DISCRETE RADIOACTIVE PARTICLE ISSUES ASSOCIATED WITH A FUEL POOL CLEANOUT

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Abstract

As Susquehanna Steam Electric Station personnel were nearing the end of a project to remove control rod blades and other irradiated materials from the fuel pools at the station, the unit that was used to process the irradiated hardware (the "advanced crusher and shearer" or ACS) was removed from the cask storage pit. As the ACS was moved over the refueling floor to a location for further decontamination prior to shipment offsite, local area radiation monitors began to alarm. These alarms were due to one or more highly radioactive particles (up to 2.8 gigabecquerel) that were generated during the fuel pool cleanout (FPC) project and were inadvertently relocated from the pool to the surface of the refueling floor. Although these particles did not contact protective clothing or skin, these particles had the potential to deliver substantial doses to personnel in a very short period of time.

Over a period of several months, more discrete radioactive particles were found as a result of processing the irradiated hardware and performing other work evolutions during the FPC project. The highest estimated personnel doses were 0.12 and 0.17 Sv shallow dose equivalent, respectively.

The presentation will emphasize the lessons learned by Susquehanna personnel regarding planning for the FPC project, management oversight of the project, underlying cultural and mindset deficiencies that contributed to lack of preparedness for risks associated with highly active particles, and the steps for ensuring adequate contamination control.

Introduction

In developing the content for the 3rd EC/ISOE Workshop on Occupational Exposure Management at NPPs, the Program Committee proposed four topical sessions, including one on management of contamination control. The Committee suggested consideration of several aspects of contamination control-measurement, management, perception, and culture.

A series of contamination control events occurred in the last few months of the year 2000 at the Susquehanna Steam Electric Station, a two-unit boiling-water-reactor plant in the eastern United States of America. Those events challenged the personnel at the station and, as soon became clear, challenged some basic perceptions about the importance of contamination control as an element of exposure management. The intent of this paper is to briefly describe the situation and its industry-wide implications. By discussing those implications, a secondary result may be to leave the audience with a questioning attitude about the situation at their home plants. That is not to suggest weaknesses in any plant's radiation safety program, but only to state that all radiation safety professionals can learn from the operating experiences at other stations.

Events of Fall 2000

The Susquehanna station was conducting a clean-out campaign from the fuel pools in the latter half of 2000. The plan was to remove control rod blades, low power range monitors, and miscellaneous irradiated hardware from the pools, by processing and packaging the hardware for shipping and then transporting the materials to a licensed waste disposal facility. The project was to be of about five months in duration. About two months into the project, a key piece of equipment began to show degraded performance. The "advanced crusher and shearer" (ACS) was repaired and returned to service. Shortly thereafter, the forearm of a contract worker was exposed to a discrete radioactive particle, and a shallow dose equivalent of about 0.12 Sv was assigned. Refinement of radiation safety practices occurred over the next month as project activities continued.

When work with the ACS was completed, the ACS was removed from the cask storage pit and moved over the refueling floor to a laydown area for further decontamination prior to shipment off-site. During the movement of the ACS, a local plant-installed area radiation monitor began to alarm. On investigation, a 2.8 gigabecquerel (Gbq) "hot particle", reading about 8 Sv/h on contact and consisting of cobalt-60, was discovered on the refueling floor. The likely source was displacement from the ACS as it was moved.

Recovery of the particle occurred over the next several days, with shielding and access control restrictions in place. A search for additional particles was conducted; three more contaminated areas were found. Additional radiation safety precautions were instituted, with some personnel surveyed for particles every 15 minutes.

Over the next two months, additional particles were identified. The two particles of highest activity were about 0.8 Gbq and 0.7 Gbq, respectively. No significant dose to personnel resulted from these particles. An additional personnel exposure occurred in early December 2000. An absorbed skin dose rate of 0.47 Gy/h resulted in an assigned shallow dose equivalent (SDE) of 0.17 Sv from a particle on an individual's protective shoe cover. Work on the project was suspended at this time. No doses in excess of any annual regulatory dose limits occurred during the project.

