Hanford Process Review

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U.S. Department of Energy
Office of Administration and
Human Resources Management
Executive Secretariat
History Division
Washington, DC 20585
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EXECUTIVE SUMMARY

This report is a summary of past incidents at the U.S. Department of Energy's (DOE) Hanford Site. The purpose of the report is to provide the major, significant, nuclear-safety-related incidents which occurred at the Hanford Site in a single document for ease of historical research. It should be noted that the last major accident occurred in 1980.

This document is a summary of reports released and available to the public in the DOE Headquarters and Richland public reading rooms. This document provides no new information that has not previously been reported.

An integral part of all nuclear facility safety programs is the reporting and investigation of all departures from normal operating conditions. The vast majority of such incidents involve no significant safety risk or damage, but reflect minor equipment or procedural irregularities that are properly dealt with by the response of safety systems or operating personnel. Only those incidents judged to have an appreciable safety implication have been selected for inclusion in this review. The criteria for including incidents and for judging their significance are given in Section 1.2 of this report. Altogether, 127 nuclear-process-related incidents* with some degree of safety significance have been identified and are described. This report is not intended to cover all instances of radioactivity release or contamination, which are already the subject of other major reviews, several of which are referenced in Section 1.3.

*This review has been limited to nuclear-process-related incidents. Construction accidents and operating accidents not related to nuclear processes have been excluded.
These incidents have been grouped into three significance categories, based on the seriousness of their actual or potential consequences. Only 14 are considered Category 1, indicating that serious injury, radiation release or exposure above limits, substantial actual plant damage, or a significant challenge to plant or personnel safety resulted. Forty-six incidents are considered Category 2, indicating less severity than Category 1, but involving significant cost or a less significant threat to safety. The remaining 67 incidents, causing minor radiation exposure or monetary cost or involving a violation of operating standards without seriously threatening safety, are assigned to Category 3. A breakdown of the incidents by significance category and by the facilities involved is given in Table ES-1. Descriptions of the incidents, arranged by category, are given in Section 2 of the report, and a database giving abbreviated descriptions of all 127 incidents is included in Appendix A. No attempt has been made to rate incidents by severity within each category.

This review covers the entire operating history of Hanford, from 1944 to the present. Most of the incidents relate to facilities that have completed their useful lives and are no longer in operation. Only eight of the incidents (about 6%) and none of the Category 1 incidents have occurred in the last 11 years.

Although a majority of the Category 1 incidents shown in Table ES-1 relate to laboratory and separations facilities operation, a majority of the Category 2 and 3 incidents relate to reactor operation. This asymmetry probably reflects a bias in the incident definition process. This review was first intended to be limited to reactor incidents, and a number of events were
included that had potential safety impact but resulted in no significant consequences. When laboratory and separation facility incidents were added, it was decided to include only those events having a significant actual impact. In addition, since Hanford radiation releases are already being studied under the Hanford Environmental Dose Reconstruction Project, only the most severe radiation releases from the separations processes were included in this review. Finally, contamination incidents that did not result in significant radiation exposure, threaten safety, or extend offsite have also generally not been included. Listings of such incidents are available in several publications maintained in the U.S. Department of Energy Field Office, Richland (DOE-RL) Public Reading Room. These differences are believed to account for the uneven incident distribution shown in Table ES-1.

A further breakdown of the Category 1 incidents is given in Table ES-2. Of the 14 Category 1 incidents, 7 were assigned that rating because they involved radiation exposure above limits to one or more workers; 5 because of major cost or production loss; 1 because of offsite environmental release of radioactivity above limits; and 1 because a primary safety system failed to function, although no damage resulted because backup systems responded as designed. Two of these incidents also involved uncontrolled nuclear criticalities and would have been assigned to Category 1 even if no damage or radiation exposure had resulted. An abbreviated summary of the Category 1 incidents is given in Table ES-3.
Reporting and Report Availability

All of the incidents appear to have been reported promptly by the operating contractors* to the cognizant government agency. For the more serious incidents, investigative reports were submitted, analyzing the causes and consequences and proposing remedial actions. In a number of cases, special DOE (or other agency) investigation committees were appointed to conduct an independent investigation. No attempt has been made to locate all references for any incident. However, Section 5 includes at least one reference for each incident. Because reporting systems in the early years of the Hanford Project were less formal and structured than they later became, limited information is available on descriptions and on corrective measures undertaken as a result of many of the earlier incidents.

Before 1971, most Hanford operations and reports were classified, and most of the early reports remained classified until recently. However, all of the Category 1 incidents and 80% of the Category 2 incidents are described in reports that have been available to the public for several years. The Category 3 incidents, in general, were less widely disclosed; however, about half of these incidents have been described previously in unclassified reports. In connection with the release of this report, all of the references cited herein have been declassified and are now available to the public in the DOE-RL Reading Room.

*The term "operating contractor" as used in this report means a contractor to DOE or its predecessors that under the procurement regulations was recognized as either a government-owned contractor-operated (GOCO) or Management and Operating (M&O) contractor.
Table ES-1. Breakdown of Hanford Incidents by Category and by Facilities Involved.

<table>
<thead>
<tr>
<th>Facilities</th>
<th>Number of incidents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Category 1</td>
</tr>
<tr>
<td>Production-only reactors</td>
<td>2</td>
</tr>
<tr>
<td>N Reactor</td>
<td>2</td>
</tr>
<tr>
<td>Laboratories and test reactors</td>
<td>3</td>
</tr>
<tr>
<td>Separations facilities</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
</tr>
</tbody>
</table>

Table ES-2. Breakdown of Category 1 Incidents by Facility and Principal Effect.

<table>
<thead>
<tr>
<th>Facilities</th>
<th>Worker radiation exposure</th>
<th>Cost or production loss</th>
<th>Environmental impact</th>
<th>Safety system failure</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>Production-only reactors</td>
<td>--</td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>2</td>
</tr>
<tr>
<td>N Reactor</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Laboratories and test reactors</td>
<td>1</td>
<td>2*</td>
<td>--</td>
<td>--</td>
<td>3</td>
</tr>
<tr>
<td>Separations facilities</td>
<td>5*</td>
<td>1</td>
<td>1</td>
<td>--</td>
<td>7</td>
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<tr>
<td>Total</td>
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<td>5</td>
<td>1</td>
<td>1</td>
<td>14</td>
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</tbody>
</table>

*One incident in each of these two groups involved an uncontrolled nuclear criticality.
<table>
<thead>
<tr>
<th>Incident number*</th>
<th>Date</th>
<th>Event description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>KW-1</td>
<td>01/04/55</td>
<td>KW tube 4669 blockage, partial melt</td>
<td>Repair cost $550,000</td>
</tr>
<tr>
<td>KW-9</td>
<td>06/19/68</td>
<td>KW tube 3560 blockage, partial melt</td>
<td>Reactor down 6 weeks</td>
</tr>
<tr>
<td>N-6</td>
<td>09/30/70</td>
<td>N safety rods failed to scram</td>
<td>Backup safety systems functioned properly</td>
</tr>
<tr>
<td>N-14</td>
<td>12/16/77</td>
<td>N fuel flushed onto manned platform</td>
<td>Four personnel exposures above limit</td>
</tr>
<tr>
<td>L-2</td>
<td>11/16/51</td>
<td>Uncontrolled criticality, subsequent fire</td>
<td>Facility decommissioned</td>
</tr>
<tr>
<td>L-5</td>
<td>07/10/74</td>
<td>Plutonium coupon shattered in press</td>
<td>Plutonium deposition above MPBB</td>
</tr>
<tr>
<td>PRTR-2</td>
<td>09/29/65</td>
<td>Heavy water reactor contaminated</td>
<td>Program delayed; cost $900,000</td>
</tr>
<tr>
<td>S-2</td>
<td>12/02/49</td>
<td>Release of $^{131}$I</td>
<td>Offsite environmental deposition above limits</td>
</tr>
<tr>
<td>S-5</td>
<td>02/16/55</td>
<td>Plutonium inhalation</td>
<td>Plutonium deposition above MPBB</td>
</tr>
<tr>
<td>S-7</td>
<td>06/18/56</td>
<td>Plutonium leak and inhalation</td>
<td>Three employees above MPBB</td>
</tr>
<tr>
<td>S-11</td>
<td>04/07/62</td>
<td>Recuplex tank criticality</td>
<td>Three personnel exposures above limit</td>
</tr>
<tr>
<td>S-19</td>
<td>04/18/70</td>
<td>Radioactive solution on gloves</td>
<td>Hand exposure above limit</td>
</tr>
<tr>
<td>S-22</td>
<td>08/30/76</td>
<td>Chemical explosion in glove box</td>
<td>Employee suffered acid burns, cuts, and contamination</td>
</tr>
<tr>
<td>S-23</td>
<td>02/27/80</td>
<td>Plant damage, crane accident</td>
<td>$1,174,000 damage</td>
</tr>
</tbody>
</table>

*The incident prefix indicates the facility involved (e.g., KW Reactor, N Reactor, Laboratory, Plutonium Recycle Test Reactor, or Separations Facilities).

MPBB = Maximum permissible body burden.
FOREWORD

This report covers a range of incidents on the U.S. Department of Energy's Hanford Site from 1944 to the present. It is based on the best information available and is subject to change as deemed warranted. It gives some insight into the causes and consequences of certain nuclear-process-related incidents at Hanford but is not intended to be a complete and comprehensive report. Many incidents are documented in official Hanford records that did not fit the criteria for this report.

Many official documents cited in this report were declassified to make them available to the public. Still more documents are being reviewed and will soon be declassified so that they, too, will be publicly available.
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1.0 INTRODUCTION

The purpose of this report is to summarize in a single document the past history of nuclear-safety-related occurrences at the U.S. Department of Energy's (DOE) Hanford Site. Although numerous production and laboratory facilities have operated with a high degree of safety and, with few exceptions, within established standards of environmental protection, incidents did occur, the most recent in 1986. Lost-time injury rates have consistently been only a fraction of those for industry as a whole. In 46 years of operation, no nuclear-process-related fatalities have occurred at the Hanford Site.

As would be expected from an operation as complex as the Hanford Project, incidents have occurred that were considered to have safety or environmental consequences or implications. This report presents the results of a review of safety-related incidents spanning the entire operating history of the Hanford Site, from 1944 to the present.

1.1 PURPOSE AND SCOPE

This review was conducted at the request of the U.S. Department of Energy Field Office, Richland (DOE-RL) in response to increasing attention to the safety of DOE nuclear facilities. A memorandum summarizing the 30 safety-related incidents of "greatest significance" that had occurred during reactor operation at DOE's Savannah River Site (Ridgely 1985) was given widespread media and congressional committee attention when it was made public in September 1988. Questions were raised as to the extent to which these Savannah River incidents had previously been reported. The DOE requested a review to determine the nature and the reporting history of nuclear-safety-related incidents that have occurred at the Hanford Site. All events in this report were previously reported, as shown in the Reference Database, Section 5.0. In addition to providing an overview of the overall safety record of the Hanford Project, it is hoped that this review will give some insight into the causes and consequences of significant nuclear-process-related incidents. This insight may, in turn, provide guidance in furthering the safety of nuclear facilities, both at the Hanford Site and elsewhere.

This review was originally intended to cover only reactor incidents, and many incidents were included that had potential safety implications but that did not result in significant harm because of corrective action by personnel or by safety systems. However, because of the diversity of Hanford Site operations, the preliminary review was expanded to include incidents in laboratories and process facilities. It was decided to limit coverage for these facilities to incidents with significant consequences in terms of radiation exposure, radioactivity release, or cost. Thus, there is an unbalance between the treatments of reactor and other facilities, resulting in many more Category 2 and Category 3 incidents being listed for the reactors than for the other facilities.
The incident listing is intended to cover events having safety implications. In particular, considerable effort was made to identify events resulting in or having the potential for radiation exposures or environmental releases above limits, or costly nuclear-process-related incidents. Chronic radiation exposures and radioactivity releases within allowable limits have not been included; such releases are the subject of the Hanford Environmental Dose Reconstruction Project, and are beyond the scope of this review. In addition, radioactive contamination incidents that did not threaten safety or result in personnel radiation exposure or offsite contamination approaching limits generally have not been included. Listings of such incidents are already publicly available (Selby and Soldat 1958; Backman 1965; Cartmell 1968; RHO 1986a; Anderson 1974; ERDA 1975; RHO 1985; RHO 1986b; HHDRC 1987; Waite 1991).

Finally, accidents in nonproduction facilities that were not nuclear-process related and did not result in injury, radiation exposure, or significant contamination are also not included. Some of these may be found in Appendix B.

Problems attributed to design inadequacies in the early plants are not included as operating incidents. More information may be found in several of the general references at the end of this section, particularly Anderson (1974). For example, the gaseous wastes generated during early fuel processing plant operation were discharged unfiltered, relying on atmospheric dilution to reduce radioactivity concentrations to acceptable levels. This approach proved inadequate, requiring such plant modifications as the following:

- Radioactive particle fallout in the B and T Plant areas was observed starting in September 1947. This situation was corrected by installing sand filters to remove particles from the exhaust.

- Radioactive iodine concentrations were found to be above limits during early operations, when fuel was processed after a relatively short cooling period. Iodine-131 emissions during 1945 were approximately 340,000 Ci. Water filters were installed in 1948 and replaced in 1950 with silver reactors. These measures, together with longer fuel cooling times, reduced iodine emissions to a few hundred curies per year in the late 1950s and to less than one curie per year in the 1970s and 1980s.

- Several incidents of unexpected ruthenium emissions occurred following startup of the REDOX Plant in January 1952. Process equipment changes made in the summer of 1954 solved the problem. Similarly, electrolytic corrosion and other factors caused a number of underground waste and process line failures in the early plants. The major contamination instances of this type are listed in Cartmell (1968) and are not included in the incidents in this review.

Section 1.2 of this report summarizes the review process. It explains the significance rating (Section 1.2.1), describes the approach (Section 1.2.2), and details the sources of information and documentation of incidents (Section 1.2.3). The incidents are ranked into three significance
categories. Section 2 provides a complete description of the incidents. Appendix A is a database listing of all 127 accidents considered by the review.

Section 3 is a brief history of Hanford Site operations, including a chronology of key events leading to Hanford's establishment and a review of facility operating dates. Section 4 describes the principal Hanford facilities and operations. These sections are intended to provide understanding of the facility functions and processes involved to assist in interpreting the incidents described in Section 2.

1.2 REVIEW SUMMARY

The Hanford Site pioneered the implementation of nuclear reactor and related chemical processing technology. In its 46-year operating history, site operations have included eight production reactors; a dual-purpose reactor; and their associated fabrication plants, chemical processing plants, and waste management facilities. Hanford Site operations have supported wartime plutonium production and peacetime maintenance of the Nation's nuclear deterrent.

Because of the potential hazards associated with nuclear facilities, Hanford, along with other nuclear sites, has maintained a policy of reporting all departures from normal operating conditions to management and to the cognizant government agencies. The vast majority of such incidents involve no significant safety risk or damage, but result from minor equipment or procedural irregularities that were properly dealt with by the response of safety systems or operating personnel. This review developed a set of criteria to determine which incidents to include and to rate their significance. A total of 127 incidents were judged to have sufficient safety implication to be selected for inclusion. A summary of these incidents by seriousness (significance category) and by the type of facility involved is given in Table 1-1. A further breakdown of the Category 1 incidents is given in Table 1-2.

1.2.1 Explanation of Significance Rating

The incidents identified were evaluated and assigned a significance rating of 1, 2, or 3 (from most to least serious). As described below, Category 1 incidents are those that resulted in serious personal injury, plant damage, or radiation release or exposure above limits, or those that seriously threatened plant or personnel safety, whether or not damage resulted. Category 2 events are those resulting in moderate damage or threat to safety, while Category 3 events are those deemed neither to have caused damage above about $100,000 nor to have threatened plant safety. No attempt is made to rank the relative significance of incidents within each category.

This review concentrated on incidents involving operation of Hanford nuclear-related processes. Industrial accidents (falls, construction accidents, etc.) have not been included. In addition, chronic or repetitive radioactivity release events generally have not been included, since they are already the subject of an intensive investigation (the Hanford Dose...
Reconstruction Project). However, a few such release incidents considered to involve operational deficiencies or greater than normal risk are included in this review.

Table 1-1. Breakdown of Hanford Incidents by Category and by Facilities Involved.

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<tr>
<th>Facilities</th>
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</tr>
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<tbody>
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<td>2</td>
</tr>
<tr>
<td>N Reactor</td>
<td>2</td>
</tr>
<tr>
<td>Laboratories and test reactors</td>
<td>3</td>
</tr>
<tr>
<td>Separations facilities</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 1-2. Breakdown of Category 1 Incidents by Facility and Principal Effect.

<table>
<thead>
<tr>
<th>Facilities</th>
<th>Worker radiation exposure</th>
<th>Cost or production loss</th>
<th>Environmental impact</th>
<th>Safety system failure</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production-only reactors</td>
<td>--</td>
<td>2</td>
<td>--</td>
<td>--</td>
<td>2</td>
</tr>
<tr>
<td>N Reactor</td>
<td>1</td>
<td>--</td>
<td>--</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Laboratories and test reactors</td>
<td>1</td>
<td>2*</td>
<td>--</td>
<td>--</td>
<td>3</td>
</tr>
<tr>
<td>Separations facilities</td>
<td>5*</td>
<td>1</td>
<td>1</td>
<td>--</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>14</td>
</tr>
</tbody>
</table>

*One incident in each of these two groups involved an uncontrolled nuclear criticality.

1.2.1.1 Consideration Given to Radiation Exposure. A number of the incidents reviewed involved unplanned exposures of personnel to external radiation or to internal deposition of radioactive material. Careful consideration was given to how such radiation exposure should be weighted in assigning incident significance ratings. These radiation exposures resulted in no observed health effects (see summaries below); therefore, it was decided that radiation exposure would not be a factor in the evaluation unless the exposure approached the annual limit or, in the case of internal deposition, the maximum permissible body burden (MPBB). Incidents involving exposures substantially exceeding those limits were assigned a significance rating of 1.
For exposures below these limits, the significance rating was generally determined by other factors, including monetary consequences and the potential that existed for the incident to have been more serious.

Radiation exposures at Hanford approaching or exceeding operational limits are listed in Appendix B, Section B.3. The listing also indicates how these exposures were treated in this review. Appendix B, Section B.3.4, summarizes the whole body dose equivalent limits applicable over the history of Hanford operations.

The following excerpts from recent studies of worker health following moderate radiation exposure indicate no observable adverse effects from such exposures.

A recent publication of data from the ongoing DOE mortality study of Hanford workers (Gilbert et al. 1989) published in January 1989, includes the following statements:

"Hanford workers continued to exhibit a strong healthy worker effect with death rates substantially below those of the general U.S. population. Comparisons by level of radiation exposure within the Hanford worker population provided no evidence of a positive correlation of radiation exposure and mortality from all cancers combined or of mortality from leukemia. Estimates of cancer risk due to radiation were negative, but confidence intervals were wide.... For all causes of death, the direction of the correlation of mortality with radiation exposure was negative."

"Four hundred fifty-seven Pu deposition cases were confirmed prior to 1 January 1979.... Of the 457 Pu deposition cases, 136 (30%) had depositions estimated to be 5 to 99% of an MPBB, while 6 (1.3%) had depositions exceeding 100% of an MPBB. There were no deaths due to multiple myeloma or leukemia among those with depositions ... and no cancer deaths among those with plutonium depositions exceeding 100% MPBB.... Analyses of internal plutonium depositions provided little evidence of adverse effects, but the power for detecting such effects was low since the number of workers with confirmed depositions was very small."

Similarly, a 42-year study of 26 Los Alamos workers who received plutonium depositions during the Manhattan Project also recently reported no observable adverse effects (Voelz et al. 1989). The workers received depositions ranging from 3.5% to 212% of a MPBB, with a median deposition of 31% of a MPBB. Voelz states:

"Four persons in the group have died.... Expected deaths based on U.S. death rates of white males, adjusted for age and calendar year, are 9.2, giving a standardized mortality ratio (SMR) of 0.44. The one death from cancer is also less than expected based on U.S. rates (SMR = 0.49). The average age of the 22 living subjects in 1986 was 66 years.... This study yields no evidence suggesting that adverse health effects have resulted from the 42 years of exposure to internally deposited plutonium."
1.2.1.2 Significance Rating Criteria.

Category 1. Incidents causing serious injury, personnel radiation exposure above permissible limits, uncontrolled radiation release, substantial plant damage or loss of production, or a serious threat to overall plant safety.

- Process-related fatality or serious injury
- Inadvertent worker exposure greater than 5 rem (whole body) or internal deposition more than twice the MPBB
- Offsite radiation exposure above limits in populated areas
- Damage to plant or loss of production on order of $1 million
- Multiple procedural, equipment, safety system, and/or personnel lapses challenging the integrity of the defense-in-depth safety philosophy
- Any uncontrolled criticality.

Category 2. Incidents less severe than Category 1, but still causing above-normal radiation exposure or monetary cost, or a minor threat to overall plant safety.

- Inadvertent worker exposure greater than 3 rem but less than 5 rem (whole body) or internal deposition above about one MPBB
- Offsite radioactivity release above limits
- Site contamination requiring unusual cleanup measures and/or minor offsite contamination
- Damage to plant or equipment or loss of production in excess of about $100,000
- Multiple procedural, equipment, safety system, and/or personnel lapses but not challenging the integrity of the safety system
- Personnel intervention required to prevent a possible Category 1 incident.

Category 3. Incidents less severe than Category 2, but causing minor radiation exposure or monetary cost or involving violation of operating standards.

- Minor radiation exposure or offsite release
- Incident resulting from violation of safety standards, with no damage or minor damage resulting
• Personnel error or equipment failure resulting in minor
equipment damage or the potential for damage or radiation
exposure

• Safety-related equipment failure, not resulting in damage,
radiation release, or risk of more severe accident.

Reportable incidents not resulting in any challenge to plant safety are
excluded from this review:

• Individual fuel failures

• Reactor scrams not safety significant

• Single component failures, operator errors, or procedure violations
properly handled by the system with no safety implications

• Radiation releases within allowable limits.

1.2.2 Approach

The complex organization and history of the Hanford Project, described in
Section 3 of this review, and the very large number of reports that have been
issued during its 46 years of operation, necessitated selectivity in
performing the document review. Certain categories of documents, such as the
monthly operating reports for the major operating departments and the safety
and environmental organizations, have been reviewed fully. Subject or keyword
indexes exist for some categories of documents, and these also have been
examined fully. However, no attempt was made to review, even by title, all of
the hundreds of thousands of reports issued at Hanford.

Several previous compilations of specific types of operating incidents
during specific periods of Hanford operation served both as information
sources and as independent checks on the adequacy of the document review
process for identifying significant incidents. The U.S. Atomic Energy
Commission (AEC), the U.S. Energy Research and Development Administration
(ERDA), and the DOE have published compilations of incidents and accidents at
nuclear facilities, and these publications have also served as a check that
major incidents have not been omitted. Listings of all Hanford worker
fatalities, radiation overexposures, and accidents involving a cost of over
$50,000 were reviewed for applicability to this study (see Appendix B).
Finally, a limited number of discussions were held with long-term operating
personnel regarding their recollection of such events.

1.2.3 Documentation of Incidents

The database (Appendix A) and reference listings (Section 5) include at
least one report reference for each incident described in this review. Before
1971, most technical and operating information about the Hanford Project was
classified. Beginning in 1971, most aspects of ongoing Hanford operations
were declassified, except for information relating to production and some
aspects of technology. However, most of the earlier reports retained
their classification. Many reports of special interest, notably several thousand documents relating to environmental effects, were released to the public (in some cases with deletions) in connection with the Hanford Environmental Dose Reconstruction Project or through an ongoing review process. These included a number of the reports referenced herein. Approximately half of the referenced reports were classified at the time of review, but have been declassified for release with this report.

All of the referenced reports can now be found in the DOE-RL Public Reading Room in Richland, Washington. All 14 of the Category 1 incidents, 80% of the Category 2 incidents, and half of the Category 3 incidents are described in reports that were already unclassified at the time this review was conducted. Most of the incidents are the subject of one or more investigative reports and are summarized in monthly operating reports. No attempt has been made to identify all references to each incident. In general, monthly reports are cited only when more comprehensive reports were not found. Several prior reviews have discussed more than one incident, and these have been cited wherever applicable because they provide a more convenient source of additional information than the voluminous investigative reports.

Insofar as can be determined, all of the incidents identified in this compilation were reported promptly to local representatives of the cognizant government agency (i.e., the Manhattan Engineer District, AEC, ERDA, or DOE, depending on the date of occurrence). During the earlier years of the project, it was customary to report daily on operations, including any unusual events. Currently, all off-normal conditions or unusual occurrences are reported promptly. DOE Order 5000.3 (DOE 1984) requires immediate notification of any unusual occurrence to the cognizant DOE field organization, an initial written report within 10 days, a final report when corrective action has been completed, and quarterly status reports on all unusual occurrence reports initiated or remaining open during the quarter. Monthly summary reports are issued covering each major activity. No attempt has been made in this review to locate the initial reporting mechanism or documentation for each incident. Rather, one or more reports that most fully describe each incident, its consequences, and steps taken to prevent a recurrence have been cited.

Summaries of many of the more significant occurrences have been included in various government compilations (refer to TID-5360, WASH-1192, and DOE/EV-0080, et seq. in the reference database, Section 5).
1.3 REFERENCES


Ridgely, 1985, "SRP Reactor Incidents of Greatest Significance," Memo to G. F. Merz, RTR-2316, Westinghouse Savannah River Company, Aiken, South Carolina.


