patient per month to four per day. With these levels, small groups of dedicated, highly educated, RAB staff members may be adequate. If, however, the number of treatments increase in the years to come, an adequate supply of skilled RAB staff will not be available. There will be no effective alternative to a highly developed, RAB qualification and training system with position descriptions, orientation

preparation, qualification testing, and structured training programs using professionally prepared training materials.

Much of the OJT occurred without a statement of training objectives or testing to determine whether those objectives had been met. It therefore can be difficult for either students or trainers to determine what has actually been learned. Retention cannot be evaluated and retraining needs cannot be assessed. The need for additional training often becomes apparent only after task performance errors have been identified. A training program with well defined objectives would allow training to be used proactively to help prevent task performance errors rather than as remediation after errors have occurred.

Based on data acquired during the site visits, there was little evidence for systematic qualification and training programs for RAB. Findings indicate that the current form of training, by itself, is inadequate. Clearly, if in-service, OJT, and apprenticeship training are going to be the primary forms of training for most RAB staff members, then local programs, policies, and materials must be sufficient to ensure that RAB staff members are adequately trained. Currently, the number of RAB staff members expressing a desire for additional training indicates that they are not.

4.1.2 Available Training Courses and Materials

Only one regularly scheduled, structured RAB training course was found. This course principally involved RAB treatment planning using a single hardware and software system. The course was not applicable for many RAB staff, particularly those who did not perform treatment planning or who did not use this manufacturer's RAB equipment.

The commercially available documents associated with specific models of RAB equipment varied in quality and format, and much of the material was not training material per se, but rather was a combination of technical manuals, medical journal articles, checklists, forms, and manufacturer's literature and brochures. There was no material designed specifically to optimize training of RAB staff such as an RAB Training Manual, nor had existing material been developed for specific job categories (i.e., Technologist's Training Course, or Nurse's Training Course, etc.). RAB staff must review all available reference information on RAB and on their particular equipment in order to identify and select relevant information that would apply to training for their job.

While much of the so-called training material collected during site visits was important and instructive it was considered to have limited value for training. The material

Discussion

varied considerably in format and content from site to site, and its training value varied accordingly. Moreover, even if training material had been developed for local training purposes, it was not consistently used by the staff. As a result, the presence of training material at sites did not indicate staff involvement with RAB training.

4.1.3 Refresher (Follow-On) Training

The number of RAB staff members who expressed desire for refresher (follow-on) training was indicative of difficulty in obtaining training. Needs for refresher training were identified by personnel in all job categories, and the information requested covered most RAB tasks. During interviews, many dosimetrists, technologists, and nurses indicated the desire for additional training in the tasks that they normally performed. This seems to reflect a general absence of training opportunities for these staff positions as well as the need for providing validation of safe and effective task performance. A desire also was frequently expressed for general training involving the overall RAB process. For example, many nurses expressed a desire for indoctrination in simulation and dosimetry procedures to give them a greater understanding of the processes their own efforts were supporting. Satisfying needs for cross-training would help promote greater integration among the RAB team and enable each member of the RAB team to check performance at each task and step in the RAB process.

4.1.4 RAB Qualification

Most RAB staff had never been formally tested on their RAB skills or been required to meet formal qualification standards for their positions. Testing helps determine not only that the person understands and can apply the material presented, but also that all of the required material was adequately presented. Qualification helps ensure that persons in a particular job category have the skills required to successfully perform RAB. Qualification also helps to standardize skill levels in a given job category. Without testing and qualification, it is possible that some RAB staff members were inadequately prepared for certain tasks, particularly those performed infrequently, such as those tasks that are the least likely to be mastered through OJT because of their infrequent occurrence.

4.2 Organizational Practices and Policies

Effective organizational policies and procedures support the safe delivery of RAB by establishing goals for the organization, determining what must be done in order to achieve the goals, selecting and motivating the staff to

work toward those goals, and monitoring and directing progress toward those goals (Luthans, 1989; Paté-Cornell, 1990; Schultz and Schultz, 1986; Steers and Porter, 1987). Organizational support of RAB ensures that needed workspaces, resources, equipment, and training are made available, and that procedures have been designed to perform tasks, link them together, and verify that they have been performed. The extent to which these needs are met contributes significantly to the functioning of a health care organization (Beckhard, 1972; Rubin and Beckhard, 1972).

The makeup of radiation therapy and radiation oncology staff varied from site to site but included physicians (radiation oncologists), nurses, medical physicists, radiation therapy technologists (also known as radiation therapists), dosimetrists, engineers, and clerical support personnel. Other important personnel components of the RAB system included hospital departments which were served by or which served the radiation oncology department. Personnel components important to RAB outside the medical facility included vendor personnel involved in training and engineering support.