Near-Term Response to Events

The station initiated several investigations during the course of the project. One root cause evaluation focused specifically on the event involving the discrete radioactive particle measuring 8 Sv/h. Another, later evaluation focused on the entire series of hot-particle events. Two evaluations focused on different aspects of project and refueling-floor management and independent oversight of the project. One evaluation even had as its emphasis a critique of the evaluation and investigation processes. Results will be described later in the paper.

After the events described above, the station's Radiation Protection Manager (RPM) left the company. The remaining investigative matters and the implementation of corrective actions were the responsibility of the incoming RPM.

The regulator (U.S. Nuclear Regulatory Commission or NRC) issued a Notice of Violation to the station for failure to conduct adequate evaluations and surveys. The emphasis of the NRC was on the potential for doses exceeding the annual limit on Total Effective Dose Equivalent (TEDE), while it recognized that no workers accrued doses exceeding either the TEDE or SDE limits. That is, the NRC wished to bring attention to the potential for significant deep-dose equivalents given the high activities (and resultant high radiation fields) around some of the particles that were identified.

The detailed consideration of the "whole-body" dose implications of discrete radioactive particle exposures was an extension from the more common evaluations primarily for shallow (or skin) doses from exposures to hot particles. Listed in the references are some of the major documents relating to discrete radioactive particle exposures that were available by mid-2000 (1, 2, 9, 11). Neither the "deep" nor the "shallow" dose equivalent components of exposure may be overlooked for high-activity particles. In the case of a 2.8 Gbq particle of cobalt-60, a one-hour exposure can lead to doses of on the order of 2,900 Gy (skin, SDE) and 2.3 Gy (skin, DDE). Note should be made that means of calculating meaningful dose from exposure to discrete radioactive particles are under review. References 10 and 12 provide relevant information, and proposals for enhanced use of effective-dose-equivalent methodologies applicable to particle exposures are in review.

Lessons Learned per Regulator and Industry Organizations

The NRC, the Institute of Nuclear Power Operations (INPO), and the World Association of Nuclear Operators (WANO), have all released documents based on the events at Susquehanna. The NRC Information Notice (reference 13) brings forth the issue described above related to the potential for substantial dose to personnel, both for SDE and TEDE. The NRC describes also the need to consider adequacy of incorporation of previous plant and industry-wide experience into project planning, to ensure prevention of recurrence at Susquehanna or other stations.

INPO, in its Significant Event Report (reference 7), noted also the potential for significant unplanned exposures in short time periods. In addition, the INPO analysis listed the following contributors to the events:

- inadequate guidance for establishing a Hot Particle Control Zone (HPCZ)
- inadequate pre-job briefings
- inadequate contamination control methods (e.g., inadequate hydrolazing and rinsing of the ACS prior to moving it); incomplete consideration of previous plant experience with discrete radioactive particles, and
- inadequate senior management presence and communication of high standards.

The staff at INPO are in the process of preparing a revision to its "Guidelines for Radiological Protection at Nuclear Power Stations" (reference 3). Increased discussion on discrete radioactive particles is to be included. A citation to the Susquehanna event (via reference 5) is included in the draft wording.

WANO, in its Significant Event Report (reference 14), stated also the potential for individuals to receive substantial unplanned exposures quickly. WANO then encouraged its member plants to consider the following:

- risk assessments that fully consider prior operating experience
- contingency work plans for evolutions that may involve higher levels of risk, and
- adequacy of communications at pre-job briefings and during shift handovers.

Questions posed for appropriate discussion by radiation protection personnel and supervision are similar in the INPO and WANO documents. Those questions emphasize pre-planning of contamination controls and contingency planning for identification of highly radioactive particles.

Susquehanna Perspective

The NRC, INPO and WANO documents described above are professionally done and should be useful to radiation protection staffs in their work planning. To supplement those evaluations, the items described below may also be useful to staff at other stations.

Root causes (RC) for the events at the Susquehanna station included the following five items:

1. Highly radioactive particles were generated during the fuel pool clean-out project and were removed from the pool and cask storage pit;

2. Personnel possessed an inaccurate risk perception of the dose consequence due to a discrete radioactive particle exposure. This was believed due to (a) the documented history of hot-particle exposure being a skin dose concern, and (b) research results identifying a lower risk from exposure to discrete radioactive particles [Workshop issue-perception];

3. Assessment processes that focused on actual personnel doses from particles that came in contact with either clothing or skin versus the potential doses that may have resulted from particles not found on personnel [Workshop issue - culture];

4. Inadequate pre-job plans with respect to control of particle exposures – survey techniques, instrumentation, and decontamination techniques were not sufficient [Workshop issues – management, measurement]; and

5. Previously identified cultural and performance issues that were not timely and effectively addressed – lack of a strong questioning attitude, inadequate communications, and incomplete use of operating experience had not yet been fully resolved [Workshop issue – culture].