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2.0 INCIDENT DESCRIPTIONS

A total of 127 safety-related Hanford process incidents have been identified and evaluated. Fourteen incidents are rated Category 1, 46 are rated Category 2, and the remaining 67 are Category 3. The events are described by category in this section, and a database giving a brief description of all 127 incidents may be found in Appendix A. No attempt is made to rank the relative significance of incidents within each category. Of the 14 Category 1 incidents, 4 involved reactor operations (2 each at KW Reactor and N Reactor), 7 were related to chemical processing, and the other 3 to experimental or laboratory operations. Twenty-nine of the 46 Category 2 incidents relate to reactor operation.

None of the incidents reviewed resulted in a worker fatality. This attests to the success of the Hanford safety program and to the multiple safety features incorporated in nuclear process facilities. Although there have been a number of worker fatalities not related to Hanford process operations,* Hanford's overall plant safety record has been exemplary.

The two Category 1 incidents that relate to KW Reactor involved fuel tube plugging, each causing failure of a single tube and part of its fuel content. One of the N Reactor Category 1 incidents exposed workers to radiation above limits (although not enough to represent a serious health risk) when irradiated fuel was discharged onto the charge elevator with workers present. The other N Reactor Category 1 event—failure of the safety rods to respond to a scram signal—resulted in no damage, because the backup ball safety system responded as designed, shutting the reactor down. This event was assigned a Category 1 rating because it involved failure of a primary safety system.

The nonreactor Category 1 incidents include two inadvertent criticality events, a chemical explosion resulting in acid burns and radiation exposure, four other radiation exposure or release events, and two accidents involving recovery costs on the order of $1 million each.

The Category 2 events were principally of four general types: (1) startup or control anomalies, often related to the complex control procedures required in operation of the production reactors; (2) radiation releases or personnel radiation exposure; (3) fires or explosions; and (4) violations of safety procedures not resulting in injury or damage. As defined in Section 1.2, the Category 2 events did not result in serious injury, major plant damage, or radiation exposure above allowable limits.

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*Most of the Hanford worker fatalities occurred during construction activities. Of those that occurred during operation, the only one related to Hanford processes was a worker fatality on August 30, 1955, from an explosion in a heat-treating operation in a supporting shop facility. Hanford nonconstruction fatalities are listed in Appendix B.1.
2.1 CATEGORY 1 INCIDENTS

A description of each Category 1 incident follows. The incidents are discussed in the order used in the incident database, that is, first by facility involved and then by chronological order if there is more than one incident involving the same facility. No attempt has been made to differentiate these incidents as to their severity. Readers unfamiliar with nuclear facilities may wish to read Section 4 for a description of the processes and facilities involved.
1. INCIDENT KW-1 - JANUARY 4 AND 5, 1955 - PARTIAL FUEL MELT-TUBE 4669

This event occurred during the initial startup of the KW Reactor. It entailed the greatest repair cost ($550,000) of any single event at a production reactor at Hanford. However, there was no significant radiation release or personnel radiation exposure, and the reactor was able to restart 9 weeks later.

During the process of gradually bringing the reactor up to operating power, a sudden reactivity and power decrease was noted, and control rods were withdrawn to compensate. Shortly later, an alarm sounded, indicating the presence of water in the reactor graphite gas atmosphere. While the operators were trying to locate the source of the indicated water leak, the reactor was automatically scrammed by a trip signal from the pressure monitoring system on tube row 46. Examination revealed that tube 4669 contained ruptured fuel and had a large water leak.

The cause of the problem was found to be a neoprene plug that had been inadvertently left in the tube outlet fitting. A number of tubes had been plugged to prevent water entry during prestartup criticality tests, and this plug had been overlooked when the others were removed. The lack of flow to this tube would normally have been indicated and should have resulted in a tube flow monitor alarm and trip before any damage could occur. However, the flow gage had been misadjusted to indicate normal flow in the no-flow condition. As a result of this combination of errors, the tube had essentially no cooling, resulting in fuel and tube failure before other safety instruments shut down the reactor.

Since the fuel was fresh, radiation levels and contamination were relatively low. Because the tube had partially melted, normal fuel and tube removal processes were ineffective, and it was necessary to drill through the rear shield wall in order to remove the tube along with its supporting graphite blocks. The blocks, tube, and fittings were replaced, the shielding repaired, and the channel returned to full service. No permanent impairment of any sort resulted, and the reactor was successfully started on March 11, 1955.

A thorough investigation resulted in a more rigid testing program applied both to KW Reactor startup and to other operations. Following the augmented testing program, the reactor was started without incident.

The incident was extensively studied and reported, including a 17-part comprehensive examination of all its aspects. The event was reviewed in the publication "Nuclear Safety" and is described briefly in two government compilations of accidents and incidents at government nuclear facilities.

References: HW-34403 HW-34856 HW-35822 Nuclear Safety 4,1 HW-34461 HW-35819 HW-41495 TID-5360 HW-34834 HW-35820 HW-73060 WASH-1192 HW-34847 HW-35821 HW-73265-RD

2-3
This event was similar to the earlier KW fuel melt, but resulted from an improbable mechanical failure rather than personnel error, and required less downtime for repair. There was a release of $^{131}\text{I}$ to the Columbia River, but only a small fraction of the annual release limit.

The reactor automatically scrammed on June 19, 1968, from a low-pressure trip on process tube 3560. It was found that flow to the tube had been completely blocked by a thermal bulb from a temperature-measuring instrument used to measure inlet coolant water temperature in the main pump house pump well. The bulb had broken loose and traveled through the system (in spite of screens meant to catch such debris) until it became lodged in the throat of the Venturi meter used to monitor coolant flow to the process tube. The fuel jackets on most of the fuel elements in the tube were melted, and about 20 Ci of $^{131}\text{I}$ were released to the river. This was about 0.5% of the allowable annual release limit. No significant amounts of other fission products were released. There were no injuries or personnel radiation exposures in excess of established limits. Due to the extensive fuel jacket melting, removal of the damaged fuel elements and the Zircaloy process tube required the reactor to remain shut down until July 28.

An extensive investigation was undertaken to determine whether design or procedural changes should be made to prevent recurrence of this type of event. It was determined that the incident had been an unlikely "freak" occurrence and that a repetition was improbable. Nevertheless, inspection and maintenance procedures were tightened.

The event was declared a Class B Reportable Incident and was reported in a comprehensive three-volume study (DUN-5001). It is also summarized in two government compilations of accidents and incidents, and was the subject of a technical paper (DUN-SA-12) presented at an American Nuclear Society conference on reactor operating experience.

References:  DUN-5000  
DUN-5001  
DUN-SA-112  
WASH-1192
3. INCIDENT N-6 – SEPTEMBER 30, 1970 – SCRAM WITH FAILURE OF ROD SAFETY SYSTEM

This was the only event in which the rod safety system of a Hanford reactor failed to respond to a scram signal. The backup ball safety system functioned as designed, shutting down the reactor without damage.

With the reactor operating at 450 MW during a startup, an automatic trip-off of No. 6 primary pump drive turbine generated a low-flow reactor scram signal (although at no time did primary coolant flow fall below that needed for adequate cooling). The rod safety system failed to respond to the scram signal. However, the backup ball safety system responded automatically to achieve a safe shutdown. The rods failed to scram because of continued energization of all rod scram solenoids through a "sneak" connection to an auxiliary circuit. The sneak circuit was created by the shorting failure of two sets of in-series diodes in the scram solenoid circuitry of rod No. 59, together with connections that had been made to electrically lock out rod No. 59 through the auxiliary circuit, following failure of a valve in the control system. Failure of the four in-series diodes had probably occurred by momentary grounding during maintenance activities.

As a result of this rod scram circuit failure, all critical safety systems were reviewed to determine whether conditions existed where a single failure could disable a critical protective system. No such situations were found. The rod scram circuitry was revised and procedures implemented to ensure against the recurrence of such a problem. The incident was reviewed with members of the AEC and the Advisory Committee on Reactor Safeguards. Authorization was received on October 16, 1970, to resume normal reactor operations.

The incident was reported in two special investigative reports (DUN-7342 and DUN-7436) as well as in monthly and annual reports. In addition, it was reviewed in a special briefing report to the U.S. Advisory Committee on Reactor Safeguards and was fully described in the publication "Nuclear Safety." Since the incident involved no damage or environmental consequences, it is not included in government incident compilations.

References: DUN-7060
DUN-7342
DUN-7436
DUN-7545
Nuclear Safety 12,6
UNI-785
4. INCIDENT N-14 - DECEMBER 16, 1977 - PERSONNEL RADIATION EXPOSURE FROM FUEL DISCHARGED ONTO CHARGE ELEVATOR

During a routine maintenance shutdown of N Reactor, four workers were on the charge (C) elevator to remove a stinger from tube 2150. (A stinger is a device with an orifice that allows backflow but no forward flow of coolant.) When the stinger was removed, the primary system pressure was sufficient to flush irradiated fuel from the tube onto the C elevator. The workers immediately left the elevator and reported that irradiated fuel was on the elevator.

Control room personnel noted that the primary coolant was at a temperature of about 95 °F and was pressurized to about 169 psi. Investigation revealed that the startup heaters had been inadvertently turned on and the vent valve closed, pressurizing the system.

The four exposed workers were given whole-body counts and their dosimeters were evaluated. Their exposures were calculated to be 5, 6, 11, and 15 rem. The annual limit is 5 rem. The workers were examined by a physician, debriefed by management, and went home at normal quitting time. All four returned to work on their next scheduled shift. The ejected fuel was recovered without appreciable additional radiation exposure, and the reactor returned to operation on December 27, 1977.

This type of incident has the potential for serious radiation exposure to operating personnel. This was declared an Abnormal Occurrence, and a Class B Incident Investigation was conducted. Several corrective actions were taken to prevent a recurrence.

In addition to the comprehensive Abnormal Occurrence Report submitted by the contractor, a DOE investigating team issued a complete report, and the event is included in a DOE compilation of operational accidents and radiation exposures at DOE facilities.

References:  AO-77-002
             DOE/EV 0091/1
             RLO-78-1
5. **INCIDENT L-2 - NOVEMBER 16, 1951 - HHRE UNCONTROLLED CRITICALITY**

The Hanford Homogeneous Reactor Experiment (HHRE) was an experimental program carried out in the Critical Mass Laboratory of the P-11 laboratory building. Its purpose was to investigate the physics of plutonium solutions to determine safety limitations for process facilities. During one such experiment a partially full spherical assembly containing plutonium nitrate solution as fuel was accidently brought to a prompt critical condition by too-rapid withdrawal of the safety rod. The safety rod was being withdrawn in steps, and the interval allowed between steps was not sufficient to allow the system to reach equilibrium. This permitted a sudden super-criticality. The geometry was such that the initial expansion of the fuel solution increased reactivity until the sphere was full, at which time further expansion shut the reactor down. Analysis indicated that a total energy release of about 3 MWs (about $8 \times 10^{16}$ fissions) had occurred over a time period of less than 0.5 s, with a peak power level on the order of 50 MW.

There was no physical damage to the facility, but gross contamination resulted from dispersal of the plutonium solution. Radiation doses to personnel in the control room, which was located about 200 ft away as a protection against such an occurrence, measured up to 600 mrem.

During decontamination of the P-11 laboratory building following the criticality, a fire occurred, causing gross contamination of the entire building and the immediate environs and extensive damage to the facility. The fire was believed to have started in contaminated storage cartons from spontaneous combustion of acid-wetted rags used in the decontamination. No personnel injuries or excessive radiation exposures were reported. Because only a small amount of experimental work remained in the program, the facility was abandoned and later decontaminated and removed.

The incident was widely reported, and is included in two compilations of accidents and incidents in atomic energy activities. Detailed reports were issued covering both the criticality and the subsequent fire.

References: HW-22936
            HW-23034
            HW-23140
            HW-24327
            TID-5360
            WASH-1192
6. INCIDENT L-5 — JULY 10, 1964 — PLUTONIUM COUPON SHATTERED IN PRESS, INJURING AND CONTAMINATING WORKER

A plutonium coupon disintegrated explosively while being shaped in a 200-ton hydraulic press in the Metallurgy Development Operations. Fragments ejected from the narrow gap between the anvils penetrated the heavy rubber hood gloves and struck a technician in the upper left arm, inflicting a cut about 0.5 in. long. A section of one fragment lodged under the skin. There was minor contamination of the working area. The technician was given medical treatment, including surgical excision of tissue. The wound was washed with diethylene triamine pentacetate (DTPA), a chelating agent used to aid in elimination of plutonium from the body, and DTPA was also administered intravenously. After two pieces of metal containing approximately 10 mCi of plutonium were removed and contaminated tissue was excised, the amount of plutonium remaining at the wound site on July 11 was estimated to be 0.3 μCi. Treatments and translocation reduced this to just over 0.1 μCi by July 31. The plutonium contamination was later estimated to be about 270% of the MPBB.

An investigation was held, and several recommendations were made for measures to prevent this type of accident. These included installation of a splinter shield around the specimen, increased control of ventilation to prevent the spread of airborne contamination, and better housekeeping.

The accident was the subject of a technical report and an investigative report and was summarized briefly in the publication "Nuclear Safety."

References: BNWL-138
HW-83457
Nuclear Safety 6,4
WASH-1192
7. INCIDENT PRTR-2 - SEPTEMBER 29, 1965 - TEST LOOP FAILURE CONTAMINATING TEST REACTOR

The Fuel Element Rupture Test Facility (FERTF) was a pressurized light-water-cooled loop in one channel of the heavy-water moderated Plutonium Recycle Test Reactor (PRTR). It was used as a pilot irradiation facility for new fuel-element designs, new operating regimes, and tests on defected fuel.

At the time of this incident, a test was being conducted on a partially molten, intentionally defected fuel rod. Enlargement of the defect caused the pressure tube to rupture, releasing substantial amounts of fission products and loop coolant water into the core and containment vessel. The heavy-water moderator was grossly degraded by light water and fission products from the FERTF. Damage to the reactor itself was slight. All engineered safeguards, including the containment system, performed as designed. The more serious locations of the contamination spread were 25 R/hour at the "C" cell rotameter rack, 43 R/hour at the "A" cell lower access, 2 R/hour in the labyrinth between "A" and "C" cells, and 0.15 R/hour in the reactor hall at the heavy water cleanup area. These contamination levels had been reduced to 400, 4000, 10, and 5 mR/hour, respectively, by the end of December 1965. Occupational exposures and releases to the environment were well within limits. Loss of materials and heavy water caused this incident to be classified as Type A under AEC regulations. The program schedule was delayed for an extended period by the cleanup. The cost of the incident was approximately $900,000. No injuries or overexposure to radiation occurred as a result of this incident, but it is included as a Category 1 event because of its high cost.

After decontamination, the reactor was restarted with a high-power-density core and was operated, as planned, with a partially molten fuel.

This incident is fully described in an investigative report by the contractor (BNWL-CC-655) and another by an AEC investigative committee. The accident was also described in three issues of the publication "Nuclear Safety." A technical paper on the fission product aerosol behavior is also available.

References:  
BNWI-918  
BNWL-CC-655  
BNWL-SA-668  
Nuclear Safety 7,2  
Nuclear Safety 7,4  
Nuclear Safety 9,3  
WASH-1195
8. INCIDENT S-2 - DECEMBER 2 AND 3, 1949 - RELEASE OF IODINE (THE GREEN RUN)

A planned release of radioactive iodine into the atmosphere was made from the T Plant as part of a program to develop instruments and technology to monitor radioactive emissions from the Soviet Union's emerging nuclear program. It was calculated that 4,000 Ci of $^{131}\text{I}$ and 7,900 Ci $^{133}\text{Xe}$ were released, although some measurements indicated that releases may have been two or three times these levels. The release occurred over a 12-hour period while processing "green" fuel, i.e., fuel that had been removed from the reactor for only 16 days instead of the usual 90 to 120 days.

The release resulted in exceeding the $^{131}\text{I}$ concentration limits for vegetation and animals for a short time, both onsite and offsite, until the radiation decayed and/or washed away. Deposits of radioactive material were high due to the existence of a moderate temperature inversion and a calm wind condition at the time of the test. Iodine-131 levels higher than the tolerance levels for continuous exposure were found temporarily on vegetation over a region bounded roughly by The Dalles, Yakima, Spokane, and the Blue Mountains. Animal specimens collected from the Hanford Site indicated that short-term thyroid irradiation ranging up to 80 times the tolerance level for continuous exposure had occurred. Iodine-131 decays with a half-life of 8 days, and activities returned to near-background levels within weeks.

Although this release was extremely concentrated, since it occurred over a 12-hour period, the total release was a very small fraction of that occurring during wartime and immediate post-war operation. For comparison, approximately 340,000 Ci of $^{131}\text{I}$ were released during 1945, when fuel was processed on an urgent basis and iodine removal systems had not yet been installed on exhaust stacks. By contrast, less than 1 Ci/year is released today. Possible health effects of these early iodine releases are being evaluated by the Center for Disease Control, in an epidemiological study to determine whether exposed populations show an increase in thyroid disease. Although the release was small compared to earlier operating releases, because of the circumstances of the test and the great amount of attention it has received, it has been included as a Category 1 event. This event was thoroughly documented in monthly and quarterly environmental monitoring reports and in a technical report (HW-17381).

References: HW-15593-Del
HW-16015
HW-17003-Del
HW-17381-Del

2-10

Plutonium contamination was detected on a pipefitter's face following replacement of a dip tube in the F-2 centrifuge at 224-T Building (the T Plant concentration building). A survey showed the employee's chin, cheeks, and nasal area were contaminated. The worker's assault mask was also grossly contaminated. Decontamination was started immediately. Reduction of nasal smears to <500 d/m, oral irrigation, and reduction of facial contamination to <1,000 d/m were completed 30 min after discovery. Bioassays done on other employees working on this job showed that a millwright was also contaminated. The internal depositions of plutonium measured for these two employees were estimated to be 290% and 80% of the MPBB.

An investigation into the cause of the incident was made. The investigative committee felt that the probable cause was transfer of contamination during removal of protective equipment. However, the possibility of a poorly fitting mask could not be ruled out. The incident was publicized to all radiation zone workers, emphasizing the extreme care that must be exercised in plutonium-contaminated areas.

Since plutonium deposition for the first employee significantly exceeded the MPBB, this has been classified as a Category 1 incident.

This incident was the subject of several investigative reports and is included in a compilation of accidents and incidents involving radiation in atomic energy activities.

References: HW-35540
HW-36034
HW-38427-AD
TID-5360
At approximately 6:30 a.m., the 233-S Building (REDOX concentration building) process operator in the control room heard an intense response from a stationary "poppy" survey meter in the adjacent change room. After checking the instrument and deciding that the response could be due to a radiation source, the operator telephoned his supervisor. The supervisor checked the poppy for response, confirmed the report of the operator, and ordered the building evacuated. As the supervisor and the operator were leaving the building, they encountered the second process operator assigned to the building. Radiation monitoring was called and a survey showed that they, several other employees, and the control room were contaminated. Skin decontamination was completed on all but three employees by 8:00 a.m. By 3:00 p.m. one employee was still contaminated, and he was taken to an offsite hospital for further decontamination. The initial bioassays for the three employees indicated deposition of soluble plutonium. Later tests showed that the internal depositions in the three employees were 780%, 114%, and 170% of the MPBB of plutonium. The 780% figure is the highest individual plutonium deposition on record at the Hanford Site.

The source of the contamination was determined to be a plutonium nitrate/nitric acid process solution that had leaked onto the floor from a failed valve bellows. The solution corroded a copper air supply line located in the control room. Plutonium aerosols were picked up by the air flow to the control room and transported throughout the building. This incident revealed the weakness of the control valve used and the need for continuous and automatic alpha air monitors.

The incident was investigated and the cause determined. The 233-S operation was shut down, the building decontaminated, and the process altered to eliminate the possibility of leaking to the control room. Several recommendations were made to prevent or mitigate the consequences of similar incidents.

This incident was the subject of at least three investigative reports and is also described in two government compilations of accidents in atomic energy activities.

References: HW-43964 HW-43990 HW-44008 TID-5360 WASH-1192
11. INCIDENT S-11 - APRIL 7, 1962 - NUCLEAR CRITICALITY IN RECUPLEX FACILITY

A nuclear excursion occurred in a general purpose transfer tank (the K-9 vessel) in the Recuplex plutonium waste recovery facility of the 234-5 Z building. At the time of the incident, Recuplex was not in operation. It had been shut down for a cleanup which was essentially complete. Two employees who were present observed a blue flash and heard a noise like an electric arc. Evacuation was immediate, and all emergency procedures were executed properly. Exposures for the four most exposed individuals were 110, 43, 19, and 1.43 rem. The annual limit is 5 rem.

The most probable explanation for the event was that plutonium solution from a stripping column had overflowed a product receiver onto the cell floor, where it was sucked into the K-9 tank through a temporary line used in a previous cleanup operation. After an initial rapid energy release and one or more later peaks, the system continued to generate energy at a declining rate for about 36 hours, shutting down when the water level decreased. It was calculated that the total number of fissions was about $8 \times 10^{17}$.

This accident had the potential for more serious consequences, including possible fatalities. Following cleanup, the recovery unit was taken out of service, and later replaced by a new safe-geometry facility, as had previously been planned.

This incident has been widely reviewed and reported, including four investigative reports covering various aspects. The incident is also included in two government accident report compilations and was reviewed in some detail in the publication "Nuclear Safety."

References: HW-75546
HW-77295
HW-77345
HW-84619
Nuclear Safety 4,4
TID-5360
TID-18431
UND-68
WASH-1192
12. INCIDENT S-19 - APRIL 18, 1970 - HIGH RADIATION EXPOSURE TO HANDS

A maintenance employee received high radiation exposure to his hands when he attempted to hook up an unloading line to a 30-ton liquid-waste cask in the B-Plant cask loadout station. It was later determined that the manifold vacuum gauge on the cask, which was assumed to be out of calibration but operating, was actually plugged and inoperative. The cask had become pressurized by gaseous radiolytic decomposition products as a result of having been unvented for approximately 30 hours. Also, the cooling water had not been hooked up to the cask in the cell prior to the occurrence. While the connection was being made from the cask to the unloading line, pressure in the cask forced radioactive liquid out and onto the gloves of the operator. Before the liquid could be removed he received an exposure of about 2,500 rems to the lower thumb and finger tips of his left hand and 2,000 rems to the dorsum of his right hand. Erythema was observed on his fingers about 10 days after the incident.

The worker suffered temporary burns to his hands from exposure to radioactive liquid. He was able to continue to work, but was not permitted to do radiation work or work where he could further injure his hands. A formal investigation of the incident was made.

This incident was the subject of a detailed investigative report by an AEC investigation committee. The event is also described in a government compilation of accidents.

References: IR-70-10A
WASH-1192
13. INCIDENT S-22 - AUGUST 30, 1976 - CHEMICAL EXPLOSION CAUSING INJURY AND AMERICIUM CONTAMINATION

Americium-241 was being removed from a waste stream by use of a cation exchange column contained in a glovebox in the 242-Z plutonium and isotope extraction facility. An explosion ruptured the ion exchange column and shattered the glass windows in the glovebox. A nuclear process operator suffered nitric acid burns of the head and shoulder and multiple lacerations from the broken glass. The operator was also contaminated by the americium. A second operator received contamination while assisting the first operator from the room. The first operator was transported to the Emergency Decontamination Facility (EDF) in Richland for decontamination and medical treatment. The second operator was decontaminated in the 200 West Area. Several other employees who received lesser amounts of contamination were also decontaminated.

An investigating committee found that the probable cause of the explosion was reaction of concentrated nitric acid with materials formed by radiolytic degradation in the cation exchange resin. Management safety overview systems (i.e., hazard reviews, audits, procedure compliance) were found to be at fault for failing to recognize the hazard of the process.

The first operator was estimated to have received approximately 165 times the MPBB of americium, as well as severe acid burns. This operator, who was 64 years old at the time and had previously suffered an acute heart attack and been treated for an abdominal aortic aneurism, was hospitalized for several months and remained under medical observation for the remainder of his lifetime. His death in August 1987 was due to complications of chronic coronary artery disease. Observed radiation effects were not associated with clinical effects on health.

The accident also resulted in property damage estimated at $500,000. Stack releases did not exceed permissible limits.

This incident was the subject of several investigative reports and technical and medical papers. The final report of the lifetime medical follow-up of the operator was published in Radiation Protection Dosimetry in 1989.

References: BNWI-1006
              BNWI-1007
              DOE-EV-0080
              PNL-SA-7401
              PNL-SA-7471
              Radiation Protection Dosimetry 26,1

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14. INCIDENT S-23 – FEBRUARY 27, 1980 – SEVERE PLANT DAMAGE CAUSED BY CRANE ACCIDENT

In order to remove and replace a failed concentrator in one cell of the 221-B Canyon facility (B Plant), 27 massive cover blocks had been removed from the hot pipe trench to provide sufficient vertical clearance to move the equipment. All of these manipulations had to be performed using a remote crane. Because of the limited space available in the canyon, the blocks had been stacked two high, except for one block that was stacked three high. After effecting the concentrator replacement, the blocks were being replaced. The crane operator at the time of the accident, who had not been on duty during the block removal and was not aware that one block was stacked three high, had a limited field of vision through the crane optics. After replacing several blocks, the operator attempted to move one of the blocks supporting the three-high one. The upper 32-ton cover block fell 19 ft into the trench, damaging piping, pipe supports, and three other cover blocks. There was localized pipe trench contamination, but no release outside the canyon facility.

Although substantial damage was done to the facility, involving a repair cost of $1,174,000, there were no injuries, and facility operation was able to continue without affecting plant production. There was no radiation release to the external environment. Because of the high repair cost, this is considered a Category 1 incident.

A Type B investigation was carried out, identifying a number of deficiencies in crane design, operator training, procedures, and supervision.

