RESPONSE, RECOVERY, AND INVESTIGATION OF A CESIUM RELEASE AND SUBSEQUENT REMEDIATION OF A RADIATION STERILIZATION FACILITY*

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ABSTRACT

In mid-June 1988, a release of ^{137}Cs from one or more sealed sources was experienced by Radiation Sterilizers, Inc. (RSI), at its facility outside Atlanta, in Decatur, Georgia. The sources, used to sterilize medical supplies, were leased to the firm by the Department of Energy (DOE). This site, one of five supplied cesium under the lease program, contained 252 doubly encapsulated CsCl capsules from the Waste Encapsulation Storage Facility (WESF) in Hanford, Washington. Immediately following notification of the radioactive release, the state of Georgia requested emergency aid from DOE, and, in turn, the Oak Ridge National Laboratory (ORNL) was requested to respond. The initial response dealt primarily with assessment of the health physics impacts and analysis/emergency action areas. Following rapidly after the initial response, the role expanded to technical oversight and responsibility, shipping suspect capsules to ORNL for analysis, and identifying and removing the failed capsule(s) from the facility. The long-term responsibility has included maintaining a subcontract with a radiological remediation firm, providing on-site technical and operational management, and examining failed capsules to determine the mode of failure.

INTRODUCTION

The Radiation Sterilizers, Inc. (RSI), facility located outside Atlanta, in Decatur, Georgia, was used commercially for the sterilization of various medical products by exposing them to intense gamma radiation. The radioactive sources were contained in two vertical racks, and when not in use, they were submerged in a 7.3-m-deep, 95,000-l, temperature-controlled, demineralized-water pool located in the floor of the irradiation cell. The batch-operated sterilization process began with the medical supplies being loaded into carriers on a conveyer system and transported through a concrete shielded maze into the heavily shielded irradiation cell. The two racks containing the gamma sources were then raised from the water. The products to be sterilized were circulated through the gamma field for a prescribed period of time, the source racks lowered back into the storage pool, and the product transported out of the cell on the conveyer. The RSI facility was designed for and initially operated with ^{60}Co. However, the company opted to change to ^{137}Cs as the radioactive source material when an industry-wide ^{60}Co supply problem developed. The ^{137}Cs sources were manufactured and stored, prior to their use at the Georgia facility, at the DOE Waste Encapsulation Storage Facility (WESF) in Hanford, Washington. RSI leased the sources from DOE and used them in its daily operations from March 1985 until the release incident in June 1988.

EXTENT OF THE RELEASE AND RESPONSE ACTIONS

On June 6, 1988, detectable radiation was observed by the facility operators in the irradiation cell following a product sterilization cycle. The state of Georgia Department of Human Resources (GA/DHR) was notified and responded to the site. The immediate evaluation was that one or more of the 252 WESF capsules, each containing ~50 kCi of ^{137}Cs as CsCl doubly encapsulated in stainless steel tubes, was breached and had released the activity. The initial evaluation of the extent of the contamination comprised the water in the storage pool and the surrounding cell area, the heating and ventilation ducts, lights, production equipment, conveyer system, and some of the sterilized product including a shipment that had left the facility. Contaminated areas also were found in the office complex at the facility.

Following notification of the Nuclear Regulatory Commission (NRC) by the state of Georgia and the designation of the Georgia Department of Natural Resources (GA/DNR) as the lead state agency, DOE was requested to provide assistance in identifying the leaking source(s), the subsequent removal of the damaged sources, and the recovery activities. Teams from DOE's Oak Ridge Field Office, assisted by experts from the Oak Ridge National Laboratory (ORNL) and the Westinghouse Hanford Company (WHC), were immediately dispatched to the site.

The initial actions of the combined recovery team were directed toward establishing control of the area and determining the boundaries and magnitude of the contamination. In addition, interaction and coordination among the various state and federal agencies, including the GA/DNR, DOE, The Environmental Protection Agency (EPA), and NRC, as well as maintaining open and credible communication with the news media were of paramount importance.

Surveys of the area surrounding the RSI facility revealed that, with the exception of the contamination on the surface of some of the products that had been sterilized two days prior

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to the detection of the release, the contaminated area was restricted to approximately 60% of the interior of the facility. Thus, the warehouse, equipment room, and irradiation complex area was isolated and maintained as a contamination zone and all access controlled by Chem-Nuclear Systems, Inc./Chemical Waste Management, Inc. (CNSI/CWM), who was retained as a subcontractor.

The second objective was the identification, removal, and *shipment* of the failed source or sources responsible for the release. This task was critical because it was not known if the breached source would fail catastrophically and release its entire content of soluble salt, ~50 kCi, to the pool environment. Identification of the failed source among the 252 candidates, while working underwater in the cramped quarters of the storage/shielding contaminated pool, presented a considerable technical challenge.

