Human Factors Evaluation of Teletherapy

Training and Organizational Analysis

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ABSTRACT

A series of human factors evaluations were undertaken to better understand the contributing factors to human error in the teletherapy environment. Teletherapy is a multidisciplinary methodology for treating cancerous tissue through selective exposure to an external beam of ionizing radiation. A team of human factors specialists, assisted by a panel of radiation oncologists, medical physicists, and radiation therapists, conducted site visits to radiation oncology departments at community hospitals, university centers, and free-standing clinics. A function and task analysis was initially performed to guide subsequent evaluations in the areas of system-user interfaces, procedures, training and qualifications, and organizational policies and practices. The present work focuses solely on training and qualifications of personnel (e.g., training received before and during employment), and the potential impact of organizational factors on the performance of teletherapy. Organizational factors include such topics as adequacy of staffing, performance evaluations, commonly occurring errors, implementation of quality assurance programs, and organizational climate.

 

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EXECUTIVE SUMMARY

Background

Teletherapy is a multidisciplinary, multiphased methodology for treating cancerous and other tissue through selective exposure to an external beam of ionizing radiation. A radioactive isotope, typically cobalt-60 (Co-60), or a linear accelerator capable of producing very high energy x-ray and electron beams, are the principal sources of radiation for this type of treatment. Treatment typically takes place on a daily basis over a period of weeks. It is planned and administered by a team of specialists including a radiation oncologist, a radiation physicist, a radiation therapist, and possibly a dosimetrist. Effective teletherapy depends upon successful performance of functions and tasks involving people, machines, and procedures. Records maintained by the Nuclear Regulatory Commission (NRC) have identified cases of teletherapy misadministration—where the delivered radiation dose has differed from the radiation prescription (e.g. instances where the treatment was to the wrong patient, the wrong body part, or the dose was too great or too little). Both human error and machine malfunction have led to misadministrations. Misadministration above the prescribed dose may destroy healthy tissue and organs; misadministration below the prescribed level may result in ineffective treatment. Either way, the consequences can be life threatening.

Objective

The present effort is part of a series of human factors evaluations sponsored by the NRC to identify the contributing causes of human error in teletherapy. There are six major phases to the overall study: 1) a function and task analysis of the teletherapy activities, 2) evaluation of human-system interfaces, 3) evaluation of teletherapy procedures and practices, 4) evaluation of the training and qualifications of teletherapy staff, 5) evaluation of organizational practices and policies, and 6) identification of human factors problems in teletherapy, and identification and evaluation of alternatives to resolve significant problems. The present report, *Human Factors Evaluation of Teletherapy: Volume IV Training and Organizational Analysis*, NUREG/CR-6277, focuses solely on the training and qualifications of teletherapy staff and on organizational policy and management practices likely to have an impact on the treatment process.

Methodology

The methodology centered around five major activities. First, a site sampling strategy for visiting departments of radiation oncology was developed that ensured geographic dispersion of sites within the U.S., a good representation of different types of facilities (e.g., university-based centers, large community hospitals, and smaller free-standing or satellite facilities), and the inclusion of Co-60 units, where possible. Second, candidate radiation oncology departments were contacted by telephone and in writing to request their participation in the study. The level of cooperation was high. Third, personnel prepared for data collection activities by researching relevant training and organizational issues and preparing the necessary data collection forms. Fourth, site visits were conducted, on-going treatments were observed, and interviews were held with teletherapy staff. Fifth, collected data were analyzed to reveal general trends. Concurrent with these activities, a review of the radiation oncology professional literature was conducted.

Results

Training and Qualifications

The examination of training and qualifications of personnel is organized under three major topic areas: training prior to employment, training during employment, and the relationship between task performance and training. The formal training that radiation therapists, physicists, and dosimetrists receive prior to employment was reviewed and while major deficiencies were not found, a few respondents indicated that some therapists lack a mastery of dosimetry and treatment planning. More extensive coverage of dosimetry and treatment planning at the two-year community colleges and centers that offer radiation therapy programs merits consideration.

With respect to training during employment, several significant findings emerged. First, extensive reliance on informal on-the-job training (OJT) for newly hired therapists makes it difficult to determine if employees have acquired the necessary skills and knowledge to independently perform job functions. Second, the training received for new equipment and new software is sometimes less than adequate. Third, no special training or emergency training is provided for responding to machine malfunctions such as stuck sources in Co-60 machines. Fourth, formal training in quality assurance procedures did not occur on a systematic basis at the sites visited. It is noted that site visits were made prior to the effective date of the NRC's quality management rule for medical licensees. Fifth, none of the respondents indicated they received any special training on the avoidance of human error. Rather than simply equating human error with therapist error (as sometimes occurred), some basic training from a system's perspective would enable both management and treatment personnel to examine the role of other contributing factors that are part of the greater teletherapy system. A theoretical framework also is provided for examining the relationship between performance levels and error types based on Rasmussen's (1986) typology, and for examining the relationship between performance level and teletherapy functional area.

Organizational Policies and Practices

Organizational policies and practices can either facilitate or impede human performance in the workplace. To better understand the impact of organizational variables in teletherapy, six major areas were examined: 1) organizational staffing issues, 2) performance evaluations, 3) identification of human error in teletherapy, 4) implementation of quality assurance programs, 5) organizational factors underlying human performance in teletherapy, and 6) the relationship between task performance and organizational factors.

Several significant findings resulted from the organizational policies and procedures review. In terms of staffing, approximately 25 percent of the sites visited were understaffed by at least one therapist. Because of staffing shortages, it is not unusual for a single therapist to be assigned to a treatment machine, despite recommended practice for two therapists to be assigned (as advocated by the Inter-Society Council for Radiation Oncology (1991) in *Radiation Oncology in Integrated Cancer Management*). Such an arrangement increases the workload of the single

therapist and reduces the likelihood of error checking and seeking clarification of details during treatment set-ups.

Performance evaluation practices were examined, especially in relation to the self-reporting of errors. If performance evaluations stress the accountability aspect of one's job to the neglect of development and growth, there might be some reluctance to report errors freely. However, respondents indicated that performance evaluations did not inhibit the self-reporting of errors. At a number of sites, favorable organizational climates were described which were more concerned with eliminating error and maximizing the quality of patient care than with looking for someone to hold accountable.

Clerical or charting errors made by therapists and calculation errors made by dosimetrists and physicists are the most frequently cited errors in teletherapy. These errors are usually detected by weekly chart checks and brought to the attention of appropriate personnel. Errors of communication, both verbal and written, were the next most frequently cited class of errors. Errors concerning the improper use of blocks and wedges were mentioned several times. Other reported errors included improper positioning of patients, setting the wrong field size, giving extra treatments, and using the wrong tattoos.

Although the NRC's quality management rule was not yet in effect, many sites were acquainted with QA guidelines from the American College of Radiology (ACR). Less easy to determine was the extent to which a given facility was seriously committed to the QA process. Some sites appeared minimally compliant with ACR's QA procedures while other sites were totally committed to the process.

Respondents were asked to identify any organizational or managerial factors that contribute to human error. Among the several factors mentioned were understaffing, old equipment that breaks down, inappropriate organizational climates as evidenced by a lack of team spirit and management being aloof to daily operations, salaries not competitive with the national average, oncologists not accessible, complexity of cases, and treatment schedules with too many patients per hour.

Finally, in discussing the relationship between task performance and organizational factors, a distinction is made between the active errors made by therapists and latent errors made by organizational decision-makers. Errors that therapists make are termed active since they are made during the treatment process and their effects are likely to be noticed in the near term. Errors that managers and administrators make are termed latent because they occur further upstream in the sequence of events, are more likely to be errors of judgment, indecision, or omission, and likely to be difficult to trace. In brief, many of the active errors that therapists make result from a unique combination of several necessary but singly insufficient factors. Many of these factors are of a latent organizational nature and are present in the system long before the actual occurrence of human error.

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The authors wish to express their gratitude to the administrative and professional personnel in the various radiation oncology departments visited during data collection activities. Their voluntary willingness to participate, interrupt their own busy schedules, and provide useful information is, indeed, appreciated. The authors also would like to acknowledge the contribution of subject matter experts—a group of highly knowledgeable radiation oncologists, radiation physicists, and radiation therapists who served as consultants to the project and were able to enhance its technical accuracy.

FOREWORD

This report is prepared for the Office of Nuclear Regulatory Research of the U.S. Nuclear Regulatory Commission as part of the work performed under NRC-04-90-053, Human Factors Evaluation of Teletherapy. Teletherapy is a treatment methodology in which cancerous tissue is selectively destroyed by exposure to an external beam of ionizing radiation. The source of radiation may be a radioactive isotope, typically Co-60, or a linear accelerator which produces very high energy x-ray and electron beams. As practiced in departments of radiation oncology, teletherapy (or radiation therapy) is a complex, multiphased, multidisciplinary process requiring the teamwork of radiation oncologists, radiation physicists, dosimetrists, and radiation therapists.

The present report, *Volume IV Training and Organizational Analysis*, is part of a study designed to identify factors that can contribute to human error in the teletherapy setting. There are five major reports resulting from this study, *Human Factors Evaluation of Teletherapy*:

Volume I Identification of Problems and Alternative Approaches

Volume II Function and Task Analysis

Volume III Human-System Interfaces and Procedures

Volume IV Training and Organizational Analysis

Volume V A Literature Review

1.0 INTRODUCTION

The purpose of this report is to summarize and describe the major findings stemming from the training and organizational analysis. The first part addresses the training and qualifications of personnel involved in teletherapy administration while the second part focuses on an evaluation of organizational practices and policies.

Training typically refers to a well designed sequence of learning activities resulting in a change in behavior, cognition, or attitudes, and intended to improve workplace performance. Qualifications, on the other hand, refer to the professional standards that must be met before a given facility allows an individual to engage in the practice of teletherapy. Qualifications can vary between facilities and are frequently stated in terms of an undergraduate or graduate degree, or in terms of the certification that is granted by a professional society. In many disciplines, a national certification examination is given to certify that the individuals entering the profession are qualified in terms of underlying skills and knowledge to perform the tasks expected of them. Both the training that personnel receive and the qualifications they possess are major factors that have potential to influence performance in the workplace. With respect to training and qualifications, the following issues were explored:

- Career path of radiation therapists entering the field
- Eligibility and certification requirements
- Formal training and certification of physicists
- On-the-job (OJT) training
- Orientation to new procedures, new equipment, and new software
- Special training in overcoming equipment differences
- Formal training in quality assurance (QA) procedures
- Formal training in the avoidance of human error.

Likewise, there were also a number of relevant issues explored during evaluation of organizational policies and practices. Organizational policies and practices may serve to either facilitate or impede human performance in the workplace. Substandard performance or human error that results from organizational policies and practices is often difficult to pinpoint, however. Errors that occur at the organizational level are frequently propagated by those in decision-making positions (e.g., department heads, hospital administrators). These are often the ill-defined errors of judgment that occur far removed from the treatment machines and control consoles of the therapists. Organizational decisions that deal with staffing levels, workload, work schedules, patient scheduling, quality assurance procedures, and policy regarding self-reporting of errors are

likely to be implicated in the job performance of teletherapy personnel and hence in the quality of treatment that patients receive. This phase examined the potential impact of these factors in the teletherapy setting and identified organizational practices that either promoted or hampered the delivery of high quality external beam treatment.

Some of the major organizational factors that were examined include:

- Adequacy of staff levels
- Work schedules, rest periods, boredom
- Performance evaluations
- Self-reporting of errors
- Implementation of quality assurance programs
- Work conditions most stressful to therapists
- Organizational factors contributing to human error.

2.0 METHODOLOGY

The principal objective of the methodology was the collection and analysis of human factors information on the training and qualifications of teletherapy personnel, and the collection and analysis of information on organizational and managerial factors likely to have an impact on the treatment process and the potential occurrence of human error. While some information on training and organizational factors was collected during performance of preceding phases of the study, this phase concentrates solely on these factors. The overall approach to the training and organizational analysis is shown in Figure 2.1.

Figure 2.1 Training and Organizational Analysis Methodology

2.1 Site Sampling Strategy

The first step of the methodology was to develop a sampling strategy for visiting sites that was both practical and responsive to the needs of the study. An essential consideration was obtaining the cooperation of a broad spectrum of teletherapy organizations. Three major factors were taken into account in identifying potential sites: 1) geographic dispersion, 2) type of teletherapy facility, and 3) inclusion of Cobalt-60 units, where possible. Selection of geographically dispersed sites for visits minimized any disproportionate influence that might be associated with a given center or region (in terms of treatment practices or philosophy). Different types of facility such as university-based centers, large community hospitals, and smaller free-standing or satellite facilities were sampled to accommodate differences in management styles, organizational factors, personnel, patient load, and other factors likely to vary among facility types. Finally, efforts were made to include centers with Co-60 units because of NRC's regulatory responsibilities.

Using these three major factors as the bases for selection, eight facilities were visited from the New York City and Seattle-Tacoma metropolitan areas. Although the findings are based primarily on information collected at these facilities, relevant information gathered while visiting sites in other locations for other phases of this effort also was used.

2.2 Contacting Candidate Centers

Given the above sampling considerations, candidate radiation oncology departments were selected from the Membership Directory of the American Society of Therapeutic Radiology and Oncology. The director of the facility, usually a Radiation Oncologist, or Chief Radiation Physicist was initially contacted by telephone. The telephone request for participation was followed by a formal letter further stating the purpose of the study. The level of cooperation of the candidate centers was considered good; only two facilities declined to participate.

2.3 Data Collection Preparation

Data collection personnel first familiarized themselves with the most salient training and organizational issues, relying on interactions with subject matter experts, review of the relevant literature, and experience from the preceding phases. The function/task analysis database, reported in *Human Factors Evaluation of Teletherapy: Volume II Function and Task Analysis*, NUREG/CR-6277 (1995), served as a useful inventory of the essential teletherapy activities for which training and organizational issues have relevance. Using information collected during the preceding phases of the project, a structured interview form was prepared to serve as the primary data collection instrument. Table 2.1 shows the data elements of the form, organized under departmental, training/qualifications, and organizational categories. The form was reviewed for technical accuracy and content before initiation of data collection activities.

