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HEALTH PHYSICS CONSIDERATIONS
DURING PRTR RECOVERY
AND DECONTAMINATION

D. McConnon

May 1968

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By

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ABSTRACT

On September 29, 1965, the Plutonium Recycle Test Reactor (PRTR) experienced a fuel element and pressure tube failure during which approximately 700 g of fuel material was released from the fuel element. This report presents the health physics approach to the recovery and decontamination phase, the radiological conditions experienced during this phase and during the subsequent startup of the reactor. No significant quantities of airborne or surface plutonium contamination were detected during either the recovery and decontamination phase or subsequent reactor operation. The approach to recovery and decontamination was the same as that which would be used at a uranium-fueled reactor.

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HEALTH PHYSICS CONSIDERATIONS
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INTRODUCTION

On September 29, 1965, an intentionally defected plutonium-bearing fuel element caused a rupture of its containing pressure tube in the Fuel Element Rupture Test Facility (FERTF)⁽¹⁾ of the Plutonium Recycle Test Reactor (PRTR).⁽²⁾ These ruptures caused a ventilation containment trip and resulted in substantial radioactive contamination of the process systems and containment vessel internal surfaces, as well as degradation of the PRTR's heavy water moderator.

Events following the incident may be divided into three somewhat overlapping phases:

1. Control and stabilization of the incident,
2. Recovery and decontamination of reactor systems, and
3. Preparation for and subsequent operation of the reactor.

Events leading up to the incident, activities and radiological conditions during phase one, and the most probable cause and sequence of events during the incident are reported elsewhere.⁽³⁻⁶⁾ This report presents the health physics approach to the recovery and decontamination phase, the radiological conditions experienced during this phase, and subsequent startup of the reactor.

SUMMARY

On September 29, 1965, the Plutonium Recycle Test Reactor, a plutonium-fueled reactor, experienced a fuel element and pressure tube failure during which approximately 700 g of fuel material was released from the fuel element. Following initial control and stabilization of the situation, the recovery and decontamination phase was begun. Health physics requirements were based on the assumption that little or no

plutonium contamination would be present in normally occupied areas. If plutonium contamination was detected by means of the routine surveillance program, then health physics procedures and controls would be altered. No significant quantities of airborne or surface plutonium contamination were detected during either the recovery and decontamination phase or subsequent reactor operation. The lack of plutonium contamination in areas normally occupied by personnel was verified by negative results obtained from the plutonium bioassay program. The approach to recovery and decontamination was the same as that which would be used at a uranium-fueled reactor.

DESCRIPTION OF PRTR AND RUPTURE EVENT

PRTR⁽²⁾

The PRTR is a vertical pressure tube type reactor, heavy water moderated and cooled, with a thermal power capability of about 85 MW. A cutaway view of the reactor and building is shown in Figure 1 and a more detailed view of the reactor core is shown in Figure 2. Fuel elements are charged into and discharged from the 85 Zircaloy-2 pressure tubes from the top face.

Control of the reactor is achieved by regulating the level of the heavy water moderator which is held in the calandria by a helium gas balance system. Emergency shutdown is achieved by rapidly draining the moderator from the calandria. The recirculating moderator system operates at essentially atmospheric pressure and a maximum temperature of 160 °F. It removes about 3% of the reactor heat.

The high pressure, high temperature recirculating heavy water primary coolant transfers the heat generated by the fuel elements from the reactor core to a heat exchanger where the heat vaporizes light water to generate up to 425 psia steam. The steam is condensed in a barometric condenser before disposal

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FIGURE 1. Plutonium Recycle Test Reactor Building

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FIGURE 2. Reactor Core and Shielding

to the Columbia River. A welded steel, cylindrical containment vessel, 80 ft in diameter, with a hemispherical dome, houses the reactor and process equipment.

FERTF⁽¹⁾

The Fuel Element Rupture Test Facility is a part of the PRTR complex. The facility is designed for irradiation of high risk or defected fuel elements in a controlled light water environment to evaluate fuel performance, to develop fuel element rupture detection instrumentation, to determine the behavior of fission products and fuel material in the coolant, and to test system decontamination methods. The facility may utilize any one of the 85 PRTR pressure tubes as the in-reactor test section. At the time of the incident, the center reactor pressure tube was being used for the FERTF.

