Human Factors Evaluation of Remote Afterloading Brachytherapy

Function and Task Analysis

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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 first phase of the project, which involved an extensive function and task analysis of RAB. This analysis identified the functions and tasks in RAB, made preliminary estimates of the likelihood of human error in each task, and determined the skills needed to perform each RAB task. The findings of the function and task analysis served as the foundation for the remainder of the project, which evaluated four major aspects of the RAB system linked to human error: human-system interfaces; procedures and practices; training and qualifications of RAB staff; and organizational practices and policies. At its completion, the project identified and prioritized areas for recommended NRC and industry attention based on all of the evaluations and analyses.

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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 Manual brachytherapy is a version of brachytherapy in which the radioactive sources are inserted and withdrawn manually from the treatment area of the patient's body.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.

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 errors 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 tasks: (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 policies and practices, 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 function and task analysis of RAB. The results of tasks 2–5 are presented in Volume 3, and the results of task 6 are presented in Volume 1.

The function and task analysis included an analysis of errors to identify actual and potential sources of human error in RAB systems. Brachytherapy treatment misadministration data from NRC reports, and radiation device failure data from the Food and Drug Administration (FDA) were analyzed. The effects of distraction and mental workload also were assessed to aid interpretation of the results of the error analysis.

Also included with the function and task analysis was a skills assessment that identified the physical and cognitive demands placed on medical staff while performing each RAB task. This assessment provided a comprehensive inventory of the skills needed to perform RAB.

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

The function and task analysis effort involved visits to two major North American distributors of RAB devices to gain familiarity with hardware, software, and manufacturer's training associated with RAB, and to seven medical facilities to gather information for the function and task analyses. A typical medical facility visit involved 2–3 project team members for 2–3 days.

Executive Summary

A comprehensive data collection procedure was used to gather the following information from each facility:

- documentation supplied by the manufacturers and distributors of the remote afterloaders, including operating manuals, equipment specifications, training manuals, and journal articles
- data from individual interviews with members of the brachytherapy staff (e.g., department chairperson, radiation oncologists, medical physicists, radiation therapy technologists, and dosimetrists) to establish their roles, responsibilities, familiarity with various tasks and functions, as well as their training background in RAB
- data from direct observation and recording (video and audio) of various RAB tasks while they were being performed or demonstrated

A set of questionnaires was developed specifically to facilitate interviews and gather information about the characteristics of each facility (e.g., staff, caseload, equipment used, training, organizational policies and practices, and procedures used during RAB). All information was analyzed to construct a coherent picture of RAB systems and the factors that might influence human error in these systems.

Function and Task Analysis

Function and task analysis, a traditional analytic tool in human factors evaluation, provided the basis for obtaining detailed descriptions of RAB. Tasks are basic units of work and system operation, and functions are unified collections of tasks. Tasks also are collections of smaller units of work, variously called steps or subtasks. Traditional task analysis describes and analyzes performance demands made on persons who interact with a system in terms of physical and cognitive factors such as information input, output, and feedback. All of these aspects of functions and tasks were collected for RAB.

Specifically, the function and task analysis characterized RAB in terms of the following data:

- Task and step sequence
- RAB system used
- Equipment arrangement
- Task performers and supervisors
- Equipment used
- Task performance time
- Input requirements
- Task output
- System feedback
- Possible errors and error likelihood
- Staff workload assessment
- Distraction levels and effects
- Skills required

Error Analysis

An error analysis was conducted after function and task sequences were identified by the function and task analysis. The error analysis included analysis of brachytherapy treatment misadministration data from NRC reports, radiation device failure data from the FDA problem reporting program, error likelihood estimates by RAB staff, and distraction and workload information developed from on-site measurements and interviews.

Skills Assessment

The skills assessment identified the skills needed to perform RAB functions and tasks. Information was gathered through observation of the operation and maintenance of the RAB system and through interviews with brachytherapy personnel. In addition, a structured job analysis instrument supplemented the observation and interview data. This instrument features a set of 50 abilities and skills that are needed to perform many types of work-related tasks and subtasks. Cognitive, perceptual, and motor abilities and skills needed for RAB tasks were identified by using flow charts supplied with this instrument to select the relevant subset from the 50-member set. Next, the amount of each ability and skill needed to perform RAB tasks was determined by applying an annotated rating scale to each ability and skill. This procedure yielded a highly reliable estimate of the abilities and skills needed to perform RAB tasks.

Results

Function and Task Analysis

The function and task analysis identified and characterized five major functions of RAB: (1) Patient Preparation, (2) Treatment Planning, (3) Treatment Delivery, (4) Post-Treatment, and (5) Quality Assurance and Maintenance. Quality assurance and maintenance activities are performed in conjunction with other functions but were combined for analytic purposes into one category. Each of the five functions was then broken down into the tasks that must be performed to satisfy the requirements of that function. A total of 27 tasks was thus obtained. Each task was further broken down into a series of steps.

Other functions of the RAB system include clinical evaluation, therapeutic decision making, and follow-up evaluation. These medical functions were beyond the scope of this project and were not assessed.

Error Analysis

The analysis of NRC and FDA reports identified tasks that were examined more carefully for potential sources of error. For the most part, these tasks were within the treatment planning and treatment delivery functions. The findings of the misadministration analysis were supported by the error likelihood estimates obtained during the site visits. Brachytherapy personnel cited treatment planning as the most difficult function, rated it highest in workload characteristics—time pressure, mental effort, and stress—and reported that they were most susceptible to distraction during treatment planning. RAB subject matter experts also rated treatment planning tasks with the greatest number of medium and high error likelihood scores.

Skills Assessment

The 27 tasks in RAB involve 19 of the skills identified in a standard skills assessment instrument. Eight of the 19 apply to only a single task; therefore, 11 skills are needed to perform most tasks in RAB. The skills assessment confirmed the importance of cognitive skills in RAB. In particular, Problem Sensitivity and Information Ordering are by far the most needed skills. Problem Sensitivity is the ability to detect and foresee problems and patterns of problems, and Information Ordering is the ability to follow explicit rules in order to perform actions in a particular order. Information Ordering is an important skill because RAB tasks are performed in a highly structured, sequential manner. Treatment planning possesses the most demanding skill requirements of all RAB functions. More skills were needed to successfully perform the various treatment planning tasks than were needed in any other function. Most of the skills comprised cognitive components that reflected requirements for extensive mental activity on the part of RAB personnel.

Conclusion

The information obtained from the function and task analyses provided the framework for accomplishing the project's goals. It guided subsequent evaluations by systematically laying out the information and behavior required to accomplish RAB so that analytical efforts could focus on factors influencing user performance at each point in the process and identify the degree to which the system facilitates or hinders the user. The potential influence of various types of factors on task performance were addressed specifically in the follow-on evaluations of (1) human-system interfaces, (2) procedures and practices, (3) training and qualifications, and (4) organizational factors in RAB and to guide the collection and assessment of information necessary to identify factors contributing to human error in RAB systems.

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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.

1 Introduction

Brachytherapy (Greek *brachy*, short) is a cancer treatment process that uses radioactive materials (sources) to retard or destroy tumors with ionizing radiation. Depending upon the area to be treated, radioactive sources are placed within a body cavity adjacent to tissue to be exposed (intracavitary) or directly into a tumor or surrounding tissue (interstitial). Most brachytherapy sources are intended to be removed after the treatment area has received a prescribed dose of radiation; however, a few rapidly decaying sources are intended to remain indefinitely.

Several approaches for implanting and removing brachytherapy sources have evolved over the years. In manual brachytherapy, sources are inserted and withdrawn manually from the treatment location on the patient. Remote afterloading brachytherapy (RAB) is a refined version of this process in which a computerized control unit remotely inserts and withdraws sources from tumor locations. The term "afterloading" refers to source placement techniques and tools that are designed to minimize staff radiation exposure.

Manual brachytherapy originated in the early 1900s, shortly after the discovery of radium. In its earliest applications, radium was placed directly into the tissue to be treated. Subsequently, treatment versions were developed using lower activity and shorter lived isotopes such as gold and cesium. More refined forms of manual brachytherapy then were developed in which the various radionuclides were loaded into prepositioned applicators. This approach, termed manual afterloading, reduced the radiation exposure of medical personnel during brachytherapy procedures. Nevertheless, there remains some occupational exposure to radiation during the manual loading and removal of sources and during nursing care.

RAB was developed in Europe during the 1960s and introduced to the United States 10–15 years later. In RAB, a remotely controlled device inserts and withdraws the sources from receptacles (applicators) that have been placed in a patient (Sauer, 1991; Interstitial Collaborative Working Group, 1990). RAB provided a greater degree of safety for medical and staff personnel by shielding them from the treatment area. This report addresses RAB only.

Two types of RAB are currently practiced in the United States: high dose rate (HDR) and low dose rate (LDR). HDR uses a high activity (nominally 10 curies) source such as iridium-192 (^{192}Ir) to deliver a therapeutic absorbed dose of 500–1000 centiGray in 5–10 minutes. HDR treatments can be conducted on an outpatient basis due to their short treatment times. 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.

LDR uses lower activity sources consisting of cesium-137 pellets (^{137}Cs) or iridium wire of a few hundred milliCuries of activity, depending on the number of pellets or length of wire chosen. Low dose rate treatments are conducted using inpatient procedures that duplicate manual afterloading treatment times (about 2–3 days). LDR treatment is similar to manual afterloading with the addition of an automated delivery system.

The Nuclear Regulatory Commission (NRC) reviews reports and investigates events related to the medical use of by-product materials. These reports and investigations indicate that therapy misadministrations in RAB have resulted from human error. A brachytherapy misadministration means the administration of a brachytherapy radiation dose:

- (1) involving the wrong patient, wrong radioisotope, or wrong treatment site (excluding, for permanent implants, seeds that were implanted in the correct site but migrated outside the treatment site),
- (2) involving a sealed source that is leaking,
- (3) when, for a temporary implant, one or more sealed sources are not removed upon completion of the procedure, or
- (4) when the calculated administered dose differs from the prescribed dose by more than 20 percent of the prescribed dose (U.S. Nuclear Regulatory Commission, January 1994).

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

The project objectives were to

- Identify factors (root causes) that 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 tasks:

- (1) function and task analysis
- (2) evaluation of human-system interfaces
- (3) evaluation of RAB procedures and practices
- (4) evaluation of training and qualifications
- (5) evaluation of organizational policies and practices
- (6) identification and prioritization of human error in RAB and alternative approaches for improving error prevention, detection, correction, and damage control

This report presents the results of the first part of the project and documents the results of the extensive function and task analysis of RAB. In addition to the function and task analysis, an error analysis of RAB functions and tasks was conducted. This included a review of brachytherapy treatment misadministration data from NRC reports, and radiation device failure data from the Food and Drug Administration (FDA). The error analysis also documented actual and potential sources of human error in RAB and manual brachytherapy systems with supporting information on workplace distractors and staff assessment of RAB workload developed from on-site measurements and interviews. A skills assessment also was conducted to identify the physical, cognitive, and perceptual skills needed to perform each RAB task. The results of tasks 2-5 above are documented in Volume 3 and the results of task 6 are presented in Volume 1.

The research was conducted by a multi-disciplinary team consisting of scientists who are experienced in applying human factors principles to medical system evaluation and design. In addition, a Chief of Radiation Oncology, two medical physicists, and a chief dosimetrist served as RAB subject matter experts.

1.1 A Systematic Approach to Human Factors Evaluation of RAB

Remote afterloading brachytherapy is a complex system in which human error contributes to misadministrations. The human factors discipline offers an approach for systematic evaluation of human-machine systems to identify potential human errors and their consequences. This systematic approach, described in the following subsections, includes evaluation of human-machine interfaces, procedures and practices, training and qualifications, and organizational policies and practices.

1.1.1 Function and Task Analysis

A function and task analysis serves the following important objectives in evaluating a system:

- It identifies the system's purpose and other important goals.
- It identifies functions required to satisfy the system's purpose and goals.
- It identifies tasks and steps necessary for users to accomplish their roles with respect to the system functions.
- It analyzes tasks and steps for the performance requirements placed on the users.

1.1.2 Human-System Interfaces

The human-system interface evaluation is based on the RAB function and task analysis and on recognized human factors engineering standards and guidelines. It identifies strengths and weaknesses of the RAB interfaces:

- Equipment
 - Simulation
 - Treatment Planning Systems
 - HDR and LDR Afterloaders
 - HDR and LDR Control Units
 - Auxiliary Equipment
- Software
 - Treatment Planning Software
 - Treatment Control Software
- Documents
 - User Manuals
 - Local Procedures
 - Forms and Checklists
- Workspaces
 - Simulation
 - Treatment Planning
 - Treatment Delivery
 - Treatment Control and Monitoring

1.1.3 Procedures and Practices

The terms "procedure" and "practice" have various meanings in task analysis, medicine, and training contexts but are assigned particular definitions for the purposes of this study. Procedures are defined as any ordered sequence of tasks or steps that has been designed and approved by local authority to serve a purpose in RAB. Practices are defined as any ordered sequence of tasks or steps used repeatedly for a purpose. Procedures must be documented

in a form that permits their use as a reference for task performers and allows deviations from the approved sequence to be detected. Practices may differ among individuals and may or may not conform to an approved sequence. The objective of this evaluation is to identify and examine in detail the effectiveness and quality of procedures and practices as they affect human performance.

1.1.4 Training and Qualifications

A training and qualifications evaluation provides an assessment of how training and qualifications should support the human performance requirements of the RAB system. It also provides an assessment of the current levels of training and qualification of the staff and of the training materials and programs available for those personnel.

1.1.5 Organizational Policies and Practices

An organizational policies and practices evaluation involves identification of organizational factors, functions, and tasks that influence human performance with respect to RAB system requirements.

1.1.6 Identification and Prioritization of Human Error in RAB

This refers to functions, tasks, and steps that, due to shortcomings in human-machine interfaces, procedures and practices, training and qualifications, and organizational policies may not be performed adequately to assure satisfaction of the system's goals. The likelihood and consequences of various problems and the evaluation of alternatives for resolving safety significant problems also were addressed.

1.2 The RAB System

RAB is the product of a complex system comprising a number of components that must function in a coordinated manner. These components include facilities, functions, personnel, and associated equipment.

1.2.1 RAB Facilities

Most RAB facilities are located within the radiation therapy or radiation oncology departments of major hospitals and clinics. RAB facilities include HDR treatment rooms, LDR treatment rooms, treatment planning areas, simulator rooms, and various waiting rooms, nurses stations, and storage and office areas. HDR and LDR treatment rooms and the treatment planning area are briefly described below.

1.2.1.1 HDR Treatment Suite

Figure 1 shows a representative, dedicated HDR brachytherapy suite. This floor-plan incorporates the essential treatment planning and treatment delivery facilities used in HDR RAB. Treatment planning and treatment delivery facilities may not necessarily be co-located; for illustrative purposes, however, they are shown adjacent in the figure.

The remote afterloader unit is positioned next to the patient, who usually is in a wheelchair or on a treatment table. The height of the afterloader's source head can be adjusted to aid in connecting the source guide tubes to the applicators that have been placed in the patient. Closed circuit TV cameras can be oriented to include both the patient and the external radiation sensor display in their field of view. This enables the brachytherapy staff to observe the patient during the treatment session as well as to check for the presence of radiation before entering the treatment room. The emergency storage container is positioned close to the afterloader to expedite emergency shielding of the source.

The afterloader control console is located outside the treatment room along with a closed circuit TV monitor and controls to manually abort a treatment session should the need arise. Treatment planning facilities are located in a separate room.

Appendix A describes RAB systems commonly used in the United States as of the beginning of this study. At that time, two major companies—Nucletron and GammaMed—manufactured the majority of remote afterloaders used in Western Europe and North America. The Nucletron corporation is located in the Netherlands and GammaMed is located in Germany. Both Nucletron and GammaMed manufacture HDR treatment planning and treatment delivery systems. Nucletron also manufactures LDR treatment delivery systems.

A third company, Omnitron, introduced an HDR RAB device at about the time this study began. Omnitron devices were excluded from this study because of their limited distribution and experience for the purposes of the study's data collection phases.

The Nucletron treatment planning computer is separate from the Nucletron afterloader control console, whereas the GammaMed 12i treatment planning and delivery systems use the same computer, monitor, and printer. Hence, no separate treatment planning area is required. The

Figure 1. Floor-plan of a representative HDR brachytherapy suite

GammaMed Ili afterloader requires a third party treatment planning system that also may be used as the planning system for other radiation therapy treatments. Figure 1 is therefore appropriate for RAB systems in most installations.

High dose rate RAB facilities are often co-located with teletherapy equipment in a remote area of the hospital, usually a basement or isolated ground floor location. This provides distance and shielding as means for controlling personnel exposure to radiation. In cases where the RAB device is co-located with a teletherapy device, the teletherapy device occupies a fixed location within the room and the brachytherapy device is rolled into position when needed. Otherwise, the HDR facility is generally the same as shown in Figure 1. The patient usually must be transported to the RAB suite from other areas of the hospital where the applicators have been installed and simulation with dummy sources has been performed.

1.2.1.2 LDR Treatment Suite

Figure 2 shows a representative treatment suite for LDR RAB. The treatment room is usually a conventional

hospital room that has been converted for radiation treatment through the addition of shielding, radiation monitors, closed circuit TV, and intercoms. The remote control console outside the treatment room is used to start and interrupt treatment sessions, communicate with the patient, and monitor the status of the afterloader unit. Appendix A provides more detail about the LDR treatment delivery systems and their associated treatment planning systems.

1.2.2 RAB Functions and Associated Equipment

The functions necessary to accomplish RAB include

- Clinical evaluation and therapeutic decision making
- Patient preparation
- Treatment planning
- Treatment delivery
- Post-treatment
- Quality assurance and maintenance

Figure 2. Floor-plan of a representative LDR brachytherapy suite

Clinical evaluation and therapeutic decision making were beyond the scope of this study. The other functions and their associated equipment are summarized in a generic way below.

1.2.2.1 Patient Preparation

Patient preparation for RAB includes patient scheduling, tracking, identification and instruction. Equipment set-up, life support attachment, and other tasks also may be performed at the same time as patient preparation. Checks and calibrations of the RAB system for treatment readiness are addressed under QA and Maintenance.

1.2.2.2 Treatment Planning

Treatment planning is the process whereby the dose distribution specified by the radiation oncologist's prescription is operationalized. The process involves determining appropriate dwell positions and times for the sources relative to the patient's treatment area. In order for a treatment plan to be implemented successfully, the

position of applicators must be accurately determined relative to the cancer tissue and other anatomy.

Treatment simulation is the part of treatment planning that determines the location of applicators and sources relative to the cancer tissue. Treatment simulation is performed using an x-ray machine and simulated sources made of inert, radio-opaque material such as lead. The simulated sources are inserted into the applicators that have been prepositioned in the patient.

X-ray images are then taken and the actual position of the simulated sources is evaluated relative to the desired position. If necessary, the sources, applicators are repositioned, and another set of x-ray films is made. This process continues until the applicators are in the desired treatment location.

The treatment planning computer and its peripheral devices (e.g., printer, plotter) are used to generate a treatment plan which is then programmed into the afterloader control computer. Specially designed software is used to determine the dwell positions and dwell times for the sources. Coordinate points related to patient anatomy and the tumor

are entered into the planning program from simulation x-ray images. The output of treatment planning is in the form of recommended positions and dwell times for the various sources used in brachytherapy. Results are displayed on a printer or a plotter. These computer print-outs serve as records of the treatment planning session.

Treatment planning computers are produced by various companies in the U.S. and abroad, including RAB manufacturers. The computers are versions of general purpose micro and minicomputers specialized for the analysis of radiation activity, dose, decay, distribution in tissue, and optimization. Most treatment planning systems can be used for manual brachytherapy and teletherapy as well as RAB.

1.2.2.3 Treatment Delivery

RAB treatment delivery is accomplished by remotely positioning the source(s) within the tissue to be irradiated for the prescribed period of time. The sources are automatically removed to a safe repository upon command from the control console following treatment. Sources also may be restored temporarily to safe storage during periods of interruption such as when staff must be in the treatment delivery area. Remote afterloaders perform all of these source transport functions.

HDR afterloaders move their radioactive source mechanically by means of a steel cable or wire attached to a precision stepping motor. All current HDR remote afterloaders use a single source composed of iridium-192 with a nominal activity of 10 Curies (Ci).

In the majority of HDRs, the source is implanted in a metal capsule about 1 millimeter in diameter and about 5 millimeters in length. One model of HDR incorporated the source into the end of the wire by which it is projected. To achieve precise dose distribution, the source can be held stationary at precise, specified, treatment positions for a variable length of time, typically only a few minutes. Two models of HDR afterloaders are shown in Figure 3.

LDR afterloaders use source trains of cesium-137 in 10–40 millicurie (mCi) pellets or iridium in ribbon assemblies of 1–2 mCi seeds. Low dose rate sources are assembled according to the prescribed dose distribution and held stationary during a prolonged (2–3 day) treatment session. The LDR remote afterloaders move iridium elements or cesium pellets using either pneumatic or mechanical power or a combination of the two. One model of LDR afterloader is shown in Figure 3.

The movement of the source between the afterloader and the patient is controlled by the afterloader control console.

For HDR afterloaders, this console is located adjacent to the treatment suite; for LDR afterloaders, it is integrated into the afterloader console. The treatment plan is entered into the treatment delivery computer at this console. The treatment session is monitored and can be interrupted or terminated at the console or, in some cases, at another remote station. Status indicators convey the condition of the afterloading system during a treatment session. Figure 1 shows the location of the HDR control console in the vicinity of the HDR treatment delivery suite.

Catheters and applicators are transport and container devices that are placed in the patient in the desired proximity to the tissue to be treated. They are used to guide movement and ensure the proper positioning of the radioactive source(s). Catheters are flexible tubes through which the source passes to reach the tumor, while applicators are usually rigid to conform to the patient's anatomy and to deliver standardized treatment patterns. Multiple catheters can be used to generate complex dose distributions that may be needed to treat particular tumors.

Source guide tubes connect the treatment channels of the afterloader to the catheters and applicators that have been placed in a patient. It is important to ensure that the correct afterloader channel is connected to its correct catheter or applicator. Manufacturers and RAB staff often use mechanical interlocks and labeling to prevent source guide tubes from being connected to the wrong channel.

All remote afterloaders have multiple safeguards for protecting patient and staff from unintended radiation exposure. These include (1) a door interlock that returns the source to a shielded position when the door to the treatment suite is opened; (2) automatic source return by a battery operated source transport system, such as in the event of a power failure; and (3) a manually operated crank to return the sources to the afterloader should primary and backup power fail. Although they vary in details, all afterloader control consoles have an alphanumeric display, a numeric keypad for entering treatment plan parameters, indicator lights showing what mode the afterloader has entered, and a keyswitch for restricting access to afterloader functions. They also have a printer for generating a permanent, hard copy record of each treatment session. This record includes treatment plan parameters, patient identification data, interruptions of treatment sessions, and error codes.

1.2.2.4 Post-Treatment

The Post-Treatment function includes preparing the patient for discharge or resumption of routine nursing care. The source guide tubes are disconnected and the applicators removed. The patient may be transported to a recovery room, allowing them time to recover from the treatment session and the effects of medication. Treatment data are

Nucletron® MicroSelectron Low Dose Afterloader with Source Storage Container

Nucletron® MicroSelectron
High Dose Afterloader

Nucletron® Selectron
Low Dose Afterloader

GammaMed® 12i
High Dose Afterloader

Figure 3. Nucletron and GammaMed remote afterloading brachytherapy equipment

printed out so that the staff can determine whether the prescribed radiation dosage was administered to the patient. Patient records are completed, checked for accuracy, and filed.

1.2.2.5 Quality Assurance and Maintenance

Quality assurance and maintenance consists of all activities required to check system operation (1) source exchange, (2) source calibration, (3) equipment and software updates, (4) troubleshooting, and (5) routine quality assurance.

Performance of these tasks helps to assure that treatment sessions are conducted as safely and effectively as possible, for both patients and staff.

Miscellaneous quality assurance appliances are used to determine whether the remote afterloader system is performing according to specifications. Source position accuracy, activity level, and source travel distance are examples of critical factors that must be tested and calibrated. These devices include source position check rulers, calibration chambers, and index rods.

1.2.3 RAB Personnel

Radiation therapy and radiation oncology departments are staffed with specially trained personnel needed for the safe and effective delivery of radiation in therapeutic doses. Staffs vary from place to place but can include 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 include those hospital departments which are served by or which serve the radiation oncology department. Personnel components important to RAB outside the medical facility include vendor personnel involved in training, information and engineering support. Finally, the patient also is an important component of the RAB system.

2 Method

This section describes the methods used to conduct the function and task analyses. It includes gathering information from RAB equipment distributors, selection of medical facilities for site visits, methods for gathering information at selected facilities, development of function and task analyses, and conduct of supporting analyses. The data gathered were used to build the function and task analytic descriptions of RAB systems and to identify factors that influence human performance in these systems.

2.1 Sites Visited for Data Collection

2.1.1 RAB Equipment Distributors

At the beginning of this study, there were two distributors of the majority of remote afterloaders in the U.S. Both distributors were visited to obtain information essential to understanding RAB systems in the U.S.

2.1.2 Medical Facilities

Seven medical facilities were visited during the function and task analysis phase. These included free standing hospitals and clinics, university affiliated hospitals and clinics, health maintenance organizations, and Veteran's Administration hospitals. Since not all medical facilities that conduct RAB could be visited, a representative sample was identified. A stratified random sampling plan (Cochran, 1977; Kish, 1965) was employed to select medical facilities for visits. Stratified sampling involves dividing the population into groups that are defined by various criteria. A random sample is then chosen from each group. Stratified sampling is very useful when, as in the present case, several characteristics of the individual population members are known before data collection begins. The selection criteria chosen to permit a representative assessment of RAB as currently practiced in the U.S. were geographic region, afterloader manufacturer, afterloader type, licensing authority, and caseload.