References: IR-80-1

2-16
2.2 CATEGORY 2 INCIDENTS

Datasheets for the 46 Category 2 incidents follow.
Incident #: B-1
Facility Name: B Reactor
Date of Event: December 22, 1952
Event: Uncontrolled Reactor Fuel Ejection
Event Type: Personnel Radiation Exposure
Significance Rating: 2

Description: During an outage at B Reactor, irradiated fuel elements in tubes being supplied by one header overheated because of insufficient cooling water flow. When this was discovered, the coolant flow was increased. One tube, 2484B, was open on the rear to set it up for recharging with poison pieces. When the water reached the hot fuel it flashed to steam, forcibly ejecting seven fuel pieces. Some of the pieces lodged on the rear catwalks and pads on either side of the discharge chutes, and one piece became lodged in a rear pigtail. While retrieving the fuel to the discharge basin, five employees received radiation exposure up to 600 mrem (300 mrem was the weekly limit). These overexposures were caused by inadequate planning and timekeeping for work in high radiation fields (10 to 20 R/hour).

Implications: The uncontrolled ejection of irradiated fuel created a potential for extremely high personnel radiation exposure had people been in the rear face area at the time. The moderate overexposure that did occur would not have occurred if the Radiation Monitoring and Operating personnel had taken more care in planning and controlling the fuel retrieval effort.

Disposition: The actions that led to the overheating incident were carefully reviewed and appropriate procedures and controls were developed to prevent fuel overheating in the future. These revised controls were the subject of personnel retraining. Also, tighter controls were placed on the planning and execution of work in high radiation fields.

References: HW-26720
HW-26889

2-18
HANFORD PROCESS REVIEW DATA SHEET

Incident #: B-3
Facility Name: B Reactor
Date of Event: February 26, 1959
Event: Irradiated Aluminum Spacers and Poison Elements Flushed onto C Elevator
Event Type: Personnel Radiation Exposure
Significance Rating: 2

Description: C Elevator was moved with the charging machine still connected to a tube nozzle following routine charging of poison material. The nozzle broke, causing irradiated aluminum spacers and poison elements to be flushed from the tube onto the C Elevator. Personnel had previously evacuated C Elevator. Maximum radiation to which personnel were exposed was 40 mr. Disposition of the irradiated material was accomplished in a maximum radiation field of 600 mr/hour. Only minor equipment damage was incurred.

Implications: Three safety devices designed to prevent such accidents were not effective. The C Elevator lockout in the control room was not used, the photocell beam was not interrupted by the Poison Column Control Facility (PCCF) charger (design deficiency), and the key lock on the charging machine, designed to prevent elevator movement, had been removed previously because of a malfunction.

Disposition: A target was installed on the charging machine, making it impossible to adjust the machine out of the photo-electric cell beam (designed to prevent this type of accident). Refinement to a key-lock control system, used in conjunction with the photo-electric cell beam, was made, and training on worker procedures was emphasized.

References:
HW-59457
HW-59585
HW-65580
HW-73060
HW-73265-RD

2-19
### Incident #:
B-7

### Facility Name:
B Reactor

### Date of Event:
April 17, 1963

### Event:
Accidental Radiation Exposure During Process Tube Removal

### Event Type:
Radiation Exposure

### Significance Rating:
2

### Description:
B Reactor was shut down at 12:50 p.m. on April 16, 1963 to remove a fuel rupture. After several unsuccessful attempts to discharge the ruptured fuel element, it was decided to remove the process tube together with the fuel elements still remaining upstream of the ruptured element. This required removal of the gunbarrel (the steel sleeve occupying the rear portion of the tube channel). The removal work continued until a portion of the 7.5-ft gunbarrel emerged from the biological shield. When the dose rate reached 3 r/hour, the health physics monitor signaled the crew to retreat, in accord with a prearranged plan. One of the workers did not hear the advice of the monitor and continued working. In the process of removing a tool, the gunbarrel slid out of the shield the remaining distance. The high radiation alarm sounded. The gunbarrel was dropped into the basin beneath and the worker immediately left the discharge area.

An evaluation of the worker's dosimeter showed that he had received 4 rems of gamma radiation during the period of March 22 through April 17, 1963, most of which was received during the above incident. This exceeded the quarterly limit (3 rem) but not the annual limit of 5 rem.

### Implications:
Faulty communications gave the potential for radiation exposure above limits.

### Disposition:
This was investigated as a Class B incident. Radiation surveys of the work locations were performed so that dose estimates could be made and checked with the personnel dosimeters of the workers. This review did not identify specific corrective measures resulting from this event.

### References:
HW-77552
Nuclear Safety 5,4
WASH-1192
Incident #: D-4
Facility Name: D Reactor
Date of Event: January 6, 1956
Event: Error in Predicted Criticality of D Reactor
Event Type: Startup Anomaly
Significance Rating: 2

Description: During a secondary cold startup* of D Reactor on January 6, 1956, the predicted reactor criticality was in error, and a power rise to a level of 50 MW was experienced in approximately 1.5 to 2 min. The indicated rising period was estimated to be in the range of 4.3 to 15.7 s, as opposed to a normal 60-s period. The reactor was not scrammed by the safety circuits because they had not been reset to low levels, as required by process standards. As soon as it was known from the proportional counter response that an unusually fast rising period existed, horizontal control rod insertion was started, and the power rise was halted at 50 MW. After a short time at this power, a normal startup operation was resumed.

Implications: An error was made in the reactivity predictions. The Chief Operator failed to reset the flux monitor trips to a more sensitive scale. However, the automatic scram circuits would have shut the reactor down within a few seconds after the operating level was exceeded and before serious damage to the reactor could have resulted. Although no harm resulted, because of the combination of calculational and procedural errors this has been included as a Category 2 incident.

Disposition: Procedural changes were made requiring the reactor to be scrammed if, during startup, any instrument indicates a rapid rise in power level or if any unusual condition develops.

References: HW-41006
HW-41495
HW-41667
HW-42468
Nuclear Safety 4,1

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*A cold startup takes place after the xenon transient has passed its peak poisoning effect. A secondary cold startup was defined as a restart within 16 hours after a cold startup. Reactivity transients were particularly difficult to predict under such conditions.
Incident #: D-9

Facility Name: D Reactor

Date of Event: January 22, 1962

Event: Temporary Loss of Coolant to Empty PCCF Tube

Event Type: Coolant Interruption

Significance Rating: 2

Description: PCCF (poison column) tube 1890-D was flush-discharged at 2:15 p.m., and, according to procedure, the inlet pigtail valve was placed in the low-flow position. Increased radiation levels were detected when a front-face crew engaged in spline-removal work on Row 40 approached the vicinity of 1890-D about 30 min later. Measured radiation levels were 2.5 r/hour at the side of the nozzle and greater than 5 r/hour in front of the nozzle. Also, the front of the nozzle was hot, as evidenced by steam formation from dripping water. The inlet pigtail valve was returned to high-flow position and radiation levels and outlet temperature returned to normal.

Subsequent inspection of the pigtail valve showed that no hole had been drilled in the low-flow position, so that the valve blocked any cooling of the tube. No personnel were exposed to the radiation beam from the tube, and inspection of the process tube showed no damage.

Implications: Because this incident had the potential for exposure of personnel to a high-intensity beam of radiation, it has been classified as a Category 2 event.

Disposition: Recommendations for preventing a recurrence of this type of incident were to revise the procedures for inspection and tagging of pigtail valves and to perform outlet temperature checks for at least 2 min after charge or discharge of PCCF tubes.

References: HW-72405
Incident #:  DR-1
Facility Name:  DR Reactor
Date of Event:  October 3, 1950
Event:  Unexpected Reactivity Excess at DR Startup
Event Type:  Reactivity Anomaly
Significance Rating:  2

Description:  During the initial startup of DR Reactor, while adjusting the fuel and poison column loading for power operation, when the last vertical safety rod was withdrawn the reactor became critical with a short rising period of 13 to 16 s with all nine horizontal control rods still inserted. This indicated a significantly greater reactivity than calculated by the area physics group. The area physicist then recommended a revised loading, including both additional fuel and additional poison elements. It was expected that the added uranium and poison columns would have the net result of reducing the reactivity so that the reactor would be just critical with all vertical rods and 1.5 horizontal rods out of the reactor. However, when the vertical rods were withdrawn, the activity rose with a period of 17 s, and the reactor was shut down by manual tripping of the safety circuit.

Several other loadings were tried until a satisfactory one was found. The unexpected excess reactivity of the initial loadings was attributed to a shadowing effect between the horizontal rod system and the poison columns. The loading of DR Reactor was somewhat different than that used in previous reactor operations, so there was no previous experience that could serve as a guide.

Implications:  A more cautious approach was needed when operating outside the range of current experience to avoid the possibility of a prompt criticality excursion. Because of the repetitive fast-period condition, this event has been classified as a Category 2 incident.

Disposition:  An investigation was conducted to understand the conditions leading to this incident and to aid in preventing a recurrence. This review did not identify specific corrective measures resulting from this event.

References:  HW-19323
Incident #: DR-2
Facility Name: DR Reactor
Date of Event: May 11, 1953
Event: Inadvertent Handling of Irradiated Aluminum Spacers
Event Type: Radiation Exposure
Significance Rating: 2

Description: During a fuel charging operation, three irradiated solid aluminum spacers were washed out of the front end of a process tube onto the charge platform. Two nearby employees, thinking that these were "cold" pieces that they were in the process of charging, each picked up one of the irradiated pieces. One of the employees handed his piece to another employee who was to charge it, before it was realized that these pieces were probably irradiated.

Eleven people were nearby at the time of the incident, but only six received exposure in excess of the permissible limits. Of these six, only the three who handled the pieces were believed to have received significant overexposure. Each of these three was estimated to have received a hand dose of 100 r. The maximum whole body dose was estimated at about 3.4 rad.

Implications: Radiation doses received were in excess of quarterly limits, but were not in excess of annual limits or sufficient to cause ill effects. However, the potential for still higher radiation levels existed, and this is considered a Category 2 incident.

Disposition: Improved prejob planning and training measures were adopted.

References: HW-28062
HW-28078
TID-5360
Incident #: DR-4

Facility Name: DR Reactor

Date of Event: December 13, 1957

Event: Forcible Ejection of Fuel Elements

Event Type: Potential Radiation Exposure/Multiple Fuel Failures

Significance Rating: 2

Description: During a discharge operation at DR Reactor, the water flow was inadvertently reduced in one crossheader, causing overheating in several of the tubes connected to that crossheader. When this condition was discovered, water flow was restored. The rear nozzle on one tube was open, and steam from the overheated fuel caused five irradiated fuel pieces to be ricocheted from the discharge area rear wall, lodging in various places in the discharge area. About 36 hours were spent in removal of these pieces. During the subsequent operating period, fuel ruptures occurred in eight tubes on this same crossheader, attributed primarily to the previous overheating. A 112-hour outage was taken for removal of these ruptures, making a total production time loss of ~149 hours as a result of this incident.

Implications: Although no significant exposure were resulted, the potential for radiation exposure and the increase in operating cost and lost production from cleanup cause this to be classified a Category 2 incident.

Disposition: This incident was investigated, and several recommendations were made to revise procedures and equipment to prevent a recurrence of this type of problem.

References: HW-54257
Incident #: DR-5
Facility Name: DR Reactor
Date of Event: December 5, 1958
Event: Flux Maldistribution and Fuel Ruptures in Four Tubes
Event Type: Startup Anomaly with Fuel Failure
Significance Rating: 2
Description: Startup poison adjustment procedures following a minimum outage were delayed when the second of 12 planned PCCF tubes could not be charged with temporary poison because of mechanical difficulties. In the meantime, power levels were increased as planned. Rate of rise was within process limits. Poison charging was continued, but it became evident that reactor power would have to be cut to effect a turnaround (i.e., control the reactivity increase caused by xenon burnout). Rupture indications were noted and the reactor was shut down. Ruptured elements were found in tubes 4070, 4076, 4071, and 4466. During this time an additional six tubes had been charged with poison, but the distribution of poison in the reactor was not as planned for the power level reached. Temperature maps taken showed a shift of heat to the top of the reactor, but none showed any temperatures outside limits. However, no complete maps were taken when the shift of heat to the top was greatest.
Implications: Damage was limited to fuel failures, and reactor safety was never seriously jeopardized. However, the incident underscores the importance of conformance to startup procedures and is considered a Category 2 incident.
Disposition: The following corrective actions were recommended: Review control-room procedures that apply to nonequilibrium conditions. Review PCCF procedures to assure that the tubes are ready for subsequent operation. Complete the Zone Temperature Monitor project (to protect against local overheating conditions) as soon as possible.
References: HW-58560
HW-73265-RD
Incident #: F-1
Facility Name: F Reactor
Date of Event: October 20, 1948
Event: Process Tube Rupture
Event Type: Target and Tube Failure
Significance Rating: 2

Description: Under the SR15 program, tritium was being produced by irradiation of LiF targets in selected process tubes. On October 20, 1948, tube 3169 at F Reactor ruptured and the resulting flooding caused a substantial reactivity loss, limiting the ability to operate the reactor at power. A similar leak had occurred at B Reactor the previous month, but that tube was low in the reactor and did not cause severe flooding.

Both leaks were caused by rupture of LiF target slugs, which reacted violently with water causing the tube failure.

Implications: There was no method available at the time, other than drying out by operation, to remove the water absorbed in the graphite. The reactor power was still limited to 40 MW at month end, causing a loss of production.

Disposition: All LiF targets were discharged from the reactors, and the SR15 program was terminated until a more reliable target element could be developed.

References: HW-11499
Incident #: F-2
Facility Name: F Reactor
Date of Event: October 26, 1950
Event: Dropped Deaerator
Event Type: Equipment/Maintenance Failure
Significance Rating: 2

Description: With the reactor operating, deaerator tanks were being removed from the 185F Building, which houses process water treatment equipment. After two tanks had been successfully removed, a mechanical failure of equipment allowed a third tank to drop about 50 ft and through the roof of the building. It damaged the supporting structure for the adjacent deaerator and came to rest at the 40-ft level, protruding into the 190F Building tank room. The 190F Building houses process water tanks and pumping facilities.

Implications: Although no major damage resulted, the potential existed for interruption of reactor coolant flow, which could have caused reactor core overheating.

Disposition: F Reactor operation was suspended for 24 hours until conditions could be corrected, to avoid jeopardizing the reactor cooling water supply. Subsequent deaerator removals were completed without incident.

References: HW-19325
HANFORD PROCESS REVIEW DATA SHEET

| Incident #: | H-1 |
| Facility Name: | H Reactor |
| Date of Event: | October 3, 1954 |
| Event: | Power Maldistribution Resulting in Numerous Fuel Failures |
| Event Type: | Startup Anomaly/Multiple Fuel Failures |
| Significance Rating: | 2 |

**Description:**
During a startup on October 3, 1954, following repair of a water leak into the reactor graphite, a rapid power rise and higher than normal temperatures were observed. The reactor scrambled while adjustments were being made. The reactor was then started up without incident. Multiple fuel element failures concentrated in the upper near-side quadrant of the reactor were subsequently experienced over a period of 2 weeks. Altogether, 22 known ruptured slugs occurred in that region, and it is estimated that 50 more among those examined would have ruptured in a short time if they had not been discharged. The cause of these failures was postulated to be thermal stresses caused by too rapid local heating of fuel elements during startup on October 3. Later analysis identified several contributing factors: unbalanced reactivity caused by water in the pile; flux monitoring chambers positioned too close together; shielding or poisoning effect of the water above the flux monitors; unbalanced rod pattern; and failure of the chief operator to notice certain instrument indications that would have alerted him to the problem.

**Implications:**
A combination of factors occurred that resulted in failure of fuel elements, but the safety of personnel or serious damage to the reactor was never threatened.

**Disposition:**
The incident was discussed with operating personnel and instruction given to prevent a similar occurrence. Corrections, changes, and improvements were made to startup instrumentation and procedures. Extra supervisory and technical personnel were scheduled for all cold startups.

**References:**
HW-33945
HW-34338
HW-34352
HW-41495
Nuclear Safety 4,1
Incident #: H-3

Facility Name: H Reactor

Date of Event: October 31, 1955

Event: Fuel element failed in a test loop and caught fire briefly during attempts to remove it.

Event Type: Irradiated Fuel Fire

Significance Rating: 2

Description: The H loop facility was a recirculating loop utilizing a zirconium process tube in channel 0961-H as an in-pile test section. In the course of an experiment being performed in the loop, a fuel element ruptured. When rupture indications were noted, the reactor was shut down. Efforts to discharge the fuel with regular equipment were unsuccessful, and an alternative method was attempted that required removal of the front nozzle, and, hence, cooling water from the tube. The elements downstream of the rupture were removed, but the ruptured element stuck at the rear nozzle tube joint. In attempting to flush the remaining elements out of the tube, a "jet of flame was noted coming out of the rear nozzle," and a few seconds later some steam was emitted, followed by a trickle of water slurried with oxide particles and more steam. The rupture was later removed without further incident. Approximately 1 Ci of activity was discharged out the stack.

Implications: No personnel overexposure occurred, and the release did not result in any permanent property damage or contamination.

Disposition: Incidents of this nature led to installation of a confinement system, the value of which was demonstrated when a similar incident occurred at KW Reactor on July 6, 1960. In the latter case the fog spray greatly reduced the radioactivity released from the stack.

References: HW-39974
HW-40115
HW-43064
HW-43557
HW-54636
HW-73265-RD
TID-5360
Incident #: H-4
Facility Name: H Reactor
Date of Event: July 17, 1956
Event: Discharge of Irradiated Fuel onto Discharge Elevator During Startup Preparations
Event Type: Radiation Exposure
Significance Rating: 2

Description: Following completion of an outage, a charge of irradiated fuel was flushed from a tube onto the discharge elevator during startup preparations. The rear face crew noticed fuel spacers coming out after a cap had come off and ran off the elevator into the labyrinth. There was no overexposure to personnel.

Implications: No personnel were overexposed, but they might have been if the rear face crew had not been alert. The basic cause was poor communications between personnel who cannot see each other (i.e., front and rear face crews and control room personnel). A secondary cause was a combination of slight deviations from good operating practice.

Disposition: Startup check list and Standard Operating Procedures were revised.

References: HW-45189
Incident #: H-5
Facility Name: H Reactor
Date of Event: September 29, 1957
Event: Rupture of Fuel Elements in Four Channels in H Reactor
Event Type: Startup Anomaly/Multiple Fuel Failures
Significance Rating: 2

Description: During startup, a temperature map at 900 MW showed a maldistribution of power. However, power was increased to 1200 MW and at 12:51 a.m. on September 29, 1957, a flow monitor scram occurred due to a drop in inlet water pressure to tube 1665. Investigation revealed the presence of a ruptured slug and a 2-in. long split in the process tube in channel 1665 and ruptured slugs in tubes 1168, 1264, and 2956. The drop in inlet water pressure to tube 1665 was attributed to the split in the process tube. The ruptures were caused by operating the center-rear region at power levels up to 24% above limits for about 26 min before the scram. After removal of the ruptured tube and fuel, 250 tubes in the affected region were discharged to reduce the chances of additional ruptures during subsequent operation.

Implications: Although no significant safety limits were exceeded, the flux and tube power distributions were not adequately controlled and the situation was conducive to exceeding safety limits. Had this occurred, the probability of fuel jacket melting would have increased.

Disposition: The chief operator and supervisor were disciplined for not responding to the initial indications of the problem.

References: HW-52918
HW-53001-RD
HW-53481
HW-73265-RD
HANFORD PROCESS REVIEW DATA SHEET

Incident #: H-10
Facility Name: H Reactor Burial Ground
Date of Event: October 4, 1960
Event: Burial Trench Controlled Burning - Loss of Control
Event Type: Fire/Personnel Injury
Significance Rating: 2

Description: A controlled burning in the H Reactor contaminated burial trench was in progress to reduce the volume of waste in the trench. Suddenly a series of eruptions occurred shooting flames 100 ft in the air and setting a nearby electrical utility pole on fire. The fire department was called to assist. After the fire appeared to be under control, a fireman equipped with a self-contained breathing apparatus entered the smoke-filled area downwind of the trench in an attempt to put a stream of water directly on the smoldering power pole. He was enveloped in flame when another eruption occurred. He was treated for 2nd and 3rd degree burns and required hospitalization (disabling injury CE & UO Inquiry 60-1). The trench was deluged as necessary until the fire was out and then filled with dirt.

Implications: The presence of drums of flammable substances was not suspected because records of burial were not kept. The injured fireman had some slight contamination, but no one else was contaminated and there was no contamination spread to the environs.

Disposition: Positive control procedures and burial ground controls and records were established.

References: HW-67034
Incident #: H-14
Facility Name: H Reactor
Date of Event: April 17, 1964
Event: A block of tubes containing target elements was mischarged, causing a reactivity discrepancy during startup.
Event Type: Startup Anomaly
Significance Rating: 2

Description: Unusual reactivity conditions were observed during a cold startup at H Reactor on April 17, 1964. It was determined that this was due to an error in charging fuel and target elements and a miscalculation by the operational physicist. All 171 tubes that had been mischarged on April 10 were discharged and replaced with the proper enriched uranium and tritium target loading.

Implications: Substantial production time and reprocessing costs resulted from this incident, but the reactor was not damaged and there were no injuries or radiation exposures. The reactor exceeded operating limits for excess reactivity with the erroneous loading.

Disposition: A Type B incident investigation was carried out to determine causes for the incident and make recommendations to prevent future incidents of this type.

References:
HW-82143
HW-82352
Nuclear Safety 6,4
TID-5360
WASH-1192
Incident #: KE-5
Facility Name: KE Reactor
Date of Event: August 5, 1960
Event: Excess Power and Rate-of-Rise to Power on Startup
Event Type: Startup Anomaly
Significance Rating: 2

Description: The reactor was started up at 10:16 a.m. on August 5, 1960, after a scram. Contrary to line responsibilities, the startup was directed by a process physicist, who relied mainly on the period meter. Power levels read off by the operator were lower than actual, either because of time-lag in the instrument or error in reading. Eleven minutes after startup, a number of warning lights showed on the temperature monitor, indicating a temperature in excess of 110 °C. At about the same time, the reactor scrambled by a tube flow monitor trip, probably caused by increased tube flow rates resulting from reduced viscosities as the temperature increased.

At the time of the scram the reactor was at a power of about 2400 MW, and the reactivity was on a rising period of 60 s. The bulk outlet temperature was indicating 62 °C, and maximum tube outlet temperature may have reached 140 °C.

Process limits require depressing the trip points on the temperature monitor 15 °C before such a startup. This was not done. Otherwise, a warning would have been obtained at a tube exit temperature of 95 °C instead of 110 °C.

Although the temporary rate-of-rise meter showed a power level increasing at a rate less than 200 MW/min, a previous shift had determined that it was reading low. Also, a calibration switch was in the wrong position, causing the instrument to read low by a factor of 2.

Implications: No reactor damage resulted from the event. The incident resulted from what appears to be an improbable series of instrument failures compounded by personnel errors.
Incident #: KE-5, Continued

Disposition: Several recommendations were made to prevent a recurrence of this type of incident. They included clarification/revision of standards and operating responsibilities and revision of hot startup check sheet.

References: HW-66454
HW-73060
HW-73265-RD
Incident #: KE-8
Facility Name: KE Reactor
Date of Event: March 26, 1963
Event: Complete Cooling-Flow Stoppage for 2 to 4 Minutes During Shutdown
Event Type: Cooling Interruption/Operator Error
Significance Rating: 2

Description: During an outage on March 26, 1963, an error in reactor valving resulted in complete coolant flow stoppage to the KE Reactor for a period believed to have been between 2 and 4 min. The reactor had been shut down for 7 hours prior to this event. While a flow stoppage of 2 min would not have resulted in any damage to the fuel elements, the exact time could not be firmly fixed.

Investigation led to the conclusion that the event was caused by failure to communicate adequately during the interchange of instructions and job progress on the front face. Corrective action consisted of returning coolant flow and valving to normal shutdown conditions to assure sweeping any steam that may have formed in the process tubes. Visual inspection of fuel elements discharged during the subsequent scheduled discharge revealed no evidence of abnormal fuel temperatures.

Implications: If flow had been stopped for as long as 4 min, an abnormal fuel-element rupture rate would have been expected.

Disposition: Several recommendations were made to prevent a recurrence of this type of incident. These related to the communication of instructions on critical phases of operations, better identification of risers on the work platform of both K Reactors, and specification of minimum flow in both the Power and Processing Standards to preclude the possibility of shutting water flow off the reactor under any circumstances.

References: HW-77209
Incident #: KE-9
Facility Name: KE Reactor
Date of Event: May 12, 1963

Event: Fuel Element Failure With Release of Fission Products
Event Type: Fuel Failure

Significance Rating: 2

Description: A zircaloy-clad element of experimental design failed in KE Reactor on May 12, 1963. This was one of three N Reactor prototype elements being irradiated under a production test. About a pound of uranium was missing when the fuel element was examined, and the measured transport of fission products by the river at 300 Area support that estimate.

Implications: This was the single largest release of fission products to the river experienced to date.

Disposition: The maximum incremental doses to any persons drinking the water were calculated to be small fractions of the annual radiation protection guide of 500 mrem suggested by the FRC.

References: HW-77749-Del
HW-79073
Incident #: KW-2
Facility Name: KW Reactor
Date of Event: August 21, 1955
Event: Loss of power from 4.16-kV system and subsequent malfunction of two emergency 4.16-kV generators.
Event Type: Power and Equipment/Maintenance Failure
Significance Rating: 2
Description: A frequency surge on the Bonneville Power Administration (BPA) system caused the 4.16-kV system in 100-K to separate from the 13.8-kV system. This scrammed the KW Reactor. Under such circumstances, the two emergency generators were supposed to pick up critical loads, and, in fact, both generators did start momentarily. However, both generators then were tripped off the line, one by its over-current relay and the other by its loss of excitation relay.

Loss of the emergency system resulted in loss of all KW Reactor low-lift process water pumps. The high-lift pumps continued to operate, but with the low-lift pumps out of service, they cavitated and coolant pressure and flow decreased. This called on the cross-tie line between KE and KW to open to help supply KW coolant requirements, causing KE to scram. When it was assured that cooling water to KW was being obtained through the cross-tie line, the KW high-lift pumps were shut off.