Eight organizational functions were identified by the organizational analysis conducted during the project. The functions were establish goals; determine tasks; acquire resources; design procedures; allocate tasks and resources; communicate goals, procedures, and information; monitor progress toward goals; and direct progress toward goals.

4.2.1 Establish Goals

All sites appeared to have considered basic safety, service, and production goals for RAB; however, most lacked a clear definition of what the RAB system was expected to accomplish, how it would be done, and who would do it. Basic guidance using established goals serves as the framework for an effective organizational support structure.

4.2.2 Determine Tasks

Documentation of the RAB tasks and approved procedures for performing them were discovered at fewer than half of the sites visited. Only a few administrative tasks had been explicitly defined or documented, and many sites failed to perform all of the organizational functions. Clarification of tasks and establishment of approved performance procedures would contribute greatly to elimination of ambiguity and reduction of potential error in RAB performance.

4.2.3 Acquire Resources

RAB capabilities usually were acquired without a plan to integrate the acquisition process. Such a plan should be based on function and task performance requirements. Staff frequently shared resources with other radiology departments within the organization, and workspaces often were adapted from those designed for other purposes. As RAB becomes more widely used, many of these shortcomings will be alleviated. RAB staffs were concerned with resource limitations and were resourceful in overcoming problems.

4.2.4 Design Procedures

All sites had developed procedures for some tasks, although for the most part the procedure design function was informal and undocumented. Effective procedure design should incorporate regular, systematic review and modification of procedures and regular indoctrination and training in their use.

4.2.5 Allocate Tasks and Resources

There was great variability in task and resource allocation among the sites visited. RAB was usually performed by small, specialized teams within radiation therapy organizations. Task and resource allocation depended upon the size of the site and the number and type of treatments performed.

4.2.6 Communicate Goals, Procedures, and Information

On-the-job training and staff meetings were the primary means for communicating goals and procedures at the sites visited. Other methods included bulletin boards, handbooks, instruction manuals, handouts, and word-of-mouth. Most communication of information among RAB staff was verbal and informal, but continuous and effective, according to comments made during interviews of individual staff members.

4.2.7 Monitor Progress Toward Goals

No formal system for comparing progress with RAB goals was found. Monitoring the efficiency of service and staff performance was usually done informally and continuously. Supervisors conducted formal staff evaluations at most sites, but staff evaluations often did not include RAB performance, because they were designed by evaluators who lacked the necessary RAB expertise. Often,

neither administrators nor staff had a clear idea of the evaluation criteria.

4.2.8 Direct Progress Toward Goals

Many sites welcomed employee participation in decision making regarding general (e.g., division of labor) as well as specific (e.g., selection of equipment) decisions affecting RAB. This form of participatory decision making was less frequent at large institutions, particularly the large universities, than at small clinics.

4.3 Conclusions

For almost three decades, there has existed in the training community a generalized model for training systems, referred to as an instructional system design (ISD) or systems approach to training (Gagne, Briggs, and Wager, 1988; Glaser and Bassok, 1989; Kaufman, Corrigan, and Nunnally, 1966). The model identifies critical steps that must be taken to ensure effective training. A variation of that model is shown in Figure 16. The need for such an approach to the design of RAB training was clearly indicated by this project and adoption of such a model would be of critical value in enhancing RAB performance.

Improved organizational practices and policies would improve performance of all RAB functions and tasks and increase the opportunity for detecting and correcting human errors. They also would provide staff with the information, policies and procedures needed to address the consequences of error in RAB. To reduce the probability of misadministrations, RAB personnel must be well trained, highly qualified, and intimately familiar with practices, procedures, and RAB equipment. RAB staff members must be able to respond to emergencies arising from any aspect of system malfunction. Effective organizational practices and policies contribute to the accurate and reliable performance of RAB tasks and to effective training programs. They are a vital component of a successful RAB system.

Figure 16. A systems approach to training (based on (Gagne, Briggs, and Wager, 1988; Kaufman, Corrigan, and Nunnally, 1966)

