Management Lessons from Radiation Accidents*

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Abstract

The most important lessons about managing radiation safety programs often are derived from involvement in accidents that release unusual amounts of contamination or result in unusually high doses to persons. Large releases result in contamination levels, air concentrations, and intakes that are measurable and can be related to amounts and radiotoxicities of nuclides in specific processes, and to probabilities of escape and intake. This information then can be used to better establish design and operational requirements. Lessons presented here include: the need to convince management that at least monthly routine inspection of safety interlocks, equipment and procedures are necessary by independent inspectors (e.g., Radiation Safety staff) when lethal exposures are possible; at least three independent checks of treatment plans and exposures should be required in radiation oncology treatments; detailed quantitative analyses of staffing requirements should be performed at least annually by Radiation Safety Officers to advise their administrators of the minimum staff needed to ensure safe operations; and internal laboratory procedures, or appropriate contractual arrangements with commercial bioassay services, must be prepared in advance of work with highly radiotoxic quantities of radioactive material. Examples of situations managed or audited by the author that revealed these principles are: a Van de Graaff incident ultimately resulting in quadruple amputation of an experienced operator; several overexposures in radiation oncology at a major university medical center that was required by the Nuclear Regulatory Commission to employ an independent auditing team; an extensive contamination incident at a major medical research center that resulted in the shutdown of a multi-million dollar research program by the NRC; and internal exposure cases managed at the University of Pittsburgh that resulted from inadequate safety and health physics procedures.

Introduction

The presentation of radiation protection management principles learned from accident experience is presented under subheadings indicating principles in coined phrases. The statements of principle are followed by selected scenarios describing the learning experience. Because space here is limited, many other scenarios and principles are incorporated by reference to the author's publications. Considering that the author has always tried to incorporate into his publications the valuable writings of others, the readers will, hopefully, forgive the author for his convenience in referencing his own work. The principles are important to managing radiation protection programs to meet good practice and regulatory standards in routine operations, as well as to minimize risks to workers and the public from accidental exposures or releases.

The Need for Routine Monitoring and Inspections, and Alarms in High-Dose-Rate Facilities

Any operations in industrial plants, research laboratories, or medical institutions that involve enough radioactive material, or radiation emitted in process or use, that could produce serious harm to workers or the public (Brodsky 1992) must be monitored by independent representatives of the institution's radiation safety organization on a regular frequency. In the Gulf Research Van de Graaff accident, a competent operator of 11 years experience, was required to have quadruple amputation, with his life saved only by the timely recommendation of a bone marrow transplant by Dr. Niel Wald (Brodsky and Wald 2004). Over the 11 years, the accident could have been avoided if an in-house radiation safety organization had provided regular inspections of interlocks and procedures. The state regulatory agency involved could not possibly provide sufficient inspections with the personnel available, even though the state was relatively well staffed for a state radiation protection agency. Lessons learned from this and many other accidents managed by the author and others, involving intakes of radioactive material as well as external exposures (Brodsky and Wald 2004), indicate the need to follow regulatory guidance and standards on radiation protection management and frequencies of monitoring.

An additional principle was adopted by the author as a result of this Van de Graaff accident, and another accelerator accident in which he served as an expert witness: some type of alarm, activated by a suitable ion chamber with circuitry completely independent of an exposure initiating mechanism, should be incorporated into any exposure chamber where high or potentially lethal dose rates might expose anyone. As soon as the author became employed in 1971 as a medical and health physicist by a hospital about to receive a new accelerator and a new cobalt therapy device, he insisted as part of the facility that an ion chamber with flashing red light, independent of the circuitry of the therapy devices, must be installed on walls near the treatment tables. He was warned that an alarming device would frighten patients, but experience showed that the silent flashing red light did not bother patients under treatment. As a result, on one day, the author's practice of rapidly opening the door to the cobalt treatment room when outside lights and timer indicated a "Beam On" condition to check the operation of the flashing light resulted in early discovery and correction of negative misadministrations. That morning, technologists had already begun treatments and believed they had treated several patients. The open door check (rapid to observe whether the red light was on within the resolving times of the ion chamber and shutdown circuitry) showed that no radiation treatment beam had been on despite the signals from all indicators. All treatments were stopped that day, and patients not receiving the believed treatments were re-scheduled until the equipment was repaired. It turned out that the cobalt source had traveled almost to the treatment position but not all the way, yet far enough to activate the visual indicators and timer outside the treatment room. After these types of experiences, the author recommended such independent, ion-chamber-activated, alarms as part of the regulatory program of the NRC, for any treatment room or facility where potentially lethal or harmful exposures could occur.