2.1.2.1 Geographic Region

One objective of this project was to obtain a geographically balanced sample of medical facilities. Figure 4 shows the geographic distribution of RAB equipment in use in the U.S. at the beginning of this project. RAB is practiced in most major geographic regions of the U.S.; therefore, any regional differences in the types of RAB equipment, staffing, or practices could be identified and evaluated. The medical facilities visited were distributed across the U.S. corresponding to the distribution of all RAB facilities as shown in Figure 4.

2.1.2.2 Afterloader Manufacturer

Different afterloading systems can impose different sets of demands on RAB personnel. To examine this possibility systematically, site visits included six hospitals using Nucletron afterloaders and one hospital using a GammaMed afterloader. This proportion of Nucletron to GammaMed sites reflects the relative number of afterloaders of each brand in use at the start of this study.

2.1.2.3 Afterloader Type

As described in the introduction, there are two basic afterloader types: high dose rate (HDR) and low dose rate (LDR). There are two models of GammaMed afterloaders in use in the U.S. and both are HDR machines (GammaMed Ili and 12i). There are three models of Nucletron afterloaders in use in the U.S., two are LDR units (Selectron LDR and MicroSelectron LDR), and the third is an HDR unit (MicroSelectron HDR). Of the six medical facilities visited that used Nucletron equipment, four practiced HDR exclusively, one employed LDR exclusively, and one used both HDR and LDR equipment.

2.1.2.4 Licensing Authority

At the beginning of this study, medical use of nuclear by-product material was licensed by the NRC in 22 states. The other 28 states (agreement states) licensed its use under agreements with the NRC. Differences in federal and state licensing requirements and regulations can produce variations in brachytherapy practices. For example, workers belonging to a given personnel category may be able to perform a particular activity in one state, but be prohibited from doing the same thing in another state. Of the seven sites visited, three were in a state regulated by the NRC and four were under state regulation.

2.1.2.5 Caseload

RAB caseload refers to the number of RAB treatments that are delivered. Caseload is an important consideration because it reflects the number of treatments to which RAB staff are exposed. Patients frequently receive more than one RAB treatment; hence, the caseload is greater than the number of patients treated. Caseloads vary from site to site and are a function of the size of the department, its organizational structure, and local variations in clinical practice. Caseloads for facilities visited in this project ranged from 3-21 cases per month.

Figure 4. Remote afterloading brachytherapy equipment installations in the U.S. in 1990

2.2 Data Collection Procedures

Data for the task analysis were collected from the following sources:

- Documentation supplied by the manufacturers and distributors of the remote afterloaders, including operating manuals, equipment specifications, training manuals, and journal articles
- Documentation from the medical facilities, including in-house procedural checklists and quality assurance procedures
- Interviews with afterloader distributors, brachytherapy personnel, and radiation therapy experts on the project team
- Direct observation and recording (video and audio) of various aspects of RAB while they were being performed or demonstrated at each site. The recordings supplied a documented record to analyze RAB functions and case history information.

2.2.1 RAB Equipment Distributors

Site visits to the distributors were conducted to: (1) examine the RAB equipment without restrictions necessitated by the presence of radioactive material, (2) observe equipment operation by manufacturer's representatives, (3) learn about the manufacturer's treatment planning systems and (4) inspect accessory appliances such as applicators, quality assurance devices, source guide tubes and connectors. Information also was gathered about each distributor's RAB training programs, training seminars, maintenance programs, and technical assistance capabilities.

2.2.2 Medical Facilities

Several data collection guidelines and questionnaires were developed specifically for this project. These assisted human factors analysts in gathering information about the characteristics of each facility, including personnel, equipment, training and organizational factors, and

procedures. A typical medical facility visit involved 2-3 project team members for 2-3 days. An individual interview was conducted with each available member of the brachytherapy staff (e.g., department chair, radiation oncologists, nurses, medical physicists, radiation therapists, dosimetrists) to establish their roles, responsibilities, familiarity with various functions, training, and qualifications in brachytherapy. Throughout, emphasis was placed on identifying factors that could lead to human error.

Videotape recordings were made of RAB treatments at the sites visited. Maintenance, calibration, and operation of treatment planning and treatment delivery equipment were recorded. Checklists were used to annotate the functions, tasks, and steps during actual and simulated treatments performed by RAB staff. Measurements of workspaces were made to determine the working area available to RAB staff. Sound level measurements were made within each workspace to establish auditory background and distraction levels. In addition to the physical layout, information was obtained about organizational and administrative structures, training systems, jobs performed by various categories of workers, and quality assurance procedures.

2.3 Function and Task Analysis

The research team's approach to the function and task analysis was to observe and record the performance of all tasks performed by the RAB staff. In addition, those aspects of RAB that could not be observed objectively, or were difficult to obtain otherwise, were assessed through detailed, structured interviews with RAB staff at each site. Interviews supplied valuable anecdotal information about equipment function, policy issues, and how personnel compensate for problematic aspects of their work environment that would have been difficult to obtain otherwise.

To guide the research team's activities prior to medical facility visits, a skeleton function and task listing was developed (1) from the medical research literature, (2) from radiation oncology experts on the project team, and (3) from the visits to RAB equipment distributors. Following each site visit, the team revised the skeleton function and task listing by building, amplifying, and modifying its structure and detail. The final function and task structure and inventory was completed after the seventh site visit.

2.3.1 Function and Task Analysis Components

The following components of the function and task analysis were recorded at each site and used to build the function, task, and step descriptions needed to develop a complete

function and task inventory and to generate a comprehensive understanding of the RAB systems.

2.3.1.1 Function, Task, and Step Sequence

Each function was broken down into the tasks necessary for performance, and each task was further decomposed into the steps necessary for task performance. Sequential relationships among tasks and steps were identified.

2.3.1.2 RAB System Used

The team recorded the details of the equipment used for RAB at each site. Tasks particular to each equipment model and those generic to all RAB equipment were noted.

2.3.1.3 Equipment Arrangement

Video camera recordings were made of RAB space layouts and equipment arrangement so that the human factors team could analyze and compare workspaces, work flow, and assess adequacy of space allocations for work and rest.

2.3.1.4 Performance/Supervision

Job titles of staff assigned to perform each task and of those staff assigned to supervise each task were recorded.

2.3.1.5 Equipment Used

Each item of equipment used to perform a task was recorded and videotaped for subsequent analysis.

2.3.1.6 Performance Time

Times required to perform each task were either measured by stopwatch or obtained from staff interviews. On-site video tape recordings also aided in determining task duration. Minimum, typical, and maximum task performance times were collected to facilitate comparison and assess task performance variability.

2.3.1.7 Task Input Requirements

The information necessary prior to performance of each task step was identified through observation of RAB treatment on site and subsequent analysis of each task.

2.3.1.8 Task Output

The information output of each step of each task was recorded during observation of RAB functions and

operation of RAB equipment. This output contained the information necessary for ongoing functioning in subsequent RAB system processes.

2.3.1.9 System Feedback

System feedback is the designation of system reactions and responses to operator input. Its purpose is to notify users of system status and provide information necessary to monitor RAB status. System feedback was collected during operation of RAB equipment and observation of RAB functions.

2.3.2 Building the Function and Task Inventory

The analysis first established the major system functions of RAB. These functions were arranged in the order in which they are performed. Next, each function was described in terms of the major tasks that must be carried out to satisfy the requirements of that function. Finally, each task was broken down into its component steps, resulting in the completed function and task structure and inventory (Appendix B).

The function and task analysis was tailored to each type of RAB system being analyzed. The human factors team was especially sensitive to differences between HDR and LDR systems and to how functions and tasks were allocated to different individuals and groups at each of the seven facilities visited.

With the permission of the supervising oncologist and—when required—the patient, the research team observed and recorded data during more than ten RAB treatments (cases). The practices and procedures followed by the RAB staff while performing each function were recorded. The team also observed and recorded preparation, equipment maintenance, and calibration activities, before and after treatments, and during four HDR source exchanges.

2.4 Error Analysis

The error analysis was accomplished concurrently with the function and task analysis. It was based on the following information: (1) analysis of misadministration data from NRC and FDA reporting systems, (2) error likelihood estimates by RAB staff, (3) workload information developed from the function and task analysis, and (4) information about potential distractions developed from the function and task analysis.

2.4.1 Misadministration Data

Misadministration and problem data from the following sources were reviewed for error type, brachytherapy type, and function:

- U.S. Nuclear Regulatory Commission, Office for Analysis and Evaluation of Operational Data (NUREG-0090): 1978–1992
- Radiological Health Bulletin, Food and Drug Administration (FDA) Center for Devices and Radiological Health: August 1989–June 1991
- Medical Devices Bulletin, FDA Center for Devices and Radiological Health: August 1989–June 1991
- Medical Device Problem Reporting Program, FDA Center for Devices and Radiological Health: 1984–1990

2.4.2 Error Likelihood Estimates

The errors possible at each task and step of RAB were obtained during performance observation, staff interview, and system walk-through with experts. In addition, the human factors analysts made qualitative estimates of error likelihood at each task step by assigning a score of high, medium, or low to that task step with input provided by RAB staff. After each subsequent site visit, the analysts revised the existing error likelihood assignments for each step, as necessary, based on the most recent feedback.

2.4.3 Workload Analysis

Staff workload was assessed for each function and task using a standard instrument, the Subjective Workload Assessment Technique, which measures three workload-related factors: time pressure, mental effort, and stress (Reid, Shingledecker, and Eggemeier, 1981). This instrument was administered to most RAB personnel at each site. Results were used to highlight functions and tasks that required the most effort, that would most likely be influenced by the potential distractions, and that would be potentially significant sources of error. Each workload factor was rated separately for treatment delivery and treatment planning. The choice of these two functions was made at the recommendation of the RAB consultant staff. A questionnaire was used to obtain ratings on a three-point scale in accordance with established procedures (Reid and Shingledecker, 1981). The scales for each workload factor were as follows:

Time Pressure

- (1) Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

- (2) Occasionally have spare time. Interruptions or overlap among activities occur frequently.
- (3) Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Mental Effort

- (1) Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.
- (2) Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.
- (3) Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

Stress

- (1) Little confusion, risk, frustration, or anxiety exists and can easily be accommodated.
- (2) Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.
- (3) High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

2.4.4 Distraction Analysis

The research team collected information on potential distractions and subjective estimates of workload from RAB staff to identify factors that contribute to errors and to independently validate the functions and tasks with the highest likelihood of error.

Background noise sources, such as intercoms, telephones, machinery noise, traffic noise, and conversational background were noted by the research team. Distraction sources and distraction levels (High, Medium, or Low) were observed and measured during RAB system performance. Each workstation was measured for overall background noise level using a sound level meter. RAB staff supplemented these observations and measurements by describing the effects on job performance, if any, of each of the potential distractors. Interviews with RAB staff at each site also were used to elicit information about other sources of distraction and to obtain qualitative descriptions of the effects of distraction on staff performance.

2.5 Skills Assessment

The completed task analysis furnished a detailed description of the functions and tasks of RAB. Following the task analysis, a structured procedure, the Job Comparison and Analysis Tool (JCAT; Seven, Akman, Muckler, Knapp, and Bernstein, 1991), was employed to determine the cognitive, perceptual, and motor skills needed to perform each task; consequently, it furnishes a comprehensive inventory of the skills required to perform RAB. The JCAT is based on Fleishman's work in task taxonomies (Fleishman and Quaintance, 1984; Fleishman and Mountford, 1989) and has been used successfully in human factors projects similar to this one.

The JCAT assessment includes two major components, decision flow diagrams and a list of 50 skills and abilities. The decision flow diagrams, which are based on the work of Mallamud, Levine, and Fleishman (1980), were used to identify the critical skills required for each brachytherapy function and task. While it does not include every skill needed to perform all work-related tasks, the JCAT provides a set of skills that can be used reliably to discriminate RAB functions and tasks from other work activities.

Three human factors raters from the research team, who were thoroughly familiar with RAB and human factors methodology, independently evaluated each RAB task using the JCAT. Raters referred to the function and task analysis (Appendix B) to ensure that they clearly understood the detailed steps involved in each task. An inter-rater reliability coefficient of 0.89 was obtained for the JCAT ratings. After all tasks had been assessed independently, raters reevaluated those few cases where their ratings differed. By discussing the rationale behind individual ratings, a consensus was reached for all RAB tasks.

This methodology made it possible to identify critical skills for performing RAB without being influenced by local practices or personnel qualification requirements at the medical facilities visited. The results of this assessment are directly relevant to the analysis of staff training and qualifications later in the project.

2.6 RAB Personnel

RAB staff assignments were analyzed at each site to determine the number of persons in each job category and the functions and tasks to which they were assigned and for which they were responsible.

Method

Medical personnel directly involved in RAB fall into the following job categories:

- Radiation Oncologist (Physician)
- Physicist/Medical Physicist
- Dosimetrist
- Radiation Therapist/Technologist
- Oncology Nurse

Radiation oncology staff who had responsibility for any aspect of RAB were interviewed during the site visits. Other medical personnel less directly involved included staff from other hospital services. These personnel were not interviewed during the function and task analysis portion of this project. Table 1 shows the numbers of staff in each RAB job category that were interviewed.

Table 1. Number of RAB Staff Interviewed at Seven Sites by Job Category

Job Category	Total
Physicist	16
RTT ¹	12
Dosimetrist	5
Oncologist	7
Total	40

¹ RTT = Radiation Therapy Technologist

2.7 Caseload Assessment

RAB caseload refers to the number of RAB treatments that are delivered. Caseload data were collected from interview and treatment records at each site. These were analyzed to establish extent of current RAB use. Estimates of future caseload also were elicited from leading oncologists at each site to establish an estimate of the future growth of RAB.

3 Results

This section describes the results of the function and task analysis, the error analysis, and the skills assessment performed as described in the preceding section.

3.1 Function and Task Inventory

The function and task analysis resulted in an inventory of the functions, tasks, and steps required to perform RAB and structured to reflect the sequence of performance. The function and task inventory is summarized in Table 2; the complete function and task analysis is presented in Appendix B. Medical functions such as clinical evaluation, therapeutic decision making, and follow-up evaluations were outside the scope of this study and are not included in the function and task analysis.

Table 2. Function and Task Inventory for RAB

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

3.1.1 Function and Task Descriptions

This section discusses each RAB function in terms of its component tasks. For a complete description of each task, refer to Appendix B which contains the detailed function and task analysis. To understand how individual tasks relate to each other, the function and task descriptions have been supplemented with the flow diagram in Figure 5, which depicts the temporal relationships among RAB functions and tasks.

3.1.1.1 Patient Preparation

Patient Preparation is the function in which a patient is scheduled for an RAB treatment session, receives instruction about the session, undergoes applicator placement, and receives medications. Critical tasks in Patient Preparation include patient identification and the placement and stabilization of the applicators. Patient misidentification, if undetected prior to treatment, results in the administration of a treatment plan that was intended for another patient. Inadequate applicator placement and stabilization can cause the patient to receive a radiation dose that is significantly different from the prescribed dose.

Patient Scheduling, Identification, and Tracking

The first task in patient preparation is scheduling a treatment session and ensuring that the correct patient will be tracked throughout the RAB process. RAB patients may be treated on an outpatient or an inpatient basis. Inpatients are those who have been admitted to the hospital and usually come to radiation oncology from another service, such as surgery, respiration therapy, or gynecology. Outpatients may come directly into radiation oncology or be admitted through a central, outpatient admitting facility. The patient admission process varies among sites and determines subsequent patient transportation, handling, and scheduling procedures.

Patient Instruction

Instructing the patient is an important part of patient preparation to ensure that the patient will facilitate—or at least not interfere with—the treatment. Instruction is especially important for patients undergoing LDR treatments because they involve source implants that must remain stable in place for several days. The medical personnel who perform or monitor each task are expected to instruct the patient about that task.

Clinical Evaluation and Therapeutic Decision Making

* QA and maintenance tasks may also occur as needed at other points in the RAB process.

Figure 5. Flow diagram of temporal relationships between major RAB functions and tasks

Life Support Monitoring

Life support monitoring includes observation of the patient's vital functions such as heart rate and blood pressure. It is necessary principally for those patients who require special care or who may be under medication, such as sedatives, analgesics, anti-anxiety drugs, or local anesthetics.

RAB patients may be sedated because of the invasive and sometimes traumatic nature of the procedure. Sedation during an invasive procedure always requires careful monitoring because it may affect the patient's response to the procedure.

Applicator Placement and Stabilization

Applicator placement is a medical procedure requiring various specialists. For example, lung catheters are positioned by a pulmonary specialist, soft tissue needles by surgeons, and cervical applicators by gynecologists. The operating room procedures, personnel, equipment, and supplies needed to place applicators in a patient are included as part of this function. These procedures can be extensive, depending upon the type, number, and location of applicators.

Patient Transportation

Patient transportation involves moving an RAB patient from one location to another, such as from the operating room to the recovery area, from the recovery area to the simulation room, and from the simulation room to the treatment room. Important steps within this task include locating and identifying the patient, determining the route, transferring the patient from the transportation equipment to the destination equipment, and passing information about the patient to the destination staff.

3.1.1.2 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. These hard copy materials serve as records of the treatment planning session.

Simulation with Dummy Sources

The purpose of treatment simulation is to establish the position of the implanted applicator relative to the target volume prior to treatment and the positions of the sources relative to the applicator. Treatment simulation equipment consists of precision x-ray machines and fluoroscopes. Fluoroscopic images of the target area are taken and the actual position of the applicators is evaluated relative to the desired position. If necessary, applicators are repositioned and another set of fluoroscopic images are made. This process continues until the applicators are in the desired location. Simulation x-rays of the area are then made to enable precise measurement of applicator location for subsequent treatment planning. Radioactive source locations are established by placing dummy sources into the applicators to provide images from which to prepare the treatment plans. In order for a treatment plan to be successfully implemented, the positions of applicators and dummy sources must coincide with the positions subsequently specified by the plan.

Target Volume Localization

Target volume localization defines the anatomical boundaries of the tumor volume that is to be irradiated and the applicators. There are three main parts to this task: reconstructing the location of the applicator(s) on x-ray film, locating specific anatomical points on the x-ray, and digitizing data from the x-ray films into the planning computer. 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. Increasingly, treatment planning computers are being used to construct two or three-dimensional anatomical images for more precise tumor localization.

Radiation Prescription

The radiation oncologist formulates a prescription/treatment directive for radiological therapy using the case history of the patient and information about the tumor and treatment applicator location derived from the simulation x-ray. The referring physician (e.g., a pulmonologist or gynecologist) may also be involved in defining the treatment volume and location parameters. The prescription is made in units of absorbed dose—in rads or Gray (SI units)—to a volume surrounding the applicator. After review and consultation among physicians, the oncologist's final prescription is delivered to the technologist, dosimetrist, or physicist, usually by writing the dose and sketching the treatment area on the simulation x-ray films. These films are used to prepare the treatment plan. Treatment plans may be developed independently

Results

(customized) for the patient, or a standard plan may be drawn from an atlas or file of standard plans.

Variations from site to site occur principally in the method by which the initial prescription is recorded and transmitted to treatment planning personnel. For example, oncologists at some sites record the prescription on the x-ray film while those at others use a locally developed form. Once treatment planning has begun, the treatment planning computer provides a complete record of the dose distributions and, at most sites, these records are signed by the responsible personnel. Another source of variation in this process occurs in patient referral. Radiation oncology patients may arrive from surgery, from bronchoscopy suites, from OB-GYN, etc. Hence, the prescription trail varies, depending upon the referral source and number of physicians involved.

Dwell Position Localization

Dwell position localization involves determining the stopping places for the HDR source along the treatment path as determined by the location of the applicators. In the case of LDR, it involves positioning source trains in applicators that will remain in place for an extended period of time. Typical HDR dwell positions are at either 5 or 2.5 mm between predetermined starting and stopping points. The dwell positions and dwell times determine the overall dose distribution.

Dosimetry

Dosimetry is the task that specifies the prescribed dose at specific anatomical points to provide optimum dosage to the affected tissue. Dosimetry consists of dose specification with prescribed dose values at specific points, mathematical optimization of dwell times, and display of dose distribution, isodose lines, and dwell times. All automated treatment planning systems display the dose distribution isodose lines in two dimensions (x, y) and some provide approximate, three-dimensional images on computer monitors. These displays can be viewed from any anatomical plane specified by the operator.

Treatment Plan Selection and Approval

The final task in treatment planning consists of verifying, reviewing, and approving the treatment plan. Treatment plan parameters are verified by independent calculations, the dose distributions are reviewed once again, and oncologist approval is given, usually by signature accompanying a dose distribution graph or on a table of treatment dwell positions and times. Typically, physicists and dosimetrists participate in this task under the direction of the oncologist.

3.1.1.3 Treatment Delivery

Treatment delivery consists of administering a specified dose distribution to a patient. The interaction of the radiation therapy technologist with the afterloader control console is a crucial aspect of treatment delivery.

Treatment Set-up

Treatment set-up is the first task in treatment delivery. Quality assurance (QA) procedures are conducted to ensure that the afterloader is working correctly, and the treatment room is readied for the patient. QA procedures include testing the operation of the afterloader and checking the stepping distance of the source cable. The afterloader unit is adjusted for height and fixed in position with the braking mechanism. The patients applicators are attached to the appropriate afterloader channels and the source guide tubes are attached to the afterloader. The intercom and video cameras are tested to ensure that the patient can be seen and heard. At most sites the radiation therapy technologists perform these duties under the supervision of a physicist.

Treatment Plan Entry

Entry of the treatment plan into the afterloader control console, is usually done by the physicist or the radiation therapy technologist. Control parameters developed during treatment planning can be entered in several ways: (1) using a memory card, (2) using the keyboard of the afterloader control console, (3) recalling a treatment plan that has been stored in the memory of the afterloader control console, or (4) by direct transfer from the treatment planning system to the treatment delivery system.

Verify Treatment Data Prior to Treatment

Correct entry of treatment data should be verified before treatment is initiated. This involves comparing the dwell position and time data entered into the treatment computer with that provided by the treatment planning computer and with the prescription, identity and diagnosis of the patient. Typically, it takes two people—one to read from the planning data output and another to compare the output with the treatment data input.

Treatment Session Monitoring

Monitoring a treatment session involves monitoring both the patient and the hardware components of the system. Patients are monitored via closed-circuit television and intercom. Low dose rate patients are monitored in their hospital rooms from a nursing station. High dose rate patients are monitored from the afterloader control console

area just outside the treatment room. The afterloader console provides a running account of system status, and the printer supplies a hard copy of each session. Indicator lights alert system operators of conditions that require attention.

Treatment Session Control

The final task in treatment delivery is controlling the treatment session. Usually, the device administers the intended treatment without incident and automatically retracts the source into the afterloader. Should this procedure fail, the afterloader operator can retract the source either by alternative automated means or by manual intervention. A treatment session can also be interrupted or aborted. Interruptions are routine occurrences in LDR treatments where sources are retracted when someone enters the treatment room. They allow the nursing staff to tend to patient needs and visitors to enter the room without danger of exposure to radiation. In contrast, interruptions in HDR treatments occur when an anomalous situation exists. Sessions are aborted when monitoring indicates a serious condition that requires the session to be terminated. Interrupted treatments are distinguished from aborted treatments by the fact that an interrupted treatment may be restarted from point of interruption, whereas aborted treatments necessitate recalculating treatment plan parameters and restarting the treatment session.

3.1.1.4 Post-Treatment

The Post-Treatment function prepares the RAB patients for dismissal or resumption of routine nursing care.

Source Guide Tube Disconnection

In the first task, the source guide tubes are disconnected from the applicators and the source head of the remote afterloader. They are removed to their standard storage locations, usually in the vicinity of the afterloader.

Applicator Removal

Applicator removal from the patient is most often performed by medical personnel, typically physicians and nurses. The equipment is either discarded or sent to be sterilized for reuse.

Patient Transportation

Inpatients are transported back to their hospital room for the resumption of regular nursing care. Outpatients are usually able to leave the medical facility on their own recognizance shortly after the completion of the treatment

session. It may be appropriate to provide outpatients with a post-treatment recovery period prior to discharging them. In this event, they may be transported by wheelchair to a recovery area.

Treatment Verification

Treatment verification is done to detect mistakes that may not have been noticed earlier. All afterloaders deliver a print-out of treatment session parameters along with a running record of events (e.g., interruptions) that occurred during each session. The radiation therapy technologist or physicist verifies that the prescribed radiation dosage was administered to the patient. If discrepancies are detected, they are recorded in the appropriate forms and the prescribing physician is notified.

Record-keeping

Patient and brachytherapy record-keeping involves gathering and collating all treatment planning and treatment session data. These data are placed in patient records, departmental records, and hospital records for storage and future access.

3.1.1.5 Quality Assurance and Maintenance

This function includes the following tasks: (1) source exchange, (2) source calibration, (3) equipment and software updates, (4) troubleshooting, and (5) routine quality assurance. Performance of these tasks helps to assure that treatment sessions are conducted as safely and effectively as possible, for both patients and staff.

Source Exchange

Source exchanges are conducted on HDR systems to maintain source activity to the desired HDR level. They are done about every three months in HDR systems that use iridium-192, because iridium-192 has a half-life of about 74 days. Source exchange is not done in LDR systems that use Cesium, given its 30 year half-life. LDR systems that use iridium ribbons replace the sources before every treatment, because the sources are specially cut to fit the patient for each treatment. Some distributors require that company service representatives perform iridium-192 source exchange in HDR systems. Qualified physicists are permitted to exchange the source for other distributors, although a service representative will be sent if requested.