5 References

- Beckhard, R., "Organizational Issues in the Team Delivery of Comprehensive Health Care," *Millbank Memorial Fund Quarterly*, 50, 287-316 (1972).
- Erez, M., "Feedback: A Necessary Condition for the Goal Setting—Performance Relationship," *Journal of Applied Psychology*, 62, 624-627, 1977.
- Fleishman, E.A., and M.D. Mountford, "Individual Attributes and Training Performance," In I.L. Goldstein, et al., eds., *Training and Development in Organizations*, Jossey-Bass, San Francisco, CA, 1989.
- Gagne, R.M., L.J. Briggs, and W.W. Wager, *Principles of Instructional System Design* (3rd ed.), Holt, Rinehart, and Winston, Fort Worth, TX, 1988.
- Glaser, R., and M. Bassok, "Learning Theory and the Study of Instruction," *Annual Review of Psychology*, 40, 631-666 (1989).
- Goldstein, I.L., *Training and Development in Organizations*, Jossey-Bass, San Francisco, CA, 1989.
- Harrison, M.I., *Diagnosing Organizations: Methods, Models, and Processes*, Applied Social Research Methods Series, Vol. 8, Sage, Newberry Park, CA, 1987.
- Holding, D.H., "Concepts of Training," In G. Salvendy, ed., *Handbook of Human Factors* (Ch. 8.2), Wiley, New York, 1987.
- Ivancevich, J.M., "Effects of Goal Setting on Performance and Job Satisfaction," *Journal of Applied Psychology*, 61, 605-612 (1976).
- Kaufman, R.A., R.E. Corrigan, and C.L. Nunnally, "The Instructional System Approach to Training," *Human Factors*, 8: 157-162 (1966).
- Latham, G.P., T.R. Mitchell, and D.L. Dossett, "Importance of Participative Goal Setting and Anticipated Rewards on Goal Difficulty and Job Performance," *Journal of Applied Psychology*, 63, 163-171 (1978).
- Luthans, F., *Organizational Behavior* (5th ed.), McGraw-Hill, New York, 1989.
- Paté-Cornell, M.E., "Organizational Aspects of Engineering System Safety: The Case of Offshore Platforms," *Science*, 250, 1210-1217 (1990).
- Phillips, J.J., *Handbook of Training Evaluation and Measurement Methods*, University Associates, San Diego, CA, 1983.
- Rubin, I.M., and R. Beckhard, "Factors Influencing the Effectiveness of Health Care Teams," *Millbank Memorial Fund Quarterly*, 50, 317-335 (1972).
- Schultz, D.P., and S.E. Schultz, *Psychology and Industry Today: An Introduction to Industrial and Organizational Psychology*, MacMillan, New York, 1986.
- Seven, S.A., A. Akman, F.A. Muckler, B.G. Knapp, and D. Bernstein, "Development and Application of Military Intelligence (MI) Job Comparison and Analysis Tool (JCAT)," Research Note 91-41, U.S. Army Research Institute, Alexandria, VA, 1991.
- Steers, R.M., and L.W. Porter, *Motivation and Work Behavior* (4th ed.), McGraw-Hill, New York, 1987.

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC, Add Vol., Supp., Rev.,
and Addendum Numbers, if any.)

NUREG/CR-6125
Vol. 3

2. TITLE AND SUBTITLE

Human Factors Evaluation of Remote Afterloading
Brachytherapy

Supporting Analyses of Human-System Interfaces,
Procedures and Practices, Training and Organizational
Practices and Procedures

3. DATE REPORT PUBLISHED

MONTH

YEAR

July

1995

4. FIN OR GRANT NUMBER

L1116

5. AUTHOR(S)

J. R. Callan, R. T. Kelly, M. L. Quinn, R. A. Moore, F. A. Muckler, J. Kasumovic, J. C. Easterly,
Pacific Science and Engineering Group
W. M. Saunders, R. P. Lepage, E. Chin, University of California at San Diego Medical Center
I. Schoenfeld, D. I. Serig, U.S. Nuclear Regulatory Commission

6. TYPE OF REPORT

Technical

7. PERIOD COVERED (Inclusive Dates)

8. PERFORMING ORGANIZATION — NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Pacific Science & Engineering Group
6310 Greenwich Drive, Suite 200
San Diego, CA 92122-5918

Subcontractor:

Division of Radiation Oncology
University of California at San Diego Med.Ctr.
San Diego, CA 92103

9. SPONSORING ORGANIZATION — NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Division of Systems Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

A human factors project on the use of nuclear by-product material to treat cancer using remotely operated afterloaders was undertaken by the Nuclear Regulatory Commission. The purpose of the project was to identify factors that contribute to human error in the system for remote afterloading brachytherapy (RAB). This report documents the findings from the second, third, fourth, and fifth phases of the project, which involved detailed analyses of four major aspects of the RAB system linked to human error: human-system interfaces; procedures and practices; training practices and policies; and organizational practices and policies, respectively. Findings based on these analyses provided factual and conceptual support for the final phase of this project, which identified factors leading to human error in RAB. The impact of those factors on RAB performance was then evaluated and prioritized in terms of safety significance, and alternative approaches for resolving safety significant problems were identified and evaluated.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

Human Factors
Remote Afterloading Brachytherapy
Human-System Interfaces
Training Practices/Policies
Organizational Practices/Policies
Task Procedures

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page)

Unclassified

(This Report)

Unclassified

15. NUMBER OF PAGES

16. PRICE