After the author joined the Nuclear Regulatory Commission (NRC) in 1975, these experiences, and many others of the author in radiation safety organizations dating back to those in the 1949-50 Oak Ridge fellowship with Dr. Elda E. Anderson (which were adopted (Brodsky 1952) at the U.S. Naval Research Laboratory (NRL)), were incorporated into a series of regulatory guides and reports of the U.S. Nuclear Regulatory Commission (NRC). These documents outlined management principles and monitoring programs for various types of operation (USNRC 1979a, 1979b, 1980a, 1980b, 1981,1982, 1988a, 1988b; Brodsky 1982). These documents were prepared at that time under the supervision of Robert E. Alexander, who provided guidance, funding and support for travel to reconcile differences with many health and medical physicists throughout the nation. Many of these visits were necessary in order to ensure careful consideration of written comments. Often, the degree of inside- and outside-agency peer review incorporated in these documents, comparable at least to that in the consensus development of other national or international standards, is not generally appreciated. Some of the administrative principles and monitoring recommendations in these documents have been included in other chapters of the Miller handbook (Brodsky 1992), and can still be helpful in establishing new radiation safety programs. Development of new radiation protection programs, however, should always consider additional regulations and regulatory guidance published by the regulatory agencies as well as the national and international standards bodies. Radiation uses and treatment modalities are always taking on new forms.

The Need for Three Independent Checks of Therapeutic Doses or Other Procedures Potentially Capable of Serious Harm to Patients, Employees, or the Members of the Public

In the late 1990s, the author was involved together with three other professors of radiological physics in an NRC-required audit of the radiation safety practices of a major university medical center in which four misadministrations or overexposures had occurred within the previous two years. One overexposure resulted when a competent medical physicist, without surveillance of a member of the radiation safety office, conducted a trial insertion with a high dose rate brachytherapy device. When the source unexpectedly stuck in a tube before entering the device, the physicist corrected the situation by grabbing the tube with his hand close to the source. This illustrates the case often observed that, even for personnel who know proper safety procedures, those involved in practices that require attention and priority will ignore safety procedures to achieve their assigned results. This scenario, together with others of the author's experience, inspired him to recommend an increase in dedicated radiation safety staffing to ensure availability of personnel to provide surveillance for such procedures, and to recommend a preference for at least three independent checks on each planned medical procedure that could result in serious overexposures. These recommendations were incorporated into the consultants' report to the medical center and the NRC. This same principle should also apply to industrial and research laboratory procedures.