Source Calibration

Calibration of source strength is done to confirm the activity level of the source as delivered by the

Results

manufacturer. From the calibrated activity at time of delivery, the source is decayed at its decay constant until it is no longer clinically useful and source exchange is needed. Source calibration is performed in both HDR and LDR systems, although it is more common in HDR systems because of the greater frequency of source changes. An ionization chamber that measures the number of disintegrations per second is the most widely used calibration device at the medical facilities visited.

Equipment and Software Updates

Treatment planning and treatment delivery software and accompanying documentation are updated periodically by either the manufacturers of afterloading and treatment planning equipment or by their distributors.

Troubleshooting

Troubleshooting and assistance from the distributor are provided to each facility as requested. Usually, facilities request this in response to an unusual or emergency situation where the correct action is not immediately apparent. Both remote afterloader distributors included in

this study maintain toll-free telephone numbers so that their customers can obtain technical assistance at all times.

Routine Quality Assurance

Routine quality assurance includes several tasks that are performed every time the RAB system is used, e.g., testing system alarms, door interlocks, and emergency responses. Other routine quality assurance checks such as those on patient records, are performed less often, usually on a weekly or monthly basis. Autoradiography of source positioning is a common, daily QA procedure in HDR RAB. To accomplish this, the source guide tube and applicator are positioned on a strip of x-ray film over which the source is programmed to move. The source stopping positions are marked by spots of film exposure that are measured to test stepping distances against manufacturer's specifications.

3.2 Function and Task Duration

Table 3 shows minimum, typical, and maximum time estimates of RAB functions and tasks. Times are given in minutes with the exception of LDR treatment delivery times, which are given in hours.

Table 3. Performance Times for Functions and Tasks

(Time in minutes except where hours indicated)

Function/Task	Performance Time		
	Minimum	Typical	Maximum
I. Patient Preparation			
1. Patient scheduling, identification, and tracking	15	30	45
2. Patient instruction	5	10	30
3. Life support monitoring	10	20	30
4. Applicator placement and stabilization	10	20	40
5. Patient transportation	1	5	15
Total HDR or LDR	41	85	160
II. Treatment Planning			
1. Simulation with dummy sources	15	30	60
2. Target volume localization	10	20	60
3. Radiation prescription	5	10	15
4. Dwell position localization	5	10	15
5. Dosimetry	10	20	60
6. Treatment plan selection and approval	2	5	10
Total HDR or LDR	47	95	220

Table 3. Performance Times for Functions and Tasks (continued)

(Time in minutes except where hours indicated.)

Function/Task	Performance Time		
	Minimum	Typical	Maximum
III. Treatment Delivery			
1. Treatment set-up	10	15	45
2. Treatment plan entry			
Initialize console (HDR)	1	5	10
Initialize console (LDR)	5	10	15
Memory card (HDR)	1	2	5
Manual entry (keyboard/keypad)	5	10	20
Program stored in computer	2	4	10
3. Verify treatment data prior to treatment	5	7	15
4. Treatment session monitoring			
LDR	36 hr	40 hr	48 hr
HDR	10	17	30
5. Treatment session control			
Normal completion (LDR)	5	10	15
Normal completion (HDR)	1	1	2
Interrupt treatment (LDR)	2	5	10
Interrupt treatment (HDR)	1	2	30
Terminate/abort treatment	1	3	15
Total HDR	37	1 hr 6	3 hr 2
Total LDR	36 hr 35	41 hr 4	50 hr 30
IV. Post-Treatment			
1. Source guide tube disconnection	1	5	10
2. Applicator removal	5	10	20
3. Patient transportation	1	5	15
4. Treatment verification	5	8	15
5. Record-keeping	5	8	15
Total HDR or LDR	17	36	1 hr 15
V. Quality Assurance and Maintenance			
1. Source exchange (HDR)	45	60	120
2. Source calibration	30	60	90
3. Equipment and software updates	—	—	—
4. Troubleshooting	5	15	60
5. Routine quality assurance			
Source positioning and timing (HDR)	15	30	60
Source position autoradiography (HDR)	15	30	60
System alarms and interrupts: Warning light	5	10	20
System alarms and interrupts: Door interlock	3	5	10
System alarms and interrupts: Abort	3	5	10
Source guide tube/applicator assembly check	2	5	7
Total HDR	2 hr 3	3 hr 40	7 hr 17
Total LDR	48	1 hr 40	3 hr 17

Results

Depending on the local procedures and job aids used, the training and qualifications of the staff, and the organizational structure, individual medical facilities could differ substantially in the time required to complete RAB tasks. Moreover, it is unlikely that any medical facility would require either the minimum or the maximum time for all tasks. The estimates for each task therefore express the range of time required for completion of that task. Nearly all RAB tasks are self-paced, so that personnel can use whatever time is necessary to complete a task. However, task performers may experience time pressures due to factors extrinsic to the task but intrinsic to the environment in which the task is performed as, for example, when a patient's medical condition requires immediate action, or when several patients are awaiting treatment.

3.3 Error Analysis

The error analysis consisted of two distinct activities: (a) an analysis of the misadministration data that had been reported to the federal government through NRC and FDA reporting programs and (b) a subjective error analysis for RAB functions and tasks conducted during each site visit. Following these analyses, the data were reviewed in light of information collected from on-site interviews with RAB staff concerning the effects of workload factors and distractions on job performance.

3.3.1 Misadministration Data

Table 4 summarizes misadministration and problem data that are relevant to RAB. Errors that occurred in manual brachytherapy have been included whenever the task in which they occurred is a task that is also performed in RAB. The upper section of Table 4 pertains to human error, the lower section to device malfunction or material failure.

3.3.2 Errors in Relation to RAB Tasks

Table 5 maps the human errors listed in the upper section of Table 4 onto RAB tasks. Most of the errors occurred in either treatment planning or treatment delivery. Dose calculation errors in the dosimetry task predominated in treatment planning. Treatment delivery errors occurred most often in three tasks: treatment set-up, treatment plan entry, and treatment session monitoring. A total of 30 brachytherapy misadministrations resulted from these errors.

3.3.3 Error Likelihood Estimates

The results of the subjective error analysis conducted on site are summarized in Table 6. HDR treatment planning is the function associated with the highest likelihood of error,

followed by treatment delivery. These likelihood estimates agree both with the misadministration report data in Tables 4 and 5 and the workload analysis presented in section 3.3.4. The consequence of an uncorrected error in HDR treatment planning is likely to be severe because of the high radiation dosages employed in HDR RAB. It is also less likely to be detected or corrected because of short treatment times.

Treatment delivery errors were most often reported in entry and verification of the treatment plan into the RAB treatment computer and monitoring the treatment session. However, multiple treatments (fractions) can be adjusted to reduce the adverse consequences of a treatment planning or data entry error if the error is detected in time. For example, errors that result in insufficient radiation being administered can be compensated for by increasing the doses in subsequent fractions. Of course, errors involving excessive exposure are more problematic, but can be alleviated by administering lower doses in subsequent fractions. Treatment is sometimes modified as necessary to account for system variation, patient response, or changes in the radiation prescription.

3.3.4 Workload Assessment

Table 7 shows the results of the workload assessment. Within treatment planning and treatment delivery, mental effort was judged to be greater than either time pressure or stress, both of which were rated equally. RAB staff subjectively experience greater workload in treatment planning than in treatment delivery. HDR treatments are associated with slightly higher levels of stress, mental effort, and time pressure than LDR treatments. HDR workload often increases when the patient is in severe discomfort, is sedated, or is attended by other clinical personnel who are anxious to proceed with the brachytherapy session.

Table 8 shows these same data when broken down among three groups of RAB personnel: oncologists, physicists, and radiation therapy technologists. Dosimetrists were combined with radiation therapy technologists to generate a statistically meaningful category and because there often is overlap in their responsibilities.

3.3.5 Distractions

Distractions and potential distractions were observed in all phases of the brachytherapy process. Our observations indicated that they can exert a significant impact on both subjective workload and error likelihood. The crowded conditions and high activity levels of most hospitals intrude to some degree into most clinical activities. Radiation therapy suites are often located in a basement or a remote wing of medical facilities. Nevertheless, intercoms, telephones, public address systems, and foot traffic produced

Table 4. Summary of Brachytherapy Misadministration Data Reported in NUREG-0090 (1978-1992)

Error or Problem	
Human Error by RAB Function (Source: NRC AEOD Annual Reports)	
Patient Preparation	Misidentify patient
Treatment Planning	Poor mapping of target volume to tumor Interpretation of imaging data inaccurate Dose calculation error Fail to independently verify plan
Treatment Delivery	Wrong treatment site Wrong number of sources loaded Wrong activity sources loaded Misenter plan values Fail to verify plan Wrong source placement in applicator Fail to detect dislodged source
Post-Treatment	Fail to account for all sources Fail to maintain adequate records
Quality Assurance and Maintenance	Improper packaging of source Calibration units different Fail to perform radiation survey
Radiation Device Malfunction or Material Failure (Source: FDA Problem Reporting Program)	
Device Malfunction	CPU failure in afterloader control unit Source (^{137}Cs) fell out of applicator
Material Failure	Source (^{137}Cs) fell out of source guide tube Capsule (^{192}Ir) fractured Source (^{125}I) leaking

**Table 5. Distribution of Human Error in Brachytherapy
Misadministrations in Relation to RAB Functions and Tasks**

Function/Task	Number of Misadministrations	Description of Human Error
I. Patient Preparation		
1. Patient scheduling, identification and tracking	1	Misidentify patient
2. Patient instruction	0	
3. Life support monitoring	0	
4. Applicator placement and stabilization	0	
5. Patient transportation	0	
II. Treatment Planning		
1. Simulation with dummy sources	0	
2. Target volume localization	1	Poor mapping of target volume to tumor
3. Radiation prescription	0	
4. Dwell position localization	2	Interpretation of imaging data inaccurate
5. Dosimetry	4	Dose calculation error
6. Treatment plan selection and approval	1	Fail to independently verify plan
III. Treatment Delivery		
1. Treatment set-up	4	Wrong treatment site Wrong number of sources loaded Wrong activity sources loaded
2. Treatment plan entry	4	Misenter plan values Wrong treatment site
3. Verify treatment data prior to treatment	1	Fail to verify plan
4. Treatment session monitoring	5	Wrong source placement in applicator Fail to detect dislodged source
5. Treatment session control	0	
IV. Post-Treatment		
1. Source guide tube disconnection	0	
2. Applicator removal	0	
3. Patient transportation	0	
4. Treatment verification	0	
5. Record-keeping	4	Fail to account for all sources Fail to maintain adequate records
V. Quality Assurance and Maintenance		
1. Source exchange	1	Improper packaging of source
2. Source calibration	1	Calibration units different
3. Equipment and software updates	0	
4. Troubleshooting	0	
5. Routine quality assurance	1	Fail to perform radiation survey
Total	30	

Table 6. Summary of Tasks Judged by RAB Staff to Have the Highest Likelihood of Errors on Subjective Error Analysis

Function/Task	Task Summary	Error Likelihood Ranking*
Treatment Planning		
Target volume localization	Defining the geometry of the area to be irradiated by reconstructing applicator locations and anatomical points. This task is more likely to be a source of error in HDR than in LDR treatments because of the shorter time frame for planning in HDR.	1
Dwell position localization and dosimetry	Selecting source dwell positions in the applicators and a dwell time at each position so that the dose distribution specified in the treatment directive will be generated.	2
Simulation with dummy sources	Taking x-rays of implanted applicator(s) using dummy sources to show applicator position relative to the target volume.	3
Treatment Delivery		
Treatment plan entry	Manually entering a treatment plan (dwell positions and dwell times for each applicator) at the afterloader control console.	4
Treatment set-up	Attachment of source guide tubes to the afterloader and to the applicators, ensuring that each source guide tube is attached to its assigned channel and is fully seated.	5

* 1 = highest, 5 = lowest

distractions and noise at several of the visited sites. The presence of family members, and personnel involved in other radiation oncology activities (e.g., teletherapy) and others not directly involved in RAB also was observed. These persons also were potential distractions to the RAB staff.

In spite of the high activity and competing demands for attention in a radiation oncology setting, brachytherapy personnel reported that their performance was impaired by these factors only during treatment planning. This report was confirmed by on-site observations. Treatment planning requires intense concentration for a period of 10-30 minutes. More time is required for complex cases or when task steps are repeated due to error recovery, independent cross-check, or system failure. Effective treatment planning depends on the execution of a series of sequential, inter-dependent steps. Ideally, treatment planning personnel can construct a plan from start to finish without being

interrupted; however, this may be the exception rather than the rule.

Background activities and distractions were noted by the site visit team during all brachytherapy functions except QA and maintenance. None were regarded as disruptive by RAB staff, except when they occurred during treatment planning. QA and maintenance tasks were accomplished when time permitted, without need for outside clinical staff and were therefore relatively unaffected by background activities.

During HDR treatment delivery, the afterloader computer controls the treatment with monitoring by brachytherapy personnel. The patient is isolated for 15-30 minutes in a shielded treatment room. External signals and other distractions did not appear to impede the staff's ability to monitor the system or the patient during treatment.

Table 7. RAB Staff Judgments of Workload Factors

RAB Type	Treatment Planning			Treatment Delivery			Mean
	Time Pressure	Mental Effort	Stress	Time Pressure	Mental Effort	Stress	
HDR	2.0	2.6	2.1	1.7	2.3	1.8	2.1
LDR	2.0	2.2	1.5	2.0	2.2	1.8	1.9
Mean	2.0	2.5	2.0	1.8	2.3	1.8	

Note: Responses were made using a 3-point rating scale. A score of 1 corresponds to a perceived low level of the workload factor, 2 corresponds to a moderate level, and 3 corresponds to a high level.

Table 8. RAB Staff Judgments of Workload Factors by Job Category

Job Category	Treatment Planning			Treatment Delivery			Mean
	Time Pressure	Mental Effort	Stress	Time Pressure	Mental Effort	Stress	
Oncologists	2.0	2.4	1.8	1.5	1.8	1.5	1.8
Physicists	2.1	2.6	2.2	1.8	2.3	1.9	2.1
Radiation Therapy Technologists	2.0	2.5	1.8	1.9	2.4	1.7	2.1

Note: Staff judgments were made using a 3-point rating scale. A score of 1 corresponds to a low level of the indicated activity or perception, 2 corresponds to a moderate level, and 3 corresponds to a high level.

During the relatively long, 2–3 day period of LDR treatment delivery, staff reported no effects on patient care due to distractions from their monitoring duties.

3.4 Skills Assessment

An important part of evaluating RAB tasks is determining what skills they require. This section presents the results of the skills assessment using the JCAT as described in the method section of this report. Decision flow diagrams were used in conjunction with a list of 50 skills and abilities to identify and characterize the performance requirements for each of the 27 RAB tasks.

The 27 tasks involved 19 of the 50 skills contained in the JCAT. Table 9 presents these 19 skills. Seven of these 19

skills—Selective Attention (#10), Deductive Reasoning (#15), Number Facility (#18), Time Sharing (#19), Speed of Closure (#20), Multi-Limb Coordination (#40), and Static Strength (#46)—applied only to single tasks. Twelve of the 19 skills are needed to perform multiple RAB tasks. Of these 12 skills, only the perceptual-visual and psychomotor skills do not have a significant cognitive aspect.

Figure 6 confirms the importance of cognitive activities in RAB. Conceptual and reasoning are the most widely used skill factors in RAB. Further analysis of the ratings revealed that these skills are required to a similar extent in each brachytherapy function.

Table 9. Skills Required for RAB

Skill Factor	Skill	Percent of RAB Tasks Using Skill
Communication Skills	Oral Comprehension ¹	11.1
	Written Comprehension ¹	14.8
	Oral Expression ¹	22.2
Conceptual Skills ²	Problem Sensitivity ¹	77.8
	Pattern Recognition ¹	7.4
	Selective Attention ³	3.7
	Visualization ¹	22.2
Reasoning Skills ²	Deductive Reasoning ³	3.7
	Information Ordering ¹	70.4
	Number Facility ³	3.7
Speed-Loaded Skills	Time Sharing ³	3.7
	Speed of Closure ³	3.7
	Perceptual Speed & Accuracy ¹	7.4
Perceptual Skills: Vision	Near Vision ¹	11.1
Psychomotor Skills	Finger Dexterity ¹	25.9
	Manual Dexterity ¹	22.2
	Arm-Hand Steadiness ¹	18.5
	Multi-Limb Coordination ³	7.4
Gross Motor Skills	Static Strength ³	7.4

¹ Skill required by multiple RAB tasks

² Most widely used skill factors

³ Skill required by only one RAB task

3.4.1 Skills Needed in RAB

Well developed communication, conceptual, reasoning, and visual motor skills are needed to perform many RAB tasks. Within each of these skill domains, more specific skills were identified by the skills assessment. This fine level analysis furnished a deeper understanding of RAB task demands.

Problem Sensitivity is the ability to detect when something is wrong or about to go wrong with part or all of the system. In the context of RAB, it is the ability to detect and foresee problems and patterns of problems relative to the patient, the treatment plan, or the treatment session itself. RAB normally proceeds in a highly structured, serial manner. An especially relevant skill is Information Ordering, the ability to follow an explicitly stated rule or set of rules in order to perform actions in a specified order.

Both Problem Sensitivity and Information Ordering require considerable competency and experience with brachytherapy tasks (requiring the staff to have a good mental model of the sequence of steps that need to be performed and of what should happen during and after each step).

A more detailed view of these findings is depicted in Table 10, which shows the skills required by each RAB task. (To aid interpretation of these results, the skills are listed in the same order as they appear in Table 9.) Treatment planning tasks require more skills (mean = 4.8 skills per task) than tasks in the other functions, which average about 3 skills per task (Patient Preparation = 3.2; Treatment Delivery = 2.6; Post-Treatment = 3.4; QA & Maintenance = 3.0). These findings on the demanding nature of treatment planning corroborate the findings on error likelihood, mental workload, and distraction effects.

Figure 6. Percent of RAB tasks requiring various skill factors

Other conceptual skills are required during treatment planning. Pattern Recognition (#9), which involves detecting a disguised pattern against a complex background, is important for tasks involving inspection of the x-ray films. These include simulation with dummy sources and target volume localization. In both these tasks, certain anatomical reference points as well as the dummy sources must be detected on the films. Because of the fine detail involved in inspecting and digitizing reference points from the films, these tasks also require Near Vision (#24). Visualization (#12) is another critical skill in treatment planning. Staff must be able to visualize in 3-dimensions applicator placement and isodose distribution from several 2-dimensional x-ray images.

Communication skills such as Written Comprehension and Oral Expression are required at key information transfer points. These include interacting with patients during patient preparation and post-treatment tasks. Another important information transfer occurs during the review and approval of the treatment plan prior to the treatment session.

Psychomotor Skills, particularly Finger Dexterity (#37), Manual Dexterity (#38), and Arm-Hand Steadiness (#39) are required for tasks involving applicator placement or removal, attachment and set-up of various apparatus, calibration and maintenance tasks, simulation, and source exchange. The minor and routine requirements for psychomotor skill involved in operating keyboards and switches were not included in this analysis.

These findings on critical skills were essential during the evaluation of staff qualifications and training to determine to what extent training programs reflect development and support of these skills.

3.5 RAB Personnel

The RAB responsibilities assumed by workers in each job category varied from one medical facility to another. These variations were of interest because they helped determine the interactions that occurred among RAB personnel. Table 11 summarizes the task responsibilities as allocated among brachytherapy staff at the sites visited.

3.6 RAB Caseloads

The medical facilities differed in how their existing caseloads were distributed among treatment types. The main types of cancers being treated with RAB at the hospitals were gynecological (GYN-uterine, cervical, vaginal), throat, lung, brain, breast, and prostate. Table 12 shows that overall there were about 3.5 times more GYN treatments than any other type of treatment. Lung cancer was the second most common form of treatment, with the other types far behind. RAB is predicted to become more prevalent with other cancers as RAB technology becomes more widespread. Table 12 also shows how long each facility has been performing RAB. The range is from 12 months to more than 6 years.

Table 10. Skills Required to Perform Specific RAB Tasks

Function/Task	Skill														
	Oral Comprehension	Written Comprehension	Oral Expression	Problem Sensitivity	Pattern Recognition	Selective Attention	Visualization	Deductive Reasoning	Information Ordering	Number Facility	Time Sharing	Speed of Closure	Perceptual Speed & Accuracy	Near Vision	Finger Dexterity
I. Patient Preparation															
1. Patient scheduling, ID, and tracking	•		•					•							
2. Patient instruction	•		•												
3. Life support monitoring				•				•							•
4. Applicator placement and 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 prior to treatment				•				•				•			
4. Treatment session monitoring				•	•					•					
5. Treatment session control				•				•							
IV. Post-Treatment															
1. Source guide tube disconnection				•										•	•
2. Applicator removal				•										•	•
3. Patient transportation			•												•
4. Treatment verification		•		•				•							
5. Record-keeping		•						•							
V. Quality Assurance and Maintenance															
1. Source exchange				•				•						•	
2. Source calibration				•			•	•							
3. Equipment and software updates	•	•	•					•							
4. Troubleshooting				•				•			•				
5. Routine quality assurance				•				•							

Table 11. Personnel Performing RAB Tasks

Function/Task	Personnel Performing Task
I. Patient Preparation <ol style="list-style-type: none"> 1. Patient scheduling, identification, and tracking 2. Patient instruction 3. Life support monitoring 4. Applicator placement and stabilization 5. Patient transportation 	Nurses, RTTs ¹ , Clerical MDs, Physicists, Nurses, RTTs MDs, Nurses MDs, Nurses, RTTs Nurses, RTTs
II. Treatment Planning <ol style="list-style-type: none"> 1. Simulation with dummy sources 2. Target volume localization 3. Radiation prescription 4. Dwell position localization 5. Dosimetry 6. Treatment plan selection and approval 	MDs, Physicists, RTTs Physicists, Dosimetrists MDs Physicists, Dosimetrists Physicists, Dosimetrists MDs, Physicists, Dosimetrists
III. Treatment Delivery <ol style="list-style-type: none"> 1. Treatment set-up 2. Treatment plan entry 3. Verify treatment data prior to treatment 4. Treatment session monitoring 5. Treatment session control <ul style="list-style-type: none"> Normal completion Temporary interrupt Terminate/abort treatment 	Physicists, RTTs Physicists, Dosimetrists, RTTs MDs, Physicists, Dosimetrists Physicists, Nurses, RTTs, Dosimetrists MDs, Physicists, Nurses, RTTs MDs, Physicists, Nurses, RTTs MDs, Physicists, Dosimetrists, RTTs
IV. Post-Treatment <ol style="list-style-type: none"> 1. Source guide tube disconnection 2. Applicator removal 3. Patient transportation 4. Treatment verification 5. Record-keeping 	MDs, Nurses, RTTs MDs, Nurses, RTTs RTTs, Nurses MDs, Physicists, RTTs MDs, Physicists, Nurses, RTTs
V. Quality Assurance and Maintenance <ol style="list-style-type: none"> 1. Source exchange 2. Source calibration 3. Equipment and software updates 4. Troubleshooting 5. Routine quality assurance <ul style="list-style-type: none"> Source positioning and timing System alarms and interrupts 	Physicists, Service Representatives Physicists Physicists, Dosimetrists, RTTs, Service Reps Physicists, Service Representatives, RTTs Physicists, RTTs Physicists, RTTs

¹ RTT = Radiation Therapy Technologist

Table 12. Monthly RAB Caseloads (cases/month)

Treatment Type	1	2	3	Site 4	5	6	7	Mean
GYN	4.3	1.1	3.3	12.5	0.1	21.6	10.0	7.6
Nose/Throat	0	0.1	1.9	1.7	0.1	0	1.7	0.8
Lung	4.3	1.4	4.4	0.1	0	4.3	0	2.1
Soft Tissue	0	0	0	2.5	3.9	0	0.1	0.9
Other	2.0	0.3	0	0	0.1	0.1	0	0.4
All	10.6	2.9	9.6	16.8	4.2	26.0	11.8	11.8
Months since RAB first used	17	12	27	32 (LDR)	30	5 (HDR) 77 (LDR)	23

Figure 7. Relationship between caseload and time since installation of the first RAB source

Two factors contribute to a measure of growth and extent of RAB use. The first is the number of RAB installations, and the second is the number of treatments performed. In order to view potential, future RAB caseload, a regression analysis, summarized in Figure 7, was conducted. The analysis demonstrated a positive, linear relationship between a facility's number of treatments per month and length of time since the first RAB source was installed

(Pearson's $r = 0.79$, $p < .02$). This relationship is consistent with brachytherapy distributors' marketing predictions about the probable growth in RAB. Caseload is greater than the number of patients treated, because most patients receive multiple RAB treatments (fractions). RAB caseload projections suggest that RAB will grow rapidly as a preferred treatment for cancer in the future.

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4 Conclusions and Related Analyses

The information that was collected on RAB and human error in RAB systems facilitated data collection, analysis, and evaluation of the five other parts of the project:

- evaluation of human-system interfaces
- evaluation of operating, emergency, and maintenance procedures and practices
- evaluation of training and qualifications
- evaluation of organizational policies and practices
- prioritization of task performance problems in terms of safety significance and evaluation of alternate approaches for resolving them

The research provided more detail on the critical areas listed above as well as on the variations in policy, procedure, and practice evident in RAB facilities throughout the United States.

4.1 Conclusions

A function and task analysis was conducted that described RAB as a series of mutually dependent activities. It characterized all crucial aspects of RAB in terms of

- (1) the functional flow of events
- (2) equipment required
- (3) potential impact of distraction on performance
- (4) staff required to perform and supervise each function and task
- (5) possible errors and their subjective likelihood of occurrence

The analysis identified functions and tasks that were particularly susceptible to human error. The skills required to perform each task were also identified.