2.4 Data Collection Procedures

At most locations, site visits were scheduled on the basis of one center a day. For the most part, interviews were conducted with the Radiation Physicists, Chief Therapists, Dosimetrists, Staff Therapists, Radiation Oncologists, Training Coordinators, and Administrative personnel. Most all of the interviews were conducted on a one-to-one basis. Supplementing the interviews were observations of on-going treatments and examination of training syllabi and performance appraisal forms.

2.5 Data Analyses

The data collected from participants consisted primarily of responses to questions from the interview form. Because of the small sample and the open-ended interview questions, no attempt was made to analyze the collected information with descriptive statistical techniques. Instead, the general trend and nature of the responses for each content area are described.

Table 2.1 Data Collection Elements

Category	Elements
Departmental	<ul style="list-style-type: none"> • Number/manufacturer of treatment unit • Manufacturer of simulator • Treatment planning equipment • Software • Number patients treated per day • Number patient simulated per day • Numbers of therapists, dosimetrists, physicists, oncologists, mold room technicians, therapists-in-training
Training/Qualifications	<ul style="list-style-type: none"> • Formal training of staff • Eligibility/certification • Formal training within department • Employee orientation • On-the-job training (OJT) • New procedures training • New equipment/new software training • Training in quality assurance • Training in machine differences • Human error avoidance training • Vendor training • Commercial off-the-shelf training • Continuing education
Organizational	<ul style="list-style-type: none"> • Reporting chain • Hiring authority • Staffing adequacy • Turnover rate • Staffing by equipment • Shift length/schedules • Coverage for absences • Policy on error reporting • Sick/vacation leave • Work alone percentage • Error occurrence • Performance evaluation • Stressful work conditions • Quality assurance practices • Organizational/managerial factors in relation to human error

3.0 RESULTS AND DISCUSSION OF TRAINING AND QUALIFICATIONS

This section summarizes responses to questions on the training and qualifications of personnel involved in the teletherapy process. The summaries are supplemented with findings from the professional literature as well as documentation from certification and accreditation boards and professional organizations where appropriate. This section is organized around three major sub-sections: training prior to employment, training after employment, and the relationship between task performance and training interventions.

3.1 Training Prior To Employment

The formal training that radiation therapists, dosimetrists, and physicists receive prior to employment constitutes the major component of their preparation and readiness to perform teletherapy services. A recent study on training and experience criteria for personnel involved in the medical use of by-product material was performed for NRC (Brodsky, Cehn, Thomas, Inge, McIndoe & Goldin, 1989). This sub-section up-dates that work and provides a context for the discussion of training after employment and the relationship between task performance and training.

3.1.1 Career Path of Radiation Therapists

The traditional career path for radiation therapists is to enroll in a two-year program. To enroll in these programs, applicants must possess a high school diploma. High school courses in mathematics, science and English are considered desirable, but are not requirements. Although qualified students may enroll in a two-year program right out of high school, not many do so. Despite a nationwide shortage of trained therapists, interview respondents indicated that high school counselors do not seem to be well informed about the field and that many young people just out of high school do not find the treatment of cancer patients an attractive occupation. Respondents also indicated that successful applicants must possess the compassion and sensitivity necessary to provide the physical and psychological comfort of distressed patients. Psychological maturity may be an important variable in selecting a career in radiation therapy. Many applicants, for example, are people who are entering the radiation therapy field at a later time in their lives and who have become more aware of opportunities in the health care profession.

Another path into radiation therapy is through previous training and employment in diagnostic radiology. Individuals with this experience typically undergo a one-year training program, where emphasis is placed on radiation physics, treatment planning, simulation, and treatment procedures. Employment practices at radiation therapy facilities vary on a state-by-state and place of employment basis. Some facilities may train diagnostic radiologic technicians for radiation therapy through on-the-job training.

3.1.1.1 Affiliated Two-Year Radiation Therapist Training Programs

Typically two-year programs in radiation therapy are affiliated with the larger community hospitals, with well-known cancer treatment centers, or with local community colleges. When such programs are part of community hospitals or cancer centers, schools for radiation therapy are established and are usually under the supervision of a full-time director. The director is frequently a former radiation therapist. When the two-year program is located at a community college, there is usually an on-site training coordinator who is responsible for ensuring that students receive the right mix of classroom instruction at the college and clinical experience at near-by hospitals. The on-site training coordinator may or may not be a former radiation therapist.

In terms of the quality of instruction received at hospital-based schools and community colleges, the study team could not discern any notable differences from interview responses, nor could the team find any comparison studies in the radiation oncology therapy literature.

3.1.1.2 Two-Year and One-Year Radiation Therapist Training Program Curricula

Subjects taught in the two-year programs include Anatomy & Physiology, Radiation Physics, Pathology, Mathematics, Treatment Planning, Terminology, Record Keeping, Ethics, Radiation Safety, Principles of Radiography, Patient Care, and Introduction to Chemotherapy and Brachytherapy procedures. Students also receive instruction in the construction of immobilization and patient support devices used during treatment. A considerable number of hours are spent on job-based practical exercises. Students also receive first-hand experience in the actual treatment process through assigned rotations to participating hospitals. During these rotations, students actively assist staff therapists with such duties as patient positioning and immobilization in preparation for treatment. Many schools prefer that the rotation assignments be performed as early in the program as is reasonable so that students may receive an early indication of their personal suitability to the profession.

A one-year program is usually undertaken by individuals whose previous training and employment was in diagnostic radiology. One-year programs also include courses in Radiation Physics, Radiation Safety, Dosimetry, Pathology, Anatomy, Simulation and Treatment Techniques, Quality Assurance, and Patient Care. One-year students also receive first-hand experience in the treatment process through clinical rotations at local hospitals.

3.1.1.3 Radiation Therapist Accreditation and Certification

The minimum standards for accrediting educational programs are described in the *Essentials and Guidelines of an Accredited Educational Program for the Radiation Therapy Technologist* (1988) which is reviewed by the Joint Review Committee on Education in Radiologic Technology. The 1988 edition of the *Essentials* has been adopted by the American College of Radiology, the American Medical Association, and the American Society of Radiologic Technologists. The standards are used for the development and self-evaluation of radiation therapy technology programs. Site visits are made by committee members to assist departments

in ensuring that programs comply with the *Essentials*. Lists of accredited programs are made available to students, employers, and the public.

Among other requirements, the *Essentials* state that the curriculum shall contain, but not be limited to, the following content areas:

- Orientation to radiation therapy technology
- Medical ethics and law
- Methods of patient care
- Medical terminology
- Human structure and function
- Oncologic pathology
- Radiation oncology
- Radiobiology
- Mathematics
- Radiation Physics
- Radiation protection
- Radiation oncology technique
- Radiographic imaging
- Clinical dosimetry
- Quality assurance
- Introduction to hyperthermia
- Introduction to computers

Certification is granted through the American Registry of Radiologic Technologists (ARRT) which administers a national examination for the purpose of determining that individuals are qualified to practice the profession of radiation therapy technology. The examination is designed to assess the knowledge and cognitive skills necessary for performance of entry level therapists. To establish the linkage between the knowledge and skills that underlie entry-level tasks and the examination content, ARRT updates and revises an existing job analysis every five years.

Table 3.1 shows the content categories and their relative weights from the 1988 *Content Specifications for the Examination in Radiation Therapy Technology*.

3.1.1.4 Certification/Eligibility for Radiation Therapists

The majority of the sites visited indicated that newly hired radiation therapists had to be certified or eligible for certification. Eligibility was established by completion of an appropriate one- or two-year program. If eligible for certification, radiation therapists could be hired provisionally without certification, but would be expected to take the exam in the first year. In those states where certification is required for licensure, certification requirements are handled by state agencies. According to respondents interviewed, these requirements vary from state to state. Many non-licensure states do not require certification. Certification of new hires at medical facilities in those states was said to be the ideal, but not a necessity.

Table 3.1 Content Categories and Relative Weights
for Radiation Therapist Examination

<u>Content Category</u>	<u>%WT</u>
A. Radiation Protection & Quality Assurance	15.5
B. Simulation & Treatment Planning	53.0
C. Treatment Procedures	16.5
D. Patient Care & Management	15.0

3.1.2 Formal Training and Certification for Physicists

In terms of general education, the radiation physicist typically has a Master of Science or doctoral degree in physics or an associated natural science or specialty area. Some graduate schools have developed specialized programs in radiotherapy as well as programs in diagnostic radiology, nuclear medicine, and ultrasound. In addition to a concentration in radiologic physics, it is important for the radiation therapy physicist to have coursework in anatomy, physiology, oncology, and radiobiology. Certification for physicists is currently not a requirement at many hospitals, but there is a movement for either licensing or certification in some states. A number of physicists that were interviewed expressed concern about individuals entering the radiation therapy physics profession with non-traditional or with less than satisfactory education and training in radiologic physics.

Physicists that seek certification can do so with either the American Board of Radiology (ABR) or the American Board of Medical Physics (ABMP). The latter board provides certification in some areas, such as hyperthermia, not provided by the ABR.

3.1.3 Formal Training and Certification of Dosimetrists

There are a limited number of university-based programs in dosimetry, providing both classroom and clinical training. The average program requires one year to complete, with the range extending from six months to two years. Entry into the programs typically requires a B.S. degree or RT certification and one year's experience. Rather than entering the field of dosimetry through one of these programs, it is much more common for hospitals to train their own dosimetrists (usually a currently employed RT). While hospital training in dosimetry may be less structured than the university-based programs, the RT in training for dosimetry is likely to be selected on the basis of a conscientious track record as an RT and a very good understanding of the teletherapy environment. Of the hospitals visited, many preferred this route for dosimetrists.

The certifying organization for medical dosimetrists is the Medical Dosimetrist Certification Board. It requires the applicant to be a graduate of a university- or hospital-based program of nine months or more in medical dosimetry, or have a BS or BA degree in the physical or biological sciences, or for someone who is a registered RT, two years of supervised training and experience in medical dosimetry. The certification examination covers the following areas: radiation physics, dose calculation methods, isodose distributions, tumor localization, clinical oncology, brachytherapy, radiation protection, and quality assurance. Most hospitals do not require certification for dosimetrists.

3.2 Training after Employment

Training after employment refers to participation in training programs after the individual has been hired and is working within a department of radiation oncology. This section addresses the training provided by various departments, orientation of new therapists to the department, training of personnel on new equipment or software, training in quality assurance procedures, and the need for training that is currently missing.

3.2.1 Formal Training Programs in the Department

Formal training implies a well-defined, structured sequence of learning activities— frequently a combination of classroom, seminar, and clinical experiences—through which individuals progress. Usually objectives are explicitly stated and there is a mechanism for assessing whether the objectives have been achieved.

Very little in the way of formal training programs was found at most hospitals or radiation oncology centers. The exceptions are the three- or four-year residency programs for radiation oncologists at some of the larger university affiliated centers. By working closely with the attending physicians and rotating through the various radiation oncology services (i.e., radiation physics, gynecology, pediatrics, head and neck, breast, lymphoma, lung, central nervous system, gastrointestinal tract, genitourinary tract, and hyperthermia), residents acquire a considerable breadth of experience. Other requirements include attendance at didactic courses (e.g., physics, radiation biology, biostatistics, hyperthermia physics), successful completion of examinations, attendance at inter- and intradepartmental conferences, and pursuit of research interests.

For the other radiation therapy personnel (i.e., dosimetrists, therapists), participation in formal training programs is limited to hospital-wide, in-service training programs on such topics as safety, AIDS, or OSHA initiatives. The only other exception would be the close supervision that a dosimetrist or physicist in training would receive while satisfying requirements for certification.

3.2.2 On-the-Job (OJT) Training

Most of the training that occurs in departments of radiation oncology is on-the-job training. Learning from one's peers or from someone more knowledgeable and experienced is a valuable method of learning. Given proper conditions, there are distinct advantages associated with on-the-job training. Some aspects of the transfer-of-training problem are certainly attenuated because

individuals are trained in the same social and physical environment in which they will perform. Fidelity of the training experience is exceptionally high since the required behaviors are those that are practiced and closely monitored. For those occupational settings where teamwork is required and where the physical layout fosters proximity among co-workers, OJT seems ideal. It also is known that learning occurs extremely efficiently when there is a strong, immediate need to know or to perform. On-the-job training provides the venue where this is likely to occur.

In general, many on-the-job training programs are poorly structured and amount to little more than a newly hired employee initially watching a more senior co-worker. Very little attention is given to specifically establishing training objectives or to structuring the trainee's work environment so that it systematically promotes learning. Many of the radiation oncology sites visited indicated that their OJT program for new therapists was informal. When asked to elaborate on the informal OJT program, many respondents would simply say that a new therapist is assigned to the chief therapist or a senior staff therapist for the first month. Informality when it comes to training does not inspire confidence. Too much is left to chance. The informal approach exposes the trainee to a broad range of experiences and then, after an interval of time, assumes that the breadth of experience is sufficient for most of the job requirements. However, the breadth of experience is rarely evaluated and so it is very difficult to know what knowledge and skills the new person has acquired.

Table 3.2 identifies four essential elements that are present in various systems approach to training models (e.g., NUREG-1220 Rev. 1, Training Review Criteria and Procedures, 1992) that the authors consider necessary for effective OJT programs. The table shows the extent to which these characteristics were observed at the sites visited. Little evidence was found for the identification of explicit learning objectives as part of the informal OJT programs. If training objectives are not identified or couched in terms too vague, the OJT program will lack direction. Foremost, well-stated objectives specify what students will accomplish as a result of receiving training. There was a slightly greater indication (moderate) that the supervisory or chief therapist scheduled work assignments for entry level therapists in a manner that provided for a sequential progression of learning opportunities. However, with the exception of two hospitals that used competency evaluation checklists, it was frequently not clear what standards the supervisory therapist used for assessing acceptable performance. Most of the time, the supervisory therapist relied on a general impression of how well the new person was doing. However, standards of performance need to be stated in observable and measurable terms in order to assess the performance objectively. With respect to the last element in the table, the organizational environment at many of the sites visited could be described as conducive to learning. Overall, the greatest limitation of the informal OJT programs is their lack of structure, especially in terms of knowing what is being taught (i.e., identifying learning objectives) and what is being learned (i.e., specifying acceptable standards of performance).