The Need for At Least Annual Staffing Analyses by Radiation Safety Management

After Applied Health Physics, Inc.(AHP) during a third-party inspection discovered a medical research laboratory that was highly contaminated throughout with tritium and carbon-14 compounds, the NRC ordered this large university-medical center to cease all research (about 30 million dollars worth at the time) with licensed radioactive material until each investigator developed new procedures and they were approved by a Radiation Safety Committee involving new membership. With the concurrence of the NRC, the author was employed as interim Radiation Safety Office (RSO) for three months while the university revised procedures. By the time the author arrived as RSO, two employees of the contaminated laboratory had already filed a lawsuit; and one had received an unnecessary bone marrow biopsy even though urine samples did not reveal a serious internal burden of tritium or carbon-14 (USNRC 1988b; Brodsky 1983). Even though the university had employed about 12 temporary radiation protection technologists from the nuclear industry to perform required surveys of all laboratories, the cognizant Vice Presidents would not believe the increase in RSO staff of 13 full-time equivalents this author recommended, until after a spreadsheet listing all of the management, survey and secretarial duties of a RSO for the large program size showed that about 13 FTEs were needed, not counting the RSO for the hospital and the medical physicists. Thus, realizing that usually the head of the RSO must advise his management of requirements because of his unique familiarity with his duties, knowing of my own previous difficulties of obtaining staffing of RSOs, and observing that this university medical center did in fact finally employ the same FTEs that I had recommended, this author published the listing of duties and analysis as an example for other RSO managers who might be short of staff (Brodsky 1991). Sometimes the tail must wag the dog. Without adequate staffing, no RSO can meet required conditions of licenses or institutional safety no matter how well procedures are prepared and documented.

Another finding as interim head of the RSO was that the certified technologists performing laboratory smear surveys did not understand the need for counting proper blanks and standards. The factors in formulas for decision level and minimum detectable activity under development for national laboratory standards (Brodsky 1986) were written onto a blackboard and were found to be useful in training the technologists about the importance of counting blank filter papers as well as standards under identical counting conditions, and in the same liquid scintillation solutions and counting geometries (Brodsky and Gallaghar 1991). After the technologists were required to re-survey using proper radiometric counting procedures, most of their "findings" of excessive remaining contamination in the decontaminated laboratory disappeared.

The Need for Duplicate Samples to Prior-Contracted Laboratories to Meet Major Survey Requirements for Accident Analyses

Among the references in Brodsky and Wald (2004) are recommendations by Dr. Wald regarding the need for advance planning and arrangements by a company or institution with third party laboratories. These requirements include the need for including advanced financial support, if adequate sample analyses with duplicates, standards, and blanks are to be ready in advance for rapid assessment of human internal exposures after an accident or terrorist attack. Also, a major case of an internal exposure that had occurred over an operating period of about two and one half years, and which resulted in about 60 times the then-considered Maximum Permissible Body Burden of americium-241, was discovered in 1967 by an alert Atomic Energy Commission inspector. The inspector noticed that prior records indicated that urine bioassay detection limits for americium were inadequate for the sample sizes taken by the company involved in the worker's exposure, and that this was not considered by the third party laboratory performing analyses. After the inspector's discovery, the AEC required that the worker be sent to the University of Pittsburgh Radiation Medicine Department bioassay and whole body counting facility. A brief summary of this case, its management over many years, and lessons learned, are included with other cases in the 2004 Health Physics Society Summer School text (Brodsky et al. 2004; Brodsky and Wald 2004).

The Need for Proper Planning and Design of Facilities, Equipment, and Procedures Prior to Operations with Radioactive Material

In operations – medical, industrial, or research – involving sufficiently high amounts of radioactivity of high levels of radiotoxicity (potential internal or external dose), neither the provision of detailed procedures for human action and safety practices, nor the provision of adequate radiation safety staff, will be sufficient to ensure safety. Appropriate combinations of facilities, equipment, and procedures will need to be invoked before the opening of the facility or laboratory for operations. One of the latest publications (Brodsky 1992) of the author's recommendations for planning and designing safe operations explains the considerations involved regarding quantities and radiotoxicities of materials involved, and the incorporation of observed fractional intakes of materials in previous accidents or routine releases (Brodsky 1965b, 1977, 1980). The 1992 publication also explains why schemes that have been published taking into account specific activity of pure nuclides are generally inappropriate for safe design; except for nuclides of extremely long half-life (e.g., natural uranium and thorium), only the specific activity and physico-chemical form of the materials handled or processed is pertinent to safe design. Also, although the probability of accidental or routine releases would also be related to the frequency of batch operations, the quantities in process that are suggested for possibly requiring each type of facility, equipment, and procedure design in the author's scheme are sufficiently conservative – yet not inordinately expensive for the related levels of operation – so that a simple criterion of quantity in process at any one time is possible, with factors depending on physical state and containment.