Implications: No reactor damage occurred. However, loss of coolant by failure of the low-lift pumps is a serious event that called upon the back-up coolant supply from the cross-tie line. This incident was described as a "close shave" in a report prepared for discussion at a joint USA-UK meeting on reactor hazards. No copies of that report were found.

Disposition: This review did not identify specific corrective measures resulting from this event.

References: HW-39501
HW-73265-RD
Incident #: KW-4
Facility Name: KW Reactor
Date of Event: April 29, 1959
Event: Uranium Fire at KW Reactor
Event Type: Fuel Fire
Significance Rating: 2

Description: A ruptured fuel element fused to its fuel tube and to a poison spline within the tube, necessitating removal of the tube and spline together. During the removal, a portion of the tube broke but instead of falling into the spent fuel basin as intended was held in the air by the spline, allowing the fuel to overheat and burn briefly. Sparks were observed coming from the tube for 3 to 4 s, then a flame lasting for 5 to 6 s, followed by a billow of golden-orange smoke about 4 ft in diameter.

About 5 Ci of radiation was released, and dose rate measurements showed temporary levels up 500 mr/hour in the exhaust system and 10 to 50 mr/hour in the lunch room. No personnel received radiation exposure beyond allowable limits. Estimates from stack filter samples indicated 1.3 Ci had been released to the environment, including $^{131}$I, $^{133}$I, $^{90}$Sr, and $^{103}$Ru. Ground surveys found no radioactive particles in the immediate KW area, but several particles at offsite locations. These particles did not constitute a significant radiation hazard to the public.

Implications: Slight offsite radioactivity release. No undue exposure to operating personnel.

Disposition: Since previous incidents of partial fuel slug burning on discharge had occurred (HW-54636), the rupture removal process was reviewed to evaluate methods to prevent air from reaching ruptured slugs during removal.

References: HW-63076
HW-73265-RD
HW-84619
Incident #: KW-5
Facility Name: KW Reactor
Date of Event: May 20, 1959
Event: Reactor scram on high tube outlet temperature caused by erroneous power level indication.
Event Type: Startup Anomaly, Equipment/Maintenance Failure
Significance Rating: 2

Description: The reactor was started up at 5:29 p.m. on May 20, 1959, and the power level increased to an indicated level of 1200 MW (about 3/4 of planned level). An alarm sounded indicating a high tube outlet temperature, and the reactor was manually scrammed at 7:11 p.m. Later, it was found that the power level indicator was reading low by a factor of two as a result of two separate instrument malfunctions. The 105 Building flow recorder was in error, indicating too low a flow by 30,000 gal/min. Also, a temperature sensor was out of order. It was later determined that the actual power had increased to about 2800 MW and the bulk outlet temperature was 74 °C (about 35 °C higher than expected for 1200 MW). Just before the scram, one tube was operating at 110 °C. No reactor damage resulted from the incident.

Implications: Operating personnel failed to appreciate the significance of the sub-normal flow indication. Other instrumentation was available but not used to the extent possible. Instrument failure (power level calculator) contributed to the event.

Disposition: To reduce the potential hazard of a large error in power level, particularly on startups, increased emphasis was placed on assuring that the power meter reading was confirmed through the use of bulk and individual tube temperature monitoring and the flux monitor instrument readings.

References: HW-60594
HW-73265-RD
Incident #: KW-8
Facility Name: KW Reactor
Date of Event: February 11, 1966
Event: $^{131}$I Release to River from Test Fuel Failure
Event Type: Test Fuel Failure
Significance Rating: 2

Description: On February 11, 1966, two sintered-pellet uranium oxide test fuel elements failed in KW Reactor. Effluent samples taken at the reactor indicated that more than 600 Ci of $^{131}$I were released from the fuel failures. The continuous sampler at the Richland water plant showed that the Columbia River carried a maximum of 600 Ci of $^{131}$I past that point.

Implications: Undesired environmental release as a result of an experimental test.

Disposition: This survey did not identify specific corrective measures resulting from this event.

References: DUN-559
HANFORD PROCESS REVIEW DATA SHEET

Incident #: N-3
Facility Name: N Reactor
Date of Event: June 21, 1967
Event: Oil Fire in Cell 3
Event Type: Fire - Equipment/Procedure/Personnel Errors
Significance Rating: 2

Description: Shortly after startup from an outage on June 21, 1967, the reactor was scrammed when it was discovered that there was a fire in steam-generator Cell 3. The fire was caused by the ignition of lubricating oil that had leaked from the pump-turbine oil system onto the mezzanine floor inside the cell. The source of ignition was never determined. The fire was quenched by actuating the fog spray in the cell, but not before extensive soot had deposited. There was no significant damage to any equipment, but extensive cleanup effort was required. The recovery costs were about $225,000 and the reactor was restarted after repairs on July 10 with Cell 3 out of service.

The oil leakage was from pump drive shaft and bearing leaks that had been inadequately controlled by shrouding and attempts to drain it into catch containers. The initial cause was an inadequate design of the turbine/pump lubrication system. Lack of rigorous maintenance and failure to clean up the oil spills were contributing factors.

Implications: Damage to critical systems could have been extensive.

Disposition: Rigorous oil system maintenance procedures were adopted. Frequent operator oil leak inspections were initiated, along with a prompt cleanup policy. An improved deluge system for all pump-turbine oil systems was installed. The hydraulic oil for the control rod system was replaced with a nonflammable type.

References: DUN-2872
DUN-2874
IR-67-1
RL-GEN 1300-6
WASH-1192
Incident #: N-7  
Facility Name: N Reactor  
Date of Event: July 1, 1971  
Event: Control Circuit Installation Error Discovery  
Event Type: Equipment/Personnel Error  
Significance Rating: 2  
Description: On July 1, 1971, during performance of an acceptance test procedure for a design change, an inadvertent electrical circuit intertie (jumper) was discovered between two independent strings of the rod safety circuit. Early project documentation indicates that the wires forming the jumper were originally connected in parallel with others in the main string. Later, the wires were disconnected and terminated as "spares" on the same terminal strip at one end and left connected at the other end, thereby forming a jumper.

This jumper compromised the designed independence of the redundant strings of the main trip circuits for the rod safety system. Specifically, for 21 of the 23 individual trip functions, actuation of both circuits instead of only one circuit was required to produce a rod scram.

Implications: The designed "either-or" scram circuit integrity was defeated by the inadvertent jumper, thus lessening the reliability of the dual circuit concept.

Disposition: The intertie was removed. Several safety circuit independence tests were formulated and conducted to supplement other prescribed tests. Circuit independence was verified. Procedures for administrative control of spare wires were placed in effect. Independence of the two circuits is verified by testing annually.

References: DUN-7436  
DUN-7867  
UNI-785
HANFORD PROCESS REVIEW DATA SHEET

Incident #: N-15

Facility Name: N Reactor

Date of Event: December 1, 1981

Event: Instrument air inadvertently shut off, reducing makeup flow and scramming the reactor.

Event Type: Equipment/Maintenance Failure

Significance Rating: 2

Description: In attempting to isolate an instrument-air dryer so that maintenance could be performed, a supervisor and chief operator closed the inlet and outlet block valves to the dryer without opening the bypass valve, interrupting the instrument air supply to N Plant auxiliary buildings. The loss of instrument air to many air-actuated items scrammed the reactor, which was operating at an equilibrium power level of 3765 MW. Makeup water flow was low because of the lack of instrument air, but overheating did not result. The occurrence did not cause any personnel injuries, radiological exposures or releases, damage to equipment, or interruption of normal cooling.

Implications: The loss of instrument air is a violation of Technical Specifications and was declared an abnormal occurrence. Several procedural and personnel errors were identified, and numerous mandatory requirements were not followed.

Disposition: A special investigation committee was established, and a set of corrective actions was developed and implemented.

References: AO-81-001
UNI-1961
Incident #: N-16
Facility Name: N Reactor
Date of Event: January 18, 1985
Event: Failure to Clear Personnel From Rear Face Before Charge/Discharge
Event Type: Radiation Exposure
Significance Rating: 2

Description: On January 18, 1985, a supervisor and two other personnel entered the rear face area of N Reactor to free a stuck fuel spacer. After the spacer was freed, the three workers returned the discharge elevator (D Elevator) to the up position. They attempted to exit through the same door they had entered, but found it closed. When they were unable to open the door, the supervisor returned to the elevator to notify the control room supervisor and charge machine operator that personnel were still in the rear face area.

Based on the indication that Door 505 was closed and the D Elevator was up, the control room supervisor assumed that the workers had left the area and ordered resumption of the refueling operation. Refueling continued for about 15 s before the operation was halted by the charge machine operator, upon hearing the rear face supervisor's unclear message. During that time, four fuel pieces were discharged into the storage basin. On indication that refueling was being resumed, the three workers exited the rear face area through doors at lower levels.

Implications: This incident had the potential for overexposure to operating personnel. The pocket dosimeters showed that actual exposures were well below DOE guideline limits. These estimates were confirmed by calculations. The major factor causing the event was failure of the control room supervisor to verify that all personnel had exited the rear face area before resuming refueling.
Incident #: N-16, Continued

Disposition: Procedures were updated to include specific directions on how personnel are verified to have left the areas. These procedures were reviewed with operations personnel. Communication systems were checked to ensure operability. Radioactive zone worker training was revised to ensure ability to operate zone doors.

References: UO-85-001
Incident #: N-17
Facility Name: N Reactor
Date of Event: November 10, 1985
Event: N Reactor Primary Cooling Check Valve Malfunction
Event Type: Equipment/Maintenance Failure
Significance Rating: 2

Description: The CV-3 valves are 18-in. check valves that prevent backflow in the primary coolant loop. There are 16 of these valves in service. On November 7, 1985, during an Equipment Maintenance Standard check to verify valve operation, a malfunction of one or more valves was suspected. Subsequent tests revealed valve CV-3-8 had malfunctioned. Upon internal examination, the hinge plate and valve disc were found in the bottom of the valve body. The studs, nuts, and nut retainers (three each) that secure the disc assembly to the valve body were missing.

There are a total of 38 valves of this design at 100 N in the Primary Coolant System: 16 CV-3s, 16 CV-5s and 6 PCSV 202s. Twenty eight of these were inspected. Except for CV-3-8, there were no parts missing, although some valves had low torques on the nuts holding the hinge plates. Subsequent inspection revealed that loose parts from CV-3-8 were transported by the primary coolant to the inlet manifolds of steam generators 1A and 2A. Damage to these two steam generators included peening of the dome region and damage to the tube sheet and divider plate.

Implications: The cause of the CV-3-8 failure was determined to be insufficient torquing of the three nuts used to secure the hinge plate to the valve body. A torque value of 30 ft-lb was incorrectly specified by the manufacturer's technical manual. The correct torque value is 600 ± 25 ft-lb. Maintenance activities applying the incorrectly specified torque allowed the nuts to vibrate loose and the hinge plate to come off. The potential existed for similar effects on all of these valves. This would negate the function of the affected valve(s) and risk the possibility of major damage to the steam generators.
Incident #: N-17, Continued

Disposition: All the inspected valves were reassembled using the correct torque and returned to service. The steam generators were repaired and returned to service. One missing piece could not be located. It was concluded that it was safe to start up the reactor with this piece missing.

References: IR-86-1
UO-85-019
LABORATORY

HANFORD PROCESS REVIEW DATA SHEET

Incident #: L-1
Facility Name: Hydromechanical Laboratory, 321 Building, 300 Area
Date of Event: January 23, 1949
Event: Explosion in REDOX Demo Unit
Event Type: Chemical Explosion
Significance Rating: 2

Description: A submerged turbine pump being life-tested for use in the REDOX plant was apparently the point of origin of a low-intensity explosion and subsequent fire. The unit was pumping IAX, an extracting solution of 0.5M HNO₃ in hexone (methyl isobutylketone) used in the REDOX process. An intensive investigation, including experimentation, led to the conclusion that the event was caused by ignition of an air-hexone mixture within the pump torque tube from overheating induced by a seized shaft bearing. This ignition, in turn, caused a pressure buildup in the IAX reservoir, resulting in the explosion.

One maintenance employee received severe bruises to the muscles of his back. Although there was substantial damage to the operating gallery and service areas, less than 1% of the experimental equipment was damaged. The repair cost was approximately $125,000.

Implications: This event highlighted the potential risk involved in experimental facilities and led to more conservatism in design and reconstruction to increase protection.

Disposition: Extensive repairs were made and redesigns incorporated in the building structure to increase personnel protection.

References: HW-12391-E
            HW-12666-E
            HW-13190
            HW-42068-RD
            UND-68-1
Incident #: L-3
Facility Name: Plutonium Metallurgical Laboratory, 234-5Z, 200 West
Date of Event: March 31, 1959
Event: Explosion
Event Type: Employee Injury and Contamination
Significance Rating: 2

Description: An explosion occurred on March 31, 1959, in a lathe hood located in Room 179-B of the plutonium metallurgy facilities in 234-5 Building, 200 West Area. The explosion was apparently caused by a spark while two laboratory employees were machining a piece of plutonium metal in a hood using trichloroethane instead of trichlorethylene as coolant, without an inert atmosphere. A piece of the broken hood front struck one of the employees above the left eye, causing a laceration approximately 0.75 in. long. Both men and four other employees working in other parts of the room left immediately. High-level plutonium surface contamination occurred on the face and shoulders of the two men working at the hood at the time of the explosion. Both employees were contaminated up to 40,000 d/m. Eventual skin decontamination was successful. Internal disposition was less than 20% of the MPBB.

Implications: Confusion arose from the trade name "chlorothene" on the trichloroethane container. The use of an inert atmosphere during the machining operation was optional, but should have been mandatory. The potential existed for more severe contamination and disposition.

Disposition: Procedures were tightened to require the use of an inert atmosphere while machining plutonium and to prevent use of the incorrect coolant.

References: HW-59717
Nuclear Safety 2,4
TID-5360

2-51
**Incident #:** L-4  
**Facility Name:** Radiochemistry Laboratory, 325 Building, 300 Area  
**Date of Event:** February 12, 1963  
**Event:** Promethium Contamination in the 325 Building, 300 Area  
**Event Type:** Contamination Spread  
**Significance Rating:** 2  

**Description:** On February 12, 1963, several laboratory employees discovered shoe contamination and sought radiation monitoring assistance. The radiation was determined to be from 239-keV beta-emitting 147Pm. Contamination was found on the floor of six laboratory rooms. When contamination was found to have been tracked into other parts of the building and out of the plant, all occupants were assembled, monitored, decontaminated if necessary, and cleared. Monitoring continued for several days. Of the 40 homes surveyed, 8 were found to have nonhazardous traces and were decontaminated. Twelve employees acquired skin contamination, but generally the activity was low. The maximum skin dose did not exceed 4.5 rads. Fourteen employees had measurable internal deposition, but less than 0.1% of MPBB.

The spread was determined to have originated from the upset of a shielded sample carrier containing promethium samples in cork-stopped glass vials. Although the carrier had a plastic covering, holes had worn in the plastic during handling. When the cover was upset, one or more of the sample vials leaked. The precise time of the incident could not be determined.

**Implications:** Several procedures were violated, leading to the incident. One or more employees failed to report the potential contamination spread at the time the sample carrier was upset, and one or more employees failed to properly monitor himself or equipment when leaving the radiation zone.

**Disposition:** A "Class A" investigation was held, and recommendations were made to prevent a recurrence of this type of incident.

**References:** HW-76596  
IR-63-12A  
WASH-1192
Incident #: L-6
Facility Name: Plutonium Fuels Laboratory, 308 Building, 300 Area
Date of Event: August 23, 1965
Event: Explosion and Fire in a Plutonium Glove Box
Event Type: Explosion/Radioactive Contamination
Significance Rating: 2

Description: At 11:10 a.m. on August 23, 1965, an explosion occurred in Glove Box #10 in Room 113 of the 308 Building. The explosion blew out a side of the glove box and two of the gloves. A subsequent fire burned one of the gloves and some rags in the box. There were no injuries. The financial loss was $76,800. The fire was probably caused by ignition of acetone vapor by a spark during cleaning of a bell jar and furnace parts.

Three of the 11 employees surveyed were grossly contaminated with plutonium. On August 24, the most highly contaminated had about 5 MPBB of plutonium. Treatment by DTPA was initiated within 4 hours of the accident and continued for several days. The body burden of the most highly contaminated employee was reduced to 3 by August 25 and to 1 by August 26. All personnel returned to duty.

Implications: Later evaluations (December 1, 1965) from bioassays indicated that the two most highly contaminated employees incurred long-term deposition of plutonium of less than 10% of the MPBB.

Disposition: One employee was restricted from further plutonium work. Several corrective actions were recommended by an investigating committee regarding better fire alarms, precautions in use of flammable solvents, and training of staff.

References: BNWL-CC-249
Nuclear Safety 7,4
WASH-1192
Incident #: L-8
Facility Name: Laboratory Storage Facility, 303-C, 300 Area
Date of Event: March 13, 1979
Event: Rupture of PuO₂ Container
Event Type: Contamination Spread
Significance Rating: 2

Description: On March 13, 1979, two specialists, accompanied by a Radiation Monitor, were unpacking a shipment of PuO₂ for storage in 303-C when they heard a sudden release of air from the package and observed a yellow-brown exhalation. They dropped the container and evacuated the building immediately. The radiation alarm for inside air sounded.

Investigation revealed the material consisted of higher exposure plutonium than previous shipments, and therefore generated about 50% more heat. The material had apparently built up enough internal pressure to breach the inner container, and the exhalation occurred when the outer can was opened. Additional factors were that the container sat for about 12 hours before delivery, and the transfer container did not provide adequate heat removal capability. The higher temperature acted on decomposition products and water in the PuO₂, leading to high internal pressure.

Implications: Specifications and procedures for the processing, transfer and storage of PuO₂ were inadequate. Approximately 1.2 to 1.3 mCi of PuO₂ were released to the atmosphere. Measurements and calculations demonstrated that no employee or member of the public received exposure or internal deposition exceeding standards. Total cost of the incident was reported to be $725,000.

Disposition: The incident was formally investigated as a Class B event, and remedial measures were developed and implemented.

References: BNWI-1017
DOE-EV-0091/1
Incident #: L-9

Facility Name: Critical Mass Laboratory, Waste Technology Center

Date of Event: October 20, 1986

Event Type: Violation of a Criticality Safety Specification

Significance Rating: 2

Description: The mix room plutonium glovebox, after being in use for about 25 years, was to be removed for disposal and replacement. After cleanup of accessible areas, approximately 1550 g of plutonium residues were estimated to remain in the box. Following a second cleanup, the glovebox was sawed up and packaged into six waste boxes for disposal, in accordance with an approved Criticality Safety Specification (CSS) and Burial Compliance Checksheet (BCC). After completing the container loading, the individual waste boxes were evaluated using neutron and gamma counting techniques. This evaluation indicated that two of the six boxes exceeded the BCC plutonium limits. One package with 600 g of plutonium contained a strippable plastic (Butvar) used for contamination control during glovebox dismantling. This package exceeded both the BCC limit of 350 g per waste box and the CSS limit of 230 g of moderated plutonium in a container. This amount of moderated plutonium, under some circumstances, could have produced an inadvertent criticality.

Although a number of other inadvertent violations of criticality safety specifications are reported in Unusual Occurrence reports, this particular incident is included in this review because the packaging of a neutron moderating material with an excess quantity of plutonium compounded the risk of a criticality.

Implications: Violation of a CSS could have led to an inadvertent criticality. Laboratory shutdown was extended by two weeks.

Disposition: A recovery plan was developed and implemented. A "greenhouse" was built for contamination control, and three waste boxes were opened and the contents adjusted to comply with safety limitations. Final evaluation of all waste boxes and drums showed compliance with the applicable BCC or CSS. Monitoring procedures for BCCs were revised.

References: UO-86-007
Incident #: S-6
Facility Name: PUREX Plant, 202A, 200 East Area (and others)
Date of Event: Several - Specific Example: February 27, 1956
Event: PUREX Facility Contamination
Event Type: Contamination caused by blowback
Significance Rating: 2
Description: Several blowback contamination events have occurred, usually caused by a pressurization of a liquid system resulting in some of the liquid solution traveling through an instrumentation line to a faulty connection or instrument. The specific incident presented was chosen because of the spread of the contamination and the expense of the cleanup.

An instrument line leading to the L-6 Tank in PUREX released about 20 gal of a nitric acid solution containing gram quantities of plutonium to the west end of the pipe gallery. The contamination was spread to the west PRV station, the chemical sewer drain, the canyon lobby, the entire pipe gallery, and then the R cell and the roof. The spread was extensive due to various exhaust fans drawing the contaminated air to their location and then to the environment.

Implications: Instrumentation is a potential source of personnel contamination and radiation exposure when off-normal operations have released contaminated materials to their surroundings and the environment.

Disposition: The contamination was cleaned up to the extent possible, with residual surface contamination covered with a strippable coating. The sewer drain was replaced, and a large portion of the facility was posted to limit access. Eventually, a filtered exhaust system was installed to prevent future releases to the environment from facility contamination.

References: HW-43073
Incident #: S-9

Facility Name: REDOX Plant, 202-S, 200 West Area

Date of Event: April 17, 1960

Event: Uncontrolled Chemical Reaction (Uranium Fire)

Event Type: Uranium Fire

Significance Rating: 2

Description: Rumbling noises and building vibration indicated that an uncontrolled chemical reaction occurred in a new multipurpose fuel dissolver in the REDOX plant. Subsequent evaluation concluded that the reaction resulted from a uranium fire. Dissolver operations did not permit complete dissolution of a fuel charge in one step. On this occasion, an unusually large "heel" of undissolved fuel was left in the dissolver, held in a volume of water insufficient to cover it, so that some of the uranium had been exposed to the dissolver atmosphere for 30 to 36 hours. The combination of fission product heat and heat from uranium oxidation raised the temperature to the point where a violent reaction took place. The dissolver was irreparably damaged, and the cell and canyon substantially contaminated.

Implications: The dissolver and some auxiliary equipment required replacement, and facility decontamination was required. There was no spread of radioactivity to the occupied zones of the building or to the plant environs. Normal dissolving activities were resumed in the two remaining dissolvers on May 12. The cost of the recovery was estimated at $250,000.

Disposition: Procedures were changed to prevent exposure of undissolved fuel to the atmosphere.

References: HW-65022
HW-64991
HW-66850-Del
HW-67164
Nuclear Safety 2,4
TID-5360
UND-58
UND-68
WASH-1192
Incident #: S-12

Facility Name: REDOX Concentration Building, 233-S, 200 West Area

Date of Event: November 6, 1963

Event: Fire in REDOX Process Building

Event Type: Fire

Significance Rating: 2

Description: On November 6, 1963, a sudden reversal of air flow, along with noises and vibrational effects, caused personnel to evacuate the 233-S facility and remotely shut down the systems. Radiation monitors inspected the building, detected a fire, and activated the fire alarm. Firemen extinguished the fire in about 1.5 hours using dry chemicals because of possible criticality considerations. The fire involved the north end of the viewing room on all four levels, as well as the anion exchange contactor enclosure. Contaminated laundry, waste cartons, and plastic panels were burned. Low levels of contamination were detected on the firemen, 10 of whom were subjected to nose smears, urine samples, and whole body counting. All tests were negative and there were no over-exposures.

Implications: The inadvertent addition of sodium dichromate solution to the ion exchange system the previous day is considered the most likely cause of the fire. Reaction of the dichromate with anion exchange resin resulted in the pyrolysis of the solution, creating a high temperature and pressure in the contactor and rupturing a gasket. This started a fire in combustible materials on the lower level. The fire spread upward through open floor grates. Damage and contamination to the building and equipment required approximately a 6-week shutdown at the REDOX Plant, and cost about $397,000.

Disposition: Operation was resumed without use of the ion exchange contactor. Recommendations were also made for improving safety in future uses of ion exchange resin systems.

References: BNWI-10011
HW-84619
Nuclear Safety 5, 4
Nuclear Safety 9, 5
TID-5360
WASH-1192
Incident #: S-13

Facility Name: PUREX Plant, 202-A, 200 East Area

Date of Event: June 12, 1964

Event: Leak of Fission Products to Discharge Swamps

Event Type: Environmental Contamination

Significance Rating: 2

Description: A coil leak in the PUREX first cycle acid waste storage tank (F15) caused the release of an estimated 10,000 Ci of mixed fission products, primarily $^{92}$Zr-$^{144}$Ce, and $^{103}$Ru, to the PUREX cooling water discharge swamps. Much of the activity settled in the mud at the bottom of the swamps and was concentrated by algae along the swamp edges.

Implications: This incident resulted from loss of control of radioactive material due to an equipment design deficiency whereby a cooling coil leak created a path for fission product release to the environment.

Disposition: Prompt action was taken to kill the algae and cover the contaminated ditches. New ditches were excavated and the contamination in the old ditches was covered with backfill.

References: ARH-780
HW-83000
HW-83102-Del
HW-84619
Incident #: S-14
Facility Name: Tank 105-A, PUREX Tank Farm, 200 East Area
Date of Event: January 28, 1965
Event: Waste Tank Steam Eruption
Event Type: Tank Instability, Potential for Failure
Significance Rating: 2
Description: On January 28, 1965, a sudden steam release occurred from Tank 105 A. The release was more intense and of a different character than steam "bumps" that had previously occurred in other tanks before airlift circulators were installed. The steam release caused contamination of tank instrumentation and a construction ditch next to the tank. The contamination was cleaned up, and an investigation was made of the nature and implications of the event.