Table 3.2 Extent of Essential Elements of Observed OJT Programs

Extent to Which Essential Elements of OJT Programs Were Observed			
Essential Elements	Extent		
	Infrequent	Moderate	Frequent
Identification of explicit learning objectives	●		
Arrangement of progressive learning opportunities		●	
Evaluation of acceptable standards of performance	●		
Provision of a supportive learning environment		●	

3.2.3 Orientation of New Therapists to the Department

As indicated above, new therapists are frequently assigned to the chief therapist when they first report to the department. Two to three days may be spent on becoming familiar with departmental rules, regulations, and policy. They may then be assigned either to a given machine with a senior therapist for a month or so, or initially rotate across machines for a few days each.

When assigned to a specific machine, therapists assist in patient set-ups and primarily observe the senior therapist's activities (e.g., entering machine parameters, administering the beam, charting). In the second month, they start to engage in a broader array of therapist's tasks, but with supervision. They may also be assigned to other machines. As they demonstrate their skills and knowledge to the satisfaction of the senior therapist, they progress to the point where minimal supervision is required for short periods and they start functioning as a fully contributing team member along with the other therapists. Some areas such as simulation may require further guidance, but by the end of six months, they typically are able to work unsupervised. As discussed above, assessment of acceptable performance frequently occurs on an informal basis during this time period. If the assessment procedure for new therapists is too informal or overlooks essential competencies, the risk of patient positioning and treatment machine set-up errors increase. At many places, the first formal performance appraisal occurs at the end of six months. An evaluation form is used and the appraisal is conducted by the chief therapist.

The nature and duration of orientation varies across departments, depending upon the particular complement of treatment machines and related equipment as well as the complexity of treatment protocols. Large university-affiliated centers are likely to require longer and more extensive orientation than the smaller centers with only a couple of machines.

3.2.4 Orientation to New Procedures, New Equipment, and New Software

For the most part, orientation to new procedures, new equipment, and new software also is accomplished on an informal OJT basis. There were a few sites, however, where procedures were very well documented. Procedures at these places are maintained in 3-ring notebooks and kept at the workstations of the appropriate personnel. Changes to existing procedures (e.g., patient scheduling, chart checks, personnel policies) are circulated in written form to the relevant personnel and then placed in the procedures manual. At those places that were less diligent in maintaining written procedures, personnel were oriented to changes in procedure through word-of-mouth. Relying on word-of-mouth is a very unreliable method for orientating all the staff to new procedures.

With respect to the introduction of new equipment and new software, most sites indicated that the vendor would come in for a couple of days or a week to provide applications training. For a new treatment planning system, for example, the chief or lead physicist might receive the initial training, and then he or she would train the other staff physicists and dosimetrists. The content not trained would have to be self-taught. It should be recognized that the quality of vendor-based training on their own product lines is likely to vary and that the ability of in-house personnel to cross-train co-workers also is likely to vary. Some respondents indicated that before a new piece of equipment or software is actually used in the treatment environment, it is bench-tested in a mode parallel to the existing system for a period of time; however, this practice also varies from one facility to another.

3.2.5 Training Programs Developed by Outside Contractors

With the exception of the training that is provided by equipment manufacturers, specialized training programs custom-developed by outside contractors or vendors are rare. One exception was at a hospital that had been undergoing organizational change for the past few years and where employee morale was low. The director of the hospital decided to bring in some fresh ideas and hired an organizational development group to facilitate the needed changes and to conduct training in employee development (e.g., team building, communication skills). These efforts were currently underway at the time of the site visit and appeared to be appreciated by teletherapy staff.

Several sites indicated they try to send personnel to annual professional conferences so they can be exposed to the state-of-the art equipment and attend paper sessions. Many of these conferences offer workshops, frequently conducted by vendors, on various procedures and topics of current interest. However, only a very small percentage (i.e., less than 10%) of the teletherapy workforce is likely to be a recipient of this form of training in a given year.

3.2.6 Use of Commercial-Off-The-Shelf Training Packages

Likewise, no evidence was found for use of commercial-off-the-shelf training packages for either technical or managerial training. All the sites visited were in agreement that they could not remember using commercial off-the-shelf training materials.

3.2.7 Special Training for Overcoming Equipment Differences

Visits to teletherapy sites revealed a variety of treatment equipment and operator interfaces due to different manufacturers and models as well as to inherent differences between Cobalt-60 and linear accelerator units. Given the differences between equipment that serves the same function, is there a need for special training to overcome these differences? Do the responses and procedures that are appropriate and correct for one type of machine interfere or inhibit performance on another type of treatment unit? Do the physical differences between Co-60 machines and Linear Accelerators or between different energy level accelerators or between simulator and treatment units result in negative transfer when therapists are rotated? As noted by Kaye, Henriksen, Jones, Morisseau and Serig (1995), a major difference between linear accelerators and Co-60 machines is the measurement unit by which delivered dose is specified. Co-60 treatments are specified by treatment time; linear accelerator treatments are specified by monitor units. When therapists who rotated between both type of units were asked whether this caused any confusion or inappropriate transfer, the response was fairly consistent that it did not. Nor was there anything in the radiation therapy literature to suggest that this is a source of confusion. None of the sites visited conducted special training for overcoming equipment differences. The interfaces of the operators' consoles for the two types of treatment machines appear to be sufficiently different and have different initiating cues such that confusion or negative transfer is minimized.

Another physical difference between Co-60 machines and linear accelerators is the source-to-axis distance (SAD). Co-60 machines usually employ an SAD of 80 centimeters while linear accelerators employ an SAD of 100 centimeters. This difference has important implications when transferring the results from simulation of the patient on the simulator to the set-up of the patient on the treatment unit when the SAD between simulator and treatment unit is not the same. Because of the differing geometries involved and operation of the inverse-square law, an incorrect transfer of parameters based on the wrong SAD would result in inappropriate field size and dose to the target area. Of the departments visited, only a few departments had simulator/treatment machines with varying SADs and although there were no reports of confusion among the individuals interviewed, the conditions for negative transfer are present. Also there are instances of misadministration where the treatment error can be attributed to failure to take into account equipment differences as the patient is transferred from the simulator unit to the Co-60 machine. It is important that appropriate designations regarding the intended treatment machine are made on the simulation data sheets.

3.2.8 Formal Training in Quality Assurance (QA) Procedures

Formal training in quality assurance procedures *per se* was not occurring with any degree of frequency at the sites visited. It should be noted that the following information on quality assurance procedures is based on visits that were made prior to the publication of the NRC's *Regulatory Guide 8.33 Quality Management Program* (1991). At a few of the sites visited there was evidence of the implementation of formal quality assurance programs. Such programs typically follow American College of Radiology QA recommendations whereby a Quality Assurance Committee (QAC) oversees the program and reports to the Director of the radiation oncology center. The committee typically includes a chairperson, radiation oncologist, physicist, and chief radiation therapist and other staff members who meet regularly for the purpose of reviewing the ongoing QA program and implementing a plan for monitoring and evaluating the quality and appropriateness of the care provided. Weekly case review meetings play an important role in the QA programs. Pertinent details of the patient undergoing treatment are reviewed, including a brief history of patient, treatment plan, portal and simulation films, and dose distributions. Unusual histological factors or problems encountered during treatment are discussed. A log is maintained on all the cases presented and any problems requiring corrective action are documented on a monthly report maintained by the QA office. The success of the corrective actions are followed-up and evaluated in subsequent meetings. When asked about training in QA procedures, staff therapists and physics personnel would sometimes refer to their involvement in these meetings.

A number of facilities had limited QA procedures in place (yet espoused the importance of QA), while other facilities were proud of their QA efforts and were able to provide on-going documentation attesting to the accountability aspects of QA. The greatest emphasis thus far has been on machine QA, stemming from the traditional QA role of physics department personnel. The success of a comprehensive QA program, however, depends upon the full support of the department's decision makers as well as the commitment and involvement of all treatment personnel. Individual efforts at QA without full departmental commitment, resources, and training are likely to fall short of what is required to make a significant difference.

3.2.9 Training for the Avoidance of Human Error or Machine Malfunction

None of the respondents interviewed indicated that they received special training in the avoidance of human error or machine malfunction. One respondent indicated that the hospital provides workshops on reducing stress and another respondent indicated that the programmers gave a talk on avoiding software errors. While some industries with complex and hazardous work environments (e.g., military, commercial aviation, nuclear power plant) have developed systematic training procedures for responding to unexpected problems and for reducing human error, there was no evidence of the use of systematic training procedures related to human error and machine malfunction in the departments of radiation oncology that were visited.

For example, a machine malfunction that can have serious consequences with some Cobalt-60 units is for the source to occasionally stick in an exposed position. The likelihood of such an occurrence can be minimized by good design and by a conscientious program of preventive

maintenance. However, when a stuck source does occur, the therapists have to intervene decisively to minimize radiation exposure. Table 3.3 shows the tasks associated with responding to a stuck source that were identified during the function and task analysis and are reported in *Human Factors Evaluation of Teletherapy: Volume II Function and Task Analysis*, NUREG/CR-6277 (1995).

Table 3.3 Tasks Associated with Responding to a Stuck Source

Function 9.00 Treatment Administration from Control Console

Subfunction 2.00 Radiation Treatment Delivery

Task State 5.00 Detect that source is stuck in open position

Task State 5.01 Re-shield source stuck in open position with emergency reshielding capability from control console (if available).

Task State 5.02 Escort patient from treatment room when source is stuck open

Task State 5.03 Manually re-shield source stuck in open position in treatment room

The probability of the therapists being able to perform what may appear to be a simple sequence of activities would be considerably greater if they had first received a systematic performance-oriented training program where they actually practiced these activities. Posting these procedures on the wall in the form of a job aid, as was observed at several facilities, may not be sufficient when such a stress-producing incident happens.

Rather than waiting for human error to compound the adverse consequences of such an incident, a more active strategy would be to design training that specifically trains therapists for responding to critical high-pressure and unexpected circumstances. Through realistic simulation exercises, similar to airline cockpit emergency procedures training, therapists could be trained in scenarios that involve equipment failures, patient complications, discovered charting errors, misunderstood communications or any combination of these infrequent circumstances. Using very similar videotape simulation exercises in the operating room environment, David M. Gaba (cited in Weinger & Englund, 1990) at the Stanford University School of Medicine, has developed a successful critical-incident based training program in which surgeons, anesthesiologists, and operating room nurses participate for targeting and reducing anesthesia-related mishaps attributed to human error. Such training helps to identify human limitations in the broader treatment process context.

While none of the respondents indicated that they received specialized training for the avoidance of human error, they generally recognized the importance of this study, expressed interest in receiving a copy of the study's findings, and appeared receptive to gaining a better understanding of human error in the teletherapy environment. Some basic training for radiation oncology personnel on the multifaceted nature of human error would be useful. While it is difficult to pinpoint a specific deficiency that such training would overcome, a greater awareness of the overall systems context in which an intricate chain of events may combine to lead to a mishap would enhance understanding for supervisory and staff personnel alike. Treating human error within a systems context rather than assuming it an immutable part of the human condition increases the likelihood that interventions will be devised to reduce its occurrence. Rather than automatically equating human error with therapist error as sometimes occurred with respondents, some basic training from a system's perspective would enable teletherapy personnel to look beyond the therapist and examine the role of other contributing factors to error— inadequate communication practices, poorly designed interfaces, indecisiveness of management— that are part of the greater teletherapy system.

Psychological research on attribution bias (Jones & Nisbett, 1971) and hindsight bias (Fischhoff, 1975; Slovic & Fischhoff, 1977) has important implications for training in the teletherapy setting as well. When attempting to infer the causes of misdirected incidents, humans frequently make the attributional error of blaming the individual and ignoring the role of situational factors. It is perhaps easier to find a single source or individual to blame than to consider all the relevant situational factors and their intricate relationships. There is also the bias or tendency to ascertain with hindsight certainty what others who experienced the incident failed to anticipate. After an incident has occurred, the investigator has the luxury of knowing how things are going to turn out, an advantage that the participant does not have. To guard against the perpetuation of these biases in the teletherapy setting, training programs which address the assessment of human error would do well to consider such content.

3.2.10 Requirements for Continuing Education

There were no uniform requirements for continuing education across the sites visited. Some states do not require continuing education for license renewal for therapists, but do require a certain number of continuing education hours for physicians. There appeared to be no requirements for physicists. Some departments required that therapists spend a certain number of hours in attendance at lectures or workshops for the year, independent of any state mandate. These departments tended to be affiliated with universities where there was access to guest lecturers. Not all the guest lecture topics would be of direct relevance to teletherapy staff and this would affect the likelihood of attendance. At the community hospitals, respondents were likely to state that there were no requirements for continuing education. The chief therapist and the physicist might be able to attend a national conference or a special workshop during the year.

3.2.11 Satisfaction with Training and Personnel Qualifications

Most of the respondents indicated a general satisfaction with the training and personnel qualifications of their staffs. This was true for both therapists and physicists/dosimetrists. A frequent caveat to the general satisfaction with entry-level personnel was a statement indicating that they were very careful whom they hired. There may be a built-in bias for supervisors to think well of their staffs, especially if they came through similar programs. While there is always a threat to objectivity in interview protocols regarding co-workers, there was no other evidence cited (e.g., personnel dismissed because of incompetence) that would indicate dissatisfaction with the qualifications of entry-level personnel.

At two sites specific content areas were mentioned that could be improved, however. At one site, the chief physicist indicated that there was a tendency to hire younger, less experienced therapists because of the lower salary structure. According to this respondent, improvements were needed in dosimetry and treatment planning. At another site, the oncologist also indicated that therapists need to have a better understanding of dosimetry and treatment planning.

3.2.12 Initiation of Training Currently Missing

Statements of general satisfaction on the part of respondents frequently lack the diagnostic sensitivity to determine that training actually provides what is needed. Respondents were further queried as to the need to initiate any forms of training that were currently missing. A few of the respondents could not identify any new forms of training that were currently needed. Other respondents had suggestions, but not always directly related to training. Table 3.4 lists their suggestions in paraphrased form.