Treatment planning was identified as the most complex, demanding RAB function. Personnel were most subject to distraction during treatment planning, and it was rated highest in workload characteristics. Treatment planning tasks also required about 50 percent more skills, on the average, than did tasks in other functions. The portion of treatment delivery that required manual entry of treatment planning parameters into the afterloader control console was also demanding.

This project also examined RAB for factors that contribute to human error in human-system interfaces, procedures and practices, training and qualifications, and organizational policies and practices. A better understanding of the interactions between equipment, procedures, and personnel

that are necessary for safe and successful RAB has emerged from these efforts.

4.2 Requirements for Related Analyses

The function and task analysis clearly indicated that RAB consists of a complex set of interacting factors. Each of these factors, as well as the relationships among them, were characterized in order to understand the root causes of error in RAB systems. The function and task analysis laid the groundwork for the more detailed series of analyses of human-system interfaces, procedures and practices, training and qualifications, and organizational policies and practices carried out in subsequent parts of the project. These analyses are summarized below and described in detail in Volume 3.

4.2.1 Human-System Interfaces

Human-system interfaces are a major factor in RAB. They include all the devices and appliances that brachytherapy staff use in performing the functions and tasks of RAB. The function and task analysis findings showed that several factors are critical to understanding human-machine interfaces in RAB including

- (1) critical human-machine interfaces in treatment simulation, treatment planning, and treatment delivery
- (2) cognitive and perceptual demands of these interfaces
- (3) environmental variables, including background noise, interference, distractors, and workload demands
- (4) display and control menus, operations, and instructions

Several human-system interface problems were identified during the function and task analysis. Examples are poor stimulus-response compatibility among controls and displays; instruction manuals that are difficult to understand; foreign words on displays and controls; non-standard units of measure; inadequate feedback of system status; and confusing menu and work process structures.

4.2.2 Procedures and Practices

Deviations from established procedures, inadequate procedures, or the lack of procedures can be important clues for detecting potential causes of error in complex systems such as RAB. Three factors have been identified through the function and task analysis as being important:

- (1) content sufficiency of procedural information
- (2) information presentation format

Conclusions

- (3) verification that the procedures are appropriate for the sequence of steps to be performed for each task

- (2) Prioritize errors in terms of safety significance.
- (3) Assist in selection and evaluation of alternative approaches.

4.2.3 Training and Qualifications

The function and task analysis, error analyses, and skills assessment served as the basis for subsequent assessment of availability and suitability of training and staff qualifications at each facility. Issues such as transfer of training, differences training, and quality of instructional materials were considered.

4.2.4 Organizational Policies and Practices

The function and task analysis also guided subsequent evaluation of organizational policies and practices. These policies and practices encompass a wide range of factors, including shift schedules, staffing, supervision, lines of authority, and accountability. Several organizational variables were assessed during the site visits: safety policies and provisions, patterns of communication, decision making, and personnel management practices. These assessments enabled a set of organizational factors to be identified that significantly influence RAB task performance:

- organizational structure
- staff selection criteria
- staff motivation methods
- staff training policies
- staff job satisfaction
- staff performance appraisal methods
- decision making methods
- decision communication methods

Subsequent analysis of these factors provided an improved understanding of the organizational dynamics that affect RAB

4.2.5 Identification, Prioritization and Alternative Approaches

The function and task analysis provided a framework to guide the collection and assessment of data in subsequent phases of the project. The information obtained from the function and task analysis was carried forward and used to

- (1) Identify and evaluate factors contributing to human error.

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Appendix A: Remote Afterloading Brachytherapy Systems Most Commonly Used In the United States (1991-1992)

This appendix summarizes the characteristics of the remote afterloading brachytherapy systems that are most commonly used in the United States and, therefore, those chosen for inclusion in this project. Emphasis is given to characteristics that are most relevant to understanding the function and task analysis that is contained in Appendix B.

Nucletron Remote Afterloaders

Three Nucletron afterloader models are used in the United States under the brand name Selectron. Two are low dose rate afterloaders while the third is a high dose rate afterloader.

Selectron Low Dose Rate Remote Afterloader

The Selectron LDR remote afterloader is housed in a free-standing unit consisting of four components: (1) source storage container; (2) pellet selection system; (3) console with keyboard and display; and (4) microprocessor. Its six treatment channels can be used for the treatment of a single patient or for the simultaneous treatment of two patients with completely independent treatment regimens.

The source material of the Selectron LDR remote afterloader is cesium-137 (^{137}Cs), encapsulated in 2.5 mm diameter pellets. Each of the six channels is programmed independently by specifying a source train composed of a sequence of radioactive and inert pellets in accordance with the desired dose distribution. The dose distribution and treatment time constitute the treatment plan that can be entered manually using the numeric keypad, or automatically by inserting a pre-programmed card into the card reader. After the treatment plan has been entered, the source trains are assembled within a safe in the afterloader and transported to the treatment position by pneumatic power. During treatment, the control console displays the positions of the source trains and the time remaining in the treatment session. The console printer provides hard copy documentation of this information as well as any anomalous conditions that may occur during a session.

The Selectron LDR remote afterloader includes a remote control unit and a nurse station display. The remote control unit is located on the wall outside the treatment room, which is a hospital room equipped with shielding. It is used to start, monitor, and interrupt treatment sessions. Its displays show the location of the source trains, the time remaining in a treatment session, and whether any emergency conditions exist. An intercom allows medical staff to speak with the patient from outside the room without interrupting the session. A door interlock automatically retracts sources into the afterloader should the treatment room door be opened during a treatment session.

The nurse station display indicates any treatment interruption, patient call, or emergency conditions with visual and auditory signals.

MicroSelectron Low Dose Rate Remote Afterloader

The MicroSelectron LDR remote afterloader delivers low dose rate interstitial treatments. It consists of two major components, the afterloader and the source storage container. There are four main parts to the afterloader: (1) intermediate storage safe, (2) console with keyboard and display, (3) a mechanical - pneumatic source assembly drive system, and (4) microprocessor. It has 15 treatment channels.

This afterloader differs from the Selectron LDR afterloader in that the source assemblies are individual radioactive ribbons containing iridium-192 wire (seeds) precut to various configurations and stored in a separate source storage container. The source storage container has 45 channels. Each channel can house one radioactive ribbon. The ribbons needed for a given treatment session are mechanically transferred from the storage container to the afterloader and then moved from the afterloader into the applicators. This afterloader uses the same remote control unit and nurse station display as the Selectron LDR afterloader.

MicroSelectron High Dose Rate Remote Afterloader

The third Selectron unit, the MicroSelectron HDR remote afterloader employs a single encapsulated, high activity iridium-192 source instead of the lower activity cesium-137. It is mounted on a steel cable and mechanically transported by a stepping motor from the afterloader into the source guide tubes, thence to the applicators. The MicroSelectron HDR afterloader is the most widely used RAB system in the United States.

This computer-controlled afterloader is programmed and operated from a control console located outside the treatment room. This contrasts with the two LDR afterloaders where the console is part of the afterloader unit. The HDR treatment room is either specially constructed as part of an HDR brachytherapy suite or is converted from a teletherapy treatment room.

Iridium-192 has a short half-life relative to cesium-137 (74 days vs. 30 years), so it must be replaced about four times per year. Therefore, source exchange and calibration devices and procedures that are not needed by LDR systems are required by HDR systems.

Treatment plan parameters are entered at the control console in one of three ways: (1) manual entry, (2) recalling a stored treatment plan from the memory of the afterloader computer, or (3) using a memory card with treatment parameters stored on it by the treatment planning computer. Treatment sessions are initiated, monitored, and, if necessary, interrupted from the afterloader control console. The console contains a display which provides alphanumeric and graphical information during data entry and treatment session initiation and monitoring.

If more than one channel is required by the treatment plan, the source sequentially enters each channel until all assigned channels have been treated. The source can be programmed to any one of 48 positions within each channel. The step size can be set to either 2.5 mm or 5.0 mm. The source control mechanism is designed to maintain the source within ± 1 mm of the programmed position.

GammaMed Remote Afterloaders

Two GammaMed models are currently used in the U.S., the GammaMed Ili and the GammaMed 12i. Both devices deliver a high activity, encapsulated, cable-mounted iridium-192 source by means of a stepping motor.

GammaMed Ili Remote Afterloader

The GammaMed Ili consists of two main components, the afterloader unit and the control console. The remote afterloader has 12 treatment channels, each of which is independently programmable. The source can be positioned sequentially at each of 20 dwell positions within each channel. The prescribed dose distribution is attained by specifying dwell positions within each applicator and dwell times for each dwell position. For complex, multi-applicator applications, an indexer sequentially switches the source cable from one implanted applicator to the next. Nominal dwell times are programmed into the control console; actual dwell times are corrected automatically for decay by the microprocessor. The source head can be raised or lowered as needed to align itself with the patient, and a friction brake prevents the remote afterloader from moving during treatment.

The control console of the GammaMed Ili is used to input the treatment plan manually, to recall a plan from its memory, to initiate and monitor a treatment session, and to interrupt a session when necessary. There is no treatment planning system designed specifically for the GammaMed Ili.

GammaMed 12i Remote Afterloader

The GammaMed 12i remote afterloader consists of a control console and an afterloader unit. A major difference between the GammaMed 12i and the other afterloaders is that its treatment delivery and treatment planning functions are integrated into the same console. The control console consists of an IBM PC AT-compatible microcomputer, a 1.2 megabyte (MB) floppy disk drive, a 20 MB hard disk, and a color monitor. Information is input to the console computer using a standard keyboard with function keys and a numeric keypad. Peripheral components include a dot matrix printer, a plotter, a light table, and a digitizer.

The afterloader unit has 24 independently programmable channels. Each channel can be programmed for up to 40 dwell positions. The source head can be raised or lowered (from 110 cm to 150 cm) and rotated (270°) into the desired treatment position. As with the other afterloaders, source decay is automatically compensated for by an internal clock in the afterloader control console. An electromagnetic brake keeps the afterloader unit stationary.

Throughout a treatment session, the GammaMed 12i updates treatment session status and displays this information on the monitor and prints it out on the console printer. Real-time comparisons of the treatment being delivered relative to the treatment plan can then be made.

Treatment Planning Systems for RAB

Both Nucletron and GammaMed produce treatment planning systems that can be used in conjunction with their remote afterloaders. The Nucletron planning system is compatible with both low and high dose rate afterloaders. The GammaMed planning system is an integral part of the GammaMed 12i remote afterloader. Various third-party treatment planning systems exist that can be used in lieu of the Nucletron and GammaMed planning systems.

Nucletron Treatment Planning System

Nucletron manufactures an independent, free-standing treatment planning system that is customized for planning brachytherapy treatments using Nucletron remote afterloaders, although it may also be used to plan manual brachytherapy and external beam treatments. This system includes a microcomputer with a mathematical coprocessor, a digitizer, a plotter, and a printer.

This planning system has four modules, each of which is specialized for a certain range of applications. For example, one module is for intracavitary therapy for applicators filled with pellets, while another module is for interstitial therapy with iodine seeds or other point sources, and another

module is for intracavitary and interstitial therapy with the MicroSelectron HDR remote afterloader. An important feature of this planning system is its ability to optimize dwell times for a given set of dose points.

When used in conjunction with a Nucletron remote afterloader, a treatment plan can be transferred to the afterloader control console via a memory card. The treatment planning computer writes the treatment plan parameters onto the card which is then hand carried to the afterloader control console where it is inserted and read by the console computer.

GammaDot Treatment Planning System

The GammaMed 12i treatment planning system, GammaDot, is fully integrated with the treatment delivery system. As such, it utilizes the same microcomputer, color monitor, keyboard, and peripheral devices as the treatment delivery system. Its menu-driven format features a series of interactive screens for entering administrative data, treatment plan parameters, and applicator information. Treatment plans can be entered manually or recalled from computer memory.

Unlike the Nucletron treatment planning system, the GammaDot system does not use a memory card. Instead, treatment plans are stored on the hard disk of the GammaMed 12i computer. They can be copied from the hard disk onto floppy disks for archival storage.

Treatment planning programs for eight standard applicators are available, as are programs for needles and catheters. Dwell positions within a three-dimensional coordinate space can be entered via digitizer or keyboard. Dose optimization can be based either on preset dose points or on dose points generated by the GammaDot planning program.

Independent Treatment Planning Systems

In addition to the treatment planning systems produced by manufacturers of remote afterloaders, several third-party treatment planning systems are used to plan RAB treatments. One such system is produced by Computerized Medical Systems (CMS). Another third-party planning system, Theraplan, is produced by a Canadian company, Theratronics. CMS and Theraplan can be used for both brachytherapy and teletherapy treatment planning.

Appliances Used in RAB

Various appliances and tools are needed to perform RAB. The specific appliances needed by any given RAB system varies according to the whether it is a high or low dose rate system, and the type of treatment being performed. In general, however, most RAB systems require catheters, applicators, needles, templates, source guide tubes, and quality assurance devices such as radiation monitors.

Catheters are slender, flexible tubes through which the radioactive source passes to reach intracavitary tumors. Applicators are rigid tubes designed to fit body cavities for precise positioning of the source delivery needles or catheters, and, in some instances, to provide shielding for sensitive anatomical areas. Needles and templates are used to position treatment channels in soft tissue tumors such as breast, brain, and prostate. Source guide tubes connect the treatment channels on the afterloader source head to the catheters or applicators that have been placed in a patient.

Quality assurance equipment determines whether the remote afterloader system is performing according to specifications. Source position accuracy, source activity level, and source timing are critical factors in this regard. Quality assurance equipment includes source position check rulers, source calibration chambers, index rods, and calibrated templates that show source position when viewed from remote video monitors.

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Appendix B: Function and Task Analysis

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MHDR = MicroSelectron High Dose Rate
MLDR = MicroSelectron Low Dose Rate

HDR = High Dose Rate
LDR = Low Dose Rate

SLDR = Selectron Low Dose Rate
GM12i = GammaMed 12i

Function and Task Analysis Glossary

The following terms are used in the function and task analysis form. Together, they specify the nature of each task in RAB.

Afterloader	The designation of the RAB system to which the task applies. For instance, Generic refers to a task that is common to all remote afterloader systems. LDR Generic is used for a task that is generic for all Low Dose Rate RAB systems. HDR Generic is used for a task that is generic for all High Dose Rate RAB systems.
Control Output	Actions taken by the system operator in response to system states and system responses to earlier operator actions.
Distraction Effects and Observations	Specific sources of distractions that contribute to the estimate of potential distractor level.
Equipment Needed	The major equipment and supplies needed to perform a task
Function No.	Based on the function and task analysis, a Roman numeral was assigned to each function that corresponded to its order of occurrence.
Function Title	Based on the function and task analysis, the function title is a descriptive label for a given function.
Info Input	The information needed to successfully perform task step.
L(E)	An estimate (Low, Medium, High) of the likelihood of an error for a given task step.
Possible Errors	Potential human errors that can occur on a particular task step.
Potential Distractor Level	An expert estimate (Low, Medium, High) of the amount of distraction that is likely to be experienced by RAB staff while performing a given task.
SKA Required	The major skills and abilities needed to perform a given task. They can be cognitive, perceptual, or physical in nature. Emphasis is given to those skills and abilities most critical to task performance.
Step Description	An explicit statement of the actions that, when performed correctly, will enable that step to be successfully completed. Each task is composed of a sequence of steps.
Supervisor	The person with the authority to give permission for a task to be performed. Ultimate accountability and responsibility for the correct execution of that task rests with the supervisor.
System Feedback	The response of the system to actions taken by the operator. These responses usually tell the operator what effects his actions have had on the system.
Task No.	Based on the function and task analysis, a number was assigned to each task in a given function corresponding to its order of execution within that function.
Task Performed By	The person who actually performs a given task. In tasks where more than one listing appears, they are arranged in order of decreasing frequency based on data gathered during the site visits.
Task Title	Based on the function and task analysis, the task title is a descriptive label for a given task.
Time Estimate	An expert estimate, given in minimum, maximum, and typical time intervals, of the time required to perform a given task.

Function I

Patient Preparation

Afterloader - Generic	
Function No. I	Function Title Patient Preparation
Task No. 1	Task Title Patient Scheduling, Identification and Tracking
Task Performed By	Receptionist, Nurse, Radiation Therapy Technologist Supervisor Physician
Equipment Needed	SKA Required Oral Comprehension, Oral Expression, Information Ordering
Time Estimate (minutes) Minimum / Typical / Maximum	15 / 30 / 45 Potential Distractor Level Low
Distraction Effects and Observations	Heavy caseload may result in more than one patient being processed simultaneously, especially in departments where brachytherapy and teletherapy are both practiced.

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Receive a request for treatment of a specific patient	Patient identity. Treatment requested.	Acknowledge request by verbal and/or written means		Receive request for wrong patient	Low
2	Schedule treatment for the patient.	Treatment times available. Patient preferences. Staff preferences.	Patient assignment to acceptable treatment time according to patient, staff, and facility availability	Patient and staff approve proposed treatment time	Schedule a time that conflicts with previously scheduled treatments or that is unsatisfactory for patient or staff	Low
3	Notify the patient and staff of the treatment schedule.	Treatment scheduled. Time scheduled.	Verbal and/or written notification to patient and staff	Staff and patient acknowledge scheduled treatment time	Fail to notify patient or staff of scheduled treatment time	Low
4	Arrange for transport of the patient to the treatment area.	Time scheduled. Transport protocol. Patient name and location.	Notification sent to personnel who transport patient to treatment area of a scheduled treatment	Transport personnel acknowledge request	Fail to arrange for patient transportation	Low
5	Wait for the arrival of the patient. Track the transport and scheduling process.	Scheduled patient's identity. Expected arrival time. Transport scheduled.	Check that scheduling and transportation arrangements have been made		Fail to track and monitor the transport and scheduling process	Low
6	Receive and identify the patient when he or she arrives at the treatment area.	Scheduled patient's identity. Identity of newly arrived patient.	Verification of patient's identity using written, verbal, or visual means		Misidentify patient	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
7	Notify the staff that the patient has arrived.	Staff to be notified. Location of staff. Notification protocol.	Verbal notification of patient's arrival at the treatment area	Acknowledgement of patient's presence by the staff	Fail to notify staff of patient's arrival	Low
8	Arrange for identification, transport and support for the patient within the treatment area.	Local patient identification procedures. Local patient transport and support procedures.	Notification sent to personnel responsible for identifying and transporting patient	Personnel who identify and transport patients arrive at treatment area	Fail to arrange for proper identification, transport, and support of patient	Low
9	Initiate and process any requests for subsequent scheduled treatments.	Treatment requested. Patient identification. Scheduling protocol.	Notification sent to personnel responsible for scheduling treatment sessions	Schedules are updated to reflect request for subsequent treatments	Fail to process requests for additional scheduled treatments	Low
10	Arrange for transport of the patient from the treatment area after treatment is completed.	Patient transport needs. Scheduling protocol. Expected treatment completion time.	Notification sent to personnel responsible for transporting patient	Transport personnel move patient from treatment area to recovery area	Fail to arrange patient transport from treatment area	Low

Afterloader Generic	
Function No. 1	Function Title Patient Preparation
Task No. 2	Task Title Patient Instruction
Task Performed By	Physician, Nurse, Physicist, Radiation Therapy Technologist Supervisor Physician
Equipment Needed	No equipment needed, unless textual or video instructional aids are used to augment verbal instructions SKA Required Oral comprehension, Oral expression
Time Estimate (minutes) Minimum / Typical / Maximum	5 / 10 / 30 Potential Distractor Level Low
Distraction Effects and Observations	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Identify the patient and the instruction needed or requested	Patient name and location. Scheduled procedure	Verify patient identity; Determine instruction needed for procedure		Fail to correctly identify patient; Fail to provide instructions appropriate for procedure	Low
2	Explain the purpose of the procedure.	Purpose of the procedure that has been proposed.	Verbal description, perhaps supplemented by written or video materials, of procedure's purpose	Patient acknowledges understanding purpose of procedure	Fail to provide instructions that can be understood by the patient	Low
3	Explain what the patient should experience during the procedure.	The expected sensory input to the patient during the procedure.	Verbal description, perhaps supplemented by written or video materials, of event sequence during the procedure	Patient acknowledges the events that will occur during the procedure	Fail to mention all relevant events	Low
4	Instruct the patient on what is expected of him or her during the procedure	The procedure's requirements of the patient.	Verbal description of responses patient is to make during the procedure	Patient correctly restates his or her responses during the procedure	Fail to provide sufficient detail to patient regarding desired actions	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
5	If a consent form is required and not yet signed explain the possible consequences of the procedure and alternatives to the procedure.	Consent requirements Status of consent forms. Possible consequences of the procedure. Procedure alternatives	Verbal description of possible consequences of procedure and alternatives to procedure	Patient acknowledges statements	Fail to explain consequences of and alternatives to the procedure	Low
6	Answer the patient's questions regarding the procedure and the instructions that have been provided.	Knowledge of the procedure. Explanation of techniques.	Verbal responses to patient questions	Patient acknowledges understanding replies to questions	Fail to provide adequate answers to the patient's questions	Low
7	Assess the patient's understanding of the explanations and instructions.	Patient understanding of information presented to him. Understanding assessment techniques.	Questions to patient about event sequence of procedure and desired patient actions	Patient responses to questions	Fail to assess patient's understanding of procedure	Low
8	Procure patient's consent if required in step 5.	Results of steps 5-7	Patient's signature on consent form		Fail to obtain patient's formal consent to undergo the procedure	Low

Afterloader Generic			
Function No. 1	Function Title Patient Preparation		
Task No. 3	Task Title Life Support Monitoring		
Task Performed By	Physician, Nurse		Supervisor Physician
Equipment Needed	Life support equipment (e.g., breathing aids), physiological monitors	SKA Required	Manual dexterity, Information ordering, Problem sensitivity
Time Estimate (minutes) Minimum / Typical / Maximum		10 / 20 / 30	Potential Distractor Level
Distraction Effects and Observations			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Attach life support monitoring devices	Standard procedure	Attach devices correctly	Devices start operating	Attach and/or set up devices incorrectly	Low
2	Check functioning of each device	Standard procedure	Perform routine performance checks	Device displays	Fail to perform device checks	Low
3	Adjust device if its operation falls outside acceptable parameters	Standard procedure	Adjust device so that it operates as intended	Device operation falls within acceptable limits	Fail to make appropriate adjustments	Low

Afterloader Generic			
Function No. 1	Function Title Patient Preparation		
Task No. 4	Task Title Applicator Placement and Stabilization		
Task Performed By	Physician, Resident, Nurse, Radiation Therapy Technologist	Supervisor	Physician
Equipment Needed	Surgical supplies / equipment; brachytherapy applicators; x-ray films; viewing box	SKA Required	Finger dexterity, Problem sensitivity, Manual dexterity, Arm-hand steadiness
Time Estimate (minutes) Minimum / Typical / Maximum		10 / 20 / 40	Potential Distractor Level Low
Distraction Effects and Observations			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Map the tumor boundaries with respect to some fixed coordinate system.	Mapping rules. Human anatomy.	Specification of tumor location	Tumor located within coordinate system	Fail to accurately specify tumor boundaries in relation to coordinate system	Low
2	Map the locations of organs and structures in the body near the tumor with respect to the coordinate system used in step 1.	Mapping rules. Human anatomy.	Specification of body structures	Critical structures mapped in relation to tumor	Fail to accurately map location of critical structures and organs in relation to tumor boundaries	Low
3	Identify a desired applicator position from which a radiation dose could be delivered to the target volume.	Results of steps 1-2. Radiation source characteristics. Dose-response characteristics of structures in steps 1-2	Specification of desired source locations		Improper choice of applicator position	Low
4	Note the characteristics of the applicators on hand.	Applicator specifications.	Visual inspection of applicators		Do not consider most appropriate applicator	Low
5	Identify tentative routes that would allow placement of an applicator in one of the desired positions.	Maps from steps 1-2. Desired applicator position. Human anatomy.	Identification of applicator routes		Identify route that does not permit applicator to be placed as desired	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
6	Select the applicator and placement route to be used.	Tentative routes. Applicator characteristics.	Selection of applicator and route		Select an applicator that is inappropriate for desired placement route	Low
7	Begin placing the applicator by moving it to the start of the placement route.	Chosen applicator and route. Insertion techniques.	Placement of applicator at start of route		Use wrong applicator; Follow wrong placement route	Low
8	Monitor progress along the placement route until the applicator reaches the desired position.	Current applicator position. Target location. Desired applicator position and route.	Placement of applicator into proper position	Radiographic images of applicator position obtained during subsequent treatment simulation	Misposition applicator	Low
9	Secure the applicator to prevent its movement from the desired position.	Movement possibilities. Stabilization methods.	Applicator secured in desired position	Applicator well secured	Fail to secure applicator in desired position; Secure applicator inadequately	Low
10	Place a distinguishing mark on the applicator. Repeat steps 6-10 until all applicators are placed.	Marking scheme. Marks already used. Number marked. Number unmarked.	Placement of unique mark on each applicator	Unique label on each applicator placed in patient	Mislabel applicator	Low

Afterloader Generic			
Function No.	I	Function Title	Patient Preparation
Task No.	5	Task Title	Patient Transportation
Task Performed By	Nurse, Radiation Therapy Technologist		Supervisor Physician
Equipment Needed	Gurney, wheelchair, patient monitoring devices	SKA Required	Oral expression, Arm-hand steadiness, Multi-limb coordination, Static strength
Time Estimate (minutes)	Minimum / Typical / Maximum	1 / 5 / 15	Potential Distractor Level Low
Distraction Effects and Observations			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Receive a transportation request with patient name, location, destination and required arrival time.	Destination description Appointment time Current time	Recognition of transportation request information		Fail to understand or respond to transportation request	Low
2	Find and identify the scheduled patient.	Patient name Other identifying characteristics	Match between request and patient	Visual and/or verbal	Misidentify patient	Low
3	Assess patient transportation and support requirements	Physician's orders. Patient needs	Transportation and support requirements		Fail to properly assess patient transportation and support requirements	Low
4	Determine the transportation route.	Destination Possible paths Path characteristics	Transport route choice		Fail to use the most efficient transportation route	Low
5	Assemble transportation and support equipment.	Requirements from step 3. Equipment available	Equipment assembled		Use wrong transport equipment; Assemble transport equipment incorrectly	Low
6	Accept patient information and responsibility from the local staff.	Patient's special requirements	Transference of information and responsibility	Verbal contact from local staff	Fail to contact local staff; Fail to ask for special instructions	Low
7	Inform the patient of the purpose of the trip.	Purpose of trip. Destination	Verbal message to patient	Patient response	Fail to inform patient	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
8	Remove the patient from the local support equipment and place him or her on the transport support equipment.	Equipment operation specifications	Patient positioned on transport equipment	Visual	Failure to transfer patient smoothly can alter applicator positions	Med
9	Move the patient along the chosen route to destination.	Chosen route Feedback along route	Transportation of patient to destination	Route markers	Failure to move patient carefully can alter applicator positions	Med
10	Transfer the patient from the transport equipment to the destination equipment.	Equipment operation specifications	Patient positioned at destination	Visual	Failure to transfer patient smoothly can alter applicator positions	Med*
11	Pass information and responsibility for the patient to the destination staff.	Patient name Scheduled procedure	Information on patient's special requirements	Acknowledgement by destination staff	Fail to pass all relevant information to destination staff	Low

* Depends on type of applicators.