RUPTURED FUEL ELEMENT

At the time of the incident, the FERTF was operating with an intentionally defected, vibrationally compacted 4 wt% PuO₂-UO₂ 19-rod cluster fuel element to observe the performance of such an element with a substantial portion of the fuel molten (maximum specific power of 27 kW/ft). One of the fuel rods of the fuel element had been defected with a drilled 1/16 in. diam hole in the peak flux zone of the rod. The total exposure of the defected fuel rod up to the time of the incident was 2.67 MWd. The calculated inventory of selected radionuclides in the rod at failure is presented in Table I.

A measured 705 g or about 50% of the fuel material was lost from the rod. Approximately 75% of the rupture debris remained in the rupture loop coolant system. Most of the remainder of the rupture material was carried away in the aqueous waste or deposited in the space between the ruptured pressure tube and its surrounding shroud tube (see Figure 2), in the spaces between the bottom and top shield and the calandria, and inside the calandria.

TABLE I. *Calculated Radionuclide Inventory
in Fuel Rod at Failure*

<u>Radionuclide</u>	<u>Ci/rod</u>	<u>Radionuclide</u>	<u>Ci/rod</u>
$^{95}\text{Zr}-^{95}\text{Nb}$	1500	^{88}Kr	1700
^{99}Mo	2800	^{131}I	770
^{103}Ru	1100	^{132}I	2000
^{106}Ru	160	^{133}I	4400
$^{140}\text{Ba}-^{140}\text{La}$	2100	^{134}I	7700
^{141}Ce	1200	^{135}I	6600
$^{239}\text{Pu}+^{240}\text{Pu}$	5	^{133}Xe	1300
$^{85\text{m}}\text{Kr}$	500	^{135}Xe	1800
^{87}Kr	1100		

The highly contaminated rupture loop coolant flashed to steam as it was released from the ruptured pressure tube, thereby producing a fission product aerosol. The aerosol escaped from the core blanket system of the reactor through blown rupture discs and through leaks in the gas seal bellows on the reactor lower face and was released to the containment vessel atmosphere. A ventilation containment trip resulted and radiation levels in the vessel reached about 40 R/hr. A detailed radiochemical study was initiated immediately after the incident to define the physical nature of the aerosol and surface contamination. Results of this study have been reported elsewhere.⁽⁷⁾

APPROACH TO RECOVERY PROBLEM

Control and stabilization of the incident consisted of supplying emergency cooling to the FERTF, shutdown of the

reactor and depressurization of the primary coolant system, disposal of liquid wastes, personnel entries into the containment vessel for damage surveys, and recovery from the ventilation containment trip.

The recovery effort began after these activities and was divided into three phases. The first phase consisted of gross decontamination of systems and operating areas to achieve radiological conditions tolerable for discharge of the ruptured fuel element and pressure tube. The second phase involved the actual removal of the fuel element and pressure tube. The third phase consisted of final decontamination and restoration of reactor systems to normal.

Phases one and two proceeded slowly and deliberately so that all information concerning the true nature of the incident might be secured. Special committees were established for directing reactor decontamination, fuel element and pressure tube removal, and FERTF decontamination. Detailed written procedures, which were reviewed by the appropriate committee, were required for each recovery step.

Health physics requirements were incorporated into the operating procedures. In general, the same health physics controls that were in effect before the incident were followed during recovery. However, the controls were expanded during recovery because of the increased airborne and surface fission product contamination and external exposure rate levels. No additional controls were imposed because of the possibility of plutonium contamination being present in working areas. The assumption was made that the plutonium, being in the oxide form and associated with heavy, dense particles, would not readily enter into aerosol formation or chemically react with aerosol-forming materials. Therefore, the probability of plutonium contamination in operating areas was small.

A plutonium surveillance program was initiated immediately after the incident to verify this assumption. If plutonium were detected on samples of airborne and surface contamination, consideration would be given to altering procedures and controls to fit the changed radiological conditions. Fuel particles containing plutonium were found in the lower access space during reactor recovery and decontamination. These particles were large enough (most were larger than 50 μ but a few were as small as 10 μ) that they did not readily become airborne and contaminate the vessel atmosphere or move to normally occupied areas.