The recommendation for a greater use of checklists (or job performance aids) to orient new staff is one that has considerable merit, given the busy and sometimes stressful nature of the chief therapist's job. Job performance aids can reduce the need for training. Any useful tools or aids that can be used to make the orientation process for new staff more systematic and comprehensive deserve to be considered. The suggestion that all new people should work with lead therapists should be standard practice and was stated to be the case at most of the sites visited. The next two suggestions—a need for therapists to know dosimetry and treatment planning better—came from independent sources: a physicist and an oncologist. Although it is risky to generalize from the comments of two individuals, if physicists and oncologists are experiencing difficulty in having their treatment plans understood by those who will implement them, then a serious training deficiency exists. This is an issue worth further exploration in departments where such training and/or communication deficiencies are evident. The suggestion expressing a need to keep up with linear accelerators came from a therapist working in a facility that housed only one Cobalt-60 unit. The last two entries in the table are concerned with performance appraisal and organizational goal setting. These topics are treated in Section 4.0 of the report.

Table 3.4 Suggested Forms of Training Currently Needed

- Greater use of checklists to orient new staff.
 - All new people should work with lead therapists.
 - Therapists should know dosimetry better. Should be able to understand treatment plans.
 - Treatment planning should be stressed more in the schools (e.g., drawing a contour).
 - Would like to keep up with linear accelerators more.
 - Competency-based evaluation system.
 - Specific goals for each quarter.
-

3.3 Relationship Between Task Performance and Training

Although a vast majority of sites visited indicated satisfaction with the qualifications and training of their personnel, there are function and task areas that can be designated as potentially in need of training. This sub-section first provides a framework for examining the relationship between performance levels and error types and then identifies task performance areas potentially in need of training.

3.3.1 Performance Levels and Error Types

Before a direct linkage is attempted between task performance in the teletherapy setting and potential training interventions, it will be useful to first examine some recent thinking on the relationship between performance levels and error types. Table 3.5 is adopted from Reason (1990) and shows a suggested relationship between performance levels and error types.

The three performance levels in Table 3.5 are based on a distinction made by Rasmussen (1986). Skill-based performance represents intended sensorimotor activity that takes place "without conscious control as smooth, automated, and highly integrated patterns of behaviour" (Rasmussen, 1986, p. 100). Such activities are of a routine, nonproblematic nature that take place

Table 3.5 Performance Levels and Error Types

<u>Performance Level</u>	<u>Error Type</u>
Skill-based (SB) level	Slips and lapses
Rule-based (RB) level	RB mistakes
Knowledge-based (KB) level	KB mistakes

Source: Reason, J., *Human Error*, Cambridge: Cambridge University Press, 1990; Reprinted with permission of Cambridge University Press

in familiar surroundings. This is the performance level that characterizes a large percentage of the tasks performed by the radiation therapists as they enter treatment parameters in the machine and set up the patient. Table 3.6 shows some examples of tasks, taken from *Human Factors Evaluation of Teletherapy: Volume II Function and Task Analysis*, NUREG/CR-6277 (1995), that conform to Rasmussen's notion of skill-based performance.

Rule-based behavior, according to Rasmussen (1986, p. 102) is "controlled by a stored rule or procedure that may have been derived empirically during previous occasions, . . . or it may be prepared on occasion by conscious problem solving and planning," while knowledge-based behavior refers to the control of performance at a higher conceptual level, where a goal is explicitly formulated and alternative plans are considered for reaching the goal. The treatment planning and dose distribution determinations of the physicist are good examples of rule-based performance—a body of explicit "know-how" exists whereby the use of goal-directed rules can be described.

The conceptual or mental model used by the oncologist in deriving the suspected tumor volume probably best conforms to knowledge-based performance. For Rasmussen (1986), knowledge based functioning refers to the capacity of humans to effectively deal with unfamiliar situations by using conceptual, structural models. This capacity for coping with complexity stems from the ability to apply knowledge from previous experiences to new situations by selecting and combining aspects of models, strategies and rules that have proven successful in the past. Determination of an appropriate treatment approach is strongly influenced by one's representation or model of the disease, and one's representation or model, in turn, is dependent upon accumulated domain-related knowledge. Radiation oncologists are most likely functioning at this knowledge-based level during their clinical evaluations of patients. This does not imply, however, that oncologists function predominately in a knowledge-based mode with other members of the teletherapy team relying predominately on rule-based and skill-based performances. Regardless of one's professional specialty, individuals are called upon to function efficiently and concurrently at all of Rasmussen's performance levels.

Table 3.6 Examples of Skill-Based Performance from the Function and Task Analysis

Function 8.00 Treatment Setup

Subfunction 3.00 Treatment Machine Setup

Task State 1.00	Program computer controlled linear accelerator control system prior to course of treatment (Site specific).
Task State 2.00	Rotate gantry and collimator to correct angle for treatment.
Task State 3.00	Adjust collimator size to prescribed size.
Task State 4.00	Readjust field light (via collimator) to field borders and/or permanent marks on patient's skin as prescribed before treatment.
Task State 5.00	Position patient for proper SSD.
Task State 6.00	Position standard (non-custom) blocks on block template.
Task State 7.00	Attach custom block assembly to treatment head.
Task State 8.00	Attach wedge to wedge holder in treatment head.
Task State 9.00	Position tissue compensator in treatment beam.
Task State 10.00	Attach electron cone to treatment machine head.
-

Errors that occur during skill-based performance are termed slips and lapses. In other words, actions deviate from current intention as a result of execution failures or memory difficulties (Norman, 1981). Slips, according to Reason (1990), can occur whenever there is opportunity for attentional "capture" through workplace distraction or preoccupation. Slips, such as using a wrong block in teletherapy, are very unpredictable since they involve momentary interruptions of highly practiced, automatic routines. Lapses are a more covert error form, usually referred to as memory failures, yet still involving a discrepancy between what was intended and what was performed. If a therapist fails to chart a treatment and thus gives an extra fraction, a lapse has occurred. The value of additional training for therapists who commit slips and lapses would be questionable since they are quite proficient at "inserting blocks" and "recording the daily treatment." On those infrequent occasions where there is a slip or lapse in the performance of these tasks, it makes more sense to try to remove the environmental or organizational factors that contribute to the slip, rather than try to improve task performance that is already at an asymptotic level. Although the momentary occurrence of a slip or lapse is difficult to predict, they can be

expected. Many slips and lapses are easily detected almost immediately or in the short-term, but a number also go unnoticed. Although double-checking procedures and computerized record and verify (R&V) systems catch a number of slips and lapses, continued effort is needed in devising better procedures and tools for detecting and correcting these deviations from intended performance.

Mistakes, on the other hand, are intended actions that can proceed as planned yet still fail to achieve the intended outcome. Mistakes thus refer to inadequacies in the planning process, to some deficiency of judgment in the selection of an objective or in the means or set of rules to achieve the objective (Reason, 1990). Mistakes made at the rule-based level may occur when a rule has worked well in the past but now no longer applies to the new conditions (*i.e.*, *strong but wrong rules*) whereas mistakes made at the knowledge-based level stem from an inadequate representation or mental model of the problem space or from only addressing a small aspect of the problem space as a result of inherent limitations of attentional focus (*i.e.*, what Simon, 1957, refers to as *bounded rationality*). Errors at the skill-based and rule-based levels are largely under the control of well-practiced automatic routines while errors at the knowledge-based level occur when individuals have exhausted their repertoire of rules and must now confront an unfamiliar situation by consciously attending to aspects of the problem space. Because of the limitations associated with inadequate mental models and bounded rationality, knowledge-based errors are less predictable in form. Mistakes at the knowledge-based level, according to Reason (1990), have a hit-or-miss quality not unlike the performance of novices. Once one's trusted rules no longer seem to apply, expert performance, defined as having a vast repertoire of routines for a wide assortment of contingencies, starts to approximate the less efficient quality of novice performance.

3.3.2 Task Performance Areas Potentially in Need of Training

Table 3.7 represents an attempt to relate the function areas of teletherapy (and their underlying supporting tasks) to Rasmussen's performance taxonomy of skill-based, rule-based, and knowledge-based behaviors and to pinpoint areas of potential training need. The eleven function areas are taken from the function and task analysis that are reported in *Human Factors Evaluation of Teletherapy: Volume II Function and Task Analysis*, NUREG/CR-6277 (1995). The reader is advised that the designations in the table should be interpreted as suggestive rather than conclusive. The functional areas identified as potentially in need of training are good candidates for training based upon the evidence collected at the sites visited. A similar note of caution needs to be exercised when interpreting the predominant (P) and secondary (S) performance designations. These designations are simply assessments regarding which of the performance levels (as in Rasmussen, 1986) are likely to be the predominant and secondary modes for the function areas in question. It is realized, of course, that many of the function areas likely comprise all three performance levels at times and the teletherapy professional may be switching back and forth among the levels. Nor are the three levels likely to be as discrete as portrayed; they are likely to have a continuous quality as well. Taxonomies rarely render a perfect fit when classifying complex performance activities, and for these reasons, both predominant and secondary designations are made in the table.

Table 3.7 Predominant/Secondary Performance Levels and Potential Training Need by Function Area

	<u>S</u>	<u>R</u>	<u>K</u>
1.0 Diagnosis, Tumor Localization, & Identification of Initial Treatment Concerns		S	P
2.0 Pre-treatment Planning Session		P	S
3.0 Treatment & Safety Equipment Checks, Adjustments & Maintenance	S	P	
4.0 Simulation		P ^T	S ^T
5.0 Treatment Computer Data Files Set Up	S ^T	P ^T	
6.0 Treatment Planning		S ^T	P ^T
7.0 Custom Blocks	S	P	
8.0 Treatment Set Up	P	S	
9.0 Treatment Administration from Control Console	P	S	
10.0 Monitor Patient Progress & Treatment Adequacy		P	S
11.0 Management of Teletherapy Facility & Staff		S ^T	P ^T
Legend:	<u>S</u> Skill-Based <u>R</u> Rule-Based <u>K</u> Knowledge-Based	P - Predominant Performance Level S - Secondary Performance Level ^T - Potentially in Need of Training	

The table shows that diagnosis and tumor localization involves predominantly knowledge-based performance. These activities are undertaken by the radiation oncologist and entail a fair degree of problem solving. The conduct of a pre-treatment planning session also is the responsibility of the oncologist and involves both rule-based and knowledge-based activities. On the other hand, the performance of treatment and safety equipment checks, adjustments, and maintenance is a proceduralized activity conducted by the physicist and is thus considered predominantly rule-based, although there are likely to be maintenance challenges that also require knowledge-based performances. The table further shows that custom blocks, treatment set-up, and treatment administration from the control console also involve both skill-based and rule-based performances while monitoring patient progress and treatment adequacy evoke rule-based and knowledge-based behaviors. The table also shows that none of the functions just discussed was cited to be in need of additional training (i.e., training above and beyond what is presently received). The functional areas discussed next are those that were cited to be in need of training.

Simulation is where the oncologist, physicist, and simulation therapist come together to simulate treatment set up and ensure the precise and accurate location of treatment fields. The process may be predominately rule-based, but there are also problem-solving or knowledge-based components. The table shows a potential need for training simulation-based tasks. While there was no indication of a training need for physicists or dosimetrists, there was a need indicated for therapists. Simulation can be a complex process depending upon the individual case and a few therapists indicated they were exposed to only some of the more routine simulation set-ups in school. At a number of sites, an experienced therapist is assigned to the simulator on a dedicated basis because of the greater skill and knowledge levels considered to be required. For these reasons, further training in simulation procedures for therapists is recommended.

Treatment Computer Data Files Set Up also was designated as an area in need of training based on information collected during site visits. Here the performance levels are rule-based and skill-based and the training population would be any dosimetrists or physicists assigned to treatment planning. Proficiency with treatment planning computers and in setting up and maintaining treatment planning data files has become an increasingly important requirement for physicists and dosimetrists during the past decade. There is no standard form of training currently provided to ensure that these skills and knowledge are acquired. To learn a new treatment planning software package, the physicists will either receive a few days of instruction that the vendor provides or will self-learn the new software. The quality of vendor-provided training is likely to vary as is the effectiveness of self-initiated efforts. Because of the hit or miss nature of existing training and because of the criticality of this function, a more systematic approach to acquiring these emerging skills is needed.

As a predominantly knowledge-based activity, treatment planning is a team effort where the oncologist, physicist, and therapist need to develop, communicate, and share the same mental model for arriving at the best possible treatment plan for a given patient. Once the dose tolerances of critical normal structures in the vicinity of the tumor have been considered and other issues addressed, the oncologist specifies the doses to the tumor and surrounding normal structures. The physicist, in turn, designs potential delivery approaches which satisfy the dose requirements, typically with the assistance of treatment planning computers. Computerized

isodose curves are generated that follow the contour of a constant percent dose level as it exists within the treatment area in the patient's body. The percent dose curves are affected by irregularities of the patient's external anatomy (i.e., contour), by different radiation attenuation properties of body structures, by the additive effects of intersecting beams, and by the placement of wedges and blocks in the beam's path. With multiple-beam treatments, which are the rule, treatment planning can become quite complex. Since the therapists are responsible for implementing the treatment plan, it is important that they know not only what to do at a skill-base level in terms of patient set-ups and entering the appropriate machine parameters, but that they understand the logic and knowledge-based models used by the oncologists and physicists during treatment planning. In the interviews with oncologists, physicists and therapists, a desire for more training for therapists in treatment planning was expressed. Given the complexity of treatment planning, the increasing use of computers to generate alternative plans, and the expressed desire for further training from treatment team members, treatment planning is identified as a potential area in need of training. Entry-level dosimetrists also would seem to benefit from some form of systematic training in treatment planning.