Function II

Treatment Planning

Afterloader		Generic	
Function No. II	Function Title Treatment Planning		
Task No. I	Task Title Simulation with Dummy Sources		
Task Performed By	Physician, Physicist, Dosimetrist, Radiation Therapy Technologist		Supervisor Physician
Equipment Needed	Treatment simulator; Source guide tubes; Dummy sources; Applicators; AP and lateral x-ray films	SKA Required	Problem sensitivity, Pattern recognition, Information ordering, Near vision, Finger dexterity, Manual dexterity, Visualization
Time Estimate (minutes)	Minimum / Typical / Maximum	15 / 30 / 60	Potential Distractor Level Low
Distraction Effects and Observations	Presence of observers or medical personnel not directly involved in the simulation task; Poor x-ray films; Inadequate viewing conditions		

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Determine and record the number of applicators requiring dummy sources.	Number of applicators to be used in treatment	Identification of applicators requiring dummy sources.		Count incorrect number of applicators.	Low
2	Select a set of dummy sources that will fit into the applicators and which are individually identifiable under x-ray.	Dummy sources available. Dummy markings. Applicator fit needs.	Selection of dummy sources.		Select dummy sources that are not individually identifiable	Low
3	Select a dummy source and insert it into one of the unfilled applicators.	Applicator-dummy source matching requirements. Insertion method	Insertion of dummy source into applicator.	Visual	Fail to place dummy source in unfilled applicator	Low
4	Verify that the dummy source is fully inserted into the applicator.	Insertion completion. Evaluation specifications.	Dummy source positioned properly in applicator.	Visual	Fail to fully insert dummy source	Low
5	Secure the dummy source to the applicator to prevent any shift of position between the source and the applicator.	Securing protocol. Movement evaluation techniques.	Dummy source secured to applicator	Dummy source well secured	Fail to secure dummy source to applicator	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
6	Repeat steps 2-5 until dummy sources have been inserted in all applicators.	Number of applicators without dummy sources.		All applicators have dummy source inserted	Fail to place dummy source in every applicator	Low
7	Position the patient, x-ray source and film for a standard x-ray view of the applicators and target volume.	Positioning protocol. Field to be imaged. Imaged field size.	Patient positioned for x-ray	Visual	Misposition patient	Low
8	Place object(s) in the image field to allow later determination of the x-ray image magnification.	Field to be imaged. Which magnification object to use. Placement location for object.	Placement of magnification object in image field	Visual	Fail to enable later determination of x-ray magnification	Low
9	Expose one sheet of x-ray film following local x-ray procedures.	Local x-ray exposure procedures.	Exposed x-ray film	Visual	Fail to expose x-ray film properly	Low
10	Record and mark the film with patient ID, date, time, position, and x-ray imaging information.	Patient ID, date, position, imaging information	X-ray image marked with required information	Visual	Fail to mark x-ray image with appropriate information	Low
11	Position the x-ray source and film for a different x-ray view of the applicators and target volume.	Previous view angle. Current view angle.	Repositioning of x-ray equipment		Misposition equipment for second x-ray view	Low
12	Repeat steps 8-9 for the second x-ray view.				Do not repeat steps 8-9	Low
13	Develop the x-ray images.	x-ray films	x-ray images of dummy sources in applicators	Visual	Incorrectly develop x-ray film	Low
14	Check that the x-ray images are clear and unobstructed and that they contain enough information to reconstruct the imaged structures. If not - repeat steps 7-13.	Image quality specifications. Reconstruction requirements.	Inspection of x-ray images	Clear, interpretable x-ray images	Fail to inspect x-ray images; Do not repeat steps 7-13 when image quality is unsatisfactory	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
15	Remove the dummy sources from the applicators. Verify that the applicators are labelled for connection to the proper afterloader channels.	Applicator labels	Removal of dummy sources	No dummy sources left in applicators	Fail to remove dummy sources	Low
16	Route the simulation x-rays and documentation to treatment planning.	Planning station location. Documents needed.	Movement of x-rays and documentation from simulation area to treatment planning area	X-rays and supporting documentation received by treatment planning	Do not route x-rays and documentation to treatment planning	Low

Afterloader		Generic	
Function No.	II	Function Title	Treatment Planning
Task No.	2	Task Title	Target Volume Localization
Task Performed By	Physician, Physicist, Dosimetrist		Supervisor Physician, Physicist
Equipment Needed	Treatment planning computer, Digitizing tablet, x-y plotter, Dot matrix printer, X-ray equipment, Dummy sources, Applicators		SKA Required Problem sensitivity, Visualization, Near vision, Pattern recognition, Information ordering, Finger dexterity
Time Estimate (minutes)	Minimum / Typical / Maximum 10 / 20 / 60		Potential Distractor Level Medium to High
Distraction Effects and Observations		Intense activity requiring maximum concentration. Noises are frequently distracting.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Initialize treatment planning system	Directory	Turn on equipment, peripherals (printer, etc.)	Display of menus and opening screens	Fail to activate all planning system components	Low
2	Select treatment planning module for type of tumor	Prescription Tumor type Patient history	Select treatment type from menu	Display prompts and highlights	Select wrong treatment module	Low
3	Input patient identification	Patient name and ID	Type in patient information	Echo of information input	Enter wrong name or ID number of patient	Low
4	Input or verify source information	Isotope type Source activity at calibration Calibration date Current date	Enter or verify information	Echo of information input Displays source decay calculation for date entered	Enter wrong date Enter wrong isotope Enter wrong calibration data	Low to Med
5	Choose dose point reconstruction method	Orthogonal Semi-orthogonal Iso-centric Variable angle	Type in choice from menu	Echo of information input	Select wrong reconstruction method	Low
6	Calibrate x-ray parameters	Film parameters from x-ray and simulator	Enter film origin, magnification factor, focus distance, orientation, and direction of both AP and lateral films	Echo of information input on CRT and / or printer	Enter incorrect data from x-ray and incorrect x-ray simulator parameters	Low to Med

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
7	Enter applicator number and position	AP and Lateral films	Enter number of applicators, number of points to describe applicators, and number of dwell positions for each applicator using digitizer	Displays points and distances between points for each applicator Printout and CRT display of points	Input incorrect point	Med
8	Identify the target volume on the simulation x-rays.	Patient name. X-ray magnification. Marked target volume from dose prescription.	Identification and marking of target volume on x-rays	Visual	Misidentify target volume	Low to Med
9	Enter location, number, and types of screens and shields	AP and Lateral films Specifications of shielding properties of applicators and shields	Digitizer entry of points and menu entry of properties	Displays points on CRT and printout	Input incorrect point and / or incorrect shield data	Med
10	Identify and mark the dummy sources for one applicator on the simulation x-rays.	Dummy source characteristics and spacing.	Identification and marking of dummy sources		Mismatch dummy sources with applicator	Low
11	Select and mark the first and the last dwell position in the applicator.	Target volume and locations from steps 8-10	Marking of first and last dwell positions	CRT display of digitized dwell positions	Fail to mark first and last dwell positions	Low
12	Measure and record the distance from the first dwell position to the end of the applicator (offset distance).	First dwell position from step 11. X-ray magnification. Dummy source characteristics	Measurement of offset distance		Mismeasure offset distance	Low
13	Mark each dwell position between the first and last positions in the applicator.	Dwell positions from step 11	Marking of all dwell positions for an applicator	CRT display of digitized dwell positions	Fail to mark all intervening dwell positions	Low
14	Repeat steps 10-14 for each applicator.	The number of applicators.			Do not repeat steps 10-14 for all applicators	Low

Afterloader Generic			
Function No. II	Function Title Treatment Planning		
Task No. 3	Task Title Radiation Prescription		
Task Performed By	Physician		Supervisor Physician
Equipment Needed	AP and lateral x-ray films, Ruler, Marking implement	SKA Required	Problem sensitivity, Information ordering, Near vision, Visualization
Time Estimate (minutes) Minimum / Typical / Maximum 5 / 10 / 15			Potential Distractor Level Low
Distraction Effects and Observations		Presence of observers or medical personnel not directly involved in the simulation task; Poor x-ray films; Inadequate viewing conditions	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Identify the patient and verify that the simulation x-rays are current and accurate	Patient identification; Simulation x-ray identification	Identification of patient and x-ray records		Misidentify patient; Get wrong x-ray records	Low
2	Identify and mark the target volume on the simulation x-rays	Target volume boundaries; X-ray magnification	Outline target volume on x-ray		Mismark target volume boundaries	Low
3	Identify the applicators on the simulation x-rays	Dummy source characteristics and spacing	Mark and label each applicator		Misidentify applicators	Low
4	Identify any shields and mark any critical structures on the simulation x-rays	Shield identification characteristics; Critical structure identification characteristics	Mark shields and critical structures on x-ray		Misidentify shields; Fail to mark critical structures	Low
5	Determine the radiation dose to be delivered to the target volume and to the critical structures.	Target volume and locations from steps 1-3; Target dose-response expectations; Critical structure radiation tolerances	Outline intended radiation dose on x-ray		Make inaccurate determination of dose to target volume	Low
6	Write and sign a prescription for delivery of the radiation dose	Desire dose from step 4; Prescription procedures	Completed prescription form		Write wrong prescription on form; Fail to sign form	Low
7	Convey the prescription to the dosimetrist	Dosimetrist work area	Prescription delivered to dosimetrist	Dosimetrist acknowledges receipt of prescription	Fail to deliver prescription to dosimetrist; Delay its delivery	Low

Afterloader Generic			
Function No. II	Function Title Treatment Planning		
Task No. 4	Task Title Dwell Position Localization		
Task Performed By	Physicist, Dosimetrist		Supervisor Physician, Physicist
Equipment Needed	X-ray films and viewing device, Marking implements, Ruler	SKA Required	Problem sensitivity, Visualization, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum	1 / 5 / 10	Potential Distractor Level Low
Distraction Effects and Observations			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Acquire the simulation x-rays for a particular patient and treatment session.	Patient name; Treatment session number; Simulation x-rays			Get x-rays for wrong patient or treatment session	Low
2	Assemble viewing and marking aids	Standard procedure			Fail to assemble proper set of viewing and marking aids	Low
3	Identify and mark the images of any shields on the simulation x-rays	Shield characteristics	Mark shield locations on x-rays	X-ray film shows shield locations	Misidentify shields on x-rays	Low
4	Identify the images of the dummy sources in one applicator on each of the simulation x-rays	Dummy source characteristics and spacing	Visual identification of dummy sources		Mismatch dummy source from one x-ray to the other x-ray(s)	Low
5	Select and mark those dummy source images that correspond to dwell positions that the source will occupy during treatment	Dummy source images from steps 2-4; Desired treatment positions based on target volume	Mark appropriate dummy source images on x-ray film	X-ray film shows marked dummy source images	Mark dummy source images that will not be occupied by source during treatment session	Low
6	Measure and record the distance from the first dwell position to the end of the applicator	First dwell position from step 5; X-ray magnification factor; Dummy source spacing	Mark distance of dwell position to end of applicator	X-ray film shows distance from first dwell position to end of applicator	Mismeasure distance from dwell position to end of applicator	Low
7	Repeat steps 4-8 for each applicator	Total number of applicators			Fail to repeat steps 4-8 for remaining applicators	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
8	Define a single coordinate system for subsequent measurements of (a) the location of patient anatomical structures and (b) simulation images of shields, applicators, and dummy sources.	A single set of orthogonal axes for measuring all images	Draw orthogonal coordinate axes on x-ray film	Coordinate system marked on x-ray film	Define coordinate system that is inadequate for making subsequent measurements	Low
9	Measure the locations of the imaged dwell positions within each applicator in the coordinate system.	The marked locations at which the source will dwell during treatment from steps 7-8	Mark all dwell positions for each applicator	Locations of all dwell positions in terms of coordinate system	Fail to accurately mark dwell positions for each applicator	Low

Afterloader Generic			
Function No. II	Function Title Treatment Planning		
Task No. 5	Task Title Dosimetry		
Task Performed By	Physicist, Dosimetrist		Supervisor Physician, Physicist
Equipment Needed	Treatment planning computer, digitizing tablet, plotter, printer, x-ray films	SKA Required	Problem sensitivity, Visualization, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum 10 / 20 / 60	Potential Distractor Level Medium	
Distraction Effects and Observations Intense activity requiring maximum concentration. Noises, etc. are frequently distracting.			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Determine the characteristics of the treatment source at the time of the proposed (or actual) treatment.	The source strength and radiation pattern as a function of time. The time of the proposed (or actual) treatment.			Fail to characterize radiation source	Low
2	Define a single coordinate system for subsequent measurements of (a) patient anatomical structures and (b) simulation images of shields, applicators, and dummy sources.	A single set of orthogonal axes for measuring all images.	Representation of coordinate system	Visual	Fail to define appropriate coordinate system	Low
3	Locate any radiation shields or critical anatomic structures in the coordinate system.	The location and extent of each shield and critical structure during treatment.	Mapping of shields and critical structures	Visual	Fail to locate all critical anatomical structures or radiation shields	Low
4	Locate the target volume in the coordinate system.	The location of the target during treatment.	Mapping of target volume	Visual	Fail to locate target volume	Low
5	Locate each applicator and each dwell position within that applicator in the coordinate system.	The locations at which the source will dwell during treatment.	Mapping of applicators	Visual	Fail to locate each applicator; Fail to locate dwell positions for each applicator	Low
6	Determine the dwell time used or proposed at each dwell position.	Source dwell time for each dwell position.	Enter dwell time for each dwell position	Listing of dwell times at each position	Use incorrect dwell times	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
7	Calculate the radiation dose distribution expected from allowing the source to dwell at those positions during treatment.	Target volume and location from steps 3-5; Dwell times from step 6; Shield characteristics. Source characteristics.	Isodose lines defining dose distribution	Dose distribution information	Do not calculate correct dose distribution	Low
8	Calculate the resultant dose to each identified structure.	Calculations from step 7. Location of structures from steps 3-4.	Doses delivered to each structure	Dose distribution information	Do not calculate doses to critical structures	Low
9	Choose isodose lines corresponding to prescribed doses. Rotate axes so that critical structures and isodose lines are visible and distinct in 3 dimensions.	Prescribed doses and critical structures. Criteria for selecting an axis orientation. Procedure for rotating axes.	Specification of isodose lines that conform to prescribed doses	CRT display of isodose lines in relation to critical structures	Select incorrect axis orientation	Low
10	Plot and display on the same coordinate axes: a) The isodose surfaces in 3-D space. b) The target volume. c) The critical structures and shields. d) The dose to each critical structure or target.	Plotting and display procedures.	Graphic of isodose lines showing dose distribution	CRT display of isodose surfaces, critical structures, target volume, and doses to critical structure and target volume	Do not generate hard copy of dose distribution for patient files	Low

Afterloader Generic			
Function No. II	Function Title Treatment Planning		
Task No. 6	Task Title Treatment Plan Selection and Approval		
Task Performed By	Physician, Physicist, Dosimetrist	Supervisor	Physician
Equipment Needed	Treatment plan generated by treatment planning computer, Manual calculations of treatment parameters, Radiation prescription, Patient records	SKA Required	Written comprehension, Problem sensitivity, Number facility, Oral expression, Visualization, Perceptual speed and accuracy
Time Estimate (minutes) Minimum / Typical / Maximum 2 / 5 / 10		Potential Distractor Level Low	
Distraction Effects and Observations		Lack of appropriate workspace area can hamper accurate evaluation of treatment plan	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Verify that treatment plan is matched correctly to patient and treatment session	Patient records, treatment plan, and treatment session number	Cross-check identifying information from patient records and treatment plan, e.g., patient name and I.D. number, tumor type and location	All identifying data match	Fail to check identifying data; Incorrectly match treatment plan or treatment session number to patient	Low
2	Verify that computer-generated parameters match with manual calculations	Information from treatment plan; hand calculations	Cross-check treatment plan parameters	Comparison of computer-generated parameters and hand calculations	Fail to check correspondence between computer-generated and manual calculations; Fail to detect discrepancies between them	Low
3	Compare treatment plan parameters with radiation prescription	Prescribed target location; critical structure locations; prescribed radiation dose to target and critical structures	Comparison of treatment plan parameters with those of radiation prescription	Treatment plan parameters match with those of radiation prescription	Fail to compare treatment plan with radiation prescription; Fail to detect discrepancies between them	Low
4	Attest that treatment plan is correct for the specific patient and treatment session number	Matching information between treatment plan, radiation prescription, and patient ID	Authorize use of treatment plan for specific patient and treatment session number		Fail to authorize treatment plan before it is used	Low

Function III

Treatment Delivery

Afterloader		High Dose Rate Generic	
Function No.	III	Function Title	Treatment Delivery
Task No.	1	Task Title	Treatment Set-Up
Task Performed By	Nurse, Radiation Therapy Technologist, Physicist		Supervisor Physicist
Equipment Needed	High dose rate afterloader, Closed-circuit TV camera, Intercom	SKA Required	Information ordering, Problem sensitivity, Manual dexterity
Time Estimate (minutes) Minimum / Typical / Maximum		10 / 15 / 45	Potential Distractor Level Low
Distraction Effects and Observations		Presence of others in work area can draw attention away from preparing the patient for a treatment session. If brachytherapy personnel are also involved in external beam treatments, competing demands made on them can result in certain tasks being either overlooked or performed in a "shortcut" fashion.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Receive and identify patient to be treated	Patient ID. Scheduled patient. Scheduled treatment.	Identification of patient		Mismatch patient and treatment session	Low
2	Instruct patient on treatment session event sequence and desired patient responses	Patient understanding and capabilities; Expected treatment session scenario	Treatment session events	Patient acknowledges instruction	Fail to instruct patient	Low
3	Place patient in treatment location and attach patient support equipment	Patient support equipment needed	Location of patient		Fail to attach all patient support equipment	Low
4	Move afterloader unit into treatment position		Locate trolley source head within range of patient		Do not position afterloader properly	Low
5	Activate afterloader brake	Proximity to patient	Press Brake switch	Brake Lock light illuminates	Do not activate brake	Low
6	Adjust source head elevation and orientation	Proximity to patient	Press Head switch	Head raises or lowers; Up or Down light on	Do not orient source head properly	Low
7	Connect patient's applicators to appropriate afterloader channels with source guide tubes	Map of afterloader channel – applicator connections desired	Connect each applicator to its correct source guide tube	Source guide tubes snap into seated position of applicators	Mismatch source guide tubes to patient applicators	Med

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
8	Attach source guide tubes to source head	Knowledge of channel assignment for each applicator	Connect each source guide tube to correct afterloader channel; Turn indexer ring on source head to locked position	Source guide tubes snap into position in their adaptors; Indexer ring seats into its detented position	Mismatch source guide tubes and channels; Fail to secure indexer ring into its locked position	Med
9	Close the door of the treatment room, leaving the patient alone in the room	Number of people in the treatment room	Close treatment room door		Leave someone in addition to patient in treatment room	Low
10	Adjust focus, pan, and zoom of camera	Video screen image	Adjust controls	Correct camera responses to controls	Do not test focus, pan, zoom	Low
11	Test intercom	Audio from treatment room	Activate intercom controls	Audio from treatment room	Do not test intercom	Low
12	Test patient support equipment	Standard pre-treatment equipment checks	Adjust controls	Equipment displays	Do not test and adjust equipment	Low
13	Verify that system is connected to main power supply and that main switch is in 'On' position	Standard start-up check	Check main power supply and main switch	Power cord connected to power supply; Pilot light adjacent to main switch illuminated	Do not check power connection and main switch status	Low
14	Verify that there is sufficient paper for printer	Standard start-up check	Check that printer paper roll is at least 2.5 cm in diameter	Diameter of paper roll	Do not check paper supply	Low

Afterloader Low Dose Rate Generic			
Function No. III	Function Title Treatment Delivery		
Task No. I	Task Title Treatment Set-Up		
Task Performed By	Nurse, Radiation Therapy Technologist, Physicist		Supervisor Physicist
Equipment Needed	Low dose rate afterloader, Closed-circuit TV camera, Intercom	SKA Required	Problem sensitivity, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum		5 / 10 / 15	Potential Distractor Level Low
Distraction Effects and Observations Use of a structured check-off list expedites performance of start-up procedures and helps to minimize the disruptive effects that any interruptions may have. Check-off lists also serve as a running record of past problems encountered with system initialization.			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	I.(E)
1	Instruct patient on treatment session event sequence and desired patient responses	Patient understanding and capabilities; Expected treatment session scenario	Treatment session events	Patient acknowledges instruction	Fail to instruct patient	Low
2	Place patient in treatment location and attach patient support equipment	Patient support equipment needed	Location of patient		Fail to attach all patient support equipment	Low
3	Move afterloader unit into treatment position		Locate it within range of patient		Do not position afterloader properly	Low
4	Verify that compressed air supply is connected to afterloader	Standard start-up check	Check compressed air supply connection	Connection is complete	Do not check air supply connection	Low
5	Verify that sufficient air pressure is present to complete the start-up sequence	Air pressure gauge; Air supply	Visual check of air pressure gauge	Reading on gauge	Do not check gauge	Low
6	Verify that system is connected to main power supply and that main switch is in 'On' position	Standard start-up check	Check main power supply and main switch	Power cord connected to power supply; Pilot light adjacent to main switch illuminated	Do not check power connection and main switch status	Low
7	Verify that there is sufficient paper for printer	Standard start-up check	Check that printer paper roll is at least 2.5 cm in diameter	Diameter of paper roll	Do not check paper supply	Low
8	Adjust focus, pan, and zoom of camera	Video screen image	Adjust controls	Correct camera responses to controls	Do not test focus, pan, zoom	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
9	Test intercom	Audio from treatment room	Activate intercom controls	Audio from treatment room	Do not test intercom	Low
10	Test patient support equipment	Standard pre-treatment equipment checks	Adjust controls	Equipment displays	Do not test and adjust equipment	Low
11	Connect treatment tube to patient applicator		Connection of treatment tube to applicator	Relation of position markers to each other	Faulty connection between treatment tube and quick connector	Low
12	Check that treatment tube is adequately supported to prevent tension on applicators		Use patient belt to support treatment tube	Little force applied on patient applicators	Do not adjust treatment tube to support applicators	Low
13	Ensure that treatment tube is ready for treatment to start		Inspect treatment tube for bends and kinks; Straighten if necessary		Fail to straighten bends and kinks	Low
14	Close door of treatment room, leaving the patient alone in the room	Number of people in the treatment room	Close treatment room door	Door closes securely	Leave someone in addition to patient in treatment room	Low

Afterloader		MicroSelectron Low Dose Rate	
Function No.	III	Function Title	Treatment Delivery
Task No.	I	Task Title	Treatment Set-Up—Transfer Source Assemblies from Storage Container to Afterloader Safe
Task Performed By	Radiation Therapy Technologist		Supervisor Physicist
Equipment Needed	MLDR afterloader, Mobile storage container, Afterloader control console	SKA Required	Problem sensitivity, Information ordering, Manual dexterity
Time Estimate (minutes)	Minimum / Typical / Maximum	5 / 10 / 15	Potential Distractor Level Low
Distraction Effects and Observations		Use of a structured check-off list expedites performance of start-up procedures and helps to minimize the disruptive effects that any interruptions may have. Check-off lists also serve as a running record of past problems encountered with system initialization.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Position storage container in close proximity to afterloader	Standard procedure for source assembly transfer	Position storage container and afterloader within 5 feet of each other	Components positioned properly	Fail to position properly	Low
2	Open storage container cover		Unlock cover, slide it up post, rotate it 180 degrees clockwise	Cover falls into locked position	If cover is not in locked position, it can slide down and injure operator	Low
3	Connect afterloader to storage container		Connect treatment tube to storage container using special connector	Connector snaps into position	If connector is not properly connected, source assemblies may not transfer	Low
4	Provide storage container with air supply		Connect storage container's air supply tube to afterloader's quick connector	Air supply tube seats into quick connector	Poor connection will prevent source assembly transfer	Low
5	Prepare to transfer sources		Connect treatment tube quick connector to storage container, aligning position markers; Turn locking mechanism counter-clockwise; Push connector down and turn clockwise until markers are realigned	Storage registration indicator on afterloader control console illuminates	Fail to make proper connection	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
6	Specify source assemblies to be transferred	Treatment plan stating which source assemblies are needed	Connect selecting tubes with corresponding transfer channel numbers to correct storage container safe numbers	Tubes connect to safe number	Fail to push connectors firmly down; Fail to connect all 15 quick connectors to correct storage container safe numbers	Low
7	Program channels for source collection	All quick connectors connected to a storage container safe number	Activate the numbered channel push buttons	Indicators for selected channels illuminate	Select a channel whose green 'Safe' indicator light is on	Low
8	Ready afterloader system for source transfer	Indicators for desired channels should be on	Turn keyswitch to 'Remote Control'; Exit treatment room, closing door	'Start' indicator on afterloader control console flashes	Fail to turn keyswitch to Remote Control position	Low
9	Transfer sources from storage container to afterloader safe	'Start' indicator should be flashing	Press Start key	'Start' indicator extinguishes; 'Treatment' indicator begins flashing	Do not press Start key	Low
10	Verify that source transfer has been successful	'Treatment' indicator extinguishes; 'Ready' indicator begins flashing	Re-enter treatment room, checking that radiation monitor is off; Check that green safe indicators are illuminated for selected channels; Check print-out for error codes	Safe indicators for selected channels are illuminated	Neglect to check radiation monitor, print-out for error codes, and safe indicator lights	Low
11	Return system to rest state	Appropriate safe indicators are lit	Turn keyswitch to Prepare position	System enters rest state	Do not turn keyswitch to Prepare position	Low

Afterloader MicroSelectron Low Dose Rate	
Function No. III	Function Title Treatment Delivery
Task No. 1	Task Title Treatment Set-Up—Verify that Correct Source Assemblies have been Transferred
Task Performed By	Radiation Therapy Technologist, Physicist
Equipment Needed	MLDR afterloader
SKA Required	Problem sensitivity, Information ordering, Manual dexterity
Supervisor	Physicist
Time Estimate (minutes) Minimum / Typical / Maximum	3 / 5 / 10
Potential Distractor Level	Low
Distraction Effects and Observations	Use of a structured check-off list expedites performance of routine procedures and helps to minimize the disruptive effects that interruptions may have.