The tank was being operated in a self-concentrating mode, with radioactive decay heat serving to boil off liquid at a moderate rate. Investigation revealed that a large area of the tank bottom liner had bulged upward to an elevation as much as 8.5 ft, creating a "void" space of about 85,000 gal between the steel liner and shell. It was believed that water, either from the concrete or from a leak in the steel liner, had collected between the steel tank floor and the concrete shell. The high temperature generated in the sludge layer at the bottom of the tank raised the pressure in this liquid sufficiently to cause the bottom liner to buckle.

Implications: Although the tank had stabilized, there was concern that a tank rupture could result in loss of the supernatant liquid, allowing excessive temperatures to develop in the remaining sludge and causing a major release of radioactivity to the ground or, less likely, to the air.

Disposition: Detailed analysis concluded that the tank could continue to be used safely in a static mode (i.e., no further addition of fresh waste), with increased recirculator flow, intensified surveillance, and provision for emergency sluicing and emptying of the tank if it became necessary. Because of limited tank space and the difficulty in retrieving such hot waste, the tank was operated in this mode until April 1967, when moderate liquid level fluctuations began to occur. Apparently due to liquid and vapor interchange between the bulge volume and the main tank volume. The tank was taken out of service and safely stabilized in 1968.
Incident #: S-14, Continued
References: ARH-78
Incident #: S-18

Facility Name: B Plant Waste Fractionation Facility, 221-B, 200 East Area

Date of Event: March 22, 1970

Event: Line Break

Event Type: Radionuclide Release

Significance Rating: 2

Description: On March 22, 1970, a contamination spread occurred at B Plant when an instrument line failed and an estimated 1000 Ci of strontium ($^{90}$Sr) solution was released to the B Plant pipe gallery. Radiation dose rates initially were 500 rad/hour at 3 to 4 in. in the pipe gallery and up to 1 r/hour in the operating gallery. The strontium solution entered the B Plant chemical sewer lines through a floor drain and flowed on into the 216-B-2 ditch inside the 200 East Area and to the 25-acre 216-B-3 pond immediately east of the 200 East Area. Water samples taken from the pond reached a maximum $^{90}$Sr concentration of $1.7 \times 10^{-6}$ Ci/L. There was no detectable spread of contamination out of the ditch or pond. Several employees received low-level contamination to small skin areas. Subsequent whole-body counts revealed internal deposition of $^{90}$Sr to be less than 10% of the allowable deposition.

Implications: A potentially serious environmental contamination spread resulted.

Disposition: This incident was investigated as a Type B occurrence. It was recommended that the canyon jumper be redesigned to preclude airlifting of the $^{90}$Sr solution that allowed it to get into the pipe gallery.

References: ARH-1503-Del  
ARH-1648  
WASH-1192
Incident #: S-20
Facility Name: 241-T Tank Farm, 200 West Area
Date of Event: April 22, 1973 to June 8, 1973
Event: High Level Radioactive Waste Tank Leak
Event Type: Ground Contamination
Significance Rating: 2

Description: High-level radioactive waste tank 106-T in the 200 West Area was reported as leaking on June 8, 1973. Subsequently, it was determined that the tank had been leaking since April 20, 1973, when the tank was filled with high-level waste. Previously, the tank was empty except for sludge impregnated with residual liquid. Failure to discover the leak resulted in the loss of approximately 115,000 gal containing 40,000 Ci $^{137}$Cs, 14,000 Ci $^{85}$Sr, 4 Ci $^{239}$Pu, and various fission products in lesser amounts.

Failure of employees to promptly review liquid level and radiation level data resulted in failure to recognize the leak earlier and minimize the quantity of fluid lost.

Implications: Loss of control of radioactive material to the environment because of negligence.

Disposition: Formally investigated by ARCO and AEC to determine basic cause(s) and develop corrective action to prevent recurrence.

References: ARH-2874
RHO-ST-1
TID-26431
WASH-1192
Incident #: S-24
Facility Name: Z-Plant Scrap Packaging, 234-5Z, 200 West Area
Date of Event: October 9, 1980
Event: Contamination by Plutonium While Repackaging Scrap
Event Type: Plutonium Contamination
Significance Rating: 2

Description: On October 9, 1980, two chemical operators were repackaging scrap material in Room 230 of Z Plant when a container of scrap material ignited, pressurized, and released radioactive material. Room 230, the surrounding areas, the two operators, and others who came to their aid were contaminated. The individuals left the room, proceeded to the decontamination room in Z Plant, and were subsequently decontaminated. The airborne release of radioactive material was within applicable DOE effluent concentration guides, and comparable to releases during normal operation. No serious physical injuries resulted from the incident. The projected dose commitments to the lung from $^{241}$Am and plutonium for the two operators were 75% and 13% of the maximum permissible annual dose. The cost to decontaminate the facility was $654,000.

The material involved had been received in a container some 15 years earlier. Analyses showed that the material was a mixture of plutonium and uranium oxycarbide solids and volatile hydrocarbons. During repackaging, the material was exposed to air. Oxidation of the oxycarbides resulted in material ignition and pressurization of the can, blew off the lid, and dispersed the material.

Implications: Costs for decontaminating the facility were large, and there was the potential for more serious contamination of the workers.

Disposition: The cause of the accident was investigated and found to be as described above. The workers and the facilities were decontaminated.

References: DOE-EV-0091/2
IR-80-1
IR-80-2
Incident #: S-26

Facility Name: Plutonium Reclamation Facility, 236-Z, 200 West Area

Date of Event: January 29, 1985

Event: Internal Deposition of Plutonium and Americium

Event Type: Contamination

Significance Rating: 2

Description: A plutonium glovebox worker was using a pointed stainless-steel dial thermometer to remove solidified scrap plutonium material from a container when he suffered a puncture wound. Initial assessment (within 3 hours) indicated deposition of 7.5 body burdens of plutonium and approximately 1.5 body burdens of americium. A solution of DTPA chelating agent was administered 1.5 hours after the injury and tissue was surgically excised from the wound site. These steps were successful in reducing the deposition of plutonium to about 2 to 4 MPBB and americium to about 0.5 MPBB. Continued DTPA treatment reduced the deposition to about 0.5 MPBB.

Implications: A significant contamination of a plutonium glovebox worker resulted from several deficiencies noted below.

Disposition: An investigation was conducted in accordance with DOE procedures. The investigation board found deficiencies in training, a number of procedures, and emergency response, as well as a lack of adequate tools. Corrective steps were taken.

References: IR-85
Incident #: S-27
Facility Name: PUREX Plant, 202-A, 200 E Area
Date of Event: February 27, 1986
Event: Configuration Change in Violation of Criticality Prevention Specifications
Event Type: Safety Violation
Significance Rating: 2
Description: On February 26, 1986, a leak was observed at a pipe fitting downstream from the plutonium nitrate product solution storage tank TK-M6 to the floor of the containment glovebox. It was decided to transfer the contents of TK-M6 to TK-N21/22, and a temporary pipe routing was identified and approved verbally by the plant management and process engineering. The temporary route was installed and the transfer made at 3:30 a.m. on February 27, 1986. During the following shift, a nuclear piping blank was installed in the outlet line from TK-N21/22 to preclude inadvertent transfer of the solution to non-geometrically favorable TK-F10.

This sequence violated several engineering and safety requirements. Failure to authorize and document the change in configuration violated engineering procedures. Failure to obtain Criticality Engineering & Analysis approval violated the Criticality Prevention Specifications (CPS). Failure to blank the outlet transfer route to TK-F10 before the transfer risked a single-failure criticality.

Implications: Failure of personnel to follow established procedures led to a risk of an inadvertent criticality.

Disposition: The nuclear blank was installed, the original leak repaired and the plutonium nitrate solution transferred back to M-cell. The CPSs and administrative procedures were revised and training sessions held on their implementation. A DOE-RL audit of the PUREX Plant configuration control management system was conducted and responded to. A review of potential routes from geometrically favorable to non-geometric systems found one such line. This line was blanked out.

References: UO-86-008
Incident #: S-28
Facility Name: Plutonium Finishing Plant, 234-5Z, 200 West Area
Date of Event: September 29, 1986
Event: Configuration Change in Violation of Criticality Prevention Specifications
Event Type: Safety Violation
Significance Rating: 2

Description: On September 19, 1986, a tygon jumper was installed to permit transfer of concentrated plutonium solutions between Tank 126, which normally stores concentrated plutonium solutions, and Tank WM-1, which normally collects low-level plutonium waste solution for discard into geometrically unfavorable vessel D-5. The transfer line from WM-1 to D-5 was not disconnected and capped to preclude the inadvertent transfer of concentrated plutonium solution to D-5. Work was not authorized or performed in accordance with the requirements of the Engineering Procedures Manual and the PFP Configuration Control Manual.

On September 29, 1986, at 5:30 a.m., a transfer was made from TK-126 to TK-WM-1. Shortly thereafter, it was recognized that the line to TK D-5 had not been capped. A cap was installed by 9:00 a.m. The pathways to a geometrically unfavorable vessel were controlled by five closed manual valves, a closed key-controlled electric valve and a pump that was turned off. Although proper recovery actions were performed, a written, management-approved recovery plan was not issued as required by the Operating Safety Requirements.

Implications: Failure of personnel to follow established procedures led to a safety violation. A criticality was possible with one additional contingency.

Disposition: A shutdown order was issued by DOE-RL to permit a comprehensive evaluation of all chemical processing operations. Internal and external review committees were established and numerous corrective actions were taken.

References: UO-86-053
2.3 CATEGORY 3 INCIDENTS

Descriptions of the remaining 67 Category 3 incidents follow.
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<td>Startup Anomaly</td>
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<tr>
<td>Significance Rating</td>
<td>3</td>
</tr>
<tr>
<td>Description</td>
<td>A hot startup was conducted with both the flow monitor and the circuit that actuates the Ball 3X System on loss of water bypassed.</td>
</tr>
<tr>
<td>Implications</td>
<td>No damage resulted from the incident. However, the incident represented a serious violation of safety procedures.</td>
</tr>
<tr>
<td>Disposition</td>
<td>This survey did not identify specific corrective measures resulting from this event.</td>
</tr>
<tr>
<td>References</td>
<td>HW-73060</td>
</tr>
<tr>
<td></td>
<td>HW-73265-RD</td>
</tr>
</tbody>
</table>
Incident #: B-4
Facility Name: B Reactor
Date of Event: September 12, 1959
Event: Reactor Scrammed Because Screen Plugged With Neoprene
Event Type: Equipment/Maintenance Failure
Significance Rating: 3

Description: Flow monitor trips caused reactor scrams at B Reactor on September 10 and 12, 1959. Both scrams were caused by small pieces of neoprene lodging on the orifice screen in the tube coolant supply line. Subsequently, the same type of neoprene material was found in all near-side crossheader screens and in all near-side basket screens in the valve pit.

The origin of this material was later determined to be a 35 ft² piece of a neoprene curtain seal installed during construction of one of the 1,900,000 gal tanks in the 190 Building. The gasket had been scheduled for removal, but removal was delayed. This incident did not cause any reactor damage.

Implications: This incident demonstrates that proper design alone is not enough to avoid safety problems. Safety devices must be carefully installed and tested.

Disposition: This survey did not identify specific corrective measures resulting from this event.

References: HW-62052
HW-73265-RD
Incident #: B-5
Facility Name: B Reactor
Date of Event: February 2, 1961
Event: Operator in Training Erroneously Withdrew Horizontal Control Rod
Event Type: Operator Error
Significance Rating: 3
Description: An operator in training withdrew a horizontal control rod (HCR), causing a reactivity surge. An alarm should have sounded, but was out of order. The event was noted by a regular operator, who took corrective steps and avoided a scram. It was later estimated that the reactor power increased about 70 MW, largely in the area near the control rod that was moved. Maximum outlet temperatures may have reached 121 °C, still under limits. The incident caused no reactor damage.
Implications: The incident points out the need for careful instruction of personnel under training.
Disposition: This survey did not identify specific corrective measures resulting from this event.
References: HW-73060
HW-73265-RD
 Incident #: B-6  
Facility Name: B Reactor  
Date of Event: February 1961  
Event: Employee Entered Air Duct With Reactor Operating  
Event Type: Personnel Radiation Exposure  
Significance Rating: 3  
Description: An employee entered a high radiation field (1 to 100 r/hour) in the 105B supply air duct. He was exposed for 1 to 3 min and received a total dose of 170 mr, which is less than the weekly radiation limit.  
Implications: Potential high radiation exposure.  
Disposition: Work control procedures were revised.  
References: HW-68718-Del
Incident #: C-1

Facility Name: C Reactor

Date of Event: March 2, 1960

Event: Operation With a Safety Rod in the Reactor

Event Type: Equipment/Maintenance Failure

Significance Rating: 3

Description: An unexplained low reactivity was noted at C Reactor after startup. The reactor was shut down after about 48 hours when parts of the reactor did not respond to the general "drying out" that was occurring in the rest of the reactor. It was determined that VSR #35, which was supposed to have been clamped in the out position, was in the reactor. The incident was caused by an inadequate method of tying the rod out and bypassing the upper limit switch, which should have scrammed the reactor. It was later calculated that the boron-steel VSR reached a maximum temperature of 800 °C. Remote inspection of the rod revealed no damage.

Implications: No damage resulted, and no unsafe condition was actually approached. The incident illustrates how communications can break down and the hazards of bypassing a safety device (in this case the upper limit switch of the VSR).

Disposition: It was recommended that the Process Standard specifications be revised to prevent deactivation of the upper limit switch unless the rod is disassembled or immobilized in a specified manner. Rod status will be physically inspected each shift. All rods removed from service will be mechanically clamped.

References: HW-64268
HW-73265-RD
Incident #: C-2
Facility Name: C Reactor
Date of Event: November 9, 1960 and December 8, 1960
Event: Uncontrolled Contamination Spreads
Event Type: Personnel Error/Radiation Release
Significance Rating: 3

Description: Two contamination incidents resulted from handling and transferring sample material irradiated in C Reactor. The first took place on November 9, 1960, when the sample was removed from the "D" test hole. At that time, there was a local contamination spread and some body and nasal contamination of the personnel involved.

The second incident occurred when a cask of the material was shipped from C Reactor to the 300 Area on December 8, 1960. When the truck arrived at the 327 Building, it was grossly contaminated. The driver's shoes and socks were contaminated up to 20,000 cpm. The cask and truck had surface contamination up to 500 mrad/hour. The contamination occurred during transit because the cask was not airtight and had not been wrapped for shipment.

Implications: Inadequate procedures led to uncontrolled personnel exposure and spread of contamination outside of controlled areas. Radiation Control Standard 7.1, which requires that shipping containers be packaged to preclude any release of contamination during handling and shipping, was violated.

Disposition: The incident was reviewed with all Testing and Operations personnel and retraining conducted on the proper application of Radiation Control Standard 7.1.

References: HW-67432
HW-67749
HW-68039-Del
## HANFORD PROCESS REVIEW DATA SHEET

**Incident #:** C-3  
**Facility Name:** C Reactor  
**Date of Event:** April 5, 1962 and April 16, 1962  
**Event:** Unusual Multiple Fuel Ruptures Observed After Two Scram Recovery Startups  
**Event Type:** Multiple Fuel Failures  
**Significance Rating:** 3

**Description:** Following equilibrium scram recoveries of C Reactor on April 5 and 16, 1962, unusual fuel ruptures were observed. In one case, two ruptures were found. In the second case, three ruptures and three incipient ruptures were found. It was concluded that these were probably caused by flux transients and flux peaking in the top near center section of the reactor, caused by an additional 50 tubes with enriched fuel surrounding an overbore pattern.

**Implications:** Enrichment in an overbore region probably increased local fuel temperatures and caused the fuel failures.

**Disposition:** Procedures for hot startups were changed.

**References:** HW-73483

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2-75
Incident #: C-4
Facility Name: C Reactor
Date of Event: October 9, 1962
Event: Flow Valved Off of Two Crossheaders During Outage
Event Type: Flow Stoppage/Personnel Error
Significance Rating: 3
Description: During a reactor shutdown, crossheaders 3 and 4 were valved off in error. The condition was found and corrected by the next shift. No fuel damage resulted.
Implications: Potential fuel damage due to overheating, or personnel endangerment if tube caps had been removed.
Disposition: The incident was reviewed with all operating crews and appropriate retraining on procedures was initiated.
References: HW-75451
Incident #: C-5

Facility Name: C Reactor

Date of Event: October 20, 1962

Event: High Tube Outlet Temperatures Observed During Startup

Event Type: Startup Anomaly

Significance Rating: 3

Description: During a secondary cold startup of C Reactor on October 20, 1962, high tube outlet temperatures in rows 35 and 36 caused the reactor to scram. Shortly before the scram, rapid increases in tube temperatures were experienced in one section of the reactor. Examination of the strip chart after the scram showed that several tube outlet temperatures exceeded operating temperature limits.

Following startup, rupture indications were found, and a ruptured enriched fuel element in tube 3857 was discharged. The reactor was restarted and shut down again on October 21, when rupture indications were noted on header 38. Discharged fuel showed no rupture indications. The reactor was restarted.

Implications: The fuel rupture was probably caused by a high rate of power rise and high coolant temperatures.

Disposition: Recommendations were made regarding restrictions on the rate of power rise; better communications between Operators, Specialists, and Processing Supervisors; and changes in the procedures for using temperature monitoring equipment on all startups.

References: HW-75600
# HANFORD PROCESS REVIEW DATA SHEET

**Incident #:** C-6  
**Facility Name:** C Reactor  
**Date of Event:** November 20, 1963  
**Event:** Reactor Operating Limits Exceeded During a Cold Startup  
**Event Type:** Startup Anomaly  
**Significance Rating:** 3  

**Description:** Reactor operating limits were exceeded at C Reactor on November 20, 1963. The incident occurred during a cold startup when outlet temperatures on 34 tubes exceeded operating temperature limits. Eight tubes of overbore metal, located in the high-temperature zone, were discharged on the November 21 outage. Only three of these had actually exceeded the operating limits.  

No reactor or fuel damage resulted from this incident.  

**Implications:** Sufficient temperature monitoring was not performed during a period when there was considerable rod movement and thus high potential for flux shifts.  

**Disposition:** It was recommended that scram limits and formalized instructions be evaluated. Operators were reminded that they should keep current on information passed on by instruction logs.  

**References:** HW-80387
Incident #: D-1
Facility Name: D Reactor
Date of Event: June 17, 1945
Event: Reactor Power Level Error
Event Type: Reactor Power Anomaly
Significance Rating: 3
Description: The reactor scrammed from 80% power level. After scram recovery was accomplished, the subsequent power level was found to be 121% of the maximum power level for about 2 min because a power level instrument was out of calibration.
Implications: Potential for exceeding an operating safety limit.
Disposition: The faulty instrument was recalibrated.
References: HW-7-1981
Incident #: D-2
Facility Name: D Reactor
Date of Event: July 2, 1946
Event: Irradiated Fuel Lodged on D Elevator
Event Type: Personnel Radiation Exposure
Significance Rating: 3

Description: On July 2, after the top limit switch of the discharge elevator had erroneously been set too low, fuel was discharged, and two metal process and several dummies were deposited on the aimer track on the elevator. (The aimer had been removed, but the track remained.) It took 8 hours to retrieve the pieces without incurring significant radiation exposure to employees. (A maximum of 40 mr exposure was incurred.)

Implications: This event had the potential for personnel overexposure. The incident was caused by inadequate planning that positioned the elevator wrongly.

Disposition: The aimer track was removed and the elevator control circuits were revised by adding an interlock to assure that the elevator would be positioned above the tubes before discharging fuel.

References: HW-7-4542
Incident #: D-3
Facility Name: D Reactor
Date of Event: September 5, 1946
Event: Reactor Power Surge
Event Type: Reactivity Anomaly/Equipment Failure
Significance Rating: 3

Description: On September 5, 1946, D Reactor experienced an over-level power surge for 3 min when a rod hydraulic pump control switch stuck in the "on" position while a control rod was being withdrawn. A peak power 140% of normal was reached before manual insertion of other control rods stopped the power increase. Trip points were not exceeded, however.

Implications: This was a brief and moderate uncontrolled reactivity increase. Safety circuit high-level trips would have prevented the reactor from exceeding safe levels if other rods had not been inserted. The operator also had a manual scram switch available to shut down the reactor in an emergency.

Disposition: The pump control switches were replaced with a more reliable type.

References: HW-7-5194
Incident #: D-5
Facility Name: D Reactor
Date of Event: June 20, 1959
Event: Discharged Fuel Elements Lodged on Rear Catwalk and on a Concrete Pad
Event Type: Fuel Discharge Malfunction
Significance Rating: 3
Description: In some cases it is desirable to discharge tubes and leave them empty. In such cases, the fuel may be flushed from the tube with water instead of being displaced by fresh fuel.

In this instance, four tubes on Row 35 were flush-discharged. Several pieces lodged on the rear catwalk and one piece lodged on a concrete pad at the base of the rear drain riser. These pieces were dislodged and dumped into the basin over a 4-day period.

The cause of this incident was probably high flushing pressure resulting from a faulty valve on the flushing machine. This caused an increase in the horizontal trajectory of the elements, causing them to land on the catwalk.

Implications: No reactor damage, personnel overexposure, or offsite releases resulted. However, the outage was extended for an additional 5 days. Accidents of this type were not rare during operation of the Hanford reactors. The fog spray and air exhaust system were designed to protect against fires that might result from this type of accident.

Disposition: This survey did not identify specific corrective measures resulting from this event.

References: HW-60918
HW-73265-RD
Incident #: D-6
Facility Name: D Reactor
Date of Event: June 26, 1959
Event: Criticality Reached Before Prediction
Event Type: Startup Anomaly
Significance Rating: 3

Description: A reactor outage, expected to be of minimum duration, was extended when it was found that a fuel element was lodged on rear-face piping. Additional poison necessary to overcome xenon burnout after reactor startup had not been charged, so when the outage had to be extended, poison splines were inserted to satisfy total control requirements. On startup, splines were removed and replaced with poison charges in ten tubes in the top part of the reactor. The work was interrupted at this point by a shift change. The oncoming shift noted that splines were being removed but didn't know that five poison tubes required in the lower region of the reactor still contained regular fuel. On startup, criticality was reached before prediction. Subcritical instrumentation showed a period of 60 s. Power was held at 1 MW and a check was made to determine the reason for the prediction error. The absence of the five poison tubes was noted, the reactor was shut down, the poison tubes charged, and the reactor restarted.

Implications: Total control requirements were violated. This in itself does not result in reactor damage, but it reduces the reserve of nuclear control available should an improbable but conceivable accident occur, such as loss of cooling water.

Disposition: This survey did not identify specific corrective measures resulting from this event. No changes would be necessary if existing procedures had been followed.

References: HW-73265-RD
HANFORD PROCESS REVIEW DATA SHEET

Incident #: D-7
Facility Name: D Reactor
Date of Event: January 15-25, 1960
Event: Failure of High-Lift Pump, Followed by Debris in System
Event Type: Equipment/Maintenance Failure
Significance Rating: 3

Description: A high-lift pump at D Reactor failed on January 15, 1960. Shortly thereafter, it was found that 19 flow-monitor gages showed reduction in pressures of 10 psi or more. Gages were stable until January 24, when additional pressure decreases were noted. The reactor was shut down manually on January 25, 1960, and screens were cleaned. The strainer on the pump discharge showed a quantity of metal particles ranging up to 0.75 in. in length. Metal particles, gasket material, neoprene, and weld metal were also found in all near-side crossheader screens. Pump failure was probably caused by foreign material being left in the casing after the pump was modified. The debris in the system was attributed to the pump failure.

Implications: No reactor damage was caused by the incident, but it does show the need for adequate strainers to be maintained in first class condition.

Disposition: The strainers and screens were cleaned. Other specific actions taken to prevent recurrence were not identified by this survey.

References: HW-64140
HW-73265-RD
Incident #: D-8
Facility Name: D Reactor
Date of Event: February 1961
Event: Failure of ball valve on PCCF tubes allowed poison pieces to be flushed out, increasing reactivity and scrambling reactor.
Event Type: Reactivity Anomaly/Equipment Failure
Significance Rating: 3
Description: Rupture of a hydraulic line on the rear face ball valve on a PCCF tube caused the valve to open, and 37 poison pieces were flushed from the tube. The reactor scrambled on a high reactivity trip. This incident caused no reactor damage.
Implications: The tube powers in the immediate vicinity were estimated to have increased 50% to 100% and the total reactor power by 10% to 15%. While efforts are made to avoid inadvertent discharge of poison columns, such accidents are assumed in safety analyses leading to process limits.
Disposition: This survey did not identify specific corrective measures resulting from this event.
References: HW-73265-RD
<table>
<thead>
<tr>
<th>Incident #</th>
<th>DR-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility Name</td>
<td>DR Reactor</td>
</tr>
<tr>
<td>Date of Event</td>
<td>January 1, 1955</td>
</tr>
<tr>
<td>Event</td>
<td>Flushing of Poison Column Caused High-Reactivity Scram</td>
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<tr>
<td>Event Type</td>
<td>Reactivity Anomaly</td>
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<tr>
<td>Significance Rating</td>
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</tbody>
</table>

**Description:**
The DR Reactor scrammed on January 1, 1955, due to a flux monitor trip caused by a sudden increase in local neutron flux and an increase in reactivity. These increases were caused by inadvertently flushing a poison column from ball valve 1069 during the process of setting this tube up for discharge by displacement. Failure to first reduce the flow on this poison column tube before opening the rear ball valve caused this incident.

The power level as monitored by the 10-tube average temperature recorder indicated a 10-MW increase (from 648 MW to 658 MW) at the time of the scram. No tube boiling or reactor damage occurred.

**Implications:**
The Standard Operating Procedure was violated. However, this type of incident is unlikely to cause fuel or reactor damage or release of radiation, especially at the power the reactor was operating at that time.

**Disposition:**
The incident was publicized internally and the procedures revised to reduce the probability of a recurrence of a similar incident.