Along with those causes were listed seven causal factors, which included items such as the inadequate procedural guidance and ineffective involvement of management that are stated in the analyses by the industry-wide organizations.

Putting the above issues into a different perspective, what is it that Susquehanna staff learned? First, there was a lack of sensitivity to the consequences of exposure to highly radioactive material (RC2) [Workshop issue – perception]. Associated with that was an attitude that significant radiological events couldn't happen at Susquehanna, a station with 18 years of operations. Also, the staff had to put more emphasis on the potential for exposure while at the same time addressing actual doses being accrued.

The staff learned that additional attention needed to be paid to contamination control planning (RC4), not only on the refueling floor but also in potentially impacted systems [Workshop issue – culture]. About a dozen systems received re-assessments of the potential for generation or release of highly active material. For the refueling floor, underwater vacuuming and filtration, hydrolazing, rinsing, and component covering were all reworked.

The need for structured, comprehensive pre-job briefings before work commences in a HPCZ is now fully recognized, as is the need for specific Radiation Work Permits (RWPs) for HPCZ work [Workshop issue – management]. In development of those RWPs, the use of respiratory protection to prevent the intake of particles needs to be carefully considered.

Radiation protection procedures have been revised to enhance radiological controls. Areas revised include survey techniques, labeling and posting, limiting dose rate and protective clothing requirements, and source term control. To supplement the enhanced survey techniques, instruments were modified for use in performance of surveys in HPCZs or when hot-particle presence is suspected. Radiation protection technicians received additional training on conducting particle surveys and on containment of identified particles [Workshop issue – measurement].

The self-assessment program is being revised to place additional emphasis on performance-based assessment of high-risk evolutions. Performance indicators have been developed. At the same time, procedures have been revised to more clearly identify high-risk evolutions and the enhanced precautions that must be taken for such jobs. Further, the need for additional management presence during the planning for and conduct of high-risk activities is considered on a case-by-case basis. Specific to contamination control, ongoing, critical self-assessment of practices is utilized and is being found to be effective in identifying and correcting contamination control deficiencies [Workshop issue – management].

Finally, there are two simply stated axioms: (1) be proactive to potential conditions rather than reactive to emergent conditions, and (2) when the mindset exists that “it can’t happen here”, it will.

Additional Commentary

INPO, in reference 4, addresses precursors for unplanned exposures. Three of the root causes described above are aligned with the precursors described by INPO. That is, the adequacy of surveys and assessment (RC3), the adequacy of work planning and RWPs (RC4), and the effectiveness of supervisory direction and oversight (RC5) are correlated with listed precursors. For information, two other precursors noted by INPO were not directly applicable to this event; that is, neither incorrect guidance by radiological protection technicians nor non-compliance with radiological protection rules were contributors to the events at Susquehanna. The re-visiting of documents such as INPO’s SER 4-08 may be advisable for all plants as high-risk activities are planned.

The Susquehanna experience was certainly a focus of attention for numerous agencies for some time. Discrete radioactive particle events are not unique to Susquehanna, however. Examples of recent operating experience at other plants are described in references 6, 8 and 15. The point of mentioning those experiences is simple – particle events can happen at any plant. It is only with defense in depth through strong management, comprehensive planning, accurate perceptions of risk, a culture of awareness and risk control, and good measurement processes that prevention of recurrences will be successful.

References

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3. Institute of Nuclear Power Operations, INPO 91-014 Revision 1, “Guidelines for Radiological Protection at Nuclear Power Stations”, October 1995.

4. Institute of Nuclear Power Operations, SER 4-98, “Unplanned Personnel Radiation Dose”, 23 November 1998.

5. Institute of Nuclear Power Operations, Operating Experience Report No. OE11779, “Highly Radioactive Particles Associated with Spent Fuel Pool Work”, 27 December 2000.

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