Some states have adopted this schema for examining adequacy of planned designs and operations. A number of incidents examined by the author indicate that the schema is sound. For example, the americium worker mentioned in the previous section was found upon inquiry by the author to have handled quantities of americium oxide powder above the level in the schema that would have suggested closed glovebox operation, at least in the absence of a full face-mask respiratory protection program. His pressing operation was performed within a glovebox that did not have gloves, and it continued with many curies of americium within the box over a period of about two and a half years before the alert inspector noticed that prior bioassay determinations were made with inadequate quantities of urine. Thus, although proper management philosophy, detailed radiation safety procedures, and adequate RSO staff are necessary, they might not be sufficient to ensure radiation safety without consideration of the design and equipment requirements.

The Need for Expert Knowledge, Training, and Readily Available Data vs. Emergency Plans and Procedures

Although written plans and procedures, and rehearsal of procedures, for managing radiation emergencies or terrorist attacks is necessary to adequately prepare a community or response team to reduce risks after an unexpected event, they are not sufficient to ensure effective action. These plans and procedures are helpful in defining likely equipment and staffing requirements and the scope of potential effects. However, the actual management of emergency operations and assessment of risks requires rapid and accurate analysis of radiation doses and risks by persons knowing how to make the necessary radiation measurements and direct appropriate actions, in accord with circumstances after the fact and within the short time frame required. Some level of training in these matters must also be given to the workers or members of the public who will need to respond appropriately within the "golden minute" (Brodsky 2004a), or obtain medical help within the "golden hour" (Goans 2004). An adequate discussion of factors required in preparing and training for emergency response is not possible within the scope of this paper. Many recommendations are presented in the summer school text (Brodsky et al. 2004), and experiences of the author in civil defense and other emergency operations are presented in Chapters 13 (Brodsky 2004a) and 20 (Brodsky and Wald 2004) of this text.

Principles of emergency management derived from managing radiation accidents are also given in Brodsky and Wald (2004), and in other chapters of the text. The referenced paper published on the first plutonium case managed at the University of Pittsburgh, before specific procedures or equipment were in place, supports the principle of needing an appropriate scientific or technical person to take charge, or to be a close advisor to the emergency director, in order to provide immediate direction and employ persons appropriately ad hoc in the event of unpredicted circumstances.

Another example of the need for the emergency director, or his close adviser, to understand rapid methods of dose assessment and to maintain readily available data comes from the response of the author to a leaking fuel shipment one night in 1960. Finding the GM counter in the emergency kit with dead batteries at 3 a.m., the author was still able to respond to the call in a Baltimore freight yard by calculating in his head while driving to the scene that an open window measurement of his ion chamber would be adequate to determine a radioactive iodine air concentration (e.g., of more than 1,000 times permissible concentrations for routine operation) in time to warn responders present and avoid serious internal thyroid doses (Brodsky 1980). A number of other experiences have convinced the author that predictions of wind patterns or other predictions of exact conditions prior to an unexpected release of radioactive material can not be relied upon after a serious release of radioactive material has occurred (Brodsky 2004a). Flexibility of judgment and action must be based on adequate knowledge and training, as well as ready availability of data and simple rules of thumb for rapid calculations. The summer school text (Brodsky et al 2004) has chapters by many authors that provide appropriate information and guidance, training materials, and a number of appendices containing principles of dosimetry, data, and ready rules of thumb for rapid estimation of doses and risks, as summarized from a number of sources (Brodsky and Beard 1960; Brodsky 1965a, 1979, 1980, 2004b).

Conclusion

The references at the end of this paper (especially the summer school text), and the references within those references, provide the vast majority of information and data needed to establish safe conditions for managing routine operations with radioactive material, or to establish and train responders to manage accidental or terrorist releases of radioactive material at all levels of risk and at all governmental or public levels of response. In addition, because NRC regulations are continually being reviewed and updated, one should stay current with the latest regulations. This information is readily available at http://www.nrc.gov/.

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