**References:**
HW-34373
Incident #: DR-6
Facility Name: DR Reactor
Date of Event: November 7, 1959
Event: Power Level Higher Than Indicated by the Power Recorder
Event Type: Power Anomaly
Significance Rating: 3

Description: At 8:15 a.m. on November 17, 1959, the sample flow from the far downcomer to the pot where the bulk outlet water temperature is measured was found to be low because the float on the valve controlling the flow was stuck. The lower water flow gave an apparent bulk temperature that was lower than actual, making the power calculating system inaccurate. As a result, the actual power level exceeded nominal limits for a short time. The discrepancy was discovered by cross-checking between other indicators that are proportional to power. It was calculated that a maximum level of 1734 MW was attained just before discovery of the restricted line. The bulk outlet water temperature at this point was 94.3 °C.

When the flow was restored, the indicated power increased from 1540 to 1753 MW. The power was then reduced to 1600 MW.

Implications: The incident caused no reactor damage. The higher power level was above the standard limit, which was based on fuel element failure control, but well within safety margins for the reactor. The consequence of continued operation at the higher power level would have been higher fuel element failure rates.

Disposition: Remedial action was taken to provide two independent methods of determining reactor power level. Until these changes were installed, power level checks were made based on average tube temperatures and neutron flux instrumentation.

References: HW-62802
HW-62900
HW-73265-RD
Incident #: DR-7
Facility Name: DR Reactor
Date of Event: December 17, 1959
Event: Abnormal temperature and flow observations caused by wood and other debris in strainer screens.
Event Type: Equipment/Maintenance Failure
Significance Rating: 3

Description: Following several days of abnormal temperature and flow indications and removal of a piece of wood from primary high lift pump on December 14, the DR Reactor was scrammed by a high-pressure trip of the flow monitor gauge on tube 4477 at 3:03 a.m. December 17, 1959. The scram was believed to have been caused by wood fibers getting into the process tube and its inlet assembly and screen. An investigation of the conditions that existed before and after the scram did not definitely determine the source or time the wood was introduced, but several likely sources were identified as (a) during installation of straightening vanes on suction piping to pump 190-DR-4 on December 8, 1959; (b) during clearwell inspection; and (c) during maintenance work on 183-DR back-wash valves.

Implications: Although the presence of wood fibers was serious enough to cause a scram, it was not believed that conditions could have caused a serious nuclear hazard.

Disposition: The wood was flushed from the system and all strainer screens between the pump and process tubes were inspected and cleaned. The importance of keeping the system clean during and after maintenance work was stressed with operating and maintenance personnel.

References: HW-63281
HW-73265-RD
Incident #: DR-8
Facility Name: DR Reactor
Date of Event: January 21, 1960
Event: Failure of Front-Face Fitting on PCCF Tube
Event Type: Poison Element Melt
Significance Rating: 3

Description: The fitting connecting the flow monitor to the front nozzle of a poison column tube blew out, causing a sizeable front-face leak. Two unsuccessful attempts were made to repair the leak. Finally, an attempt was made to discharge the tube during operation by throttling flow and opening the rear nozzle valve. This attempt was also unsuccessful. Each time the flow was throttled, the reactor power dropped rapidly, and after the third try the reactor was manually scrammed.

It was later found that some poison pieces and a small spot in the tube had melted. It is probable that reverse flow occurred during throttling, displacing the poison pieces to a higher neutron flux position upstream and decreasing neutron reactivity. The reverse flow, or boiling, reduced cooling and allowed the lead-cadmium poison pieces and tube to melt.

The channel was retubed and restored to service.

Implications: Perhaps more serious than the damage itself were the implications of the events leading to the incident. The lack of understanding of the events leading to the incident and the apparent lack of communications between shifts was a problem.

Disposition: It was recommended that the 2-min delay in flow monitor trips for poison columns be eliminated.

References: HW-63852
HW-67185
HW-73060
HW-73265-RD
Incident #: DR-9
Facility Name: DR Reactor
Date of Event: April 12, 1960
Event: Loss of Power to Three High-Lift Pumps
Event Type: Power Failure/Operator Error
Significance Rating: 3
Description: Failure of a transformer supplying power to 190-DR Building turned out the lights in the control room and caused two high-lift pumps to trip off. Due to an operator error a third pump was turned off. If a pump does not start within 2.5 min, a "power failure" relay opens. This relay can be bypassed, but in the confusion of the moment, this was not done. The relay opened, scrambling the reactor. Flow reduction resulting from loss of the high-lift pumps caused the temperature of the coolant to rise only 1.7 °C. This caused no reactor damage.
Implications: A larger increase of the coolant temperature would have occurred had the operator turned off additional pumps. However, no reactor damage would have been expected.
Disposition: This survey did not identify specific corrective measures resulting from this event.
References: HW-73265-RD
Incident #: DR-10
Facility Name: DR Reactor
Date of Event: July 11, 1961
Event: Power Loss and Trip of Ball 3-X System
Event Type: Power Loss
Significance Rating: 3

Description: On July 11, 1961, a loss of power to the No. 1 bus at 151-D occurred as a result of personnel checking equipment. This resulted in a scram of both D and DR Reactors and loss of power to two electrically driven main coolant pumps each at D and DR. At DR Reactor the resultant drop in water pressure caused a trip of the Ball 3-X System. All vertical safety rods dropped and all VSR channels were filled with balls. The ball drop should not have occurred under these conditions. An investigation revealed that the mercoid low pressure (LP) and very low pressure (VLP) switches had probably been set incorrectly when the covers of the LP and VLP switches were inadvertently switched during maintenance/modifications in October 1960. As part of the effort to recover the balls, borescope and television traverses were made of the VSR channels. Significant graphite block damage was revealed. This breakup had occurred over a period of time and was not necessarily a result of this incident.

Implications: No potential for a nuclear incident existed as a result of this incident; however, recovering from a ball drop is costly and time-consuming. Additional fuel enrichment was required to compensate for the boron-steel balls remaining in the reactor.

Disposition: Switches were recalibrated and covers chained to the switch cases to preclude a recurrence. Instructions and information were issued to personnel to guard against this kind of incident.

References: HW-70454
HW-71294
HW-77123
Incident #: DR-11
Facility Name: DR Reactor
Date of Event: November 19, 1963
Event: Normal Rate of Power Rise Exceeded for a 4-Minute Period
Event Type: Startup Anomaly
Significance Rating: 3

Description: The normal rate of power increase was exceeded for 4-min at DR Reactor on November 19, 1963, following a cold startup. A total power rise of 339 MW occurred at an average rate of 85 MW/min. Corrective action was taken immediately to bring the rate of rise to the planned rate of 50 MW/min, thus preventing a reactor shutdown due to abnormal process tube water temperature. The cause of the power rise was the inadvertent withdrawal of Rod #7.

Implications: This incident showed a lack of attention by the control room staff to rod movement and power level changes during a critical period of non-equilibrium operation.

Disposition: Several recommendations were made, including relocation of phones, installing an audible alarm to indicate withdrawal of HCRs, and reinstruction of operating personnel that proper attention at the operating console is mandatory at all times.

References: HW-79802
Incident #: F-3
Facility Name: F Reactor
Date of Event: December 31, 1957
Event: Fuel Overheating During Outage
Event Type: Coolant Interruption/Personnel Error
Significance Rating: 3
Description: Because of a valving error during an outage, fuel on two rows was overheated to a maximum temperature estimated at 300 °C. Suspect tubes were discharged before startup and no subsequent fuel failures were experienced.
Implications: Monetary loss of prematurely discharged fuel.
Disposition: This survey did not identify specific corrective measures resulting from this event.
References: HW-54291
Incident #: H-2
Facility Name: H Reactor
Date of Event: October 23, 1954
Event: Flow Stoppage to 92 Tubes Served by One Crossheader
Event Type: Cooling Loss/Operator Error
Significance Rating: 3

Description: On October 23, 1954, during an unsuccessful attempt to perform a quick discharge of a ruptured fuel piece from tube 2864-H, rear crossheader #27 was closed off without being valved to the drain. This resulted in almost complete stoppage of flow to all tubes served by crossheaders #27 and #28 for about 2 hours 15 min with water pressure at 75 psi. As a result, there was considerable generation of steam and probably boiling in all 92 tubes (although the reactor was shut down). Temperatures in excess of 120 °C were reached in the tubes. Water flow was restored and slugs in three tubes were discharged and examined in the underwater viewer. No damage sufficient to warrant discharge of additional tubes was found.

Implications: Procedures were not followed. It is very unlikely that this incident could result in serious radiation releases or injury to personnel.

Disposition: Discharged fuel was checked for damage. None was found. Tubes 2770 and 2864 were hydrostatically tested, and the reactor was restarted. Appropriate disciplinary action was taken.

References: HW-33839
HW-34353
Incident #: H-6
Facility Name: H Reactor
Date of Event: May 5, 1958
Event: Attempts to clear a stuck dummy poison element caused a rapid local reactivity surge and boiling of water in the tube.
Event Type: Reactivity Anomaly
Significance Rating: 3

Description: During attempts to charge an empty PCCF tube with poison pieces, the first piece (a perforated dummy) cleared the charging machine but the second (another perforated dummy) stuck. An attempt was made to free the second piece by opening the charging machine. Water flowed out of the front nozzle and a spurt of water and steam was seen to emerge from the open rear ball valve. A reactivity surge was noted in the control room and work on the tube was stopped. The operation was repeated about 4 hours later. This time the reactivity surge was sufficient to cause a flux-monitor trip, scramming the reactor. Apparently, on both occasions when flow was taken off the tube, water boiled out causing the high-reactivity trip.

Implications: No reactor damage resulted from this incident. Had the tube flow been left off for a sufficient time without a reactor scram, melting of the empty tube could have occurred. The operating crew failed to understand the implications of the series of events following the first attempt to clear the charging machine.

Disposition: The event was documented (HW-56005) to explain the cause and thus help prevent a recurrence at any PCCF-equipped reactor.

References: HW-56005
HW-73060
HW-73265-RD
Incident #: H-7
Facility Name: H Reactor
Date of Event: October 20, 1959
Event: Erroneous Power Level Indications During Startup of H Reactor
Event Type: Startup Anomaly
Significance Rating: 3

Description: The reactor was started up at 6:30 a.m. after a minimum outage. Two hours later, the indicated power was 800 MW. At this time the operating personnel concluded that the actual power was higher than the indicated power. The flow indicated at the 190-H Building was found to be normal—about 82,300 gal/min, whereas the total flow recorder (which feeds data to the power recorders) was indicating a flow of about 23,000 gal/min lower. The trouble with the flow recorder which caused the power recorder to read low was located and corrected at 3:45 p.m.

Implications: The incident resulted in no reactor damage, and in fact no limits were violated. However, such a flow indicator error of about 25% should have been detected before startup.

Disposition: The flow recorder was corrected.

References: HW-73265-RD
HANFORD PROCESS REVIEW DATA SHEET

Incident #: H-8

Facility Name: H Reactor

Date of Event: March 11, 1960

Event: Loss of Power to H Area

Event Type: Power Failure

Significance Rating: 3

Description: H Reactor was operating under special procedures while the secondary source of power from D Area had been purposely removed for maintenance. The second source of power from F Area tripped out when a line relay at F Area was grounded, isolating H Area from its remaining source of BPA power and removing power from the primary coolant pumps. The reactor automatically scrammed, and the backup system, steam powered pumps, responded. The reactor shut down without incident. Available instrumentation did not show a temperature surge although a small surge did undoubtedly occur. No reactor damage was experienced.

Implications: The backup coolant system performed as designed. The last ditch cooling system (ECCS) was not activated and represented an additional back-up.

Disposition: An investigation of the incident was made and the cause and sequence of events were determined. Four unrelated events occurred. The absence of any of the four would have prevented the incident.

References: HW-64676
HW-66364
HW-66767
HW-73060
HW-73265-RD

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REACTOR

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Incident #: H-9

Facility Name: H-1 Loop

Date of Event: April 13, 1960

Event: Failure of a Tube Fitting on H-1 Loop

Event Type: Equipment/Maintenance Failure

Significance Rating: 3

Description: In the course of recalibrating one of the pressure switches in the H-1 Loop, an instrument technician closed a valve to isolate the system. The technician proceeded to loosen a fitting upstream of the valve by about 1/8 turn, turned a valve out of the way so it would not interfere with his test equipment, and retightened the fitting. The fitting was on the part of the 0.25-in. tubing still pressurized. He stepped back to obtain a tool, and at that time the tubing blew out of the fitting. All personnel evacuated the scene to determine contamination spread. On April 14, it was determined that the line heaters had not been turned off, damaging the heaters and a portion of the loop piping. While the loop operator and technician received some slight external contamination, no overexposure occurred.

Implications: This incident points to the need for a thorough orientation of personnel (who are normally familiar with working on low-temperature, low-pressure systems) to work on high-temperature, high-pressure systems.

Disposition: Several recommendations were made regarding changes in training and procedures for installing fittings.

References: HW-64966
HW-73265-RD
### Incident Data Sheet

**Incident #:** H-11  
**Facility Name:** H Reactor  
**Date of Event:** January 10, 1961  
**Event:** Discharge of Enriched Fuel Elements onto the Rear-Face Platform  
**Event Type:** Fuel Discharge Accident  
**Significance Rating:** 3

**Description:** Ordinarily it is impossible to operate the charging machine unless the rear-face platform is in the "up" position above the tube pattern and the doors giving access to the rear face are closed. At the time in question one of the access doors was being repaired and the charging machine interlock was bypassed to permit charging operations. Several tubes were discharged normally. At about 7:40 a.m. on January 10, high rear-face radiation levels were noted after tubes 1792-H and 1792-H were discharged. It was found that the rear work platform had descended to a point below these tubes and the fuel elements had been discharged onto the platform. The fuel elements on the platform were cooled by intermittent operation of the rear-face fog spray to prevent overheating. Removal of the elements was completed at 1:55 a.m. on January 14, 1961. An investigation was conducted that revealed that the electrical system controlling the elevator movement had failed.

**Implications:** The incident underscores the importance of maintaining safety systems in first-class condition. The value of the fog spray system for preventing fuel overheating and possibly fuel burning was demonstrated. No reactor damage, personnel overexposure, or release of contamination resulted from this incident.

**Disposition:** The elevator control system was repaired.

**References:**  
HW-68213  
HW-73265-RD
HANFORD PROCESS REVIEW DATA SHEET

Incident #: H-12
Facility Name: H Reactor
Date of Event: January 16, 1961
Event: Replacement of a front-face process-tube fitting before safety evaluations were completed.
Event Type: Coolant Interruption
Significance Rating: 3

Description: An operations supervisor noted a leak on the front nozzle of a process tube and called for maintenance personnel to shut the reactor down. The supervisor then contacted the process engineer to determine if flow could be taken off the tube immediately to repair the leak and start up before reactivity was lost from the xenon transient. They determined it was not safe to do so. In the meantime, the maintenance supervisor replaced the fitting.

Implications: No reactor damage resulted from the incident. However, had difficulty been experienced in installing the new fitting and in reestablishing flow, fuel overheating could have occurred.

Disposition: As a precautionary measure, the fuel was discharged from the tube.

References: HW-73265-RD
Incident #: H-13
Facility Name: H Reactor
Date of Event: July 10, 1962
Event: Momentary Actuation of the Emergency High-Tank Water System
Event Type: Partial ECS Trip
Significance Rating: 3

Description: During testing of a main coolant pump at H Reactor on July 10, 1962, with the reactor shut down, the incoming breaker to the power supply bus was relayed out, momentarily interrupting this source of power. The one electrically powered condenser water pump in service dropped off the line, causing the loss of water supply to the barometric condensers in the 190 Building. The reactor coolant pressure, being maintained at a normal shutdown pressure of 75 psi by the 190 steam turbines, dropped due to a loss of turbine vacuum, causing the actuation of the high-tank check valves for a brief (not precisely known) period. The high tank is part of the last-ditch cooling system, and is intended to be actuated only in an emergency. The 190 turbines continued to operate, but not under condensing operation. Manual adjustments to the turbine speed were immediately made and the coolant pressure was returned to normal.

Implications: The amount of flow from the pumps was at no time below that required by the Process Standards and was always sufficient to prevent boiling in the process tubes.

Disposition: This survey did not identify specific corrective measures resulting from this event.

References: HW-74511
<table>
<thead>
<tr>
<th>Incident #:</th>
<th>KE-1</th>
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<tbody>
<tr>
<td>Facility Name:</td>
<td>KE Reactor</td>
</tr>
<tr>
<td>Date of Event:</td>
<td>December 13, 1957</td>
</tr>
<tr>
<td>Event:</td>
<td>Uncooled Control Rod Inserted Into Operating Reactor</td>
</tr>
<tr>
<td>Event Type:</td>
<td>Reactor Damage/Personnel Error</td>
</tr>
<tr>
<td>Significance Rating:</td>
<td>3</td>
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<tr>
<td>Description:</td>
<td>HCR #4 rod tip was replaced on December 13, 1957, during reactor operation. The new tip was inadvertently pushed into the active core of the reactor before the cooling water was connected. The tip was damaged beyond repair and the reactor had to be shut down to remove the rod because it was stuck in the rod channel.</td>
</tr>
<tr>
<td>Implications:</td>
<td>Monetary and production loss.</td>
</tr>
<tr>
<td>Disposition:</td>
<td>The rod was replaced on January 7, 1958.</td>
</tr>
<tr>
<td>References:</td>
<td>HW-54291</td>
</tr>
<tr>
<td></td>
<td>HW-73265-RD</td>
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</tbody>
</table>
Incident #: KE-2
Facility Name: KER-1 Loop, KE Reactor
Date of Event: June 28, 1959
Event: Reactor Scram and Rapid Loop Depressurization
Event Type: Equipment/Maintenance Failure
Significance Rating: 3

Description: The incident was caused by malfunctioning of a flow indicator on the KER-1 test loop, resulting in a low-flow trip. This scrammed the reactor and opened a dump valve, depressurizing the loop. A second instrument failure allowed the dump valve to close again and again be opened by the flow indicator trip. After the second cycle, the malfunctioning of the flow indicator disappeared and the dump valve remained closed. Minutes later the flow dropped to about 20% and manual measures were taken to open the dump valve, shut off the pumps, and isolate much of the loop from the in-reactor channel. The loop was then cooled by regular process water and normal shutdown conditions attained. No damage to the reactor or experimental facility occurred as a result of this incident.

Implications: This incident shows how events can compound. In addition to the failure of two different pieces of equipment, the incident was aggravated by the error by the operator in isolating part of the loop from the in-reactor section before assurance was obtained that the dump valve and check valve had opened.

Disposition: The incident was investigated and actions were recommended for an operator in similar circumstances.

References: HW-55900
HW-61447-RD
HW-73265-RD
Incident #: KE-3
Facility Name: KE Reactor
Date of Event: January 31, 1960
Event: KER Loop #2 Rapid Depressurization
Event Type: Equipment/Maintenance Failure
Significance Rating: 3

Description: On January 31, 1960, both diaphragms in the air-operated dump valve of the 1706-KER Loop #2 failed, causing the valve to open the high-pressure, high-temperature loop to atmospheric pressure. (A similar incident occurred in 1706-KER Loop #1 on June 28, 1959—see incident KE-2.) It was estimated that boiling occurred in the process tube for about 2.5 min during the depressurization transient. The maximum fuel element surface temperature was estimated to have been no greater than the pre-incident value of 310 °C. An analysis indicated that the thermal stresses in the process tube during the incident were not severe enough to cause concern about the integrity of the tube.

Implications: Safety of workers was not threatened. Maintenance and replacement of old diaphragms on all KER loops was indicated.

Disposition: It was recommended that the loop be returned to recirculation operation following successful completion of a standard pressure test. The failed neoprene diaphragms were found to be severely damaged by rotting and they were replaced.

References: HW-64443
Incident #: KE-4

Facility Name: KE Reactor

Date of Event: March 19, 1960

Event: Loss of Power to 2 of 5 Pumps, Scramming Reactor

Event Type: Power and Equipment/Maintenance Failure

Significance Rating: 3

Description: An attempt was made to start a high-lift process water pump at 190-KE. When the breaker supplying the pump motor was closed, a 13.8-kV bus was tripped off, and power to two of the five other primary pumps was lost. The remaining three pumps went into cavitation. The reactor scrammed from a flow monitor low trip. The pumps were shut off and put back on line at a lower speed to eliminate cavitation. An investigation determined that the incident leading to the electrical failure was caused by using improper size studs in the grounding device during repair.

Implications: No reactor damage resulted from the incident. However, loss of the primary coolant supply must be regarded as a serious event although two levels of backup are provided for such occasions.

Disposition: A change in procedures was recommended to prevent future occurrences.

References: HW-64624
HW-64767
HW-73265-RD
Incident #: KE-6
Facility Name: KER-1 Loop, KE Reactor
Date of Event: January 19, 1961
Event: Loss of Cooling to KER-1 Loop
Event Type: Equipment/Maintenance Failure
Significance Rating: 3

Description: The front-face thermocouple of KER Loop 1 failed, causing a reactor scram, reduction in system pressure, and boiling in the process tube before the dump valve was opened. Upon examination of control room charts and discussion with staff, it was concluded that the fuel in the loop was not damaged.

Implications: Safety systems worked normally, and no additional damage resulted.

Disposition: It was recommended that the fuel not be discharged since there was no indication of fuel overheating.

References: HW-68229
Incident #: KE-7
Facility Name: KE Reactor
Date of Event: January 12, 1963
Event: Failure of a Front-Face Nozzle Scrammed Reactor
Event Type: Equipment/Maintenance Failure
Significance Rating: 3

Description: KE Reactor was scrammed on January 12, 1963, by a low trip on flow monitor gauge 1162-KE. The outage resulted when the front-face nozzle of tube 1162 was completely fractured. Investigation led to the conclusion that the most probable cause was upward movement of the C platform striking a spline inserter that was inadvertently placed and left on the nozzle.

Implications: Under less favorable conditions the fuel charge might have been ejected onto the work area. It was estimated that under the existing conditions a rear-to-front flow condition probably did exist with a rear header pressure of about 20 psi.

Disposition: The broken nozzle was replaced. Operation resumed at 6:00 a.m. January 13, 1963. Several operational changes were recommended to prevent and/or mitigate accidents of this type.

References: HW-76354
HW-76431
Incident #: KW-3

Facility Name: KW Reactor

Date of Event: February 5, 1958

Event: Low Flow on Crossheaders

Event Type: Cooling Anomaly

Significance Rating: 3

Description: KW personnel were completing a charge-discharge on February 5, 1958. Upon removing the front-face cap from an empty tube, 0260, it was found that there was no water on the tube. The by-pass valve controlling water from row #02 was found to be essentially closed. Water was returned to the crossheader and the outlet temperature rose to 75 °C. Immediately thereafter, the flows to adjacent crossheaders were measured. Flow monitor readings lower than 20 in. of water pressure (instead of the required 26 in.) were found on crossheaders #3, 4, 5, 6, and 7. Water flow was returned to the crossheaders and outlet tube temperatures measured again. Only row #3 showed a temperature rise. It showed temperatures as high as 30 °C instead of the expected temperature of 15 °C.

An investigation of the incident indicated that no fuel damage had occurred and that it would be safe to start up on schedule. The incident was caused when the "telltale" lines were erroneously valved shut following charge-discharge. The telltale lines on each crossheader are used to determine when the crossheader water pressures are equal to the required 26 in.

Implications: If the low-flow condition had not been discovered and corrected, the fuel and tube could have been damaged.

Disposition: A number of recommendations were made for changes to the procedure for maintaining the necessary flow on crossheaders during charge-discharge.

References: HW-54983
Incident #: KW-6
Facility Name: KW Reactor
Date of Event: March 8, 1961
Event: Flux Perturbation During Attempted Shutdown
Event Type: Operator Error/Power Anomaly
Significance Rating: 3

Description: Plans were made to shut down the reactor with HCRs and to insert only one VSR to permit a rapid recovery. The operator attempted to shut the reactor down by more fully inserting two half-rods. Only the tips of the half rods are strongly poisonous. Hence, driving the rods all the way in actually increased reactivity.

When the half rods were further inserted, a temperature monitor trip was obtained on tube 2186 KW. While efforts were made to take corrective action, the alarms on a number of other tubes were also received, and the reactor scrambled on a high tube temperature trip.

The incident was caused by the operator failing to remember the effect of using half rods to shut the reactor down. No reactor damage resulted from this incident.

Implications: While personnel errors are to be avoided to the maximum degree possible, such mistakes are sure to happen occasionally. The incident points out the effectiveness of safety alarms and shutdown devices.

Disposition: This survey did not identify specific measures resulting from this event.

References: HW-68939-RD
HW-73060
HW-73265-RD
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<thead>
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<th>Incident #:</th>
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<td>Facility Name:</td>
<td>KW Reactor</td>
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<tr>
<td>Date of Event:</td>
<td>April 24, 1963</td>
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<tr>
<td>Event:</td>
<td>Inadvertent trip of a primary pump with activation of emergency steam turbine pump and ECS backup diesel system.</td>
</tr>
<tr>
<td>Event Type:</td>
<td>Partial ECS Trip</td>
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<tr>
<td>Significance Rating:</td>
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</table>

**Description:**
On April 7, 1963, at approximately 11:30 p.m., the reactor was shut down and being supplied by two pumps. Procedurally, one of these pumps was to be taken off-line, leaving one pump to supply the normal shutdown flow. The discharge valve of one pump was closed preparatory to shutting the pump off. However, through operator error, the wrong pump was shut off, leaving virtually no pumps on-line to supply the reactor. The action of the decaying line pressure on a pressure switch resulted in starting of three emergency diesel pumps and a steam turbine pump. Flow was never completely removed from the reactor due to the automatic start of these pumps. No damage to the fuel or reactor occurred.

**Implications:**
Loss of coolant by a single procedural error occurred. Procedures should be changed to reduce the chance that this can happen again. The emergency backup system worked as designed to prevent any damage.