During the interviews with teletherapy personnel, most of the focus was on the active errors that the therapists were likely to make. Active errors are typically associated with personnel who operate the direct control interface while latent errors are spawned further upstream by managers and those in decision-making positions. Decision-making consequences accrue gradually over time, interact with other variables, and are difficult to isolate. Yet organizational policy regarding staffing, lines of communication, workload, scheduling of patients, and quality assurance procedures are sure to have their impact. The active errors of therapists result, in part, from the latent or delayed consequences of poor management decisions and practices. At the sites visited, there seemed to be little appreciation or recognition of the latent effect that management decisions or organizational policy can have. For these reasons, Table 3.7 shows that Management of Teletherapy Facility and Staff is another area that is recommended for training.

4.0 RESULTS AND DISCUSSION ON ORGANIZATIONAL POLICIES AND PRACTICES

Far removed from the front-line activities of the therapists are the organizational policies and practices that set into place and govern the teletherapy process. It is generally recognized that organizational policies and practices may serve to facilitate or impede human performance in the workplace. To better understand the impact of organizational variables in teletherapy, this section examines six major areas: 1) organizational staffing issues, 2) performance evaluations and their implications, 3) identification of human error in teletherapy, 4) implementation of quality assurance programs, 5) organizational factors underlying human performance in teletherapy, and 6) the relationship between task performance and organizational factors.

4.1 Organizational Staffing Issues

Organizational staffing issues focus on the effective use of personnel given an organizational mission such as the delivery of high quality patient care. In the present context, staffing issues will focus on how radiation oncology departments are organized, adequacy of staffing levels, rotation of staff, work schedules, and sick- and vacation-leave policy.

4.1.1 Formal Organization of Radiation Oncology Departments

Only a few of the sites visited could actually produce an up-to-date organization chart to provide a basis for making comparisons. The initial impression of the formal organizational structure of the radiation oncology departments visited was that they varied considerably. However, upon closer examination, the slight differences in position titles and the varying number of functional areas appear to exaggerate differences among departments. In their most fundamental form, most departments had the heads or chiefs of the functional areas (e.g., clinical, physics, administrative) reporting directly to the medical director of the radiation oncology unit. Larger centers affiliated with a university, for example, would have the business manager or administrator and various section chiefs (e.g., clinical, physics, research, satellite clinical, computer support services) reporting to the director. At these larger centers there may be associate directors that assist the director as well as collateral committees (e.g., steering, quality assurance) that report to the director. The business manager and his or her staff are typically responsible for patient accounts, personnel and payroll operations, information dissemination, budgets, grants and finance. A separate clinical section chief may be responsible for the attending and resident oncologists if the size of the department warrants it; otherwise, the clinical section chief is responsible for oncologists as well as therapists. Staff radiation therapists will report to a chief therapist, who in return, reports to the associate director or medical director. If a center operates a school for radiation therapists, the school is likely to have a director who reports to either the clinical section chief, associate director or the medical director. Depending upon the size and influence of the physics section, it may either have its own section chief or be subsumed under the clinical section.

The organizational chain of command can have important repercussions on communication patterns, coordination, and continuity for patient care. Respondents at one facility that was visited indicated that oncologists and physicists were considered professional personnel and were employed by the university; dosimetrists and therapists, on the other hand, were considered technical personnel and were hired by the hospital. The two groups had separate chains of command. The radiation oncology department had recently completed an organizational assessment by a radiation oncology specialist from outside the center. Notes taken from the organizational assessment indicated that responsibilities were not well defined in the department, clinical information for day-to-day operations was not communicated very well by oncologists, oncologists' schedules did not provide for full coverage in the department, there were too many part-time oncologists, and departmental changes were made too frequently and arbitrarily, creating confusion for the therapists who had to implement the changes. Under these conditions, there is potential for patient care to be compromised.

4.1.2 Adequacy of Staffing Levels

Factors associated with staffing can have a profound effect on job performance. Inadequate levels of staffing can increase the workload of existing personnel and thereby add stress to the job. Stress is a term that carries a variety of meanings, and depending on its type, magnitude, and duration, can either debilitate (e.g., slips, lapses) or enhance performance. A sense of fair treatment and job satisfaction are also associated with staffing.

When asked to describe their staffing situation, respondents at most of the sites visited prefaced their remarks with the statement that they try to have two therapists assigned to a treatment machine. If this goal was met, the respondent was more likely to respond that the staffing situation was quite adequate. If two therapists were not assigned to a machine, the respondent would say the department was understaffed by one therapist. At approximately 25 percent of the sites visited, respondents said they were understaffed by at least one therapist. Most respondents acknowledged that they were able to maintain adequate staffing levels of therapists despite the nationwide shortage. A couple of chief therapists, although stating they were adequately staffed, indicated a desire for hiring one more therapist since it would make scheduling vacations and covering absences much easier. Respondents indicating they were adequately staffed also indicated that about 10% of the time a therapist would be working alone on a machine as a result of absences. Absences were handled at times by the chief therapist filling in where needed, by bringing in temporary staff, or by leaving the position vacant. At one fairly sizable university hospital, one therapist was assigned as a "floater" in the treatment area to cover unanticipated absences. Staffing levels for dosimetrists and physicists were somewhat easier to fulfill.

For the most part, turnover of therapists did not appear to present a problem. Respondents at many hospitals indicated that they had one person leave during the past year. Observations and interviews at the limited number of sites visited indicated that turnover occurred more frequently at some of the large, urban centers (e.g., 4 out of 19 in a year at one place visited). With the high demand for therapists and the competitive job market in urban areas, a certain

amount of turnover is understandable. Boredom and unpleasant organizational environment were two other reasons given for turnover.

The responsibility for hiring or terminating therapists resided most often with the chief therapist and sometimes the business manager. Many chief therapists indicated that selection of the right person was very important in filling staff therapist positions. Many relied on their own professional networks to hire "known quantities." Other times, they would hire promising graduates of the two-year schools that had rotated through their departments. Among the qualities looked for in entry-level staff therapists were technical proficiency, conscientiousness, communication and team-work skills, and compassion and sensitivity to the needs of patients. Staff therapists are typically hired with a six-month probation period provision. Although terminations were relatively infrequent, respondents at a few sites reported they had terminated therapists in the last two years. Specific reasons were not given for the terminations.

4.1.3 Rotation of Staff Across Treatment Machines/Simulator

At most of the places visited, therapists rotated across treatment machines for greater breadth of experience. Sometimes therapists rotated to the simulator, but typically respondents indicated that therapists were assigned permanently to the simulator. The practice of rotating therapists across treatment machines reflects the conventional wisdom that a certain amount of variety and stimulus change is important for maintaining optimal levels of arousal and attention to the tasks that are performed. Excessive redundancy or repetitiveness of task activity is frequently cited as being associated with lower levels of performance although the research literature identifies a large number of organismic, situational, and task variables that moderate the suspected relationship (Rohmert, 1987). The rationale for a permanent rotation to the simulation unit is founded on the greater complexity and diversity of the simulation process. A more experienced and technically proficient therapist is usually assigned to the simulator.

Another reason for the interest in rotation of staff among treatment units is the potential for negative transfer. To what extent are the responses and procedures that are appropriate and correct for one type of machine likely to be inappropriately made when the therapist transfers to a different machine (e.g., from a Co-60 machine to a linear accelerator)? As was discussed in Section 3.2.7, there were no reports from therapists that rotation between machines resulted in negative transfer. Examination of the interfaces of the therapist's consoles for the two types of treatment machines found them to be sufficiently different and to have different initiating cues requiring different responses. This observation also is compatible with the transfer of training literature which finds that negative transfer decreases as the dissimilarity of the stimuli increases (Gibson, 1941; Ellis, 1965).

4.1.4 Work Schedules, Rest Periods and Boredom

There was some variation in work schedules among the sites visited, but the variation was limited. At several sites, the therapists worked less than a 40 hour week (e.g., 35 hours, 37.5 hours) distributed across five days. At yet another site, therapists work four 10-hour days while the dosimetrists and physicists worked five 8-hour days. The stated rationale for the four 10-hour

day schedule was to lessen the requirement for child care by one day for the therapists. Many therapists reported only a minimal need or desire for working overtime; however, for some therapists it was a source of extra income.

Rest periods or short breaks have been reported as relieving fatigue and enhancing job satisfaction and productivity in machine-paced jobs (Krueger, 1989). Scheduling rest periods in the morning and afternoon for therapists was a common practice at the sites visited; however, when patient scheduling became backed up it was not uncommon for rest periods to be skipped. Although attempts have been made to determine the optimal timing and duration of rest breaks for vigilance tasks, not much is known about the optimal frequency and duration of rest periods for most occupations. The nature of the activity engaged in during scheduled breaks or lunch periods may be a significant factor.

For people in sedentary occupations, walking or light aerobics is often recommended; however, the recommendations of health experts regarding specific types of rest period activity are often made in the absence of empirical support.

The potential occurrence of boredom among therapists merits examination. Boredom refers to information underload and occurs with tasks that are predominately skill-based, repetitious, and somewhat automatic or routine in their execution. In a study of train accidents on the Japanese National Railway, Haga (1984) found that boredom and automatic behavior were the major contributing factors to human error in train driving. Whether or not the work of therapists approach conditions of boredom is difficult to say. Although many of the tasks performed are routine and not fully mentally absorbing, each patient requires a different set-up and the execution of some different sub-tasks. Boredom was rarely mentioned by the therapists interviewed. At sites that had high patient volume (i.e., 4 or more patients per hour), workload stress rather than boredom was more frequently reported.

It is thus doubtful whether boredom is a term that can be used to characterize the work conditions of radiation therapists. Although the therapists interviewed did not state that their work was boring, a few therapists indicated they changed hospitals to accept more challenge and be exposed to more varied treatments. Also those therapists who had moved into dosimetry mentioned a need for greater challenge as a reason for making the change.

4.1.5 Sick Leave and Vacation Leave Policy

Policies regarding sick leave varied among the sites visited, ranging from nine to 15 days. The most typical number of days was 12, accruing at one day a month. At some locations, sick leave time could accrue over the years; at other places, it could not. At one site, once it reached a certain amount (e.g., 552 hours), the excess could be cashed in. At one of the facilities that allotted 12 days a year, the average sick leave taken per therapist was nine days. Sick leave absentee rate is used by some organizations as a productivity indicator along with several other indicators. A high absentee rate is frequently associated with departments that have poor organizational climate, low morale, and employee dissatisfaction. In the teletherapy environment, high absentee rates have the potential to have a direct impact on the quality of patient care. As

noted by one respondent as the absentee rate increases, so does the percentage of time that a therapist is likely to work alone with a patient.

Policies regarding vacation leave also varied among the sites visited, ranging from 12 days to 24 days. Several sites had an incremental schedule with vacation days increasing as years of service increased (e.g., after five years, three weeks of vacation granted; after ten years, four weeks of vacation granted). Although there was no indication of dissatisfaction with the number of vacation days allotted, one chief therapist indicated it was not always possible to grant vacation during the time period requested because of competing requests among the staff therapists at popular times during the year. This was a source of grievance for some therapists. In order to keep all the treatment machines covered, there was a limit on the number of therapists that could be on vacation at the same time.

4.2 Performance Evaluations and their Implications

Performance evaluations of teletherapy personnel were in widespread use across the various departments visited and were of interest to the present study because they frequently reflect the knowledge, skills and attitudes that management considers important. The conduct of performance evaluations, the relationship between performance evaluations and salary, and the relationship between performance evaluations and the self-reporting of errors are examined next.

4.2.1 Conduct of Performance Evaluations

All of the sites visited reported the use of performance evaluation procedures for assessing the relevant job performance of teletherapy personnel. When requested, many sites were able to provide samples of the evaluation form used for therapists. Typically, entry-level therapists receive an evaluation at the end of a three- or six-month probation period, and then on their anniversary date, and then every year thereafter. The chief therapist or lead therapist in a work group is responsible for performing the evaluation. Similar procedures exist for dosimetry and physics personnel with the chief physicist conducting the evaluations. Performance evaluations in general were conducted by the appropriate supervisor in the staff member's chain of command.

Many of the evaluation forms for therapists were based on a rating scale, whereby descriptive items appearing under major evaluation categories are rated on a 1 (Unsatisfactory) to 5 (Outstanding) scale. Spaces for additional comments are also typically provided. Table 4.1 shows some sampled items from such a form that was in use at one of the sites visited. Reliance on evaluation-by-the-numbers can be criticized on several accounts (e.g., the arithmetic operations performed on the numbers are often questionable psychometrically, the numbers themselves become the focus of the evaluation rather than employee development or contribution to organizational mission, the reliability and validity of the instruments are rarely established); however, because of advantages in terms of simplicity and ease of administration, evaluation instruments with rating scales are probably the norm.

Table 4.1 Sample Items from Evaluation Form for RTs

JOB KNOWLEDGE

- A._____ Demonstrates understanding of job duties and responsibilities
- B._____ Demonstrates understanding of established procedures and policies

QUANTITY OF WORK

- A._____ Amount of work performed, regularly does fair share of work
- C._____ Manages time effectively, maintains daily treatment schedule to best of their ability

QUALITY OF WORK

- D._____ Demonstrates proficiency in accurately setting field sizes, treatment distances, gantry, collimator, and table angles
- N._____ Demonstrates responsibility to consistently and accurately perform daily warm-up procedures, weekly and monthly quality assurance practices for each treatment unit as assigned

RESPONSIBILITY, ADAPTABILITY AND INITIATIVE

- C._____ Demonstrates ability to adapt to new situation and/or change
- E._____ Demonstrates good attitude toward management

WORKING RELATIONSHIPS

- A._____ Self motivation in assisting and supporting co-workers and patient
- D._____ Demonstrates ability to relate well with patients and patients' families
-

Other evaluation instruments in use at departments of radiation oncology allow performance and development objectives to be prepared (i.e., written in the first column of the form). Then in an adjoining column written comments or evaluations of performance are entered that compare the results expected as stated in the objective with the results actually obtained. The evaluator assesses whether the performance level exceeds the standard, meets the standard, or does not meet the standard. Additional pages are provided for specifying an individual development plan for the employee. The performance appraisal literature suggests that when an individual employee has a voice in determining his or her own performance objectives and is provided with a constructive development plan for improving performance and career growth, the evaluation process becomes a more meaningful opportunity for employee and supervisor to jointly pursue individual and organizational goals (Bernardin & Beatty, 1984). Although two hospitals had evaluation forms that allowed for a more constructive evaluation process, when the process was described in a rather perfunctory manner, it led the current authors to question whether the manner and spirit by which the evaluation process was implemented at these sites was truly conducive to individual growth.