LOCATING AND SHIPPING THE LEAKING SOURCE

A team from WHC conducted a visual examination, using underwater video equipment, of each source and identified several capsules that were judged to show potential corrosion in the weld area. The basis for these tests was that the assumed mode of failure was stress corrosion cracking in the end cap weld areas. Several capsules were identified as showing discoloration and were also marked as failure candidates. Further, underwater ultrasonic tests were made on each capsule and two capsules yielded signals that could be interpreted as an indication of the presence of water in the annular region between the inner and outer stainless shells. One capsule was chosen to be removed from the storage pool and shipped to ORNL for examination. The source selected was the one judged to show the greatest potential for having undergone weld cracking. A second, follow-on shipment contained the two capsules that gave positive ultrasonic indications of having water in the annular region.

To effect shipment of the suspect capsules from the Decatur, Georgia, facility to hot cells at ORNL for examination to verify or disprove the leaking hypothesis, the NRC required that each source be placed in a sealed, dried, metal overpack before installation in a shipping cask. Two overpacks were designed, built, and tested. The capsules were loaded into the overpacks at a pool depth of approximately 7 m. Details of the design and procedures used in the initial shipments served as the basis for removing all the remaining sources once the breached capsule had been identified and shipped.

Hot cell examination, using varied detection methods, of several sources judged to show underwater evidence of corrosive attack and those capsules yielding ultrasonic signatures of the presence of water in the inter-encapsulation annular region revealed that none were the breached source. These findings demonstrated that neither visual nor ultrasonic observations would serve to identify the source(s) responsible *for the radioactive release.*

The activity of the water in the pool continued to decrease as a result of the continued operation of the ion exchangers installed by CNSI/CWM. The pool activity was monitored by the state of Georgia, and analysis of this data indicated that, with time, the ^{137}Cs activity reached a steady-state equilibrium that was more than an order of magnitude greater than the demineralizer effluent. The interpretation of this observation was that one or more of the sources continued to release activity into the storage pool at a calculated rate of ~25μCi/h.

As a result of this deduction, an *in situ* detector system was designed and built at ORNL that would operate underwater and isolate three sources simultaneously from the pool environment. The system allowed the water that was in contact with the isolated capsules to be sampled for evidence of increased activity. The system was put into operation but progress was slow. During these investigations the apparent release rate from the breached source(s) increased from 25 to ~150μCi/h. A continuous pool water activity monitor was installed to provide alarm conditions, and a new, more aggressive leak detection device was designed and built at ORNL. This system incorporated the ability to isolate underwater up to six sources simultaneously from the pool environment and subject them to cyclicly imposed, elevated hydrostatic pressures and elevated temperatures. The water in contact with the sources was continually monitored for any increase in activity. Each source to be tested was placed in individual compartments within the device, and during the loading operation a source was encountered that would not fit within the cylindrical sheath. Isolation of this source in a shipping overpack resulted in an immediate decrease in the pool water activity and a corresponding increase in the ^{137}Cs activity in the overpack. These observations strongly indicated that the leaking source had been located. A second source with similar physical deformity, but not demonstrating any radioactive release, was also isolated in a shipping overpack. Both of these capsules were transported to ORNL in December 1988 for failure-mode analysis.

LEAKING CAPSULE EXAMINATION AND ANALYSIS

The source examination strategy was divided into two phases. The first was nondestructive and included all tests up to the actual removal of the outer containment shell. The nondestructive phase has been completed for both capsules. The second phase, the destructive examination directed toward obtaining salt samples and metallurgical investigation of the steel and steel-salt interface, has been delayed. In developing the examination plan, extreme care was taken to ensure that the tests performed in one area or phase would not adversely affect the results desired from tests in other phases. A summary of the nondestructive tests and results are shown in Table I.

The first of the nondestructive examinations dealt with obtaining a complete metrological profile of the sources. This included performing low-magnification photography and making dimensional, thermal, and radiological measurements. These data formed a baseline from which any changes induced by subsequent measurements could be assessed. The initial underwater visual observation that the leaking capsule was swollen at one end was confirmed in the hot cell examinations. The shape of the capsule resembled that of a "bowling pin," but without the exaggerated bulge at the bottom. The inner capsule was locked to the outer capsule indicating that the cause of the swelling required an "inside-out" mechanism. The inner capsule is normally free to move within the outer capsule because both its length and diameter are less than the inside dimensions of the outer capsule. The fact that the failed source had an immobilized inner capsule formed the basis for testing the entire WESF inventory, including leased sources at other irradiation facilities. This test, the "clunk test," detected whether the inner capsule was mobile by shaking each source underwater and listening for the clunk.