**Disposition:**
Recommendations resulting from an investigation of this incident were to (1) revise the coolant shutdown procedure to eliminate, insofar as possible, the inadvertent total loss of coolant by a single procedural error, and (2) explore the personnel implications and take appropriate disciplinary action.

**References:**
HW-78633
Incident #: N-1  
Facility Name: N Reactor  
Date of Event: January 25, 1965  
Event: Partial Depressurization of Primary System  
Event Type: Equipment/Maintenance Failure  
Significance Rating: 3  

Description: On January 25, 1965, the reactor scrammed from 4000 MW because of a low-pressure trip, followed immediately by a pressurizer low-level trip. These were caused by a spurious opening of one of the two primary pressure relief valves (RV-2). The primary system pressure decreased rapidly from 1450 psig to 375 psig, and the liquid level in the pressurizer fell below the range of the instrumentation. All four injection pumps started correctly, and both pressure and level recovered to normal post-scram levels in approximately 2 min.

Examination revealed that the RV-2 valves were correctly set to relieve at 1650 psig, but that leakage through the spring-loaded pilot valves could build up enough internal pressure to trigger actuation before the system pressure reached 1650 psig.

Implications: The safety features of the primary loop control system functioned as designed to protect the reactor from sudden depressurization.

Disposition: New pilot valves of special design were installed, and the trip settings of the RV-2 valves were staggered to preclude simultaneous double valve opening upon failure of a pilot valve. No subsequent failures of this type were experienced.

References: RL-NRD-150-1
Incident #: N-2
Facility Name: N Reactor
Date of Event: January 24, 1966
Event: Loss of Recirculating Graphite Cooling Flow
Event Type: Personnel Error
Significance Rating: 3

Description: At about 9:55 a.m. on January 24 the GSCS systems dumped from recirculation to once-through cooling. The reactor was shut down manually from 9:55 to 10:37 a.m. This graphite system dump was caused by a draftsman tracing wires to update engineering drawings of the electrical circuits. He moved a loose wire attached to the graphite cooling system dump circuit, interrupting that circuit. The reactor was shut down manually to return the system to normal recirculation flow.

Implications: Inadequate supervisory control of plant activities. Working on critical control systems jeopardized plant and equipment safety.

Disposition: Procedures controlling access to critical circuits were adopted.

References: RL-NRD-660-1
Incident #: N-4
Facility Name: N Reactor
Date of Event: January 1970
Event: Control Rod Left in Reactor Without Cooling for a 26-Day Operating Period
Event Type: Procedure/Personnel Errors
Significance Rating: 3

Description: Control Rod 34 was taken out of service in July 1969 due to a coolant leak in the tip section. During an outage in November 1969, maintenance personnel inserted the rod tip into the reactor to reduce radiation levels in the inner rod room where they were working. This action was not reported to nor cleared through operations. The rod was not withdrawn to its full out position prior to reactor startup. Since the coolant was valved off, the rod became overheated during reactor operation and some melting occurred.

During a subsequent outage the rod was removed, the channel cleared, a new tip was installed and the rod was returned to service.

Implications: Damage caused by uncontrolled personnel actions resulting from deficient work control procedures.

Disposition: Control procedures revised.

References: DUN-6594
DUN-7545
UNI-785
Incident #: N-5

Facility Name: N Reactor

Date of Event: January 29, 1970

Event: Failure of Control Rods to Respond to Manual Control

Event Type: Equipment Failure/Personnel Error

Significance Rating: 3

Description: During a reactor startup, the control rod system failed to respond to manual control signals. The operator promptly shut down the reactor using the manual scram button. All the rods scrammed normally. Investigation revealed that breaker CS-29 had tripped open due to failure of a surge suppressor on control relay 8K4-1. The opening of CS-29 interrupted the "in-out" control function from the operating console. The surge suppressor was the wrong type for this service.

Implications: Failure of vital controls to respond as required demonstrated the importance of having alternate control functions available to neutralize single component failures.

Disposition: Proper equipment was installed and safety system circuits were inspected to assure that all installed components were proper for their intended use.

References: DUN-6594
DUN-7545
UNI-785
Incident #: N-8
Facility Name: N Reactor Radioactive Chemical Waste Handling Facility
Date of Event: June 27, 1972
Event: Piping Leak in Waste Handling Facility
Event Type: Ground Contamination by Contaminated Liquid
Significance Rating: 3

Description: On the 4-12 shift of June 27, 1972, following a reactor decontamination process, an operator making a routine surveillance of the 1310-N waste handling facility noticed liquid leaking into the pump house at the point where the recirculating pump discharge line passes through the concrete building wall. This pipe runs underground from the building to a point near the spherical waste tank, where it rises to enter the top of the tank. A failure in the underground section of this pipe caused discharge of radioactive chemical waste from the tank to the ground.

Implications: It was estimated that about 90,000 gal (10% of the liquid in the tank) leaked to the ground. This discharge contained approximately 35 Ci, of which 26 Ci was $^{60}$Co. The potential existed for more extensive leakage. Failure of operating personnel to recognize the significance of the lowering tank liquid level over a period of several days contributed to the volume of liquid waste lost to ground.

Disposition: Recirculation of liquid was stopped until permanent corrective action to stop the leak was completed. Operating personnel were instructed in the proper way to monitor tank liquid level.

References: UO-72-006
Incident #: N-9

Facility Name: N Reactor

Date of Event: October 23, 1972

Event: Failure to Maintain Tempered Water Supply for Emergency Cooling System

Event Type: Equipment/Maintenance Failure

Significance Rating: 3

Description: On October 23, 1972, with the reactor operating, water was inadvertently drawn from the Emergency Cooling System (ECS) tempered water storage tank until the tank was nearly empty. Failure to maintain an adequate supply of tempered (i.e., warm) water for the ECS violated Process Standard.

During this occurrence, two high-lift pumps were in operation as required by process standards, while the third was out of service for routine equipment checks. The cause of the water loss was diversion of water from the pump discharge header to the drain via the No. 3 pump jacket cooling water system, through two jacket water flow control valves which should have been closed with No. 3 pump shut down. The gradual loss of water was not detected for about 4 hours until an ECS pump discharge gage in the 105-N Control Room dropped to about half its normal value. Two level indicators that monitor tank level had failed.

Implications: Tempered water was not available to minimize thermal stress on piping components if emergency reactor cooling had been required. However, the low-lift pumps at 191-N Building were on standby (automatic start) and could supply adequate cold water flow to the high lifts in the event that the ECS actuating circuits were tripped.

Disposition: An investigation report was prepared listing ten corrective actions that were to be carried out to prevent reoccurrence of the event. These included both equipment maintenance and training items.

References: UNI-785
UO-72-025
Incident #: N-10
Facility Name: N Reactor
Date of Event: May 23, 1973
Event: Failed Valve Bushings; Debris in Cooling System
Event Type: Equipment/Maintenance Failure
Significance Rating: 3

Description: During a routine steam generator inspection with the reactor shut down, numerous metal fragments were found. These were found to be from stellite bushings of the CV-3 and PCSV-202 valves. The debris consisted of about three dozen pieces of magnetic and non-magnetic metallic fragments which varied in size from approximately 0.5 to 2.5 in. in maximum dimension.

Implications: There was no indication of check-valve malfunctioning. A nuclear safety evaluation was made of the effect of unrecovered material being left in the primary loop. It was concluded that this would not cause complete or near-complete loss of flow to one or more process tubes, and on this basis, the reactor was safe to operate.

Disposition: New bushings and shafts were installed in the 16 CV-3 valves and the six PCSV-202 valves. Three of the CV-5 valves, which have similar components, were inspected and found to be in excellent condition.

References: UNI-138
UNI-785
UO-73-016
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<td>N Reactor</td>
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<tr>
<td>Date of Event:</td>
<td>June 12, 1973</td>
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<tr>
<td>Event:</td>
<td>Fire in Relay Panel PR-39 (Reactor Power Setback Controls)</td>
</tr>
<tr>
<td>Event Type:</td>
<td>Fire</td>
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<td>Significance Rating:</td>
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### Description:
During an extended outage, smoke detectors in the Room 6 electrical equipment room actuated the fire alarm in the 105-N Building and in the 609 Building fire station. Personnel located the fire in relay panel PR-39 and immediately extinguished it using portable CO₂ fire extinguishers. When Fire Department personnel arrived, they confirmed that the fire had been extinguished.

The fire was in relay panel PR-39, which contains relays and other electrical gear for the reactor power setback controls. Inspection revealed that a plastic-covered relay about midway up in the vertical panel had overheated and ignited. Flames and smoke damaged relays and wiring above the relay, and dripping resinous material may have damaged relays below the ignited relay. About 20 relays were involved.

### Implications:
Electrical circuits affected or potentially affected by the fire were de-energized. It was confirmed that removal of these circuits would not have an impact on the nuclear safety status of the reactor. Emergency Cooling System diesel-driven pumps were started and availability of reactor coolant from this source was confirmed. The reactor was in an extended scheduled outage, and was in a safe shutdown condition.

### Disposition:
The investigation committee recommendations to replace all damaged relays of the type that failed with a different type and to mark sockets to distinguish AC from DC were carried out. The damaged wiring and equipment were restored to normal, acceptance tested, and returned to full service status. Emergency procedures were reviewed and updated as necessary.

### References:
- UNI-138
- UNI-785
- UO-73-017
Incident #: N-12
Facility Name: N Reactor
Date of Event: December 7, 1973
Event: Delayed Detection of Fuel Failure
Event Type: Fuel and Equipment/Maintenance Failure
Significance Rating: 3

Description:
N Reactor was shut down at 2:07 a.m. on December 7, 1973, because of general fuel failure indications. At the time of shutdown the location of the failure had not been identified, but radiation levels at primary piping after shutdown confirmed that a failure had occurred. After first discharging another tube, the failed fuel element was found to be in Tube 2350. The end cap was separated from the upstream end of the failed element, and it was determined later that approximately 1.6 lb of uranium was missing. The 0.95% $^{235}$U Mark IV fuel had attained 41% (1009 MWd/T) of goal exposure.

Investigation of the rupture monitor system after shutdown revealed that the valve in the sample line for tube 2350 had been left closed following a backflush operation on its sample chamber following an indication of high radiation. Post-shutdown surveys revealed that radiation levels around the primary piping were from 3 to 10 times normal.

Implications: Approximately 220 Ci of $^{131}$I were contained in the 1.6 lb of uranium released to the primary coolant stream.

Radioanalysis samples of effluent water entering the 1301-N crib and of ground water entering the river from the crib indicated $^{131}$I concentrations on the order of 100 times the normal concentration. Some increase in discharges to the atmosphere was evident.

Disposition: Six permanent corrective action items were identified. These included: tightened operational procedures, additional fuel failure monitoring, additional training, evaluation of release of radioactive materials as a result of this incident, and a study of ways to minimize future releases.

References: UNI-138
UO-73-53
Incident #: N-13

Facility Name: N Reactor

Date of Event: July 29, 1977

Event: Total Loss of BPA Power While Returning "A" Bus to Service Following a Maintenance Outage

Event Type: Power Failure

Significance Rating: 3

Description: The N Reactor "A" Bus was being returned to service following a scheduled maintenance outage in accordance with written procedures. However, the procedure was altered so that the "A" Bus could be fed from the K-N Tie Line instead of from the main 230 kV source. At 6:09 a.m., while loading "A" Bus in preparation for a scheduled "B" Bus outage, the feeder breaker was tripped by a faulty reverse power relay designed to protect the turbine generator from exporting too much power. At 6:13, the Substation Operator, attempting to restore service, opened the bus tie breaker, briefly interrupting all BPA power to 100-N. Then the bus tie breaker and the feeder breaker were closed feeding K-N Tie Line power to both "A" and "B" Bus. At 6:25 a.m., the feeder breaker tripped again (probably due to starting a river pump). At this time the 230 kV source breaker was closed, the K-N Tie Breaker was opened, and the feeder breaker was closed. This restored power to A Bus, but momentarily caused power to be lost to B Bus. A stable power condition was then established with both A and B Buses fed from the 230 kV loop.

Implications: During this period, N Reactor coolant pumps were being powered from A Bus. The diesel powered ECS was on standby but not called on to actuate. The 105-N Control Room Supervisor timed the coolant flow stoppage and reported it to be 5.5 min the first time and 4 min the second. The allowable flow interruption time was 13 min. The pressurizer level dropped from 23 to 20 ft and the bulk outlet coolant temperature rose about 3 °F.
Incident #: N-13, Continued

Disposition: Power was restored, and normal coolant flow was established. An evaluation was made that no equipment was damaged. The cause of the incident was determined, and the reverse power relay for the breaker was bypassed. N Plant Operations and maintenance personnel were instructed to coordinate maintenance activities more closely with substation personnel.

References: UO-77-26
Incident #: R-1
Facility Name: All 100 Areas
Date of Event: April 6, 1962
Event: General Power Loss to 100 Areas
Event Type: Power Failure
Significance Rating: 3

Description: Power to all the 100 areas was interrupted for approximately 2.5 min at 3:09 p.m. on April 6, 1962. Instrumentation indicated that a double phase-to-ground fault occurred in the No. 3 line and travelled back into the Midway Substation. The fault was "seen" by breaker relaying on the No. 1 line at 151B and the No. 2 line at 151F which tripped the breakers. All the reactors shut down safely, and reactor cooling was maintained without interruption by the secondary cooling systems. This was the only event where all electrical power was lost to all the reactors.

Implications: No damage resulted. This demonstrated the reliability of safety back-up systems.

Disposition: An investigation report of the 230-kV power outage was completed and forwarded to the AEC on May 4, 1962. The principal recommendation for immediate action was the replacement of all GCX-15 relays installed in the HAPO transmission system.

The General Electric Co. Technical Hazards Council at New York requested that an independent audit be made of the HAPO electrical transmission and distribution system as a result of the power failure incident of April 6, 1962.

References: HW-73473
HW-73528
HW-74499
Incident #: PRTR-1
Facility Name: Plutonium Recycle Test Reactor
Date of Event: November 9, 1961
Event: Stoppage of Coolant Flow for 3 Hours During Shutdown
Event Type: Coolant-Flow Stoppage
Significance Rating: 3

Description: On November 9, 1961, during low-flow shutdown conditions, a helium vaporlock occurred in the primary-coolant pump, which resulted in a stoppage of primary-coolant flow to the reactor for about 3 hours. The reactor had been shut down for 9 days at the time of the incident. No damage to the fuel elements or reactor resulted.

Implications: If the low-flow conditions had continued for a longer time, complete exposure of the fuel and subsequent fuel-element melt would have been possible. If the same incident had occurred more closely following shutdown from equilibrium operation, and if the incident had continued for a few hours longer, some melting could have occurred.

Disposition: Further operation was suspended until low-flow instrumentation and procedures for use were installed. Improvements were made to the pump venting system. Several design reviews were initiated to reduce the chance of recurrence of a similar incident.

References: HW-72001
Incident #: L-7
Facility Name: Z Plant Analytical Laboratory, 234-5Z, 200 West Area
Date of Event: November 19, 1968
Event: Contamination Spread
Event Type: Radiation Exposure
Significance Rating: 3

Description: A plutonium contamination occurred on November, 19, 1968, at an employee's work station, Hood #1 in Room 156 of the Z Plant analytical laboratory. The contamination went undetected over a shift change. As a result, minor contamination spread to the women's locker room and beyond. Follow-up surveys included 14 private residences.

Implications: The spread occurred because surveys were not made at work stations as required, and complete personnel contamination surveys were not performed at shift end.

Disposition: Minor clothing contamination was found in three instances. Lung counts of the three employees most closely involved showed no significant lung deposition. No off-plant contamination was found.

References: ARH-310-Section J
Incident #: S-1
Facility Name: T Plant, 221T, 200 West Area
Date of Event: March 1946
Event: Personnel Contamination
Event Type: Radiation Exposure
Significance Rating: 3

Description: The waste line from the diversion box in the T Plant to the diversion box in the U Plant was clogged after some active waste had been put through. In an attempt to unplug the line, an air hose was used to apply air pressure at the U Plant end of the line. The air connection was broken without first reducing the air pressure. Active waste was sprayed on one man's face and on his clothing. His contaminated clothing was removed immediately, and he was rushed to a shower. Readings taken on his face and hands indicated exposure levels of 25 rep/hour and 50 rep/hour, respectively. Exposure time was a maximum of 5 min and total estimated exposure was 2 rep to face and 5 rep to hands. Urine samples later indicated probable deposition of 0.1 μCi internally. No radiation effects were observed and none would be expected from the levels involved. Surrounding ground and a crane were grossly contaminated.

Implications: Radiation contamination due to unsafe action taken by employee, with potential for excessive exposure.

Disposition: Contaminated earth was removed for burial and the equipment was decontaminated. The employee was monitored for after-effects with negative results. Procedures were changed, and the plugged line was successfully cleared.

References: HW-7-3751
Incident #: S-3

Facility Name: Plutonium Fabrication, 234-5Z, 200 West Area

Date of Event: February 28, 1952

Event: Puncture Wound and Plutonium Contamination of Right Hand

Event Type: Plutonium Contamination

Significance Rating: 3

Description: A routine bioassay urine sample obtained from a construction employee on April 15, 1955, revealed results above the detection limit. Extensive sampling confirmed the initial indication of a deposition of soluble plutonium of about 100% of the maximum permissible limit (MPL). Although a review of his work in construction did not indicate any association with plutonium work, he had earlier worked in the 234-5Z Building. A review of radiation survey log sheets showed that the employee punctured a hood glove and a surgeon's glove on February 28, 1952, while performing maintenance in Hood 8 in Room 229 of the 234-5 Building. The employee later stated that he received the injury from sharp steel bristles on a brush he was using in the hood. A spot of contamination of 2,000 d/m was observed on his hand. The spot was readily removed to below the detection level. The survey log does not mention any wound, so it is presumed that no one in Radiation Monitoring suspected a skin puncture at this time. A survey on March 3, 1952, revealed about 500 d/m of contamination in the same general area and a small scab was observed. Follow-up surveys were all below the detection level and the employee was released.

The quantity of plutonium initially deposited is estimated to be 0.048 μCi, which is 120% of the MPBB. In August 1962 this was estimated to have been reduced by excretion to 0.0432 μCi, or approximately 110% MPBB of soluble plutonium.

Implications: This incident appears to reflect a lack of understanding by the employee that plutonium can enter the body through a minor wound and the seriousness of the consequences.

Disposition: The amount of plutonium contamination in the employee was measured periodically, once the contamination was detected.

References: HW-38428
### HANFORD PROCESS REVIEW DATA SHEET

<table>
<thead>
<tr>
<th>Incident #</th>
<th>S-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facility Name:</td>
<td>REDOX Plant, 202-S, 200 West Area</td>
</tr>
<tr>
<td>Date of Event:</td>
<td>November and December 1952 plus June and September 1953</td>
</tr>
<tr>
<td>Event:</td>
<td>Contamination of REDOX Swamp and 207-S Basin in 200 West Area</td>
</tr>
<tr>
<td>Event Type:</td>
<td>Contamination</td>
</tr>
<tr>
<td>Significance Rating:</td>
<td>3</td>
</tr>
<tr>
<td>Description:</td>
<td>Process tank coil and jacket failures were a persistent problem in the canyon buildings. Several such failures in 1951 and 1953 combined to produce excessive contamination of the REDOX cooling water basin and pond. In November 1952, the steam coil in the REDOX D-12 Waste Concentrator failed, releasing contaminated water to the 207-S Basin and then to the 216-S-17 Pond, referred to as the REDOX Swamp. The following month the REDOX H-4 Oxidizer Coil failed, resulting in a second gross contamination. The following June the D-12 concentrator coil failed again, adding to the contamination level. Then, in September, another H-4 Oxidizer coil leak created high radiation levels in the 207-S Basin and the swamp. Waterfowl were contaminated to levels up to 250 mr/hour.</td>
</tr>
<tr>
<td>Implications:</td>
<td>Uncontrolled spread of contamination to the environment.</td>
</tr>
<tr>
<td>Disposition:</td>
<td>Helium filled balloon &quot;scarecrows&quot; and a noise maker were used to discourage wildlife from entering the contaminated area. In April of 1954 the REDOX Swamp was covered by clean earth and posted.</td>
</tr>
</tbody>
</table>
| References: | ARH-780  
HW-26376-Del  
HW-26720-E  
HW-60807 |
Incident #: S-8
Facility Name: PUREX Plant, 202-A, 200 East Area
Date of Event: February 13, 1958
Event: Uncontrolled Chemical Reaction in Silver Reactor
Event Type: Chemical Explosion
Significance Rating: 3

Description: The primary function of the silver reactor in PUREX is to remove radio-iodine from the dissolver offgas vapors. An uncontrolled chemical reaction occurred in the bottom portion of the silver reactor in A Cell of the 202-A (PUREX) Building on February 13, 1958. The explosion occurred while the dissolver was essentially at rest, following a completion of the first dissolution step (coating removal). The reaction was presumed to be due to unstable products formed from the reaction of ammonia with silver salts. The source of the ammonia was either an ammonium hydroxide flush solution used to regenerate the reactor after extended use or the offgas from the coating-removal operation in the dissolver. The estimated loss was $75,700. There was no detectable spread of contamination to the environs.

Implications: Because the silver reactor is contained in a heavily shielded cell, the danger to personnel from an explosion is minimal. However, cleanup, repair, and recovery from this type of incident is very expensive.

Disposition: An investigation was conducted and recommendations were made to reduce the chance of this type of incident happening again. The recommendations included revision of operating temperatures, elimination of ammonium hydroxide from flushing solutions, and provisions to bypass the silver reactor during the coating-removal step.

References: HW-55223
UND-68-1
HANFORD PROCESS REVIEW DATA SHEET

Incident #: S-10
Facility Name: UO₃ Plant, 224-U, 200 West Area
Date of Event: December 1960
Event: Inhalation/Ingestion of Uranium
Event Type: Radiation Exposure
Significance Rating: 3
Description: An employee using a fresh air mask inhaled/ingested 7-12 mg (about 5000 μCi) of uranium. The air supply hose was blocked by condensate in the line and the mask was improperly adjusted. This was the highest recorded deposition at the U Plant.
Implications: Potential serious injury to employee. However, within 24 hours, 80% of the intake had been eliminated, reducing the body burden to 10% of the permissible level, and a subsequent whole body counter examination a week after exposure showed no detectable uranium.
Disposition: Corrective measures to prevent this type of incident included elimination of the cause of the condensate, revision of procedures to ensure a proper fresh air supply at all times, and retraining of personnel in the proper fitting and adjusting of masks.
References: HW-67954
HW-67985
Incident #: S-15
Facility Name: 221-U Canyon, 200 West Area
Date of Event: September 8-11, 1967
Event: Cask Insert Radiation Incident, N Reactor Fuel, 221-U Canyon
Event Type: Radiation Exposure
Significance Rating: 3
Description: Three employees received exposure in excess of that planned, and a fourth employee narrowly averted excessive exposure in the 221-U canyon when a supposedly empty fuel canister containing four irradiated fuel elements was removed from an NPR Cask Car.

On September 7, 1967, NPR Cask Car No. 945 was moved into the 221-U building, where the old cask insert was to be replaced with a new insert. On September 8, 1967, at approximately 12:30 p.m., the crane operator using the 75-ton shielded crane removed the four canisters from the cask and placed them on the canyon deck at Section 4. That afternoon, a utility operator making weekly fire and safety inspections traversed the length of the canyon. He did not take a dose rate instrument on this inspection of the canyon, but was wearing gamma pencil dosimeters. On September 11, two chemical operators and a radiation monitor entered the canyon, going to Section 5. The crane operator moved the fuel canisters to Section 5. When the last canister was moved, a high radiation level was noticed. The canister was placed in the empty pool cell, where it was found to contain four N Reactor fuel elements.

Implications: Gamma pencils worn by the utility operator making the September 8 fire and safety inspection indicated that the total dose to the wearer did not exceed 25 mr. Film badge readings for the three employees involved on September 11 showed estimated exposure for the day of 360, 320, and 300 mr.

Disposition: Recommendations were made to review, and revise as necessary, cask car procedures; to stress the importance of monitoring when opening any canister that has been used for transporting highly radioactive materials.

References: ARH-30
Incident #: S-16
Facility Name: PUREX Plant, 202-A, 200 East Area
Date of Event: November 14, 1967
Event: PUREX Sample Carrier Incident
Event Type: Radiation Exposure
Significance Rating: 3
Description: On November 14, 1967, a PUREX Operator grossly contaminated the cuff of his right protective coverall sleeve when placing the screw caps on a shielded sample carrier. As a consequence of repeated violation of the Standard Operating Procedure for sampling and the Radiation Work Procedures, the high-level contamination went undetected for 44 min, resulting in a maximum probable localized extremity exposure of 370 rem to 1 cm² of the skin and low-level contamination spread to non-Radiation Zone areas.
Implications: Possible serious overexposure to the staff member and spread of contamination resulted from failure to follow procedures.
Disposition: The contamination was removed from the operator and the low level contamination in the non-Radiation Zone was cleaned up.
References: ARH-233
WASH-1192
**HANFORD PROCESS REVIEW DATA SHEET**

**Incident #:** S-17

**Facility Name:** PUREX Plant, 202-A, 200 East Area

**Date of Event:** June 18, 1968

**Event:** PUREX Sampler Incident

**Event Type:** Radiation Exposure

**Significance Rating:** 3

**Description:** Radioactive liquid was sprayed onto an operator's coveralls at the left knee while he was observing the removal of an obstruction from the F-26 PUREX sampler riser on June 18, 1968.

The tip of a polyethylene pipette was broken off in the F-26 sample riser. The operator assigned to remove the tip obtained the assistance of a second operator and a radiation monitor. A decision was made to "float out the tip" using the installed water backflush system. The second operator positioned himself in front of the sampler to watch for the pipette tip emerging from the riser valve, while the first operator attempted to "crack open" the external water flush valve to provide a minimum flow of water to the system. The valve first stuck closed, and then opened suddenly, spraying liquid out of the riser. The spray was deflected from the roof of the sampler hood and out through the slots in the hood face onto the second operator. Knowing his coveralls were grossly contaminated, the second operator rapidly removed them with the assistance of the first operator. They proceeded to the SWP lobby where another survey was conducted.