4.2.2 Relationship between Performance and Salary

When asked whether performance is tied to salary, most respondents indicated it was not. Responses ranged from "not really, get it anyway" to "loosely" to "generally no" to "not the case, everybody gets 4 1/2 to 5 1/2 %, they think it will create conflicts." Nor were there strong beliefs expressed that there should be a relationship between performance level and salary.

The issue of whether salary should be tied directly to performance evaluations is a recurring one in many professions. There are several reasons why organizations conduct performance evaluations other than as a basis for merit increases. Such evaluations are conducted to provide feedback to employees for self-evaluation and improvement, to evaluate the effectiveness of selection and placement decisions, to diagnose training and development needs for given job categories, and to assess the effectiveness of on-going programs (e.g., quality assurance), among others. To be sure, discussions concerning the advantages and disadvantages of tying salary increments to performance will continue. The appropriateness of the practice is likely to vary for different occupational settings. It is not uncommon to find rewards and salary increments tied directly to professions that rely heavily on individual initiative (e.g., sales) while for those professions that rely on teamwork, the relationship between individual performance and salary increments is less explicit.

4.2.3. Performance Evaluation and the Self-Reporting of Errors

Another avenue of inquiry was to examine the relationship between performance evaluations and the self-reporting of errors, with a specific emphasis on whether performance evaluations inhibit the self-reporting of errors. It is difficult to judge the accuracy of responses about this issue given a normal tendency for many individuals to portray themselves in a socially acceptable manner. If performance evaluations are routinely given, and if the emphasis is on the evaluation and accountability aspects of evaluation rather than the developmental aspect, it may be reasonable to suspect that there might be some reluctance to report errors freely. According to respondents, this is apparently not the case. Most of the respondents indicated that performance

evaluations do not inhibit the self-reporting of errors. This statement was frequently followed by a description of a very favorable organizational climate that was most concerned with eliminating error and maximizing the quality of patient care rather than looking for someone to hold accountable for the error. In those departments that had constructive evaluation policies and a genuine concern for continuous quality improvement, there is little reason to suspect that the reporting of errors is adversely influenced by performance evaluations. There indeed may be departments where performance evaluations adversely influence the self-reporting of errors. Two of the respondents indicated that it might occur at some places; however, at the places visited in the present study, respondents did not perceive such a relationship.

4.3 Human Error in Teletherapy

The occurrence of human error was readily acknowledged in the teletherapy settings visited. Commonly occurring errors, the self-reporting of errors, and the work conditions that therapists find most stressful are addressed below.

4.3.1 Commonly Occurring Errors

A recurring question that was part of the interview process was to have respondents list the most commonly occurring errors that they could think of. Respondents were mostly therapists and a few dosimetrists and physicists. Table 4.2 simply represents the recall of commonly occurring errors by teletherapy personnel rather than an absolute frequency distribution of these types of error as a function of possible occurrences. The present study does not address how common these "commonly occurring errors" actually are. It should also be kept in mind that not all errors have the same degree of detectability; those that are less detectable are likely to be under-reported.

The table shows that clerical and calculation errors were by far the most frequently stated errors. For the most part, clerical errors refer to charting (e.g., confusing monitor units with the fraction dose) and simple arithmetic errors that are made by therapists while calculation errors refer to a variety of computational errors that can be made by dosimetrist and physicists. There is good reason to believe that these are the most commonly occurring errors since they are frequently corrected and brought to the attention of appropriate personnel by the weekly chart checks that are common practice in most departments. The chart checks are performed by dosimetry/physics personnel. At the same time, it is recognized that there are some errors in Table 4.2 that may not be detected given current practice (e.g., use of the wrong tattoos on a patient with multiple tattoos; twice treated field).

The next most frequently cited class of error were failures of communication. Communication failures referred to both breakdowns in verbal communication (e.g., inadequate transfer of clinical information to appropriate personnel; unreliable verbal communication instead of written documentation) and written instructions (e.g., written instructions not adequate for proper positioning of raised arm). One therapist indicated that a prescription notation of "200

Table 4.2 Commonly Occurring Errors According to Interview Respondents

<u>Error</u>	<u>Frequency (%) Listed</u>	
Clerical (charting) numerical errors	10	(17.00)
Calculation errors	8	(14.00)
Communication failure (verbal & doc.)	5	(08.00)
Wrong block	4	(07.00)
Omitted block	2	(03.00)
Incorrectly mounted/inserted block	2	(03.00)
Labeling on block wrong	1	(02.00)
Custom block crowding the field	1	(02.00)
Putting wedge in incorrectly	3	(05.00)
Omitted wedge	2	(03.00)
Wrong wedge	1	(02.00)
Patient/position alignment	3	(05.00)
Incorrect field size	3	(05.00)
Use of wrong tattoos	1	(02.00)
Misdiagnosis	1	(02.00)
Moving from one machine to the next	2	(03.00)
Software errors	1	(02.00)
Differences bet. sim & treatment table	1	(02.00)
Incorrect MV/dosage given	2	(03.00)
Machine misalignment	1	(02.00)
Twice treated field	1	(02.00)
Using previous patient's settings	1	(02.00)
Failing to chart treatment	1	(02.00)
Giving extra treatments	2	(03.00)

rads AP/PA" leaves open the question of whether it is 200 rads altogether or 200 rads AP and 200 rads PA. The attending oncologists were the most frequently cited source of inadequate communication.

Errors concerning the omission or improper use of blocks and wedges were mentioned several times. Using the wrong block for the treatment field was cited four times, forgetting or omitting the block for a treatment was mentioned twice, incorrectly mounted or inserted block was listed twice, inaccurate labeling on a block was stated once, and using a custom made block that

improperly covered the treatment field was also listed once. Similar problems exist with wedges. Wedges can be inserted improperly (e.g., interlock not functioning), they can be omitted, and the wrong one can be used. Altogether errors associated with blocks and wedges accounted for 27% of the commonly occurring errors reported by respondents.

Unlike an incorrectly mounted block which constitutes a systematic error since it is reproducible with each treatment, improper positioning or alignment of patients constitutes a random error since the error is not reproducible nor is the extent of the error easily verifiable. Errors associated with patient alignment and positioning were cited three times during the interviews and are frequently noted in the literature as well (Bentel, Nelson, & Noell, 1989). Despite the use of immobilization and positioning devices, achieving the same patient position treatment after treatment (when there are changes in attending therapists and in the patient's body contour) represents a very persistent source of error. Obese patients with pelvic treatments and intricate head and neck treatments can be especially troublesome, according to respondents.

Setting the wrong field size was mentioned three times as well. This fairly common error occurs when the therapist reverses the X-Y coordinates, setting the field, for example, for 12 cm X 14 cm rather than 14 cm X 12 cm. This is a good example of a routine, semi-automatic activity that is susceptible to skill-based errors as discussed in the previous section. In the absence of a record and verify system (typically not found on Co-60 units) and in the absence of a systematic double-checking procedure, this type of error might not be detected.

Other errors in Table 4.2 that were mentioned twice included moving from one machine to the next (instances of negative transfer discussed earlier), incorrect MV/dosage given, and giving extra treatments (e.g., thinking that the total prescribed dose was 4400 rads rather than 4000, or failing to notice that treatment to a given port terminates earlier than treatment of other ports). Incorrect MV/dosage refers to the type of error associated with dual energy linear accelerators as noted by Karzmark (1987) and Purdy (1991a). A dual energy accelerator provides the capability for a low energy x-ray beam of 6 MV and a high energy x-ray beam of 10 to 20 MV along with several electron beam energies ranging typically from 6 to 20 MeV. When operating in normal x-ray mode, the electron beam is intercepted by the x-ray target and x-ray flattening filter. In normal electron therapy, the electron beam is spread out by a scattering foil (or spread out electromagnetically) and is of the order of 1/1000 of the beam current for the x-ray therapy mode. In the event of hardware or software failure, a large electron beam intended for x-ray operation could exit without being intercepted by the x-ray target and/or x-ray flattening filter. With only the scattering foil or electromagnetic scanning capability in place, a dose rate of approximately 4,000 Gy/min is possible (Purdy, 1991a). In addition to hardware or software failure, the possibility of selecting the wrong energy level exists. It should be clear that the increased treatment flexibility and options of multimodality machines are associated with an increased responsibility for their safe operation and maintenance.

The remaining errors of Table 4.2 that were cited once include software errors, errors resulting from differences between the simulation and treatment table, machine misalignment, treating the same field twice, using a previous patient's settings, and failing to chart treatment. Because an error was listed just once or twice does not mean that it is insignificant or even that it occurs infrequently.

It is useful to note that the present study agrees fairly well with a study by Swann-D'Emilia, Chu, and Daywalt (1990) with respect to the types of errors that occur. These authors documented incidents involving misadministration from prescribed dose at a treatment facility during 1988 and 1989. Focusing on 1988, 1092 patients were treated through a total of 71,760 fields (i.e., an average of 92 patients per day X an average of 3 fields per patient X 5 days per week X 52 weeks). Using their criteria, a total of 54 misadministrations were recorded. Six machine malfunctions accounted for 11.1% of the misadministrations, four dosimetry calculation and documentation errors accounted for 7.4%, and four block fabrication errors accounted for 7.4%. By far the greatest number were treatment delivery errors, accounting for 40 misadministrations or 74.1% of the total. Table 4.3 shows the Swann-D'Emilia et al. (1990) frequency of occurrence data for treatment delivery misadministrations for the years 1988 and 1989. Table 4.3 shows the same type of treatment delivery errors as reported in Table 4.2 of the present study. Of the 40 treatment delivery errors in 1988, 10 were the result of using a wrong block for the treatment field; using a wrong wedge accounted for 4 of the errors as did setting the wrong field size. Omitting a wedge, omitting a block, and using the wrong photon energy level occurred three times. Using the wrong tattoos to set up the treatment field occurred twice and failing to chart a treatment thus giving an extra fraction also occurred twice. Miscellaneous errors (e.g., omitting a bolus) were those that occurred once, accounting for a total of nine of the errors.

The misadministrations of the Swann-D'Emilia et al. (1990) study are so statistically infrequent as to suggest that treatments are consistently delivered with a high degree of accuracy. Indeed, there may be reason to suspect that the reported misadministrations are on the low side since the data were collected concurrently with/and as part of a highly visible quality assurance program. The impact of the program on the actual occurrence of errors remains unknown; the decline in errors in the second year (1989) of the program supports the notion that it may have had a suppressing effect. Furthermore, the study did not exhaust the full range of misadministrations that could occur. The study is of value, however, for confirming the more recognizable types of errors that do occur. There is now at least some documented evidence which can serve as a source of guidance for departments wishing to reduce the number of treatment delivery errors.

A follow up question to the above question on commonly occurring errors asked respondents to list some uncommon or atypical errors. Many of the respondents had difficulty in distinguishing between common and uncommon or atypical errors since all errors occur relatively infrequently. Treating the wrong patient and treating the wrong side of the patient were among those mentioned as atypical, but that have occurred.

Table 4.3 Frequencies for Treatment Delivery Misadministrations

<u>Type of Misadministration</u>	<u>1988 Incidents</u>	<u>1989 Incidents</u>
Wrong block	10 (25%)	5 (18%)
Wrong field size	4 (10%)	3 (11%)
Wrong wedge	4 (10%)	---
Omitted wedge	3 (7.5%)	2 (7%)
Omitted block	3 (7.5%)	4 (14.3%)
Incorrect energy	3 (7.5%)	---
Wrong tattoos	2 (5%)	4 (14.3%)
Treatment not recorded*	2 (5%)	---
Incorrect SSD	---	2 (7%)
Incorrect gantry angle	---	2 (7%)
Twice treated field**	---	2 (7%)
Miscellaneous errors***	9 (22.5%)	4 (14.3%)

* Treatment not recorded; therefore, patient treated 1 extra fraction.

** Anterior field of parallel opposed pair treated 2X without rotating gantry.

*** Any error occurring only once in 1 year; must be non-related incidents.

Source: Reprinted from *Medical Dosimetry*, 15, Swann-D'Emilia et al., "Misadministration of Prescribed Radiation Dose" pp. 185-191, 1990 with permission of Elsevier Science Ltd, The Boulevard, Langford Lane, Kidlington OX5 1GB, UK

4.3.2 Self-Reporting of Errors

When asked if there was a policy for the self-reporting of errors, respondents at most sites indicated that there was. Most of the times, however, the policy seemed to be informally implemented. It was common for the error to be reported to the chief therapist or to the physics department when the error was made by the staff therapist. The chief therapist, in conjunction with the physics department, informs the oncologist and he or she determines if a change needs to be made to the patient's prescription. At a few places, a more formal procedure was evident. A quality assurance (QA) memo would be prepared by the staff therapist for the chief therapist's review. The memo would then be discussed at weekly chart rounds and departmental follow-up actions would be initiated if considered necessary. At another facility, the individual who made the error prepared a deviation memo and was potentially subject to a write-up or personnel action, perceived as a reprimand.

A follow-up question inquired about the organizational climate and whether it supported or inhibited self-reporting of errors. At the vast majority of sites visited, the organizational climate was described as quite conducive to the self-reporting of errors. Nobody reported feeling threatened or that punitive actions would ensue if errors were reported. At one location, a

therapist reported an unpleasant working relationship she had with an oncologist (at a previous hospital) who was very demanding, had difficulty communicating, and was very intolerant of any questioning of his directions. Such a relationship was not conducive, she indicated, to self-reporting of errors. At yet another site, the therapist indicated that the reduction of errors was everybody's responsibility—attending oncologists, residents, dosimetrists, physicists—and not just that of the therapists. It was generally found that departments that had active QA programs also tended to report the most favorable climate for the self-reporting of errors. In these departments, emphasis was placed on openness, trust, team spirit, and patient care rather than the assignment of blame on individuals. "Covering up a mistake is worse than making a mistake," was the sentiment of one individual. It would be nice to think that such a sentiment characterizes all teletherapy personnel; however, this way of thinking does not conform to what is known about individual differences. Those departments that make a conscientious effort in fostering a supportive organizational climate for the self-reporting of errors are likely to better understand the underlying conditions that give rise to human error.