EXPERIENCE DURING DECONTAMINATION AND RECOVERY

AIRBORNE CONTAMINATION

During initial entries into the containment vessel immediately following the incident, self-contained supplied air respiratory protection was worn. Gross beta-gamma particulate and iodine air concentrations at this time were on the order of 10^{-5} $\mu\text{Ci}/\text{cm}^3$. As the air concentration decreased (Table II) due to decontamination and radioactive decay, respiratory protection requirements were relaxed. Assault masks were worn for entries starting October 3, 1965. The assault masks were fitted with charcoal-bearing canisters for removal of iodine. After October 9, 1965, respiratory protection was no longer needed in the reactor hall level of the containment vessel. Assault mask respiratory protection was worn in other levels of the containment vessel for some time, depending upon when the area was decontaminated. Even after mask requirements were relaxed in an area, they were reestablished for short periods of time based on the potential for release of radioactive material during each specific task. Samples of airborne radioactive contaminants showed that no significant quantities of plutonium were present in the containment vessel atmosphere during recovery and decontamination. Air samples were analyzed for gross alpha and beta activity by a coincidence counting technique. (8)

TABLE II. *Decrease of Airborne Beta-Gamma Particulate Contamination in the Reactor Hall Following the Incident of September 29, 1965*

<u>Date</u>	<u>Concentration, $\mu\text{Ci}/\text{cm}^3$</u>
September 30	2×10^{-5}
October 1	9×10^{-7}
October 2	7×10^{-7}
October 3	2×10^{-7}
October 6	6×10^{-9}
October 7	2×10^{-9}
October 9	1×10^{-9}
October 10	$<1 \times 10^{-10}$

Note: 1) No significant alpha contamination was present in the samples.

2) Subsequent contamination levels increased at times due to specific work. The increased levels were usually very short-term.

EQUIPMENT AND SURFACE CONTAMINATION

The initial survey for loose contamination in the containment vessel was made on October 4, 1965. The results of this survey are given in Table III. The greatest portion of the contaminants settled out on the horizontal surfaces of the containment vessel. This was accompanied by some plating out on vertical surfaces. The principle radionuclides detected were ^{99}Mo , ^{140}La , ^{136}Cs , ^{132}Te , ^{132}I , ^{103}Ru , ^{131}I , and ^{133}I .

A radiochemical study⁽⁷⁾ has indicated that the material deposited on containment vessel surfaces was rather low in plutonium content relative to that contained in the ruptured rod. This indicates that plutonium was not as readily transported by aerosol formation as were some of the fission products. Also, an analysis of the fuel residue showed that the material was relatively rich in plutonium and poor in

fission products.⁽⁹⁾ This confirmed the basic assumption made prior to recovery efforts that relatively little plutonium contamination would be present in working areas. The subsequent routine surveillance program of loose contamination also confirmed this assumption.

Table III. *Removable Contamination Detected
During a Survey of the Containment
Vessel on October 4, 1965*

<u>Location</u>	<u>Surface Concentration, $\mu\text{Ci}/\text{ft}^2$</u>
Reactor Hall	0.75
-11 ft "C" Cell	1.2
-21 ft "C" Cell	3.9
Regulated Shop	15.
"B" Cell	4.8
"A" Cell	1000.

The protective clothing required for initial decontamination efforts consisted of two pairs of coveralls and gloves, a hood, one pair of canvas boots and a pair of rubbers. If the area or the work was very wet, an acid suit consisting of a rubber jacket and trousers was worn in place of the outer pair of coveralls.

Wet mopping with detergent and water proved to be an effective decontaminating method. Contamination levels in areas above the -32 ft level were reduced to $0.075 \mu\text{Ci}/\text{ft}^2$ or less with one or two applications by October 14, 1965. The -32 ft level (lowest level) of the containment vessel was decontaminated to approximately $0.3 \mu\text{Ci}/\text{ft}^2$ and the floor was covered with plastic sheeting.

On a number of occasions, contamination was tracked by personnel from the lower to the upper levels of the containment

vessel, necessitating recleaning of previously decontaminated areas. A procedure was instituted wherein personnel changed their outer shoe covering when entering or leaving the -32 ft level. In this way, gross contamination was confined to the lower levels of the containment vessel. Final decontamination of reactor systems and operating areas was completed during April 1966.

PERSONNEL CONTAMINATION

All personnel exiting from the containment vessel are given a complete contamination survey by Radiation Monitoring personnel as specified by routine procedure. Several instances of beta-gamma contamination were noted on the skin and personal clothing of those involved in the recovery effort. No alpha contamination was detected. For the most part, the skin contamination was confined to the hands and forearms and was received when protective clothing was removed. In most cases, the contamination was removed rather easily by one washing with soap and water. The more stubborn cases required vigorous brushing with a stronger detergent and water.