TABLE I
Summary of Nondestructive Tests and Results

Test	Result
Metrology	Changes only in azimuthal asymmetry after thermal cycling. No thermal cycling induced volume or circumference changes.
Gamma-ray autoradiography	Large void space above the CsCl salt column. Salt fills the swollen region of the inner capsule. Evidence of ^{137}Cs in the annular region at the bulged end of the source.
Annular gas analysis	Radiolytic products observed indicating water in the inter capsule region of the leaking source but not in a swollen non-leaking source.
Helium leak detection	Three tests: external pressurization - sealed capsule; external pressurization - internal vacuum; internal pressurization - external vacuum. No evidence of a leak greater than $1{\bullet}10^{-7}$ to $1{\bullet}10^{-8}$ standard cm^3/m.
Additional leak tests	Application of a "wet blanket" to leach activity from the surface; immersion in a temperature controlled water bath. No unambiguous evidence for a leak site.
Dye penetrant	Full application of a high-temperature penetrant. No evidence for cracks or holes in either the shell or weld area.

Autoradiographs of the capsules were made on both an axial and radial grid to determine the distribution of radioactive material within the inner capsule and in the annular region. From analysis of the data, it was concluded that a void existed above the salt column and that CsCl salt filled the deformed region. These conclusions indicate that the failure mechanism must account for both a densification (to produce the pressure required to deform two type 316L stainless steel shells each 0.35cm thick) and expansion of the CsCl (to fill the expanded bulge volume).

Penetration into the annular region between the inner and outer capsules was accomplished by drilling through the end caps and withdrawing gas samples for analysis and determination of radiolytic decomposition products of water. The data from the gas analysis withdrawn from the leaking capsule are consistent with water having been present in the annular region. Similar analysis of the gas from the annular region of the companion, deformed (but not breached) capsule demonstrated that there was no evidence of water ever having been in the inner capsule volume.

Helium leak detection was performed to determine the site of the leak. The tests included 1) external pressurization followed by external vacuum, 2) external pressurization with vacuum applied to the annular region, and 3) pressurized annuli with external vacuum. Despite the high sensitivity of the helium leak detection method, neither the site of the leak nor the presence of the leak could be detected. The conclusion was that either the leak site was effectively sealed by thermally induced equalization of the hoop stresses in the stainless steel or the gas leak rate was smaller than the detectable limit.

High-temperature dye penetrant was applied to the entire surface of both capsules. No evidence of cracks or holes was found for either source.

An analysis of the manufacturing data searching for correlations that would help in understanding the mode of failure was conducted. Coupling the results of the exhaustive nondestructive tests with the manufacturing data has narrowed the list of possible causes and suggests specific definitive tests to be conducted during the destructive examination. However, at this time there appears to be no direct correlation between the manufacturing process and the onset of swelling in WESF capsules.

FACILITY REMEDIATION

The decontamination of the RSI facility was accomplished by employing the subcontracted professional services of Chemical Waste Management (CWM). The details of the task, the problems encountered, and the solutions implemented are contained in a companion presentation (1) to this conference. The following is a brief summary of the systematic decontamination program that was conducted using NRC criteria for release for unrestricted use of a contaminated site. Because Georgia is an agreement state, the conditions for release were established and administered by the state, under the GA/DNR.

Following the removal and shipment of the leaking source to ORNL for examination, all remaining capsules were returned to Hanford for reinstallation into their storage facility. This task, the responsibility of WHC, was completed in November 1990. Concurrent with capsule shipping, the conveyer system, racks, hoisting equipment etc., were either decontaminated and certified as releasable and returned to RSI for use or disposed of as contaminated waste.

The water in the stainless-steel-lined storage pool was decontaminated to a specific activity an order of magnitude lower than EPA drinking water standards. However, permission to dispose of the water in the DeKalb County sewer system was denied. While alternative disposal methods were investigated, the inventory decreased due to natural evaporation and the remainder was solidified and used as stabilization in the waste boxes.

The solution to the critical path water disposal problem permitted the remedial efforts to be concentrated on the areas with the highest degree of contamination. It is now estimated that the magnitude of the total release was on the order of 8–10 Ci with approximately 4 Ci reporting to the pool water and the remainder dispersed as an aerosol. The water pathway resulted in contamination, by adsorption, of the pool liner, the concrete pool retaining wall and structural collar, and the soil beneath the concrete irradiation cell floor. All of the structural materials were packaged and disposed of as contaminated waste. The airborne released activity resulted in surface contamination of those areas in both the primary and secondary airflow zones. These surfaces were decontaminated by removing the contamination to levels significantly below the guidelines.

The decontamination efforts were completed at the end of August 1992. CWM initiated a final release survey to demonstrate that the facility meet the criteria for free release. An independent confirmation survey was concurrently initiated by the state to confirm the compliance with the applicable criteria. Both surveys were completed by mid-November and detailed findings and recommendations were forwarded to the state. The state accepted the recommendations and returned control of the facility to RSI on January 5, 1993, thus completing the commitment made by DOE to the state.

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REFERENCES

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