4.3.3 Work Conditions Most Stressful to Therapists

Therapists also were asked to identify work conditions that they consider most stressful. The radiation therapists that were interviewed had little difficulty in citing the conditions they found most stressful. Table 4.4 lists the conditions.

The first five entries in Table 4.4—understaffed, high patient load, getting behind schedule, when machine goes down, and complex treatments—can be considered indicators of workload. All have the effect of increasing the amount of work that must be accomplished per unit of time. The same case can be made for treating very ill patients since it, no doubt, takes greater time to set up and position very ill patients that are likely undergoing other forms of concurrent medical treatment. The performance of excessive duties and treatment plans that contain an overload of information also contribute to workload.

With respect to excessive duties, one therapist identified the following duties that she believed served as a source of interference in providing quality patient care: 1) telephone calls coming to therapist from patients, 2) telephone calls coming to therapist from residents requesting information on patients, 3) telephone calls coming to therapist for blood counts, 4) patients walking in and asking therapist questions, 5) doing dose calculations, and 6) billing patients. The therapist had very little control over the first four sources of interference which sometimes occurred when the beam was on.

The clarity of treatment plans is yet another issue. Treatment plans frequently contain a wealth of information with multiple entries from different members of the treatment team. Some of the information is likely to be illegible and some of it may be beyond the therapist's level of understanding or need to know. Treatment plans that are difficult for the therapist to understand readily and that require extra efforts to decipher can have the effect of increasing his or her workload.

Table 4.4 Work Conditions Most Stressful for RTs

<u>Condition</u>	<u>Frequency</u>
Understaffed	1
High patient load	2
Getting behind schedule	3
When machine goes down and patients start piling up	1
Complex treatments	1
Very ill patients	2
Treating children	1
Several patients dying in short period of time	1
Excessive duties	1
Treatment plan contains an overload of information	1

Treating children and several patients dying in a short period of time are not workload related in the same sense as the others in Table 4.4. Therapists described these sources of stress as more emotional in nature. Although therapists were not very specific on this source of stress, a sense of apprehension and uneasiness was expressed in relation to the treatment of young children, and a sense of loss and despair when several patients die within brief time periods.

The number of patients treated per day with a given treatment machine depends on a number of factors, but one of these factors is the efficiency and quickness by which therapists can set up, treat, and then get ready for the next patient. To maximize the use of technologically sophisticated and costly equipment treatment units and to be of service to as many patients seeking treatment as is possible, the existing practice in the U.S. is to schedule patients back-to-back, with as many as four to five an hour. As a consequence, therapists perceive a need to work as quickly as possible. Making efficient use of resources constitutes good management practice, but only up to a point. If departmental administrators become overly ambitious in the number of patients they decide to treat, work conditions are likely to become stressful for therapists and errors more likely to occur. Swann-D'Emilia et al. (1990) report a disproportionate number of errors as patient production schedules increase. These investigators tallied frequencies of occurrence of both average monthly patient census (per treatment machine) and misadministrations. The average monthly patient census was obtained by reviewing the daily patient totals for each machine and tabulating the frequency of how often the average monthly census was within a certain range (i.e., successive patient census intervals of < 15, 15-19, 20-24, 25-29, 30-34 and so forth). Number of misadministrations were tallied within those intervals for the treatment machines in operation at their facility in 1988 and 1989. For both their 1988 and

1989 data, there was a disproportionate number of misadministrations at the higher census intervals even though these higher census intervals occurred less frequently.

4.4 Implementation of Quality Assurance Programs

Respondents at the sites visited were able to describe quality assurance procedures in varying levels of detail. Many places were acquainted with the QA guidelines from the American College of Radiology and were able to produce various QA forms which further attested to familiarization with the process. Less easy to determine was the extent to which a given facility was seriously committed to the QA process. Although further investigation would be needed to confirm initial impressions, some sites appeared to be minimally compliant with QA procedures while other sites were totally committed to the process and prided themselves on developing noteworthy QA programs. As indicated earlier, the sites were visited prior to the effective date of implementation of NRC's *Regulatory Guide 8.33* on quality management for medical licensees.

Appendix A describes a formal quality assurance program that was implemented at one of the university-based facilities and its smaller satellite clinics. It is described in Appendix A, not as an ideal model for other facilities to adopt, but simply to depict the major areas of QA focus in a program that is operational and well documented.

The success of such initiatives, however, appears to depend on broader organizational factors. At one site that lacked a serious QA program, the physicist indicated that quality of treatment depends on a strong physics department and that if there is a lack of communication between oncologists and physicists, quality will suffer. This individual also expressed concern about a trend of cutting back on physicists' time at some smaller hospitals and clinics to reduce operating expenses. At yet another site, the chief physicist indicated that the difficulty with implementing QA programs was in following through and in maintaining continuous emphasis on quality rather than allowing the program to "fizzle out." Experience with total quality management (TQM) and QA programs has made it clear that the active commitment of upper management is a necessary condition for the effective implementation of such programs. Individual efforts at QA without full departmental approval, support, resources and procedures are likely to be short-lived. It is suspected that those places that lack serious QA programs also lack organizational commitment at the levels of departmental director and hospital administrator.

4.5 Organizational Factors Underlying Human Performance

Three major topics are addressed in this section: organizational factors and management practices perceived as likely to contribute to human error, organizational factors perceived as successful and contributing to high quality treatment, and reported suggestions for making improvements.

4.5.1 Organizational Factors Contributing to Human Error

Earlier in the report it was noted that managerial and organizational factors play a more significant role in contributing to human error than is usually realized. Because these factors are of an administrative, decision-making nature and are far removed from the front line operation of the treatment unit, their near- and long-term effects are not easily recognized. For an increasing number of investigators, these factors represent the submerged greater causal mass of the human error iceberg (Headrick, 1986; Reason, 1990; Senders and Moray, 1991). For this reason, respondents were asked if they could identify any organizational characteristics, administrative decisions, or management practices that are less than desirable and likely to contribute to human error or misadministration of dose.

Table 4.5 lists the organizational factors that were mentioned. Both the first and last entry in the table reflect a concern about adequate staffing. Understaffing directly increases the percentage of time that therapists have to work alone. As advocated by the Inter-Society Council for Radiation Oncology (1991) in *Radiation Oncology in Integrated Cancer Management*, recommended practice is to assign two therapists per machine; however, respondents at one of the visited sites that was understaffed estimated that therapists work alone 50% of the time. At another site, a physicist was critical of management for allowing old equipment to keep breaking down and not solving the problem. The next five comments, starting with threatening environment and ending with lack of team spirit, all seem to be related to the presence of an inappropriate organizational climate. Team spirit is very much likely to suffer in organizational climates that are threatening and where it appears to the staff that management does not involve itself in daily operations. This impression is often reinforced when management has little or no

Table 4.5 Organizational Factors Contributing to Human Error

-
- Understaffed
 - Old equipment that breaks down
 - Threatening environment
 - Management not in touch with daily operations
 - Failure to ask questions
 - Management setting the wrong organizational climate
 - Lack of team spirit
 - Assignment of wrong therapist to simulation
 - Salaries not competitive with national average
 - Complexity of cases
 - Turnaround time in dosimetry
 - Difficulty in terminating problem employee because of union
 - Uncooperative physicians/not available enough
 - Schedules with too many patients per hour
 - Use of only one qualified RT
-

working relationship with the staff. A total team commitment to the elimination of errors and quality patient care is unlikely unless management fosters a very supportive climate. Assigning the wrong therapist to simulation is a personnel placement issue that has widespread implications for quality patient care. Also having an impact on patient care, but in less obvious manner, is the department's salary structure which influences management's ability to attract highly qualified personnel. If management establishes a salary structure below the national average, it may be attracting the less qualified personnel. The complexity of cases and turnaround time in dosimetry were issues raised by a dosimetrist. He indicated that the complexity of some treatment plans sometimes appeared to exceed the ability of staff to reliably treat the patient. Some treatment plans take as long as 10 hours to do which results in a backlog of other plans requiring attention. Work allocation and staffing may be underlying issues here. Incompetent or problem employees that are protected by unions or other organizational systems represent very complex issues that are probably best addressed on an individual basis. Concerns about physicians that are unavailable or that lack effective communication skills have been expressed before in response to other questions. Although it is difficult to assess the magnitude of the problem, the fact that it is a deficiency that has been commented upon at other times suggests that it is a significant issue. This is a departmental issue that is probably best addressed within the context of a comprehensive QA program. Just as QA measures have been developed for the physical and clinical aspects of radiation oncology therapy, similar QA measures need to be devised for the human to human interfaces that need to occur. Finally, the comment about pumping through five rather than four patients per hour reflects a therapist's concern about hospital management attempting to treat too many patients per treatment unit in a given day to the detriment of quality care. Many departments of radiation oncology are profit making centers for their respective hospitals and the number of patients treated per hour per machine has a direct relationship with the amount of profit realized. While it is difficult to determine the optimal number of patients per hour per machine to treat and still maintain quality treatment, this is an organizational decision that is directly related to the number of misadministrations likely to occur as shown by the Swann-Emilia et al. (1990) research discussed earlier.

4.5.2 Organizational Factors Contributing to High Quality Treatment

Respondents were asked if they could identify any organizational characteristics, administrative decisions, or management practices that have been particularly successful and contribute to high quality treatment. At one level of analysis, eliminating (or improving) the organizational factors that contribute to human error will provide a good start for ensuring high quality treatment. In fact, many of the respondents identified positive aspects of the same factors as contributing to high quality treatment. Table 4.6 lists the responses.

As was the case in the preceding table, having physicians accessible to answer questions was considered very important. One therapist indicated it was extremely frustrating when they could not be reached. Good intradepartmental coordination and the closely located offices of therapists and physicists also reflect recognition of a need for information to be available when and where it is needed. An oncologist listed an administration that is responsive to departmental needs as a contributing factor, adding that the hospital should leave the oncologist alone and let him focus on the department. From his perspective, the hospital administration was not being responsive to his needs. Good staff morale and letting the staff know it is appreciated were contributing

factors to high quality treatment, according to therapists. In teletherapy, therapists are the front line workers who have the greatest degree of interaction with patients. If their daily efforts to deliver

Table 4.6 Organizational Factors Contributing
to High Quality Treatment

-
- Physicians are accessible
 - Intradepartmental coordination is good
 - Offices of physicists and therapists are close together
 - Administration is responsive to staff needs
 - Staff knows they are appreciated
 - Staff morale is good
 - Staff attend professional meetings
 - New books for up-to-date information are ordered
 - Chart rounds are helpful to therapists/physicists
 - Dosimetry checks charts weekly
 - Monthly QA sessions are held
 - Nurse/social worker is on hand
 - Staff positions are full
-

high quality care are not recognized and appreciated, the overall quality of treatment is likely to suffer. A continuing education need is reflected in the next two comments—permitting staff to go to professional conferences and allowing new books to be ordered. Education and training were discussed in Section 3.0. It should be noted that radiation oncology departments that had healthy organizational climates also were likely to have policies that were conducive to continuing education and training. The next few comments once again focus on QA practices. These include attendance by therapists and physicists at weekly chart round meetings, weekly dosimetry chart checks, and monthly QA sessions. And finally, the presence of a nurse or social worker as part of the radiation oncology therapy team was mentioned as a contributing factor to high quality care as was the organizational practice of remaining fully staffed.

4.5.3 Suggestions for Making Improvements

As a final question, respondents were asked what they would do differently if they could make improvements. Although many of the respondents referred to their comments in the two immediately preceding sub-sections, there were some new suggestions as well. A physicist suggested that some of the profit should be allocated to applied research, such as establishing an electronic network of successful treatment plans. Another physicist said he would decorate the basement with brighter lights, put in an aquarium, and create a more attractive visual environment. He noted that an attractive treatment environment is important for both patients and employees. At another facility, a therapist indicated that there could be better supervision of their satellite clinics, that there could be better coordination between headquarters and

downtown sites, and that staff problems could be handled better. At yet another facility that was poorly equipped, improvements needed were a simulator (which they did not have), laser lights for the treatment unit, and a community education and outreach (preventative medicine) program.

4.6 The Latent Nature of Organizational Factors

Based on the project staff's observations and on all the collected comments regarding organizational policies and practices, Table 4.7 was constructed to identify and summarize those factors discussed in the preceding sub-sections that serve to facilitate task performance in the teletherapy setting. The corollary is that their absence serves to impede task performance.

The factors in Table 4.7 have been discussed earlier in this section and require no further elaboration here. However, a few comments are in order on the relationship of organizational factors, such as those identified below, to the task performance requirements of the teletherapy system. A recent paper on human error in teletherapy introduced the notion that a full range of factors needs to be considered and not just those activities associated with the front-line operation of the system (Henriksen, Kaye, & Morisseau, 1991). Errors that can be traced to managerial and organizational factors remain poorly understood due, in large measure, to their dormant and delayed nature. To use Reason's (1990) metaphor, these are the resident pathogens that lie dormant for some time, yet combine with other unsuspected pathogens to thwart the system's defenses and lead to error. Errors that therapists make are termed active errors since their effects are noticed almost immediately or in the near term. Errors of judgment, indecision, or omission, which are more likely to be made by managers and administrators, are termed latent errors because they occur further upstream in the sequence of events and are more difficult to trace. Those who make organizational policy and implement managerial decisions are less likely to be

Table 4.7 Organizational Factors with Potential to Facilitate Task Performance

-
- Adequate staffing levels
 - Supportive climate for self-reporting of errors
 - Effective communication practices among team members
 - Effective coordination of satellite sites
 - Optimal workloads for therapists/dosimetrists
 - Elimination of sources of distraction for therapists
 - Optimal scheduling of patients to avoid peak loads
 - Accessibility of oncologists
 - Clarity of treatment plans
 - Department-wide commitment to QA procedures
 - Appropriate patient census on treatment machines
 - Replacement of less reliable equipment
 - Procurement of needed equipment
 - Organizational climate for enhancing self-worth and professional growth of all team members
-

held accountable for the consequences of their actions. Oftentimes, the consequences accrue gradually over time, interact with other variables, and are not that easy to determine. Yet organizational practices regarding staffing, communication, workload conditions, scheduling of patients, and quality assurance procedures will surely have their impact. The active errors that therapists make result from a unique combination of several necessary but singly insufficient factors. Many of these factors are of a latent organizational nature and are present in the system long before the actual occurrence of human error.