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Prepare to generate print-out listing afterloader channels that contain source assemblies	Source assembly transfer has been completed	Press channel select keys on afterloader control console for channels that should contain sources	Corresponding channel lights illuminate	Press wrong channel number	Low
2	Program a mock treatment session	System prepared for treatment session	Turn keyswitch to Treatment; enter a treatment time, press Enter; enter a patient number, press Enter	Print-out of entered data	Incorrect entries; Keyswitch not turned to Treatment position	Low
3	Return system to rest state	Print-out completed	Turn keyswitch to Prepare position	System enters rest state		
4	Compare print-out of source assembly data with original programming list	Print-out of source assembly data; Original programming list	Visually and verbally compare the two sets of parameters to make sure channels have been loaded correctly		Fail to detect discrepancies that exist between the two sets of parameters	Low
5	If parameters match, input treatment plan data. See Function III, Task 2 (MLDR afterloader).	Identical match of source assembly data and originally specified parameters				

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
6	If parameters do not match, correct all discrepancies	Discrepancies among channel assignments and treatment plan	Correct discrepancies so that all channels are loaded with correct source		Fail to correct all discrepancies	Low
7	Recheck amended channel assignments; if they are correct, see Function III, Task 2 (MLDR). If discrepancies still exist, repeat step 6	Discrepancies among channel assignments and treatment plan	Visual and verbal check of match between channel assignments and treatment plan	All channel assignments are correct	Fail to detect remaining discrepancies	Low

Afterloader GammaMed 12i	
Function No. III	Function Title Treatment Delivery
Task No. 2	Task Title Treatment Plan Entry—Manual
Task Performed By	Radiation Therapy Technologist, Physicist
Supervisor	Physicist
Equipment Needed	GammaMed 12i afterloader
SKA Required	Problem sensitivity, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum 5 / 10 / 20
Potential Distractor Level	Medium
Distraction Effects and Observations	Glare from overhead lighting can make the afterloader control console display hard to read. Presence of observers can draw attention from task, making keyboard entries more error-prone.

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Initialize afterloader system	Standard procedure	Unlock source head; Power up afterloader control console and peripherals	MS-DOS and GammaMed/ GammaDot control programs load; Opening menu appears	Do not turn on all system components	Low
2	Select manual programming option from opening menu	Opening menu	Selection of manual programming option	Monitor displays manual programming menu	Fail to select manual programming screen	Low
3	Check date and time on display	Date and time	Visual check for correctness of date and time	Monitor displays date and time	Fail to note discrepancies between true and displayed date and time	Low
4	Enter patient name and ID number	Patient name; Patient ID number	Enter patient name and ID using keyboard	Monitor displays patient name and ID	Enter wrong patient name and/or ID	Low
5	Enter fraction number (treatment session number) for that patient	Fraction number	Enter fraction number using keypad	Monitor displays fraction number in appropriate field	Enter wrong fraction number	Low
6	Enter nominal total time	Total time for all dwell positions in all applicators irrespective of current source activity level	Enter nominal total time using keypad	Monitor displays nominal total time in appropriate field	Enter wrong nominal total time	Low
7	Enter channel number	Channel to be programmed	Enter channel number using keypad	Monitor displays channel number	Select wrong channel	Low
8	Enter distance value (step size) for selected channel; either 5 mm or 10 mm (default)	Treatment plan parameters	Enter distance using keypad	Monitor displays distance value (5 mm or 10 mm)	Enter wrong distance value	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
9	Enter origin value (offset distance between most distal stopping position and first dwell position)	Treatment plan parameters	Enter origin using keypad	Monitor displays origin value	Enter wrong origin value	Low
10	Enter position values (dwell times for each dwell position for selected channel)	Treatment plan parameters	Enter position values using keypad	Monitor displays dwell times (sec) for each dwell position in selected channel	Enter wrong position values	Low
11	Repeat steps 7-10 for each remaining channel to be programmed	Treatment plan parameters			Fail to repeat steps 7-10 for all remaining channels	Low
12	Save treatment plan onto hard disk	Treatment plan completed	Press F2 to save plan onto hard disk	Monitor shows plan has been saved	Fail to save treatment plan	Low
13	Recall treatment plan from hard disk and transfer it to the afterloader control console	Patient treatment schedule	Press F3 to recall plan from hard disk, then F4 to transfer it to afterloader control console	Monitor shows plan has been recalled and transferred	Recall and transfer wrong plan for scheduled treatment session	Low

Afterloader				GammaMed 12i							
Function No.		III		Function Title		Treatment Delivery					
Task No.		2		Task Title		Treatment Plan Entry—Stored in Computer Memory					
Task Performed By		Radiation Therapy Technologist, Physicist				Supervisor		Physicist			
Equipment Needed		GammaMed 12i afterloader				SKA Required		Problem sensitivity, Information ordering			
Time Estimate (minutes)		Minimum / Typical / Maximum				2 / 4 / 10		Potential Distractor Level		Low	
Distraction Effects and Observations				Presence of observers and medical personnel not directly in the remote afterloading task can distract primary workers							

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Initialize afterloader system	Standard procedure	Unlock source head; Activate afterloader control console and peripherals	MS-DOS and GammaMed/ GammaDot control programs load; Opening menu appears	Do not turn on all system components	Low
2	Select GammaDot treatment planning option from opening menu	Opening menu	Selection of GammaDot treatment planning option	Monitor displays GammaDot treatment planning menu screen	Fail to select GammaDot treatment planning screen	Low
3	Check date and time on display	Date and time	Visual check for correctness of date and time	Monitor displays date and time	Fail to note discrepancies between true and displayed date and time	Low
4	Enter patient name and ID number	Patient name; Patient ID number	Enter patient name and ID using keyboard	Monitor displays patient name and ID	Enter wrong patient name and/or ID	Low
5	Enter fraction number (treatment session number) for that patient	Fraction number	Enter fraction number using keypad	Monitor displays fraction number	Enter wrong fraction number	Low
6	Read selected plan into active memory	Patient name and ID; Fraction number	Press F3 to read stored treatment plan from hard disk into active memory	Monitor displays treatment plan parameters	Fail to read stored treatment plan; Read in wrong plan	Low
7	Transfer treatment plan to the afterloader control console	Patient treatment schedule	Press F4 to transfer plan to afterloader control console	Monitor shows that treatment plan has been transferred	Fail to transfer plan; Transfer wrong plan for scheduled treatment session	Low

Afterloader MicroSelectron High Dose Rate			
Function No. III	Function Title	Treatment Delivery	
Task No. 2	Task Title	Treatment Plan Entry—Memory Card	
Task Performed By	Radiation Therapy Technologist, Physicist		Supervisor Physicist
Equipment Needed	Nucletron Planning System, Special Mode keyswitch	SKA Required	Problem sensitivity, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum	1 / 2 / 5	Potential Distractor Level Low
Distraction Effects and Observations	Important to double-check that memory card used contains treatment plan devised for patient who is to undergo treatment.		

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	I.(E)
1	Enter command to initialize afterloader system	Standard procedure	Insert On/Off key into left-hand keyswitch and turn to 'Prepare' position	Prepare light illuminates when key is inserted; Program light illuminates when key is turned to 'Prepare'	Do not turn key to 'Prepare' position	Low
2	During automatic initialization cycle, monitor system self-checking procedure	Program light on	Visually monitor system diagnostics	Safe light illuminates; afterloader type and serial number appear on display and are printed out	Fail to monitor system self-checks	Low
3	Turn left-hand keyswitch to Prepare	Standard procedure for reading data off memory card	Turn left-hand keyswitch to 'Prepare' position	Program light illuminates	Do not turn keyswitch	Low
4	Insert Special Mode key in right-hand keyswitch and turn to Special Mode position	Need to input treatment data from a memory card	Insert Special Mode key	Special Mode light illuminates	Use wrong key; Do not fully insert it; Do not turn to Special Mode position	Low
5	Insert memory card into its holder on afterloader control console	Special Mode light on	Press memory card into holder until an audible click is heard	Display prompts for special mode number	Do not insert memory card completely into holder	Low
6	Enter '7' on keypad and press Enter key	Special Mode light on	Enter '7' on keypad and press Enter key	Mode line displays 'Read Program Card' and System status field displays 'Busy'	Enter wrong number	Low
7	Wait for program to load fully	Mode line and System status field displays as in step 5		'Busy' disappears from display when program is fully loaded	Do not let program fully load before proceeding	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
8	Turn Special Mode keyswitch to Normal Mode and remove key	Program fully loaded	Turn keyswitch to Normal mode	Normal mode indicated on console display	Do not turn key to Normal mode and remove it	Low
9	Return Special Mode key to proper authority	Key removed from keyswitch	Give key to authority	Authority accepts key	Key given to wrong person	Low
10	Remove memory card by pressing on both sides of its holder	Display shows treatment plan is loaded	Memory card removed from afterloader	Memory card ejects from its slot	Do not remove card; Remove card by pulling directly on it instead of pressing on sides of its holder	Low
11	Store memory card in proper location	Treatment plan loaded	Card stored in proper location		Store card in wrong location	Low

Afterloader				MicroSelectron High Dose Rate					
Function No.		III		Function Title		Treatment Delivery			
Task No.		2		Task Title		Treatment Plan Entry—Manual			
Task Performed By		Radiation Therapy Technologist, Physicist				Supervisor		Physicist	
Equipment Needed		MHDR afterloader				SKA Required		Problem sensitivity, Information ordering	
Time Estimate (minutes)		Minimum / Typical / Maximum 5 / 10 / 20				Potential Distractor Level		Medium	
Distraction Effects and Observations		Glare from overhead lighting can make the afterloader control console display hard to read. Presence of observers can draw attention from task, making keyboard entries more error-prone.							

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Enter command to initialize afterloader system	Standard procedure	Insert On/Off key into left-hand keyswitch and turn to 'Prepare' position	Prepare light illuminates when key is inserted; Program light illuminates when key is turned to 'Prepare'	Do not turn key to 'Prepare' position	Low
2	During automatic initialization cycle, monitor system self-checking procedure	Program light on	Visually monitor system initialization	Safe light illuminates; afterloader type and serial number appear on display and are printed out	Fail to monitor system self-checks	Low
3	Assure that system is in rest state	Standard preparation for keyboard entry	Check that left-hand keyswitch is in Prepare position and right-hand keyswitch is in Normal Mode position	Program light illuminates	Do not have both keyswitches in correct position	Low
4	System enters Program mode	Program light on	Press Program key	Program light off; Step size 1 (2.5 mm) or 2 (5.0 mm) displayed	Do not press Program key	Low
5	Enter step size	Display shows 1=2.5 mm and 2=5.0 mm	Press '1' or '2' on keypad	Selection appears on display; Non-Standard, Standard, Safe, and Cancel lights illuminate	Press '1' instead of '2' or vice versa	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
6	Press Non-Standard key	Non-Standard, Standard, Safe, and Cancel lights on	Press Non-Standard key	Non-Standard light off	Press wrong key	Low
7	Enter channel number	Display prompts for channel number (1-18)	Default (1): press Enter; Non-default: enter on keypad, press Enter	Graphical depiction of selected channel	Select wrong channel	Med
8	Press Length key	Length, Time, Position lights on	Press Length key	Length light turns off	Press wrong key	Low
9	Enter length, the distance from the afterloader indexer ring to the first dwell position, in mm	Display prompts for Length	For default (995 mm), press Enter; for non-default (≥ 725 mm), enter on keypad, then press Enter	Length and position cursor values change	Select wrong length	Med
10	Press Position key	Display prompts for dwell position	Enter position (1-48) using keypad and press Enter	Cursor moves to selected position	Select wrong position	Med
11	Press Cancel key	Display prompts for another dwell position	Enter position (1-48) using keypad and press Enter; if none desired, press Cancel key	Cursor moves to selected position	Select wrong position	Med
12	Press Time key	Display prompts for dwell time	Enter dwell time (0.1-999.9 sec) using keypad and press Enter	Small black square appears in selected position	Select wrong time	Med
13	Repeat steps 10-12 for positions with different dwell times; If several adjacent positions have a common dwell time, see step 14	Treatment plan	Execute appropriate sequence of steps		Fail to perform steps 10-12 for different dwell times; Fail to use common dwell time entry feature for common dwell times	Low
14	Enter common dwell time	Prompt for dwell time	Enter a common dwell time (seconds) using keypad	Dwell time value shown on display	Enter wrong dwell time	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
15	Press Active then Enter keys		Press Active and Enter keys	Prompt to select active or spacer	Do not press Active and Enter keys	Low
16	While holding down Active key, press cursor key	Prompt for active/spacer positions	Select active positions	Black squares displayed in active positions	Do not select correct active positions	Low
17	Pressing Spacer key, press cursor key	Prompt for active/spacer positions	Select spacer positions	Spacer positions have no black squares	Do not select correct spacer positions	Low
18	Press Cancel key	Completion of channel programming using a common dwell time	Press Cancel key	Length, Time, Position lights illuminate	Do not press Cancel key	Low
19	Go to step 7 to reset parameters prior to entering data for another channel; Go to step 12 to exit	Treatment plan			Fail to select correct option for treatment plan	Low
20	Press Cancel key twice	Treatment plan	Press Cancel key twice	System enters rest state	Do not press Cancel; Press Cancel only once.	Low

Afterloader				MicroSelectron High Dose Rate					
Function No.		III		Function Title		Treatment Delivery			
Task No.		2		Task Title		Treatment Plan Entry—Stored in Computer Memory			
Task Performed By		Radiation Therapy Technologist, Physicist				Supervisor Physicist			
Equipment Needed		MHDR afterloader			SKA Required		Problem sensitivity, Information ordering		
Time Estimate (minutes)		Minimum / Typical / Maximum 2 / 4 / 10			Potential Distractor Level			Low	
Distraction Effects and Observations		Presence of observers and medical personnel not directly in the remote afterloading task can distract primary workers							

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Enter command to initialize afterloader control console	Standard procedure	Insert On/Off key into left-hand keyswitch and turn to 'Prepare' position	Prepare light illuminates when key is inserted; Program light illuminates when key is turned to 'Prepare'	Do not turn key to 'Prepare' position	Low
2	During automatic initialization cycle, monitor system self-checking procedure	Program light on	Visually monitor console displays	Safe light illuminates; afterloader type and serial number appear on display and are printed out	Fail to monitor system self-checks	Low
3	Change system mode to Program status	Program light on	Press Program key	Program light off; Step size 1 (2.5 mm) or 2 (5.0 mm) displayed	Press wrong key	Low
4	Enter step size	Display shows 1 = 2.5 mm and 2 = 5.0 mm	Press '1' or '2' on keypad	Selection appears on display	Press '1' instead of '2' or vice versa	Low
5	Enter Standard mode for retrieving a treatment plan	Non-Standard, Standard, Safe, and Cancel lights on	Press Standard key	Display prompts for standard number	Press wrong key	Low
6	Enter number of the standard to be recalled from memory	Display prompts for standard number (1-99)	Default, press Enter; Non-default, enter standard number with keypad, then press Enter	Graphical depiction of selected standard	Select wrong standard	Low
7	Enter channel number to be programmed with the recalled standard program	Display prompts for channel selection (1-18)	Default (01), press Enter; Non-default, enter channel number with keypad, then press Enter	Display prompts for Length (distance to position 1)	Select wrong channel	Low
8	Press Length key for selected channel	Length, Time, Position lights on	Press Length key	Length light off	Press wrong key	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
9	Enter length, the distance from the afterloader indexer ring to the first dwell position, in mm	Display prompts for Length	Default (995 mm), press Enter; Non-default, use keypad, then press Enter	Length and position cursor values change	Select wrong length	Low
10	Press Cancel key	Display prompts for another dwell position	Enter position (1-48) on keypad, press Enter; else press Cancel	Program light illuminates; system returns to rest state	Select wrong position	Low
11	Enter another channel number if more programming is required	Program light on	Press Cancel key, then enter channel number on keypad	Channel number displayed	Press wrong channel number	Low

Afterloader				MicroSelectron Low Dose Rate					
Function No. III		Function Title		Treatment Delivery					
Task No. 2		Task Title		Treatment Plan Entry—Manual					
Task Performed By		Physicist, Radiation Therapy Technologist			Supervisor		Physicist		
Equipment Needed		MLDR afterloader		SKA Required		Problem sensitivity, Selective attention, Time sharing			
Time Estimate (minutes)		Minimum / Typical / Maximum		3 / 5 / 10		Potential Distractor Level		Low	
Distraction Effects and Observations		Use of a structured check-off list expedites performance of start-up procedures and helps to minimize the disruptive effects that any interruptions may have. Check-off lists also serve as a running record of past problems encountered with system initialization.							

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Initialize afterloader control console	Standard procedure	Insert key into keyswitch and turn key from 'Off' to 'Prepare' position	'Prepare' light illuminates; Print-out of date, time, afterloader model	Do not turn key to 'Prepare' position	Low
2	Program afterloader control console for treatment session	Treatment plan parameters	Turn keyswitch to Prepare position; Enter patient number and treatment times for each channel via keypad	Print-out of treatment time shown in two timer displays for each channel: Primary timer starts when sources reach treatment position; Secondary timer starts when sources leave afterloader safe	Enter wrong treatment time and/or patient number	Low
3	Prepare to transfer sources to applicators	Complete print-out of treatment and source data	Turn keyswitch to Remote Control position	Safe lights illuminate; Indicators for selected channels illuminate	Do not turn keyswitch to Remote Control position	Low
4	Enter treatment time	Treatment time required for patient	Enter treatment time using keypad	Echo on primary and secondary timer displays	Enter wrong treatment time	Low
5	Enter patient I.D.	Patient I.D.	Enter patient I.D. using keypad	Print-out echoes patient I.D.	Enter wrong patient I.D.	Low

Afterloader Selectron Low Dose Rate			
Function No. III	Function Title Treatment Delivery		
Task No. 2	Task Title Treatment Plan Entry—Memory Card		
Task Performed By	Physicist, Radiation Therapy Technologist		Supervisor Physicist
Equipment Needed	SLDR afterloader, Memory card, Nucletron marker pen	SKA Required Problem sensitivity, Information ordering	
Time Estimate (minutes) Minimum / Typical / Maximum 5 / 10 / 20			Potential Distractor Level Low
Distraction Effects and Observations Lack of familiarity with memory cards can complicate entry of correct values			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Initialize afterloader control console	Standard procedure	Insert key into keyswitch and turn key from 'Off' to 'Prepare' position	'Prepare' light illuminates; Print-out of date, time, afterloader model	Do not turn key to 'Prepare' position	Low
2	Program treatment parameters of a single channel on a memory card	Treatment plan parameters	Darken appropriate spaces on text side of memory card using marker pen: Rows 1-3 = treatment time; Row 4 = channel number; Rows 5-6 = source positions (1-48)		Do not use Nucletron marker pen; Do not make all marks on text side of card; Mismatch data with correct rows	Low
3	Prepare system to receive programmed parameters	Completed memory card	Insert card into card reader (text side of card faces front, grey triangular arrow points down); Press Program key	System enters Program mode	Insert card in improper orientation; Do not press Program key	Low
4	Read in treatment parameters	Completed memory card	Pull memory card slowly and steadily out of card reader	Afterloader display shows treatment parameters that have been read in; system returns to rest state	Withdraw card from card reader too fast or with an irregular motion	Low
5	Verify that treatment parameters have been correctly read from card into afterloader memory	Data on memory card; afterloader display	Compare channel treatment parameters on display with those on card	Visual	Do not detect existing discrepancies between card and display	Low
6	Repeat steps 2-5 for all other channels specified by treatment plan	Standard procedure for inputting treatment plan with multiple channels			Fail to repeat steps 2-5 for remaining channels	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
7	Compose pellet train for programmed channel	At least one channel is programmed and assigned a treatment time greater than 0	Press Compose key	Indicators near keypad and Reset key flash; Status display for channel being assembled shows letter 'C'; Pellet counter displays show number of pellets outside main safe; After composing is completed, the letter 'O' appears in channels status display	Do not press Compose key	Low

Afterloader Selectron Low Dose Rate			
Function No. III	Function Title Treatment Delivery		
Task No. 2	Task Title Treatment Plan Entry - Manual		
Task Performed By	Physicist, Radiation Therapy Technologist		Supervisor Physicist
Equipment Needed	SLDR afterloader	SKA Required	Problem sensitivity, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum 5 / 10 / 20			Potential Distractor Level Low to Medium
Distraction Effects and Observations Presence of observers and medical personnel not directly involved in the brachytherapy treatment session may draw attention from task.			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Initialize afterloader control console	Standard procedure	Insert key into keyswitch and turn key from 'Off' to 'Prepare' position	'Prepare' light illuminates; Print-out of date, time, afterloader model	Do not turn key to 'Prepare' position	Low
2	Prepare afterloader for manual entry of treatment plan	Procedure for manual entry	Press Program key	Indicator lights next to the numerical keypad and the Reset key start flashing	Do not press Program key	Low
3	Specify a channel number	Prompt for channel number	Enter a legal single-digit channel number	'P' appears in status display of selected channel; position and time indicators flash	Enter unacceptable channel number, 'Illegal Channel Number' printed	Low
4	Prepare to enter source configuration (position) of selected channel	Position indicator light flashes	Press Position key	Indicators next to numerical keypad and Reset key start flashing	Do not press Position key	Low
5	Specify a position number for an active pellet	Keypad light flashing	Enter two-digit position number from 01-48 using keypad	Indicator light corresponding to selected position on source configuration display begins flashing	Enter out-of-range position number	Low
6	Assign a source pellet to position selected in step 5	Indicator lights next to Source, Spacer, and Reset keys begin flashing	Press Source key	Indicator light on source configuration display lights continuously	Assign a spacer pellet to selected position	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
7	Assign a spacer pellet to position selected in step 5	Indicator lights next to Source, Spacer, and Reset keys begin flashing	If spacer pellet is to be assigned to selected position, press Spacer key;	Indicator light on source configuration display extinguishes	Assign a source or spacer to selected position	Low
8	Repeat steps 5-7 for all pellet positions assigned to the selected channel. When all positions have been assigned, go to step 9				Fail to repeat steps 5-7 as required	Low
9	Prepare to enter treatment time of selected channel	Prompt for channel treatment time	Press Time key	Indicators next to numerical keypad and Reset key begin flashing	Do not press Time key	Low
10	Specify treatment time for selected channel	Time shown in time display of selected channel	Enter 4-digit treatment time number using the format: hh mm/hr (i.e., hundredths of an hour)	Entered digits displayed	Enter wrong treatment time	Low
11	Exit Program mode	Channel programming complete	Enter valid 4-digit treatment time or Press Reset key three times	Afterloader enters rest state	Do not exit Program mode after completing channel programming	Low
12	Compose pellet train for programmed channel	At least one channel is programmed and assigned a treatment time greater than 0	Press Compose key	Indicators near keypad and Reset key flash; Status display for channel assembling pellet train shows letter 'C'; Pellet counter displays show number of pellets outside main safe; After channel has been composed, letter 'O' appears in channel status display	Do not press Compose key	Low

Afterloader Generic	
Function No. III	Function Title Treatment Delivery
Task No. 3	Task Title Verify Treatment Data Prior to Treatment
Task Performed By	Physicist, Radiation Therapy Technologist, Physician Supervisor Physicist, Physician
Equipment Needed	Treatment plan, Radiation prescription, Patient identification SKA Required Problem sensitivity, Information ordering, Perceptual speed and accuracy
Time Estimate (minutes)	Minimum / Typical / Maximum 5 / 7 / 15 Potential Distractor Level Low
Distraction Effects and Observations	Glare of overhead fluorescent lighting on afterloader control console display can hinder reading display information; Presence of observers and other medical personnel can draw attention from primary task to secondary tasks or irrelevant events.