Contamination of other areas of the body was also experienced due to improper clothing fit or tape pulling loose. In these cases, showers were used for complete decontamination.

PERSONNEL DOSE EQUIVALENTS

The general exposure rates observed in the containment vessel immediately after the incident are given in Table IV. For the first 24 hr after the incident, the activity seemed to be decaying with a 4.5 hr half life.

Personnel borrowed from other sections of Battelle-Northwest assisted in the gross decontamination of the reactor. The persons selected had not received any significant dose equivalent prior to the incident. The total whole body dose equivalent received by all borrowed personnel is estimated to be 37.5 rem or an average of 400 mrem/individual.

TABLE IV. *Containment Vessel Radiation Levels
Following the September 29, 1965 Incident*

<u>Location</u>	<u>September 30, 1965</u>	<u>October 4, 1965</u>
Reactor Hall	450 mR/hr	20 mR/hr
-11 ft "C" Cell	100 mR/hr	20 mR/hr
-21 ft "C" Cell	12 R/hr	600 mR/hr
-32 ft "C" Cell	5 R/hr	600 mR/hr
-32 ft "A" Cell	3.5 R/hr	600 mR/hr
-21 ft "A" Cell	7 R/hr	---
-19 ft "A" Cell	3 R/hr	---
Lower Access Space	43 R/hr	34 R/hr
Lower Access Space Walkway	15 R/hr	5 R/hr
-32 ft "B" Cell	---	200 mR/hr

The dose equivalent received during the recovery period by operating and maintenance personnel normally assigned to the PRTR is given in Figure 3. The group is comprised of some 70 to 80 employees. Note that the whole body dose equivalent during recovery is similar to that received prior to the incident. Measurements of dose equivalents were made with the Hanford Beta-Gamma Film Badge Dosimeter.⁽¹⁰⁾

INTERNAL EXPOSURE

Approximately 75 examinations were made in the Hanford Mobile Whole Body Counter⁽¹¹⁾ of personnel who were involved in decontamination and recovery efforts. In addition, bioassay samples for plutonium analysis were collected from 15 employees who were considered most likely to have received plutonium deposition. No positive plutonium results were obtained for any of the bioassay samples collected. Trace quantities of fission products were detected in approximately 30 employees during whole body counter examinations. However, no employee received an internal deposition of any radionuclide in excess of 1% of the applicable maximum permissible body burden.⁽¹²⁾

FIGURE 3. Dose Equivalent Received by Operating and Maintenance Personnel Assigned to PRTR During Recovery Period (group comprised of 70 to 80 employees)

EXPERIENCE FOLLOWING STARTUP

The PRTR began critical experiments in preparation for the Batch Core Experiment portion of the High Power Density Program on July 16, 1966. Power tests were begun on January 25, 1967. Through December 31, 1967, the PRTR has operated some 6000 MWd with no significant radiological problems. In general, exposure rates at present, both during shutdown and operation periods in operating areas, are lower than before the incident. This is due to physical decontamination of operating areas, effective cleaning of the reactor core, moderator and gas blanket systems, and chemical decontamination of the FERTF and reactor primary coolant systems. Loose contamination in the -32 ft level is, however, about 50% to 100% higher today than before the incident. The

higher contamination has necessitated a procedural change wherein personnel now change shoe covering when going to or coming from the -32 ft level of the containment vessel. All other protective clothing requirements and health physics procedures remain the same today as before the incident.

There has been no significant evidence thus far of any long-lived fission product or plutonium contamination in the containment vessel atmosphere. Airborne contaminants at present are identical to those experienced before the incident;⁽¹³⁾ i.e., tritium, fission gases and fission gas daughter products. Levels of airborne contamination appear to be quite similar to or less than the levels experienced before the incident.

CONCLUSIONS

The experience following the PRTR rupture indicates that normal reactor health physics procedures and controls need not be changed just because a rupture occurs in a plutonium-fueled reactor. A reasonable estimate of the likelihood of plutonium contamination being present in operating areas is necessary at the start of recovery efforts. If this estimate indicates that the likelihood is small, as in the case of the PRTR, then no unusual protective procedures and controls are necessary, other than an expanded program due to increased airborne and surface fission product contamination. After this estimate is made, however, it must be verified by a routine surveillance program for plutonium contamination. The approach to recovery and decontamination is basically the same as that which would be used at a uranium-fueled reactor.

The experience gained at the PRTR may be applicable to other plutonium-fueled reactors if a similar rupture occurs.

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