The human factors literature, of late, has become increasingly aware of the importance of organizational and managerial factors (Reason, 1990; Senders & Moray, 1991; Weiner, 1989). Reason (1990) notes that lessons learned from major disasters during the past two decades are pointing to latent error conditions spawned by management as a very significant contributing factor. In a very enlightening chapter on latent errors and systems disasters, he discusses and summarizes (pp. 173-216; 251-257) the analyses of some well-known systems disasters—Three Mile Island, Bhopal, Challenger, Chernobyl, Herald of Free Enterprise, and King's Cross Underground Fire—and finds that latent errors, not active operator errors, are the greatest threat to system safety. As quite aptly stated by Reason (1990):

Rather than being the main instigators of an accident, operators tend to be the inheritors of system defects created by poor design, incorrect installation, faulty maintenance and bad management decisions. Their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in the cooking (p. 173).

5.0 CONCLUSION

Teletherapy has been defined as a multidisciplinary and multiphased treatment methodology for treating cancerous and other tissue through selective exposure to an external beam of ionizing radiation. Since treatment takes place on a daily basis (in fractions) over a period of weeks, a concern for the factors that affect precision and consistency of treatment is paramount. The present report focuses solely on training and qualifications of teletherapy staff and on organizational factors that are likely to have an impact on human performance and human error in the teletherapy setting. The following conclusions, based upon findings from the training and organizational areas, underscore the relevance of this concern.

5.1 Training Area

- The formal training that radiation therapists, physicists, and dosimetrists receive prior to employment was reviewed and while major deficiencies were not found, a need for a greater conceptual understanding of dosimetry and treatment planning by therapists was mentioned by respondents.
- Once hired, extensive reliance on informal on-the-job (OJT) training for newly hired therapists makes it difficult to determine if therapists have acquired the necessary skills and knowledge for unsupervised job performance.
- When new equipment or software is purchased by a facility, the training received by staff members is frequently less than adequate (e.g., left to the individual's initiative, an operator's manual, or vendor's ability to provide training).
- None of the respondents indicated they received any special training (e.g., emergency training) for responding to machine malfunctions such as stuck sources in Co-60 machines.
- Formal training in quality assurance procedures did not occur at many of the sites visited. It is noted that visits were made prior to the effective date of implementation of NRC's *Regulatory Guide 8.33* on quality management for medical licensees.
- Most teletherapy personnel focus on the active errors that therapists are likely to make to the neglect of the latent role that training factors are likely to have on human error. Greater awareness of the latent effect that inadequate training and qualifications can have on the functions and tasks performed by teletherapy personnel is needed.

5.2 Organizational Area

- Personnel at approximately 25 percent of the sites visited stated they were understaffed by one therapist, necessitating a single therapist to be assigned to a machine at times. Staffing shortages increase the workload of therapists; excessive workloads can increase the likelihood of treatment delivery errors.
- Favorable organizational climates for the self-reporting of errors were described at most of the sites visited. At these sites, emphasis was placed on reducing error and maximizing the quality of patient care rather than affixing blame.
- Errors were cited by all members of the teletherapy team: calculation errors by dosimetrists and physicists, communication errors by oncologists, and charting and patient set-up errors by therapists.
- In terms of quality assurance, most sites were acquainted with various QA guidelines. More difficult to determine was the extent to which a given site was seriously committed to the QA process.
- Respondents identified the following organizational factors as contributing to human error: understaffing, old equipment that breaks down, management not actively involved in daily operations, salaries not competitive with the national average, oncologists not accessible, complexity of cases, and treatment schedules with too many patients per hour.
- Finally, it was noted that many of the active errors that therapists make may have their origins in the less recognized latent errors that are spawned by organizational decision-makers. Further, management practices regarding staffing, scheduling of patients, and quality assurance programs are sure to have their impact on treatment planning and treatment set-up tasks. Undesirable organizational factors may be present in the system long before the actual occurrence of human error. Once these undesirable factors are recognized and their impact understood, the optimistic conclusion is that appropriate resources will be used to eliminate them.

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APPENDIX A

A QUALITY ASSURANCE PROGRAM AT A UNIVERSITY-BASED FACILITY WITH SMALLER SATELLITE CLINICS

The following sections describe a formal quality assurance program that was implemented at a university-based facility that was affiliated with five smaller clinics. A more extensive discussion of the program can be found in Purdy (1991b). Central to the program is a Quality Assurance Committee (QAC) that oversees the program, emphasizing a team approach involving all teletherapy personnel. The QAC consists of a chairperson, chief radiation oncologist, clinical physicist, and chief therapists from each of the clinics. Five major areas of focus of the program are: treatment machine QA, treatment planning QA, chart review, conferences, and monitoring and evaluation of the QA program.

A.1 Treatment Machine QA

Machine QA was organized around four different levels of testing: daily checks, weekly checks, monthly checks and annual full calibration. Tables A.1 through A.4 outline the four levels of testing (Purdy, 1991b). Daily checks, performed each morning by the therapist or machine maintenance technician, are shown in Table A.1. All daily measurements are recorded chronologically in a notebook.

Table A.1 Daily Machine Checks

-
- Machine operating parameters and interlock self-test
 - Photon beam output (cGy/mu) constancy
 - Photon beam symmetry (machine meter)
 - Laser-isocenter lights (visual check)
 - Optical distance indicator (visual check)
 - Patient audio-visual communication
 - Treatment door interlock (functional check)
 - Beam-on room indicator lights (visual check)
-

Weekly checks, listed in Table A.2, are performed during non-patient hours (noon hours, evenings) by the dosimetrist.

Table A.3 shows the monthly checks performed by the dosimetrists or physicist in the evenings or on specific afternoons set aside for machine QA. Both weekly and monthly QA checks are recorded on forms specific to each machine and placed in notebooks kept at each machine's workstation.

Table A.2 Weekly Machine Checks

-
- Light-radiation field congruence (visual check)
 - Electron beam output (cGy/mu) constancy (twice weekly)
 - Laser-isocenter lights (quantitative check every two weeks)
 - Optical distance indicator (quant., check every two weeks)
 - Treatment machine status report by therapist
-

Table A.3 Monthly Machine Checks

-
- Visual inspection of mechanical parts of treatment unit, including blocking tray assembly and treatment aids
 - Safety devices
 - Mechanical and digital indicators
 - Light-radiation field congruence (densitometer)
 - Beam symmetry
 - Constancy of calibration of assigned dosimetry system
 - Photon and electron beam output (cGy/mu) constancy
 - Off-axis factor (photon beam energy check)
 - Depth-ionization ratio factor (electron beam energy check)
-

Annual full calibration checks are performed on a weekend or evening by a medical physicist. The data from the annual QA checks are recorded and kept in the bound notebooks containing the monthly forms. A written report is prepared and kept in the QA office. Table A.4 lists the checks and adjustments made for the annual full calibration.

Dosimetry kits and various checking devices (e.g., plastic constancy phantom, laser alignment cube) are assigned to each machine to enable personnel to take QA measurements on a regular basis with minimal set up time.

A.2 Treatment Planning QA

Treatment planning QA comprises multifaceted activities. Treatment planning computer systems were assigned to each clinic and thus a QA requirement was established for verifying the appropriateness of the beam data in use, for testing the dose calculation model in use, for

Table A.4 Annual Full Calibration

-
- Safety devices and major interlocks
 - Alignment of therapy beam, light field, laser localizing lights, isocenter
 - Optical distance indicator
 - Mechanical and digital indicators
 - Beam uniformity as a function of gantry indicator
 - Monitor linearity
 - Monitor end effect
 - Output (cGy/mu) calibration
 - Output field size dependence
 - Dose calibration dependence on gantry orientation
 - Percentage depth dose factors/tissue-phantom ratios
 - Off-axis factors
 - Wedge transmission factors
 - Blocking tray transmission factor
 - Arc therapy calibration
-

testing data input and output, and for examining the relevant documentation. As indicated in *Human Factors Evaluations of Teletherapy: Volume III Human-System Interfaces and Procedures*, NUREG/CR-6277 (1995), treatment planning is relying more and more on the integrity of new hardware/systems and it is up to physics and software support personnel to make sure that the programs are error free and that the stored data is appropriate for each patient. To facilitate an accurate flow of data for treatment planning, simulation and dosimetry staff were integrated as one group under the supervision of a clinical physicist. All treatment plans are reviewed, signed, and dated by the treatment planner and independently checked by a physicist. An independent computation of monitor units (time) also is performed by the physicist or dosimetrist using a separate system. Custom-made blocks, block cutting equipment, and the fabrication of compensators is checked by physics/dosimetry personnel. To ensure that the treatment plan is properly implemented, a member of the planning team is available at the treatment machine the first day to address any questions regarding set up. Double exposure portal films are taken the first day and weekly thereafter and are reviewed by the oncologist and therapist.

A.3 Chart Review

Entries in the patient's chart are reviewed by a number of individuals at different times over the course of treatment. Before two fractions of the dose have been delivered, an independent check of the monitor units (time) is performed by a physicist or dosimetrist. The duplicate check is performed for each field at the initiation of treatment for that field, for any change in

dose/fraction, after any change in calibration or source change, and after discovery of any treatment error. The therapist verifies that the dose prescription, dose calculations, all the required forms, and patient photo are in the chart prior to treatment. Cumulative dose is checked by a dosimetrist on a weekly basis and all charts are reviewed and signed by an oncologist on a weekly basis. Five days prior to completion of treatment, the physics department reviews the treatment plan and dose prescriptions, checking total doses and point dose calculations to critical structures. If errors between 3% and 5% are noted, the physics department corrects the chart and the chart and error message is sent to the oncologist who then has the opportunity to alter the remaining fractions. If the difference between dose prescription and total dose delivery is greater than 5%, the staff oncologist is notified immediately.

A.4 Conferences

Weekly and/or monthly conferences that address QA concerns include Case Presentation, Morbidity, Treatment Planning, and Current Case Review. The Current Case Review Conference is probably best suited for discussion of QA issues. It meets once a week to review the charts, films, and other pertinent details of patients undergoing radiation treatment and brings together oncologists, residents, therapists, physicists, dosimetrists, and nursing staff. Patient histories, treatment plans, portal and simulation films, and dose distributions are presented and reviewed; any unusual treatment concerns are discussed. Specific problems encountered and recommendations made are recorded. Corrective actions are documented on a monthly report and submitted to the QA office.

A.5 Monitoring and Evaluation of QA Program

The same university-based facility had implemented a plan, based on ACR and JCAHO guidelines, to evaluate the quality and appropriateness of the care provided. The plan provides a method for identifying prospective problems, delineating quality indicators and or criteria, and initiating preventive and/or corrective procedures for improving patient care. An important step is the identification of relevant quality indicators and measurable criteria that reflect current knowledge and clinical experience. These indicators are used as a basis for reporting on the QA activities at each of the five clinics and are reported on a quarterly basis to the QAC. Table A.5 lists the indicators and threshold criteria for monitoring and evaluating the QA program under discussion.

When problems in quality of care are identified, the QAC initiates actions to correct the problem and takes the opportunity to improve patient care. Records kept by the QAC describe the analysis, conclusions, recommendations and actions to be taken when a departure above threshold occurs. After corrective action is taken, monitoring and evaluation continues until there is documented evidence of the needed improvement.

As indicated earlier in the report, there was substantial variation among the sites visited with respect to implementation of formal QA programs. The above discussion was based on a large university-based facility that was very serious about QA. The emphasis on the physical or equipment-related aspects of treatment reflects the strong role of the physics department in the

design and implementation of the program. In fact, at quite a few sites, physics personnel were responsible for implementing QA initiatives.

Table A.5 Indicators and Associated Threshold Criteria

<u>Indicator</u>	<u>Threshold</u>
Misadministration of dose	10% of total dose
Side effects requiring plan modification	Dose reduction by 10%
No Polaroids of treatment area (except total body and hemi-body irradiation)	0%
Weight loss during treatment	> 20 lbs or 20%
Unscheduled admission to hospital within 30 days after therapy due to radiation effects	0%
Patients not treated/# consults	-
Patients expired during therapy (radiation therapy related deaths)	0%
Patients treated with no pathological diagnosis obtained	0%
Treatment machine calibration	> $\pm$ 3%
Treatment machine distance, localization indicators	> $\pm$ 3 mm
Treatment machine light field/ radiation field congruence	> $\pm$ 3 mm
Treatment machine "downtime"	$\geq$ 5%

Source: Purdy, J.A., "Organization of a Quality Assurance Program: A Large Radiotherapy Facility with Affiliated Clinics." In G. Starksall & J. Horton (Eds.), *Proceedings of the American College of Medical Physics Symposium—Quality Assurance in Radiotherapy Physics*. Galveston, TX, pp. 299-317, 1991; Reprinted with permission from The American College of Medical Physics.

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10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

A series of human factors evaluations were undertaken to better understand the contributing factors to human error in the teletherapy environment. Teletherapy is a multi-disciplinary methodology for treating cancerous tissue through selective exposure to an external beam of ionizing radiation. A team of human factors specialists, assisted by a panel of radiation oncologists, medical physicists, and radiation therapists, conducted site visits to radiation oncology departments at community hospitals, university centers, and free-standing clinics. A function and task analysis was initially performed to guide subsequent evaluations in the areas of system-user interfaces, procedures, training and qualifications, and organizational policies and practices. The present work focuses solely on training and qualifications of personnel (e.g., training received before and during employment), and the potential impact of organizational factors on the performance of teletherapy. Organizational factors include such topics as adequacy of staffing, performance evaluations, commonly occurring errors, implementation of quality assurance programs, and organizational climate.

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