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Display treatment parameters that have been entered into the afterloader control console for the scheduled treatment.	Treatment plan parameters; Patient I.D.; Fraction number; Radiation prescription	Display of treatment parameters	Treatment plan parameter values	Display wrong treatment plan	Low
2	Locate approved treatment plan for treatment about to be administered	Patient I.D.; Fraction number; Approved treatment plan	Location of treatment plan		Fail to locate the correct treatment plan for scheduled treatment	Low
3	Compare entered parameters with those from approved treatment plan	Treatment plan parameters entered into computer; Approved plan parameters	Visually and/or verbally compare the two sets of treatment plan parameters	Degree of match between entered and approved treatment plan parameters	Fail to detect discrepancies between entered and approved parameters	Low
4	If entered parameters do not match approved parameters, correct discrepancies	Results of comparison in step 3	Correct all discrepancies so that entered values match prescribed values	Mismatch(es) between entered and approved plan parameters	Fail to correct all discrepancies before authorizing plan to be administered to patient	Low
5	If entered parameters match approved plan parameters, authorize plan to be administered	Results of comparison in step 3	Sign treatment plan	Complete match between entered and approved plan parameters	Wrong person authorizes plan; Plan not verified prior to authorization	Low

Afterloader Generic		
Function No. III	Function Title Treatment Delivery	
Task No. 4	Task Title Treatment Session Monitoring	
Task Performed By	Radiation Therapy Technologist (HDR), Nurse (LDR), Physicist	Supervisor Physician
Equipment Needed	Remote afterloading system, Intercom, Closed-circuit TV camera	SKA Required Time sharing, Selective attention, Problem sensitivity
Time Estimate (minutes)	Minimum / Typical / Maximum 10 / 17 / 30 (HDR) 36 hr / 40 hr / 48 hr(LDR)	Potential Distractor Level Low
Distraction Effects and Observations	Presence of fellow workers and observers in workspace during treatment; Extraneous tasks during treatment session, e.g., answering telephone, responding to questions, can detract from monitoring patient session.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Monitor afterloader control console for progress of treatment and system status	Information about dwell times and positions for each channel; cumulative total treatment time; unusual or hazardous conditions requiring session to be interrupted or aborted	Monitor visual and auditory displays; respond to system error messages and alarms	Changing system status	Fail to be vigilant while monitoring session; Fail to make correct responses to anomalous conditions	Low
2	Monitor closed-circuit camera for patient movement	Patient image on monitor	Observe patient for any excessive movement that could shift applicator position	Patient image on monitor	Fail to monitor patient image	Low
3	Monitor intercom for patient comments	Patient verbalizations	Monitor intercom	Auditory	Fail to monitor patient verbalizations	Low
4	Instruct patient or terminate treatment as indicated.	Patient interference with equipment; malfunction of afterloader; patient instruction protocol; treatment termination protocol	Verbal or physical responses to system condition	System response to input	Fail to make appropriate responses	Low

Afterloader High Dose Rate Generic			
Function No. III	Function Title	Treatment Delivery	
Task No. 5	Task Title	Treatment Session Control—Interrupt Treatment	
Task Performed By	Radiation Therapy Technologist, Nurse, Physician		Supervisor Physician
Equipment Needed	MHDR afterloader; Door Interlock	SKA Required	Problem sensitivity, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum	1 / 2 / 30	Potential Distractor Level Low
Distraction Effects and Observations	Presence of observers in workspace can complicate monitoring of afterloader operation; Lack of familiarity with afterloader operation can slow response to interrupt treatment session; Problematic interpretation of error codes can hamper decision making.		

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Interrupt treatment session	Need to interrupt treatment (e.g., enter treatment room to reassure patient)	Press Interrupt button on afterloader control console	Yellow (treatment) lights flash as sources retract; Green lights illuminate; Radiation monitor indicates no radiation	Fail to make a needed interruption; Fail to press Interrupt button before entering treatment room	Low

Afterloader High Dose Rate Generic			
Function No.	III	Function Title	Treatment Delivery
Task No.	5	Task Title	Treatment Session Control—Normal Completion
Task Performed By	Radiation Therapy Technologist, Physicist		Supervisor Physicist
Equipment Needed	HDR afterloader		SKA Required Problem sensitivity, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum 1 / 1 / 2		Potential Distractor Level Medium
Distraction Effects and Observations		Presence of observers in workspace complicates performing every aspect of task.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	If another patient is scheduled immediately following current patient, refer to Function III, Task 2: Treatment Plan Entry	Treatment session schedule	Turn On/Off keyswitch to Prepare position	Program light on; system enters rest state	Do not turn keyswitch to Prepare	Low
2	If no additional patients are scheduled, verify that radioactive source is no longer exposed	Treatment session schedule; Radiation monitor information	Observe radiation monitor	Radiation monitor inactivated if source is not exposed	Do not check radiation monitor	Low
3	Turn On/Off keyswitch to Off and remove it	Standard procedure	Turn On/Off keyswitch to Off position and remove it	All indicator lights inactivate	Do not turn keyswitch Off or remove it	Low
4	Return keys to proper authority or store in designated location	Standard procedure	Give keys to authority or store in designated location		Give keys to wrong person or fail to store keys correctly	Low
5	Turn off all peripheral components	Standard procedure	Turn off power switches to peripherals	Peripherals inactivated	Do not turn off all peripherals	Low

Afterloader High Dose Rate Generic			
Function No.	III	Function Title	Treatment Delivery
Task No.	5	Task Title	Treatment Session Control—Terminate / Abort Treatment
Task Performed By	Radiation Therapy Technologist		Supervisor Physicist
Equipment Needed	HDR afterloader; User manual		SKA Required Problem sensitivity, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum 1 / 3 / 15		Potential Distractor Level Medium
Distraction Effects and Observations	Presence of observers in workspace complicates task of monitoring afterloader operation during treatment; Lack of familiarity with afterloader operation can slow decisions to abort treatment session; Problematic interpretation of error codes can hamper decision making.		

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Abort treatment session from afterloader control console area	Anomalous or dangerous system condition indicated	Press Emergency button on wall in afterloader control console area	Display shows source retraction; Radiation monitor indicates no radiation in treatment room	Fail to recognize emergency situation	Low
2	If source does not retract or radiation monitor remains on, go to step 3					
3	Abort treatment session by opening treatment room door	Performing step 1 did not retract source	Open treatment room door, activating door interlock mechanism to retract source	Radiation monitor indicates absence of radiation in treatment room	Fail to take appropriate alternative action after step 1 fails	Low
4	If source does not retract or radiation monitor remains on, go to step 5					
5	Abort treatment session by pressing Emergency button on afterloader trolley	Performing steps 1 and 3 did not retract source	Enter treatment room and press Emergency button on afterloader trolley	Source retraction displayed; radiation monitor inactivates	Fail to take appropriate alternative action after step 3 fails	Low
6	If source does not retract or radiation monitor remains on, go to step 7					
7	Abort treatment session by manually retracting source with hand crank	Performing steps 1 to 5 did retract source	Enter treatment room and turn hand crank on source head to retract source	Source retracts, radiation monitor inactivates	Fail to take proper action after steps 1 to 5 fail; Source not cranked completely back into source head	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
8	If source does not retract or radiation monitor remains on, go to step 9					
9	Disconnect source guide tube with stuck source from afterloader source head and patient	Performing steps 1 to 7 did not retract source; Source visible in source guide tube	Disconnection of source guide tube from afterloader and patient		Fail to remove source guide tube; Drop source guide tube while moving it	Low
10	Place hot source guide tube in emergency source container using long-reach forceps	Emergency procedure	Placement of hot source guide tube in emergency container	Radiation monitor inactivates	Drop source guide tube; Use wrong container for emergency source storage; Do not use long-handle forceps to retrieve source	Low
11	Remove patient from treatment room and seal room	Emergency procedure	Take patient from room then seal room		Leave patient in room longer than necessary; Fail to seal room	Low
12	Notify hospital / clinic personnel designated to recover unshielded source	Source not in afterloader safe	Request presence of radiation emergency personnel	Personnel respond to request	Fail to notify proper emergency personnel; Failure of these personnel to respond in a timely manner	Low
13	Notify remote afterloader distributor regarding afterloader malfunction	Operability problem with afterloader	Notify afterloader distributor by telephone and in writing	Personnel advise regarding appropriate action	Service personnel do not provide needed information in a timely manner	Low

Afterloader Low Dose Rate Generic	
Function No. III	Function Title Treatment Delivery
Task No. 5	Task Title Treatment Session Control—Terminate / Abort Treatment
Task Performed By Radiation Therapy Technologist	Supervisor Physicist
Equipment Needed Low dose rate afterloader; User manual	SKA Required Problem sensitivity, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum 1 / 3 / 15	Potential Distractor Level Medium
Distraction Effects and Observations Presence of observers in workspace complicates task of monitoring afterloader operation during treatment; Lack of familiarity with afterloader operation can slow decisions to abort treatment session; Problematic interpretation of error codes can hamper decision making.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Abort treatment session from remote control console outside treatment room	Anomalous or dangerous system condition indicated	Press Stop button on remote control unit (Stop button is labeled Interrupt on some units)	Yellow (treatment) lights flash as sources retract; Green lights illuminate; Radiation monitor indicates no radiation in treatment room	Fail to recognize emergency situation	Low
2	If source does not retract or radiation monitor remains on, go to step 3					
3	Abort treatment session by opening treatment room door	Performing step 1 did not retract source	Open treatment room door, activating door interlock mechanism to retract source	Yellow (treatment) lights flash as sources retract; Green lights illuminate; Radiation monitor indicates no radiation in treatment room	Fail to take appropriate alternative action after step 1 fails	Low
4	If source does not retract or radiation monitor remains on, go to step 5					
5	Disconnect source guide tube with stuck source from afterloader source head and patient	Performing steps 1-3 did not retract source; Source visible in source guide tube	Disconnection of source guide tube from afterloader and patient		Fail to remove source guide tube; Drop source guide tube while moving it	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
6	Place hot source guide tube in emergency source container using long-reach forceps	Emergency procedure	Placement of hot source guide tube in emergency container	Radiation monitor inactivates	Drop source guide tube; Use wrong container for emergency source container; Do not use long-reach forceps to retrieve source	Low
7	Remove patient from treatment room and seal room	Emergency procedure	Take patient from room then seal room		Leave patient in room longer than necessary; Fail to seal room	Low
8	Notify hospital/clinic personnel designated to recover unshielded source	Source not in afterloader safe	Request presence of radiation emergency personnel	Personnel respond to request	Fail to notify proper emergency personnel; Failure of these personnel to respond in a timely manner	Low
9	Notify remote afterloader distributor regarding afterloader malfunction	Operability problem with afterloader	Notify afterloader distributor by telephone and in writing	Personnel advise regarding appropriate action	Service personnel do not provide needed information in a timely manner	Low

Afterloader Low Dose Rate Generic	
Function No. III	Function Title Treatment Delivery
Task No. 5	Task Title Treatment Session Control—Interrupt Treatment
Task Performed By	Nurse, Radiation Therapy Technologist, Physicist Supervisor Physicist
Equipment Needed	Remote control unit outside treatment room SKA Required Problem sensitivity, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum	2 / 5 / 10 Potential Distractor Level Low
Distraction Effects and Observations	Observers in workspace complicates task of monitoring afterloader operation ; Lack of familiarity with afterloader operation can slow decisions to interrupt session; Problematic interpretation of error codes can hamper decision making

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Interrupt treatment session for routine purposes (e.g., visitors, meals)	Non-critical need to interrupt treatment	Press Stop button on remote control unit (Stop button is labeled Interrupt on some units)	Yellow (treatment) lights flash as sources retract; Green lights illuminate and radiation monitor indicates no radiation	Fail to press Interrupt button before opening treatment room door	Low

Afterloader		MicroSelectron Low Dose Rate	
Function No.	III	Function Title	Treatment Delivery
Task No.	5	Task Title	Control Treatment Session - Normal Completion (Return Source Assemblies to Storage Container)
Task Performed By	Radiation Therapy Technologist		Supervisor Physicist
Equipment Needed	MLDR afterloader, Source storage container		SKA Required Problem sensitivity, Finger dexterity, Manual dexterity, Arm-hand steadiness
Time Estimate (minutes) Minimum / Typical / Maximum			Potential Distractor Level
5 / 10 / 15			Low to Medium
Distraction Effects and Observations		Presence of non-essential personnel can draw attention from the primary task. Competing demands of other tasks can create time pressure to perform tasks as quickly as possible. Both these situations increase error likelihood.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Verify that the correct source storage container is being used	Print-out of source storage container connections; Number on storage container	Container number on print-out matches that on source storage container	Visual	Fail to check correspondence of container numbers	Low
2	Verify that source selection tubes and storage container positions match print-out data	Print-out of storage container connections	Print-out data match source selection tubes and storage container positions	Visual	Fail to check correspondence of selected source channels	Low
3	Open source storage container cover	Standard procedure	Unlock cover, slide it up post, rotate it 180 degrees clockwise	Cover falls into locked position	Fail to secure cover in locked position	Low
4	Position source storage container close to remote afterloader and attach treatment tube	Standard procedure	Position storage container and afterloader within 5 feet of each other; Connect treatment tube to storage container		Fail to position storage container and afterloader correctly	Low
5	Make required connections to transfer source assemblies from remote afterloader to storage container	Standard procedure	Attach quick connector to storage container; Push connector down and turn clockwise to align position markers; Connect storage container to wall connector via cable	Source registration indicator on afterloader control console illuminates	Fail to make proper connections	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
6	Specify source assemblies to be transferred to storage container	Treatment plan assignments for source assemblies	Select all channels with sources to be stored using keypad	Corresponding channel indicators illuminate	Select wrong channels; Fail to push connectors firmly down; Fail to connect all 15 quick connectors to a storage container safe	Low
7	Transfer source assemblies to storage container	All necessary connections have been made	Turn keyswitch to Treatment position on afterloader control console; Exit treatment room, closing door; Press Start key on remote control console	Start and Safe lights inactivate after Start key is pressed; Treatment light flashes after Start key is pressed; When transfer is complete, Start light flashes	Do not turn keyswitch to Treatment position; Do not press Start key	Low
8	Verify that source assemblies transfer is complete and successful	Start indicator flashing; Radiation monitor off	Re-enter treatment room; Check that green channel indicators are off; Check print-out for error messages	Channel indicators and radiation monitor light inactivate; Print-out from afterloader control console	Fail to check channel indicators and any error messages that may have printed out	Low
9	Shut down afterloader system	Standard procedure	Disconnect treatment tube from storage container; Close and lock storage container lid; Disconnect air tube from afterloader		Fail to perform all actions needed to shut down system	Low

Afterloader Selectron Low Dose Rate	
Function No. III	Function Title Treatment Delivery
Task No. 5	Task Title Treatment Session Control—Normal Completion
Task Performed By	Nurse, Radiation Therapy Technologist, Physicist Supervisor Physicist
Equipment Needed	SLDR afterloader, Nurse station monitor, Remote control unit SKA Required Problem sensitivity, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum 5 / 10 / 15 Potential Distractor Level Low to Medium
Distraction Effects and Observations	Length of LDR treatment sessions means they can end during off hours for LDR staff; consequently, LDR staff may not be available. Even if session ends during working hours, LDR personnel may be involved in other activities, delaying performance of this task.

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Determine that treatment session is over	Displays on treatment status timers on remote control unit	Observe treatment status timers	Timers show no treatment time remaining for channel receiving longest treatment	Fail to check timers	Low
2	Determine that all sources have returned to intermediate safe	Green channel indicators on remote control unit are on; Yellow channel indicators are off	Check channel displays for expected configuration	Visual	Do not check channel displays on remote control unit; Misinterpret channel displays	Low
3	Enter treatment room, checking independent radiation monitor	Radiation warning light should off	Check radiation monitor inside treatment room	Visual	Do not check radiation monitor	Low
4	Turn keyswitch on afterloader control console to Prepare position	Normal termination of treatment session	Turn keyswitch to Prepare position	Total errors encountered during treatment are printed	Do not turn keyswitch to Prepare position	Low
5	Prepare to sort all channels used during the session	Normal termination of treatment session	Press Sort key	Indicators next to numerical keypad and Reset key begin flashing	Do not press Sort key	Low
6	Sort all used channels	Indicators next to numerical keypad and Reset key are flashing	Enter number of each channel to be sorted, followed by pressing '0'	Channels status display shows 'S' while specified channels are sequentially sorted; Pellet counter displays are updated each time a pellet is detected by a sorter detector	Do not specify all used channels; Do not press '0' to initiate sorting	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
7	Acknowledge termination of sorting	Channel status display is blanked; Source configuration and Treatment time displays are cleared	Observe display for termination of sorting	Channel indicators show that sorting is completed	Do not realize that sorting is completed	Low
8	Move remote afterloader away from its bedside position	Standard procedure	Move afterloader away from bed	Position of afterloader	Do not move afterloader out of the way	Low
9	Move bed shields from their bedside positions	Standard procedure	Move bed shields from their bedside positions	Position of bed shields	Do not move bed shields	Low
10	Turn keyswitch on afterloader control console to Off position and remove it	Standard procedure	Turn keyswitch to Off	Afterloader control console displays go blank	Do not turn keyswitch to Off; Do not remove key	Low
11	Return key to proper authority or store in designated location	Standard procedure	Give key to authority or store in designated location		Give key to wrong person or fail to store keys correctly	Low

Function IV

Post-Treatment

Afterloader Generic	
Function No. IV	Function Title Post-Treatment
Task No. 1	Task Title Source Guide Tube Disconnection
Task Performed By	Radiation Therapy Technologist, Nurse, Physicist, Physician Supervisor Physician
Equipment Needed	Remote afterloader, Radiation monitor, SKA Required Problem sensitivity, Manual dexterity, Finger dexterity, Arm-hand steadiness
Time Estimate (minutes)	Minimum / Typical / Maximum 1 / 5 / 10 Potential Distractor Level Low
Distraction Effects and Observations Presence of personnel not directly involved in task can hinder task performance.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Determine that treatment session is over	Displays of treatment status on afterloader control console	Evaluate displays	Displays show that treatment is completed	Do not check displays	Low
2	Check for presence of radiation in treatment room	Light on independent radiation monitor	Check light on independent radiation monitor	Radiation monitor light will be on or off	Fail to check independent monitor	Low
3	Enter treatment room	Afterloader control console display indicates source has retracted; Radiation monitor is inactivated	Open treatment room door		Fail to check afterloader control console and radiation monitor displays before entering treatment room	Low
4	Disconnect source guide tube from applicator	Procedure for disconnecting source guide tubes	Source guide tube disconnected from its applicator		Fail to detach all source guide tubes from applicator	Low
5	Disconnect source guide tube from its channel on afterloader	Procedure for disconnecting source guide tubes	Source guide tube disconnected from its afterloader channel		Fail to detach all source guide tubes from afterloader	Low
6	Repeat steps 4-6 for each source guide tube				Fail to repeat steps 4-6 for all source guide tubes	Low
7	Move afterloader out of treatment position	Standard procedure	Afterloader moved out of treatment position	Brake light inactivates	Fail to release brake. Fail to move afterloader.	Low
8	Prepare source guide tubes for later re-use	Local procedure for preparing source guide tubes	Source guide tubes ready to re-use		Fail to prepare source guide tubes for re-use	Low
9	Label and store source guide tubes for later re-use	Local procedure for labeling and storing source guide tubes	Source guide tubes labeled and stored in proper location		Fail to label and store source guide tubes	Low

Afterloader Generic		
Function No. IV	Function Title Post-Treatment	
Task No. 2	Task Title Applicator Removal	
Task Performed By	Physician, Nurse, Radiation Therapy Technologist	Supervisor Physician
Equipment Needed	Applicators, Applicator removal tools	SKA Required Problem sensitivity, Manual dexterity, Finger dexterity, Arm-hand steadiness
Time Estimate (minutes)	Minimum / Typical / Maximum 5 / 10 / 20	Potential Distractor Level Low
Distraction Effects and Observations Presence of personnel not directly involved in task can hinder task performance.		

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Prepare the patient medically for applicator removal	Medical requirements for applicator removal	Patient preparation procedures	Patient ready for applicator removal	Fail to prepare patient	Low
2	Note the curvature, size, and flexibility of the applicator to be removed	Applicator characteristics that affect removal procedures	Inspection of applicator	Visual	Fail to take applicator characteristics into account	Low
3	Select a removal route and procedure	Possible applicator removal routes	Selection of applicator removal route and procedure		Select poor removal route and/or procedure	Low
4	Gently pull the applicator, guiding it out of the patient's body so as to produce minimal tissue damage and minimum trauma during its removal	Applicator position and progress along the removal route; Tissue damage and trauma expected as a consequence of applicator removal	Removal of applicator from patient	Applicator removed from patient	Injure patient during applicator removal	Low
5	Repeat steps 2-5 for each applicator	Number of applicators to be removed			Fail to repeat steps 2-5 for each applicator	Low
6	Treat the patient medically for any trauma caused by the removal procedure	Trauma caused by applicator removal; Patient treatment needs	Patient treatment	Patient response to treatment	Fail to administer to patient's treatment needs	Low

Afterloader High Dose Rate Generic			
Function No. IV	Function Title	Post-Treatment	
Task No. 3	Task Title	Patient Transportation	
Task Performed By	Nurse, Radiation Therapy Technologist	Supervisor	Physician
Equipment Needed	Gurney, wheelchair, patient monitoring devices	SKA Required	Oral expression, Arm-hand steadiness, Multi-limb coordination, Static strength
Time Estimate (minutes)	Minimum / Typical / Maximum	1 / 5 / 15	Potential Distractor Level Low
Distraction Effects and Observations			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Remove patient from treatment delivery area and move to recovery or discharge area.	Destination description that takes current condition of patient into account	Recognition of transportation request information		Fail to understand or respond to transportation request	Low
2	Assess patient transportation and support requirements	Physician's orders. Patient needs	Transportation and support requirements		Fail to properly assess patient transportation and support requirements	Low
3	Determine the transportation route.	Destination Possible paths Path characteristics	Transport route choice		Fail to use the most efficient transportation route	Low
4	Assemble transportation and support equipment.	Requirements from step 2. Equipment available	Equipment assembled		Use wrong transport equipment; Assemble transport equipment incorrectly	Low
5	Accept patient information and responsibility from the RAB staff.	Patient's special requirements	Transference of information and responsibility	Verbal contact from local staff	Fail to contact local staff; Fail to ask for special instructions	Low
6	Inform the patient of the purpose of the trip.	Purpose of trip. Destination	Verbal message to patient	Patient response	Fail to inform patient	Low
7	Remove the patient from the local support equipment and place patient on the transport support equipment.	Equipment operation specifications	Patient positioned on transport equipment	Visual	Failure to transfer patient smoothly can alter applicator positions	Med
8	Move the patient along the chosen route to destination.	Chosen route Feedback along route	Transportation of patient to destination	Route markers	Failure to move patient carefully can alter applicator positions	Med

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
9	Transfer the patient from the transport equipment to the destination equipment.	Equipment operation specifications	Patient positioned at destination	Visual	Failure to transfer patient smoothly can alter applicator positions	Med*
10	If destination is recovery room, pass information and responsibility for the patient to the destination staff.	Patient name Scheduled procedure	Information on patient's special requirements	Acknowledgement by destination staff	Fail to pass all relevant information to destination staff	Low

* Depends on type of applicators used.

Afterloader				Generic			
Function No.		IV		Function Title		Post-Treatment	
Task No.		4		Task Title		Treatment Verification	
Task Performed By		Radiation Therapy Technologist, Physician, Physicist				Supervisor Physician, Physicist	
Equipment Needed		Remote afterloader; Radiation prescription		SKA Required		Written comprehension, Problem sensitivity, Information ordering	
Time Estimate (minutes)		Minimum / Typical / Maximum		5 / 8 / 15		Potential Distractor Level Medium	
Distraction Effects and Observations		Competing demands for time and attention (e.g., preparing for another treatment session) can interfere with verification task.					

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Obtain hard copy of treatment session data	Treatment session is over	Retrieve print-out of session from afterloader printer	Hard copy of treatment session data	Do not obtain print-out of treatment session	Low
2	Verify that radiation delivered to patient matches radiation prescription	Radiation prescription; Print-out of treatment session data	Check correspondence between prescribed and delivered radiation dosages	Visual	Do not detect existing discrepancies between prescribed and delivered dosages	Low
3	If discrepancies are found, include them as part of the record for that treatment session	Discrepancies between prescribed and delivered dosages	Report of these discrepancies		Do not report discrepancies	Low

Afterloader Generic	
Function No. IV	Function Title Post-Treatment
Task No. 5	Task Title Record-keeping
Task Performed By	Physician, Radiation Therapy Technologist, Nurse, Physicist Supervisor Physician, Physicist
Equipment Needed	Patient treatment session records (print-out from afterloader control unit); Treatment plan; Signature sheets for treatment; Hand calculations of treatment parameters; QA forms for treatment session SKA Required Written comprehension, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum 5 / 8 / 15 Potential Distractor Level Low
Distraction Effects and Observations	Possible concurrent tasks with treatment termination can interfere with the collection and correct routing of treatment and session records and files; Important to assign record-keeping tasks to personnel who are not likely to experience competing demands for their time.

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Collate patient brachytherapy forms into patient file	Brachytherapy records, Treatment plan, Hard copy from printer, patient therapy form	Collate patient forms into file for that patient		Fail to collate forms properly	Low
2	Collate treatment session forms into proper department files	Forms about QA procedures, any irregularities in equipment operation, any events during treatment session that could affect treatment outcome	Collate all forms in proper department files		Fail to collate forms into proper files	Low

Function V

Quality Assurance and Maintenance

Afterloader High Dose Rate Generic			
Function No. V	Function Title Quality Assurance and Maintenance		
Task No. 1	Task Title Source Exchange—Install a New Source		
Task Performed By	Physicist or Afterloader service personnel		Supervisor Physicist
Equipment Needed	HDR afterloader, source installation equipment (source loading tools, source transport container, etc.)	SKA Required	Problem sensitivity, Information ordering, Finger dexterity
Time Estimate (minutes) Minimum / Typical / Maximum		20 / 30 / 60	Potential Distractor Level Low
Distraction Effects and Observations		This task is done about once every 3 months. Because of its criticality, it is important to perform it correctly.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Position source transport with new source adjacent to afterloader with afterloader source head in its lowest position	Standard procedure for source installation; Checklist of procedure Same for all steps below	Container and afterloader positioned for source installation		Fail to position container and afterloader properly	Low
2	Open transport container		Container lid opened		Do not open container; Open wrong container	Low
3	Check readiness of transport container to install new source		Verify that source clamp on transport container is locked	Visual confirmation of clamp position	Do not lock source clamp lever	Low
4	Prepare source drive cable for installation		Remove and unwrap source drive cable from transport container		Do not remove and unwrap cable	Low
5	Connect load tool to afterloader source head		Insert load tool into channel 1 of source head		Connect load tool to other than channel 1; Do not check that locking ring is locked	Low
6	Insert end of source drive cable into load tool, feed it until it reaches cable drum inside source head		Cable fed into source head and abuts cable drum	Cable cannot be pushed any farther into source head	Do not feed cable far enough into source head	Low
7	Attach the source drive cable to its cable drum using appropriate technique for afterloader cable drum		Feed cable until it enters the cable drum	Cable attached to cable drum	Do not seat cable into cable drum	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
8	Perform visual and physical checks of cable seating		Visually check that cable end is seated in the cable drum slot and that cable stops at the end; Pull on cable to test its connection to cable drum	Visual conformation of proper seating of cable into cable drum	Do not check for proper seating; Do not pull on cable	Low
9	Prepare to transfer new source from transport container to afterloader		Unlock source clamp on transport container		Do not move lever to up position	Low
10	Exit treatment room		Treatment room unoccupied		Do not leave room; Do not close door completely	Low
11	Program afterloader control console to transfer new source from storage container to afterloader		Programming of afterloader	Afterloader enters system source transfer mode	Fail to program afterloader correctly	Low
12	Transfer source from storage container to afterloader		Activate appropriate control on afterloader control console	Afterloader control console display shows that source has moved from storage container to afterloader	Do not activate appropriate control	Low
13	Check radiation monitors before re-entering treatment room		Observe radiation monitors	Radiation monitors will be illuminated if radiation is present in treatment room	Do not check radiation monitors before entering treatment room	Low
14	If radiation monitors indicate no radiation, enter treatment room		Transfer of new source from storage container to afterloader completed	Source cable should be extended and source in afterloader	Do not check radiation level before entering treatment room; Do not leave door open	Low
15	Remove load tool from afterloader source head		Load tool detached from source head		Do not disengage load tool	Low
16	Close empty storage container and store it		Close and lock lid of container; Store container in authorized location		Do not lock container lid; Do not store in authorized location	Low

Afterloader High Dose Rate Generic					
Function No.	V	Function Title	Quality Assurance and Maintenance		
Task No.	1	Task Title	Source Exchange—Remove an Old Source		
Task Performed By	Physicist or Afterloader service personnel			Supervisor	Physicist
Equipment Needed	HDR afterloader, Source unloading tools, Source transport container		SKA Required	Problem sensitivity, Information ordering, Finger dexterity	
Time Estimate (minutes)	Minimum / Typical / Maximum 20 / 30 / 60			Potential Distractor Level	Low
Distraction Effects and Observations	This task is done about once every 3 months. Because of its criticality, it is important to perform it correctly.				

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Position empty transport container adjacent to afterloader with afterloader source head in its lowest position	Standard procedure for source removal; Checklist of procedure Same for all Steps below	Container and afterloader positioned for source removal		Fail to position container and afterloader properly	Low
2	Open empty source transport container		Container lid opened		Do not open container; Open wrong container	Low
3	Connect unload tool to afterloader source head and to empty transport container		Connect one end of unload tool to afterloader source head and other end to source transport container	Unload tool clicks into place at both its ends	Fail to connect unload tool properly	Low
4	Check readiness of transport container to receive old source		Verify that source clamp on empty transport container is unlocked	Visual confirmation of clamp position	Do not check that source clamp is unlocked	Low
5	Exit treatment room		Treatment room unoccupied		Do not leave room; Leave someone in room	Low
6	Program afterloader control console to transfer old source from afterloader to storage container		Programming of afterloader	Afterloader enters system source transfer mode	Fail to program afterloader correctly	Low
7	Transfer source from afterloader to empty container		Activate appropriate control on afterloader control console	Afterloader control console displays show that source has moved from afterloader to storage container	Do not activate appropriate control	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
8	Check radiation monitors before re-entering treatment room		Observe radiation monitors	Radiation monitors will be illuminated if radiation is present in treatment room	Do not check radiation monitors before entering treatment room	Low
9	If radiation monitors indicate no radiation, enter treatment room		Transfer of old source from afterloader to transport container completed	Source cable should be extended and source in transport container	Enter treatment room with radiation monitors illuminated	Low
10	Lock transferred source into transport container		Move source clamp lever on container to locked position	Source clamp lever in down position	Do not lock source container	Low
11	Disengage the drive cable for the old source from the afterloader		Source drive cable detached from afterloader source head	Drive cable separated from source head	Do not detach source drive cable	Low
12	Disengage unload tool from afterloader and transport container		Unload tool disconnected from afterloader and container	Unload tool separated from afterloader and transport container	Do not disengage unload tool from afterloader and container	Low
13	Place source drive cable in container		Source drive cable coiled into container	Drive cable in transport container	Do not coil cable into transport container	Low
14	Close transport container and store it		Close and lock lid of container; Store container	Container lid locked; Container stored	Do not lock container lid; Do not store in authorized location	Low

Afterloader High Dose Rate Generic			
Function No. V	Function Title Quality Assurance and Maintenance		
Task No. 2	Task Title Source Calibration		
Task Performed By	Physicist		Supervisor Physicist
Equipment Needed	High dose rate afterloader, Ionization chamber, Dosimeter, Jig for holding source guide tubes and ionization chamber	SKA Required	Problem sensitivity, Deductive reasoning, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum		30 / 60 / 90	Potential Distractor Level Low
Distraction Effects and Observations		This task should be done immediately after every source exchange. In principle, the basic procedures are the same regardless of whether calibration occurs in air, water, or a phantom.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Place ionization chamber and source source guide tube in the activity check jig	Standard procedure for setting up calibration equipment	Place ionization chamber and source guide tubes into their correct locations in the activity check jig	Components located in their correct position in jig	Imprecise positioning of components	Low
2	Connect source guide tubes to afterloader unit	Standard procedure for setting up calibration equipment	Connect source guide tubes to afterloader source head via adaptors; Check that adaptors are locked in position	Locking ring on source head snaps into position	Adaptor plungers not pushed in completely; Locking ring not put into its locked position	Low
3	Exit treatment room, closing door completely	Standard procedure for setting up calibration equipment	Exit treatment room, closing door completely	Door closes	Fail to close door completely	Low
4	Ensure that source can be observed while in extended position in jig	Visual image supplied by closed circuit camera	Orient and focus closed circuit camera on jig so that source can be seen while it is extended	Visual	Fail to adjust camera so source can be viewed while extended	Low
5	Ready dosimeter for calibration procedure	Standard procedure for setting up calibration equipment	Activate dosimeter power switch; Allow dosimeter to warm up before calibrating source	Power indicator illuminates	Fail to turn on dosimeter; Fail to allow sufficient warm-up time before starting calibration procedure	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
6	Program afterloader control console to extend source	Channels to be programmed; Length of time source is to be extended in each channel	Specify channel(s) to which source guide tubes are connected; Specify the time source is extended into each channel	Echo of entered information on the afterloader control console display	Specify wrong channels and / or wrong dwell times	Low
7	Check that dosimeter display is zeroed out	Value on dosimeter display	Visual check of dosimeter display; Reset display if it does not show '0'	When reset, display shows '0' reading	Fail to reset dosimeter when it shows a non-zero reading	Low
8	Start calibration procedure by extending source from afterloader	Readiness of system to begin calibration	Press Start key on afterloader control console	Radiation indicator illuminates; Afterloader control console display shows that treatment has begun; camera image shows source in correct position in jig	Fail to extend source	Low
9	Verify via closed circuit camera that source is in proper position during calibration procedure	Image on closed circuit camera screen	Visually check that source is extended into correct position so that dosimeter reading is valid	Visual	Fail to visually check location of source	Low
10	Upon source retraction, record dosimeter reading on proper QA form	System indications that source has retracted: Radiation indicator off, Afterloader control console display shows all channels treated, visual image shows source has retracted	Record value on dosimeter display onto QA form; Reset dosimeter	Properly filled out QA form	Fail to record dosimeter value or record wrong value; Fail to reset dosimeter after recording value	Low
11	Repeat steps 6-10 using another exposure time, if required by in-house protocol	Particular source calibration protocols vary from site to site			Fail to adhere to calibration protocol	Low
12	Enter treatment room; Record air temperature and atmospheric pressure on QA form	All procedures involving source movement are completed	Record readings on thermometer and barometer installed in treatment room	Visual	Fail to record readings or record incorrect values for readings	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
13	Calculate source activity level based on calibration data	Dosimeter source activity value, room temperature, and atmospheric pressure	Manually calculate source activity using correct source calibration equations and correct temperature and pressure adjustments		Commit computational error; Use wrong formulas; Fail to make all necessary adjustments for environmental conditions	Low
14	Compare results of manual computations with expected source activity value for calibration date (based on activity value supplied by source manufacturer and taking half-life of iridium-192 into account)	Source activity values based on manual computations using calibration data and based on manufacturers data	If calculated activity value differs from expected activity value by more than 5%, recheck calculations done in step 13. If discrepancy still exists, repeat steps 6-13		Fail to check and/or detect calculated values that differ by more than 5% from expected values	Low
15	Enter source activity into afterloader control console	Valid source activity value	Enter calculated source activity value into afterloader control console; If necessary, set afterloader control console hardware to calibration date	Echo of entered information on afterloader control console display	Enter indicated data incorrectly	Low
16	Independently verify that the correct values for source activity and calibration date have been entered into afterloader control console	Indicators on afterloader unit and / or computer display for source activity value and calibration date	Preferably done by a person other than the one who entered the data; Confirm that source activity and calibration date have been entered correctly	Data entries for source calibration and source activity calculation	Fail to independently cross-check correctness of entered data; Fail to detect discrepancies between calculated and expected values	Low

Afterloader Generic			
Function No. V	Function Title Quality Assurance and Maintenance		
Task No. 3	Task Title Equipment and Software Updates		
Task Performed By	Physicist, Dosimetrist, Radiation Therapy Technologist, Service Representatives		Supervisor Physicist
Equipment Needed	Updated software and user manuals	SKA Required	Oral comprehension, Oral expression, Written comprehension, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum			Potential Distractor Level Low
Distraction Effects and Observations Heavy schedule of regular activities can make arranging meetings problematic.			

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Receive updated instructions for operation and maintenance of remote afterloading system	Various instructional materials	Inform, via memos and formal and informal meetings, all concerned medical and support staff of the changes that have occurred in operating and maintenance procedures. File updated instructional materials in proper places		Fail to apprise brachytherapy staff of updated instructions; fail to file instructions in correct places	Low
2	Receive updated computer program for treatment planning, treatment delivery, and/or maintenance activities	Updated computer programs	Inform, via memos and formal and informal meetings, all concerned medical and support staff of the software changes and how these changes will affect current procedures.		Fail to inform staff that updated software has been received; fail to explain changes adequately	Low

Afterloader Generic			
Function No. V	Function Title Quality Assurance and Maintenance		
Task No. 4	Task Title Troubleshooting		
Task Performed By	Physicist, Remote afterloader service personnel (via telephone or in-person), Radiation Therapy Technologist	Supervisor	Physicist; Facility Radiation Safety Officer
Equipment Needed	Remote afterloader, User manuals	SKA Required	Problem sensitivity, Speed of closure, Inductive reasoning, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum 5 / 15 / 60	Potential Distractor Level Low	
Distraction Effects and Observations	If the malfunction is critical (i.e., it entails exposing patient or staff to excessive levels of radiation) the urgency of removing this hazard may lead to deviations from set procedures. The presence of observers and others not directly related to treatment administration may hamper brachytherapy personnel in isolating and rectifying the problem.		

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Given an afterloader malfunction, interpret error code generated by afterloader	Error code shown on afterloader display	Refer to user manual to determine meaning of error code	Identification and explanation of error in user manual	Fail to refer to most appropriate section of user manual; Fail to understand explanation of error given by user manual	Low
2	Given identification of error in step 1, determine appropriate remedial action	Error explanation supplied by user manual	Remedial action to correct error	Various, depending on error	Incorrect remedial action selected to correct error	Low
3	If error can be rectified by on-site personnel, do so	Information about error obtained in step 1	Take appropriate action to rectify error and resume afterloader operation	Various, depending on action taken	Fail to select proper course of action; Fail to correctly execute a properly chosen course of action	Low
4	If error cannot be rectified by on-site personnel, initiate telephone contact with afterloader service personnel	Information about error obtained in step 1	Notify service personnel of problem; follow their recommendations	Comments of service personnel	Fail to notify service personnel; Fail to understand their recommendations	Low

Afterloader Generic	
Function No. V	Function Title Quality Assurance and Maintenance
Task No. 5	Task Title Routine Quality Assurance—System Alarms and Interrupts: Door Interlock Test
Task Performed By	Physicist, Radiation Therapy Technologist Supervisor Physicist
Equipment Needed	Remote afterloader, Door interlock SKA Required Problem sensitivity, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum	3 / 5 / 10 Potential Distractor Level Low
Distraction Effects and Observations	QA procedures are often conducted in a less structured manner than treatment-related activities. More opportunity thus exists for some QA tasks to be overlooked or performed in a way that deviates from the prescribed procedures.

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Program afterloader to extend a source through one channel	Standard procedure for door interrupt test	Program afterloader to extend a source through one channel	Indicator lights confirm programming has been done as intended	Program afterloader incorrectly	Low
2	Start mock treatment session	One channel of afterloader has been programmed	Press Start key on afterloader control panel	Indicator lights illuminate, showing that source is being extended into the programmed channel	Do not press Start key	Low
3	Open treatment room door	Test door interlock operation	Open treatment room door	Sources retract, Radiation indicators on afterloader control console and in treatment room inactivate	Do not open treatment room door far enough to trigger source retraction	Low
4	Record results of door interrupt test on proper QA form	Results of door interrupt test	Record results of test on proper QA form	Successful completion of door interrupt QA test	Do not record test outcome on QA form	Low

Afterloader Generic	
Function No. V	Function Title Quality Assurance and Maintenance
Task No. 5	Task Title Routine Quality Assurance—System Alarms and Interrupts: Radiation Warning Light Test
Task Performed By	Physicist, Radiation Therapy Technologist Supervisor Physicist
Equipment Needed	Radiation warning lights: outside and inside treatment room SKA Required Problem sensitivity, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum 5 / 10 / 20 Potential Distractor Level Low	
Distraction Effects and Observations	QA procedures are often conducted in a less structured manner than treatment-related activities. There is thus more opportunity for certain QA procedures to be overlooked or performed in a way other than intended. Potential deviations can be overcome by using standard forms that explicitly list each step in a given QA procedure.

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Test radiation monitor outside treatment room	Standard procedure for programming remote afterloader	Program one channel of afterloader to extend source for a short time period; Extend source	Radiation monitor should illuminate as source extends and inactivate after source retracts	Fail to correctly program afterloader and extend source; Fail to note radiation monitor response while source is extended	Low
2	Test independent radiation monitor inside treatment room	Standard QA procedure for radiation monitor check	Test the radiation monitor powered by the backup battery (unplug from house power source); Use the check source	Radiation monitor should illuminate when exposed to check source	Fail to test independent radiation monitor; Fail to unplug primary power source and use backup battery	Low
3	Record test results on proper QA form and sign it	Results of radiation monitor tests in steps 1–2	Recording of results of tests in steps 1–2	Record of test results	Fail to record test results; Fail to sign QA form	Low

Afterloader Generic			
Function No. V	Function Title Quality Assurance and Maintenance		
Task No. 5	Task Title Routine Quality Assurance—Autoradiography of Source Position		
Task Performed By	Radiation Therapy Technologist, Physicist		Supervisor Physicist
Equipment Needed	Remote afterloader, X-ray film	SKA Required	Problem sensitivity, Information ordering
Time Estimate (minutes)	Minimum / Typical / Maximum	15 / 30 / 60	Potential Distractor Level Low
Distraction Effects and Observations		QA activities are often done in a less structured manner than are other remote afterloading activities. The use of a checklist helps to assure that steps are done in the proper sequence.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Attach a source guide tube to x-ray film	Standard QA procedure	Tape source guide tube to treatment table on top of single sheet of x-ray film; Connect source guide tube to an afterloader channel	Source guide tube placed as desired	Do not tape source guide tube securely to film and table; Use wrong type of film; Connect source guide tube to wrong channel	Low
2	Prepare film for source position check	Standard QA procedure	Place pinprick in film at tip of source guide tube	Pinprick in film	Imprecise placement of pinprick in film	Low
3	Position closed circuit camera to view film	Standard QA procedure	Center camera image on film and source guide tube assembly	Image on CRT	Do not center image	Low
4	Program afterloader for autoradiography position check	Program light on	Specify channel connected to source guide tube; dwell position and dwell time parameters; When finished turn keyswitch to Start (or Remote Control) position	Display shows specified channel, length, position number, and dwell time parameters; Start (or Remote Control) light illuminates	Specify incorrect parameters for QA session; Do not turn keyswitch to correct position	Low
5	Close treatment room door	Start light on	Close treatment room door, making sure no one is left inside		Do not close door securely; Fail to check for personnel left inside treatment room	
6	Extend source from afterloader	Display shows specified channel, length, position, and dwell time parameters	Press Start key on afterloader control panel	Source stays in each programmed position for the specified time	Do not press Start key	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
7	Observe QA session	Control panel displays showing that source has extended	Observe appearance and exit of source through the source guide tube	Video image of source on closed circuit CRT	Fail to observe activity of source during QA session	Low
8	Retrieve exposed film	Source fully retracted; Radiation warning light off	Enter treatment room, remove film from treatment table; Send it for processing	Afterloader control console display shows tht source has retracted; Radiaton warning light off	Do not accurately check position of indicator; Do not record this value on the appropriate form	Low
9	After film is exposed, interpret image in terms of programmed dwell positions	Knowledge of x-ray image interpretation	Measure distances between dwell positions and compare them to programmed values	Image on x-ray film	Neglect to measure distances or measure them imprecisely	Low

Afterloader Generic	
Function No. V	Function Title Quality Assurance and Maintenance
Task No. 5	Task Title Routine Quality Assurance—Interrupt and Abort Tests
Task Performed By	Radiation Therapy Technologist, Physicist Supervisor Physicist
Equipment Needed	Remote afterloader; Emergency stop switches SKA Required Problem sensitivity, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum	3 / 5 / 10 Potential Distractor Level Low
Distraction Effects and Observations	QA tasks are often conducted in a less structured manner than treatment-related activities. Opportunity exists for them to be overlooked or performed in a noncompliant manner.

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Program afterloader to extend source	Standard QA procedure for interrupt test	Afterloader programmed to extend source	Afterloader control console display confirms programming	Program afterloader incorrectly	Low
2	Start mock treatment session	Standard QA procedure for interrupt test	Extend source	Radiation monitors illuminate, showing that source is being extended	Do not extend source	Low
3	Interrupt mock treatment session	Standard QA procedure for interrupt test	Press Interrupt key on remote control unit (LDR) or on afterloader control console (HDR)	Source retracts, Radiation monitors inactivate	Do not interrupt mock session	Low
4	Document interrupt test results on appropriate forms; Report any malfunctions to proper authorities	Standard QA procedure for interrupt test	Documentation of interrupt test results		Do not document test results; Fail to report malfunctions	Low
5	Steps 5–11 should be performed only for HDR systems. Repeat steps 1 and 2	Standard QA procedure for abort test			Do not repeat steps 1 and 2	Low
6	Check that the master Emergency Stop switch is armed	Standard QA procedure for abort test	Inspect the indicator light for armed condition	Indicator light should be green	Do not check that master switch is armed	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
7	Abort mock treatment session with master Emergency Stop switch	Standard QA procedure for abort test	Press Emergency Stop switch on master switch panel	'Activated' light on Emergency Stop switch and slave switches illuminate; Source retracts and radiation monitors inactivate	Do not press master Emergency Stop switch	Low
8	Document abort test results on appropriate forms; Report any malfunctions to proper authorities	Standard QA procedure for abort test	Documentation of abort test results		Do not document test results; Fail to report malfunctions	Low
9	Repeat steps 1 and 2	Standard QA procedure for abort test			Do not repeat Steps 1 and 2	Low
10	Abort mock treatment session with slave Emergency Stop switch	Standard QA procedure for abort test	Press Emergency Stop switch on slave unit	Activated light on master panel and all slave switches illuminate; Source retracts and radiation monitors inactivate	Do not press Emergency Stop switch on slave unit	Low
11	Document abort test results on appropriate forms; Report any malfunctions to proper authorities	Standard QA procedure for abort test	Documentation of abort test results		Do not document test results; Fail to report malfunctions	

Afterloader High Dose Rate Generic			
Function No.	V	Function Title	Quality Assurance and Maintenance
Task No.	5	Task Title	Routine Quality Assurance—Source Positioning and Timing
Task Performed By	Radiation Therapy Technologist, Physicist		Supervisor Physicist
Equipment Needed	HDR afterloader, Source positioning check ruler, Stop watch, QA form	SKA Required	Problem sensitivity, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum		15 / 30 / 60	Potential Distractor Level Low
Distraction Effects and Observations		QA activities are often done in a less structured manner than are other remote afterloading activities. The use of a checklist helps to assure that steps are done in the proper sequence.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Connect source position check ruler to channel on source head to be tested	Standard QA procedure	Connect ruler to channel to be tested	Ruler securely connected to source head channel	Connect ruler to wrong channel; Do not connect ruler securely to source channel	Low
2	Set indicator on ruler to zero mark	Standard QA procedure	Set ruler indicator to zero mark	Indicator set at zero	Do not set indicator at zero	Low
3	Exit treatment room	Standard QA procedure	Exit room, closing door	Treatment room unoccupied	Do not close door completely; Leave someone in treatment room	Low
4	Program afterloader control console to extend the source a specified distance through the channel to which the check ruler is attached	Distance parameter; Channel number; Dwell time parameter	Entry of program parameters	Afterloader control console displays channel, distance, and dwell time parameters	Specify incorrect parameters	Low
5	Extend source from afterloader to its programmed position; Activate stop watch when source reaches dwell position	Standard QA procedure	Source transits to its programmed dwell position	Afterloader control console shows that source has extended; Radiation monitor activates	Do not extend source; Do not activate stop watch when source reaches its dwell position	Low
6	Inactivate stop watch when source starts to retract and record elapsed time on QA form	Testing time	Inactivate stop watch	Source returns to safe	Do not inactivate stop watch when source begins to retract; Do not record time on QA form	Low

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
7	Verify that radioactive source is no longer exposed before entering treatment room	Radiation monitor information	Observe radiation monitor	Radiation monitor inactivates	Do not check radiation monitor	Low
8	Enter treatment room, inspect check ruler, and record indicator position on QA form	QA test over	Record indicator position on check ruler on QA form	Indicator position	Do not accurately note position of indicator; Do not record correct value on QA form	Low
9	Compare observed versus programmed distance and time values. If they match, QA check is completed; if they do not match, see step 10	Observed values; Programmed values	Comparison of time and distance parameters	Stop watch time; Distance on source position check ruler	Fail to note discrepancies between programmed and observed values	Low
10	To do another source position and timing check, repeat steps 1-9			Discrepant time and/or position values	Fail to perform additional position and timing test to confirm mismatch observed in step 9	Low

Afterloader Generic			
Function No. V	Function Title	Quality Assurance and Maintenance	
Task No. 5	Task Title	Routine Quality Assurance—Check of Source Guide Tube-Applicator Assemblies	
Task Performed By	Physicist, Radiation Therapy Technologist	Supervisor	Physicist
Equipment Needed	Source guide tubes, Index rod, Applicators	SKA Required	Finger dexterity, Problem sensitivity, Information ordering
Time Estimate (minutes) Minimum / Typical / Maximum 2 / 5 / 7		Potential Distractor Level Low	
Distraction Effects and Observations		Competing tasks along with interruptions from other personnel can interfere with task performance.	

No.	Step Description	Info Input	Control Output	System Feedback	Possible Errors	L(E)
1	Attach each source guide tube to its correct applicator	Standard procedure for QA check of source guide tubes	Correctly seat applicator into source guide tube	Positive seating of source guide tube	Fail to seat source guide tube correctly	Low
2	Index rod test of source guide tube-applicator for length and obstructions	Standard procedure for QA check of source guide tubes	Insert rod into source guide tube-applicator assembly	Overall length of source guide tube-applicator assembly relative to index rod; Presence or absence of obstructions	Fail to insert rod completely	Low
3	Discard source guide tube-applicator assemblies failing this test	Standard procedure for QA check of source guide tubes	Blockage present in source guide tube and/or applicator	Discard all defective source guide tube-applicator assemblies	Fail to discard defective assemblies	Low

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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 first phase of the project, which involved an extensive function and task analysis of RAB. This analysis identified the functions and tasks in RAB, made preliminary estimates of the likelihood of human error in each task, and determined the skills needed to perform each RAB task. The findings of the function and task analysis served as the foundation for the remainder of the project, which evaluated four major aspects of the RAB system linked to human error: human-system interfaces; procedures and practices; training and qualifications of RAB staff; and organizational practices and policies. At its completion, the project identified and prioritized areas for recommended NRC and industry attention based on all of the evaluations and analyses.

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