**Implications:** The estimated exposure sustained by the second operator was determined from a study of the contaminated coveralls and from a time study of the undressing operation. The localized exposure to a small area near the left knee was 30 rads, and to the entire front surface from knee to ankle was 3.6 rads. These results were reported as a localized exposure and not as whole body nor extremity exposure.

**Disposition:** Decontamination of personnel was prompt and successful. Recommendations were made to develop methods and written procedures for safely removing obstructions from the sampler system; to train operators in removing obstructions; and to study the cause of pipette breakage and develop ways of eliminating pipette breakage.

**References:** ARH-723
Incident #: S-21
Facility Name: 241-S Tank Farm, 200 West Area
Date of Event: November 14, 1973
Event: 241-S Tank Farm Contamination Incident
Event Type: Radiation Release
Significance Rating: 3

Description: Feed solution from Tank S-107 located in the 200 West Area was being pumped through a 3-in. line into a 6-in. header and then into a 12-in. riser emptying down into Tank S-102. The reduction in velocity and the cooling that took place in the 12-in. riser allowed the buildup of salt cake until the riser totally plugged. The solution being pumped into the riser then sprayed out around the top flange, which was not adequately gasketed, flooding an area approximately 200 ft by 50 ft above the S-102 and S-103 tanks. A chemical operator in the 242-S facility noted the spray and turned off the Tank S-107 pump. Dose rates of 2.5 rads/hour at 4 in. from the liquid, 700 mrads/hour at 15 ft, and 12 mrads/hour at 150 ft were measured. Barricades were erected on adjacent roadways and the spill area was roped off. Investigation of the 12-in. riser on November 15, 1973, showed the riser to be plugged with 2 ft of salt.

Implications: Sixteen employees received a total of 3.5 R exposure as a result of the activities connected with the incident; however, none were exposed beyond the acceptable standards of radiation control.

No injuries to onsite or offsite personnel occurred as a result of the occurrence, nor was there any damage to property, other than the incremental contamination of the surface soil in the vicinity of Tanks S-102 and S-103.

Disposition: An Investigative Committee recommended that an engineering review be made to determine how to prevent similar spills; consistent practice related to the control of risers on underground tanks be established; and an engineering study be done to determine the proper device to be installed for early detection of any future spills. A review of transfer systems in the 241-S and 241-SX Tank Farms was conducted to determine if similar conditions existed elsewhere. A similar system was found on Tank S-103. The system was changed.
Incident #: S-21, Continued

References:
ARH-2907
ARH-2935
RL0-74-1
WASH-1192

2-136
Incident #: S-25
Facility Name: PUREX Plant, 202-A, 200 East Area
Date of Event: April 2, 1982
Event: Radioactive Nitric Acid Spill
Event Type: Radiation Release
Significance Rating: 3
Description: On April 12, 1982, a misrouting of dilute nitric acid solution during a routine transfer of liquid at the PUREX plant resulted in a 2500-gal spill which spread radioactive contamination into parts of the facility which are normally occupied by operating personnel. No radiation exposures to personnel above DOE limits resulted from the incident, and no airborne radioactive material was released to the environment. Operators were transferring solution from one tank to another through a header from which a jumper line had been removed in error. This provided a direct path for the acid leakage.

The incident was the result of a loss of configuration control.

Implications: Fortunately, the PUREX process was not in operation; otherwise risk to personnel may have been serious.

Disposition: Formally investigated by DOE with corrective actions that had to be completed before facility was started up.

References: IR-82-1
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3.0 HISTORY OF THE HANFORD PROJECT

The Hanford Project began in January 1943, when Colonel F. T. Matthias recommended and General Leslie R. Groves approved the selection of a large tract of land, including the towns of Richland, White Bluffs, and Hanford, as the site for nuclear reactors and chemical separation plants for production of plutonium for the Manhattan Project. This decision followed an accelerating series of scientific developments that had brought nuclear energy from a mere conjecture to an implemented program of immense magnitude. Some of the key events relating to the wartime Hanford Project are listed in Table 3-1.

3.1 PRE-HANFORD DEVELOPMENT

Although many other studies and observations (e.g., the discovery of radioactivity, X rays, electrons, and protons) had preceded it, Albert Einstein's announcement of his theory of relativity and the relationship of mass to energy in 1905 was a key step in pointing the way to an enormous potential new source of energy. The discovery of the neutron in 1932, followed in 1938 by the observation that a neutron could be captured by a uranium atom and cause that atom to divide into two atoms of lower atomic weight with the release of energy, provided a demonstration of Einstein's analysis. The further discovery that additional neutrons were released in the fission process suggested the possibility of a neutron chain reaction in uranium that conceivably could be used as a power source or even as a bomb.

World War II began in 1939. Although the United States was not yet a participant, the possibility that Germany might develop an atomic bomb was a great concern. At the request of other scientists, Einstein signed a letter to President Roosevelt, which was delivered in October 1939. The letter outlined the possibility that an enormously powerful bomb might be developed in time to affect the course of the war. It requested Federal support for nuclear research. The president quickly appointed an Advisory Committee on Uranium to investigate the possibilities, and government support was provided to a number of laboratories to explore various aspects of the problem.

In 1941, it was found that a new element, plutonium, was formed by neutron capture in uranium and that plutonium could also be caused to fission, opening another possible pathway to a nuclear explosive. Plans were already underway for accelerating the nuclear program and moving toward building one or more industrial-scale plants to produce material for a nuclear explosive when the bombing of Pearl Harbor caused the United States to enter the war in December 1941. This provided the impetus for even further accelerating the U.S. nuclear program.

There were several possible approaches to production of a nuclear bomb, all of which would require enormous technical effort and cost. The task of designing and constructing the necessary facilities was assigned to the U.S. Army, and the Manhattan Engineer District was formed in July 1942 to manage the program. After some initial confusion as to priorities and approaches, Colonel Leslie R. Groves was promoted to Brigadier General and placed in charge of the Manhattan Project, a position he held throughout the war.
<table>
<thead>
<tr>
<th>Date</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pre-Hanford history</strong></td>
<td></td>
</tr>
<tr>
<td>1905</td>
<td>Einstein relativity theory postulates convertibility of mass to energy</td>
</tr>
<tr>
<td>1932</td>
<td>Chadwick publishes discovery of neutron</td>
</tr>
<tr>
<td>1938</td>
<td>Hahn and Strassman announce neutron fission of uranium</td>
</tr>
<tr>
<td>09/02/39</td>
<td>Germany invades Poland--World War II begins</td>
</tr>
<tr>
<td>10/11/39</td>
<td>Einstein letter delivered to Pres. Roosevelt--says nuclear bomb may be possible</td>
</tr>
<tr>
<td>02/41 to 05/41</td>
<td>Seaborg announces discovery of plutonium, identifies properties</td>
</tr>
<tr>
<td>12/07/41</td>
<td>Japan bombs Pearl Harbor; United States enters war</td>
</tr>
<tr>
<td>07/17/42</td>
<td>Manhattan Engineer District (U.S. Army) established</td>
</tr>
<tr>
<td>09/23/42</td>
<td>General Groves given control of atomic project</td>
</tr>
<tr>
<td>12/02/42</td>
<td>Fermi et al. achieve first man-made nuclear chain reaction</td>
</tr>
<tr>
<td><strong>Site selection and construction</strong></td>
<td></td>
</tr>
<tr>
<td>12/21/42</td>
<td>Du Pont signed to construct/operate atomic plants under Manhattan Engineer District</td>
</tr>
<tr>
<td>01/01/43</td>
<td>Hanford Site recommended for plutonium plants</td>
</tr>
<tr>
<td>01/43</td>
<td>Du Pont begins reactor design at Wilmington</td>
</tr>
<tr>
<td>09/43</td>
<td>Construction starts at Hanford</td>
</tr>
<tr>
<td>07/44</td>
<td>Construction force level peaks at 45,000 workers</td>
</tr>
<tr>
<td><strong>Operation</strong></td>
<td></td>
</tr>
<tr>
<td>09/26/44</td>
<td>B Reactor critical and starts to power</td>
</tr>
<tr>
<td>10/09/44</td>
<td>T Plant completed (fuel reprocessing)</td>
</tr>
<tr>
<td>12/17/44</td>
<td>D Reactor critical</td>
</tr>
<tr>
<td>12/18/44</td>
<td>U Plant completed (fuel reprocessing)</td>
</tr>
<tr>
<td>01/25/44</td>
<td>First charge from B Reactor dissolved at T Plant</td>
</tr>
<tr>
<td>06/45</td>
<td>First shipment of plutonium to Los Alamos Lab</td>
</tr>
<tr>
<td>08/25/45</td>
<td>B Reactor critical</td>
</tr>
<tr>
<td>08/05</td>
<td>Enola Gay (Bomber) explosion at Hiroshima, Japan, uses Hanford plutonium</td>
</tr>
<tr>
<td>08/06</td>
<td>B Reactor critical</td>
</tr>
<tr>
<td>08/07</td>
<td>Enola Gay (Bomber) explosion at Hiroshima, Japan, uses Hanford plutonium</td>
</tr>
<tr>
<td>08/09/45</td>
<td>Tinutonium bomb explodes over Nagasaki, Japan</td>
</tr>
<tr>
<td>08/14/45</td>
<td>Japan surrenders and World War II ends</td>
</tr>
</tbody>
</table>
On December 2, 1942, Enrico Fermi and his group at the Metallurgical Laboratory achieved the first controlled nuclear chain reaction in a graphite pile in Chicago. This step demonstrated the scientific feasibility of producing plutonium in nuclear reactors fueled by natural uranium. The du Pont Company, which had already agreed to design and build chemical plants to separate plutonium from uranium fuel, also agreed to design and construct the required nuclear reactors. It had originally been planned to build the reactors at Oak Ridge, Tennessee, but the Oak Ridge site was neither large enough nor sufficiently isolated, and did not have an adequate source of cooling water. After a quick survey of possible sites across the United States, the Hanford Site was chosen for this key part of the program.

3.2 CONSTRUCTION AND EARLY OPERATION

The Manhattan Project activities would have represented challenging undertakings under any circumstances, but to carry them out on a wartime emergency basis without normal pilot plant scale testing or even design review represented enormous technical risks. That all of the approaches were successful is remarkable. The Hanford Project was an example of the pace of the entire programs. Reactor design began in January 1943 and construction started in March. By mid-1944 the construction force reached 45,000 workers. The first reactor began operation in September 1944, only 18 months after the start of construction. The first fuel reprocessing plant was completed in October 1944, processing began in December, and the first shipment of Hanford plutonium to Los Alamos took place in early February 1945. The first test of a plutonium weapon—the first nuclear explosion in history—took place at Alamagordo, New Mexico, on July 16, 1945. A uranium bomb, not directly involving Hanford, was exploded over Hiroshima, Japan, on August 6, 1945. The second plutonium bomb was exploded over Nagasaki, Japan, on August 9, 1945, and 5 days later Japan surrendered, ending the war.

3.3 POSTWAR OPERATING HISTORY

Hanford plans originally called for six reactors and four reprocessing plants. Three reactors (B, D, and F—the letters designating location, rather than any differences in design) and three reprocessing plants (T, U, and B) were completed initially. The U Plant was not needed, however, and was placed on standby in April 1945, after initial nonradioactive testing. It was later retrofitted to another process. Tank "farms" for temporary storage of radioactive waste pending development of permanent disposal methods were constructed at each processing plant site. A separate plant, the 231-Isolation Plant, was built to recover pure plutonium nitrate from the product streams of the reprocessing plants. These were the principal plants completed during the war. As the defense requirement for plutonium and other nuclear products continued and increased following the war, additional reactors and processing plants were built and operated. The Manhattan Engineer District was dissolved and its responsibilities transferred to the newly formed AEC on January 1, 1947. The following sections summarize the operating history of the Hanford facilities. Brief descriptions of the principal facilities are given in Section 4.
3.3.1 Production-Only Reactors

The first eight Hanford reactors were intended solely for the production of nuclear materials, principally plutonium, and no effort was made to use the energy produced. In contrast, the later N Reactor was designed as a dual-purpose reactor, producing both nuclear materials and steam for electricity generation. The operating histories of the Hanford production reactors are summarized in Table 3-2.

Table 3-2. Hanford Production Reactor Operating History.

<table>
<thead>
<tr>
<th>Reactors</th>
<th>Startup date</th>
<th>Shutdown date</th>
<th>Design power level (MW)</th>
<th>Maximum power level (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>09/26/44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>02/12/68</td>
<td>250</td>
<td>2090</td>
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<tr>
<td>D</td>
<td>12/17/44</td>
<td>06/26/67</td>
<td>250</td>
<td>2050</td>
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<tr>
<td>F</td>
<td>02/25/45</td>
<td>06/25/65</td>
<td>250</td>
<td>2040</td>
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<tr>
<td>H</td>
<td>10/29/49</td>
<td>04/21/65</td>
<td>400</td>
<td>2140</td>
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<tr>
<td>DR</td>
<td>10/03/50</td>
<td>12/30/65</td>
<td>250</td>
<td>2015</td>
</tr>
<tr>
<td>C</td>
<td>11/18/52</td>
<td>04/25/69</td>
<td>650</td>
<td>2360</td>
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<tr>
<td>KW</td>
<td>01/04/55</td>
<td>01/28/71</td>
<td>1850</td>
<td>4400</td>
</tr>
<tr>
<td>KE</td>
<td>04/17/55</td>
<td>02/01/70</td>
<td>1850</td>
<td>4400</td>
</tr>
<tr>
<td>N</td>
<td>12/31/63&lt;sup&gt;b&lt;/sup&gt;</td>
<td>01/06/87</td>
<td>4000</td>
<td>4800</td>
</tr>
</tbody>
</table>

<sup>a</sup>B Reactor was placed on standby on March 19, 1946, because of graphite distortion. It was restarted on July 2, 1948. This early problem is discussed in Section 4.1.2.

<sup>b</sup>N Reactor was made critical on December 31, 1963, but did not begin operating at its design power level until December 1964. Electricity-generating facilities were added later and dual-purpose operation began in 1966. N Reactor was shut down for safety upgrades on January 6, 1987, and later placed on indefinite standby.

The three initial reactors provided enough plutonium to produce the bombs used in the war. After the war, U.S. defense plans called for a large stockpile of plutonium, and a number of new reactors were built. In addition, the power levels of the existing reactors were greatly increased, as described in Section 4.

A graphite distortion problem threatened to cut short the operating life of the reactors, and B Reactor was placed on standby in March 1946. It was reactivated in July 1948, after the graphite problem was solved. The next three reactors built, H, DR, and C, were very similar to the original three. The DR Reactor was intended as a replacement for D Reactor, using a different type of graphite, but with the solution of the graphite problem, both continued to operate. The H and C Reactors were slightly modified to increase the number of control and safety rods. The final two production-only reactors, KE and KW, were significantly larger than the six earlier reactors.
3.3.2 N Reactor

All of the production-only reactors operated at low coolant temperature and pressure and were cooled directly by water drawn from and returned to the Columbia River. By the end of the 1950s, power reactor concepts were being developed, and the AEC was charged with supporting power reactor development as well as nuclear material production. Therefore, N Reactor was designed as a demonstration dual-purpose reactor, capable of producing both nuclear materials and steam for electricity generation. For this mission, N Reactor operated at high temperature and pressure, and its primary coolant was recirculated back to the reactor after being used to generate steam in a secondary coolant loop. The N Reactor began power operation in 1964. The electrical generating plant was added in 1966, and N Reactor was for a number of years the largest U.S. nuclear electric power producer.

As requirements for plutonium production decreased, the earlier production reactors were shut down, starting in December 1964. With the closure of KW Reactor in January 1971, only N Reactor continued to operate. The N Reactor was shut down for safety upgrades in January 1987 and later placed on indefinite standby.

As indicated in the table, all of the Hanford reactors were able to operate at well above their original design power rating, an eight-fold increase in the case of the earlier plants.

3.3.3 Reprocessing Plants

As with the reactors, the fuel reprocessing plants at Hanford have evolved, as summarized in Table 3-3. Initially, four separations plants were planned, and three (T, U, and B) were completed. However, only two were necessary, and the U Plant was placed on standby after initial testing on nonradioactive materials. A portion of the U Plant was later retrofitted to become the TBP Plant (see Section 4.3.5).

The early separation plants used the bismuth phosphate process, described briefly in Section 4, to separate plutonium from the uranium and fission products in the spent fuel. A plutonium purification plant, called the Isolation Plant, prepared purified plutonium nitrate, which was sent from Hanford to Los Alamos, where it was converted to plutonium metal for use in bombs. It was not until completion of Z Plant (now part of the Plutonium Finishing Plant) in 1949 that Hanford had the capability to produce plutonium metal onsite.

The bismuth phosphate process was chosen for the first processing plants because it was flexible, comparatively easy to scale up from laboratory results, and required relatively simple equipment. However, it generated large quantities of radioactive solids that had to be disposed of, involved a number of batch operations, and left all of the uranium and about 5% of the plutonium unrecovered. Solvent extraction processes were later developed that overcame these disadvantages. The REDOX solvent extraction plant was completed in 1952, and B Plant was shut down shortly thereafter, while T Plant continued operating for several more years. The UO₃ Plant, also completed in 1952, operated in conjunction with REDOX to recover and purify the uranium metal.
Table 3-3. Hanford Chemical Processing Plant Operating History.

<table>
<thead>
<tr>
<th>Plant name</th>
<th>Building number</th>
<th>Location</th>
<th>Function</th>
<th>Completed</th>
<th>Shut down</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>221-T</td>
<td>200-W</td>
<td>Plutonium recovery-bismuth phosphate process</td>
<td>10/08/44</td>
<td>03/56</td>
</tr>
<tr>
<td>U</td>
<td>221-U</td>
<td>200-W</td>
<td>Plutonium recovery-bismuth phosphate process</td>
<td>10/08/44</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>221-B</td>
<td>200-E</td>
<td>Plutonium recovery-bismuth phosphate process</td>
<td>02/10/45</td>
<td>08/52</td>
</tr>
<tr>
<td>Isolation</td>
<td>231-Z</td>
<td>200-W</td>
<td>Plutonium nitrate purification</td>
<td>01/45</td>
<td>01/57</td>
</tr>
<tr>
<td>Z(PFP)</td>
<td>234-5Z</td>
<td>200-W</td>
<td>Plutonium metal finishing</td>
<td>07/49</td>
<td></td>
</tr>
<tr>
<td>REDOX</td>
<td>202-5</td>
<td>200-W</td>
<td>Solvent extraction fuel reprocessing</td>
<td>02/52</td>
<td>12/66</td>
</tr>
<tr>
<td>UO₃</td>
<td>224-U,Ua</td>
<td>200-W</td>
<td>Uranium recovery and purification</td>
<td>04/52</td>
<td></td>
</tr>
<tr>
<td>TBP</td>
<td>221-U</td>
<td>200-W</td>
<td>Uranium recovery from bismuth phosphate residues</td>
<td>11/52</td>
<td>03/57</td>
</tr>
<tr>
<td>Recuplex</td>
<td>234-5Z</td>
<td>200-W</td>
<td>Plutonium recovery from waste and scrap</td>
<td>07/55</td>
<td>04/62</td>
</tr>
<tr>
<td>PUREX</td>
<td>202-A</td>
<td>200-E</td>
<td>Solvent extraction fuel reprocessing</td>
<td>/56</td>
<td></td>
</tr>
</tbody>
</table>

a The U Plant was not needed for the wartime mission, and after testing on a nonradioactive basis, was placed on standby. A portion of the plant was later retrofitted as the TBP Plant.
b Currently operable.
c The PUREX and UO₃ Plants were placed on standby in 1972, and were restarted in 1983 and 1984, respectively. Currently they are being placed on a standby status.
content of the irradiated fuel. At about the same time, a portion of the U Plant, which had never been operated, was converted to the TBP plant to recover uranium from the stored bismuth phosphate process residues. Uranium recovery had not been included in the original installations. The Recuplex facility was added to the Z Plant in 1955 to recover plutonium from waste and scrap material.

The PUREX Plant, using a somewhat different solvent extraction process than the REDOX Plant, was completed in 1956. It was later modified to enable it to process N Reactor fuel, and operated until 1972, when it was placed on standby. It was restarted in 1983, along with the UO₃ Plant and the Plutonium Finishing Plant. The UO₃ Plant also was shut down in 1972, and was restarted in 1984. The PUREX and UO₃ plants are being placed on a standby status, pending completion of an Environmental Impact Statement covering their use in Hanford Site restoration and possible other missions. The Plutonium Finishing Plant remains operable.

### 3.3.4 Operating Contractors

Hanford operating history is complicated by the large number of operating contractors that have been involved. A listing of the major contractors is provided in Table 3-4. This list includes only the contractors who managed the operations of Hanford nuclear facilities and does not include construction or service contractors.

In the table, reactor facility operation includes fuel manufacturing, and fuel reprocessing includes waste management. The Fast Flux Test Facility (FFTF) is included as a research and development rather than as a production reactor in Table 3-4.

As previously indicated, du Pont was the original contractor for the design and operation of all of the Hanford nuclear facilities. However, du Pont had accepted this assignment reluctantly and was determined to withdraw when the war emergency was over. Consequently, the General Electric Company (GE) was persuaded to take over the operation in September 1946 and continued until 1965, when GE expressed its intent to withdraw from the Hanford contract. The AEC decided to split the contract into a number of parts and invite separate bids for each. The facility operating contract was divided into the three major parts indicated in the table.

Isochem, Incorporated was formed to operate the chemical processing facilities in the expectation that a commercial market for radioisotopes would develop. When that expectation did not materialize, Isochem withdrew, and Atlantic Richfield Hanford Company assumed management of the chemical operations in 1967. Atlantic Richfield was replaced by Rockwell Hanford Company in 1977. Douglas-United Nuclear Corporation (DUN) was formed as a joint venture between Douglas Aircraft Corporation and United Nuclear Corporation to take over management of the production reactor operations. This transfer was accomplished in two phases, with GE retaining control over the operation of N Reactor until its power generation capability became operational in 1967. At that time, GE terminated its 21 years of Hanford operation. United Nuclear Corporation acquired Douglas' interest in DUN in 1973, changing the name of the entity to UNC Nuclear Industries.
### Table 3-4. Hanford Facility Operating Contractors.

<table>
<thead>
<tr>
<th>Contractor</th>
<th>Reactors</th>
<th>Reprocessing</th>
<th>Labs</th>
<th>Operating period</th>
</tr>
</thead>
<tbody>
<tr>
<td>du Pont</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>01/43-09/46</td>
</tr>
<tr>
<td>General Electric</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>09/46-11/65</td>
</tr>
<tr>
<td>PNL&lt;sup&gt;a&lt;/sup&gt;</td>
<td>x</td>
<td></td>
<td></td>
<td>01/65-Present</td>
</tr>
<tr>
<td>Isochem&lt;sup&gt;b&lt;/sup&gt;</td>
<td>x</td>
<td></td>
<td></td>
<td>12/65-09/67</td>
</tr>
<tr>
<td>DUN&lt;sup&gt;c&lt;/sup&gt;</td>
<td>x</td>
<td></td>
<td></td>
<td>11/65-04/73</td>
</tr>
<tr>
<td>ARHCO&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
<td></td>
<td>x</td>
<td>09/67-06/77</td>
</tr>
<tr>
<td>UNC Nuclear Industries&lt;sup&gt;e&lt;/sup&gt;</td>
<td>x</td>
<td></td>
<td></td>
<td>09/73-06/87</td>
</tr>
<tr>
<td>Westinghouse Hanford Co.-HEDL&lt;sup&gt;f&lt;/sup&gt;</td>
<td></td>
<td></td>
<td>x</td>
<td>07/70-06/87</td>
</tr>
<tr>
<td>Rockwell Hanford Co.&lt;sup&gt;g&lt;/sup&gt;</td>
<td>x</td>
<td></td>
<td>x</td>
<td>06/77-06/87</td>
</tr>
<tr>
<td>Westinghouse Hanford Co.&lt;sup&gt;h&lt;/sup&gt;</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>06/87-Present</td>
</tr>
</tbody>
</table>

<sup>a</sup>Battelle Memorial Institute assumed responsibility for management of the Hanford Laboratories which had been operated by General Electric. These were renamed Pacific Northwest Laboratories.

<sup>b</sup>Isochem, Inc. was a joint venture between the U.S. Rubber Company and Martin Marietta Company.

<sup>c</sup>Douglas-United Nuclear Corporation was a joint venture between Douglas Aircraft Company and United Nuclear Corporation. DUN assumed operation of the production-only reactors in November 1965, but GE retained operation of N Reactor until 1967.

<sup>d</sup>Atlantic Richfield Hanford Company, a subsidiary of Atlantic Richfield Corporation.

<sup>e</sup>United Nuclear Corporation acquired the 50% interest of Douglas Aircraft in DUN and formed a new subsidiary, UNC Nuclear Industries, to take over the reactor operating contract.

<sup>f</sup>Westinghouse Hanford Company was formed to manage Research and Development activities of the Hanford Engineering Development Laboratory as well as to design and operate the Fast Flux Test Facility.

<sup>g</sup>A subsidiary of Rockwell International.

<sup>h</sup>Upon consolidation, Westinghouse Hanford Company assumed the additional management of the operations previously performed by UNC, Rockwell, and HEDL.
In January 1965, Battelle Memorial Institute was given responsibility for operation of the Hanford Laboratories, which were renamed Pacific Northwest Laboratories.

A new activity was added in 1970, with the award of a contract to Westinghouse to design and manage the FFTF operations and its associated research and development laboratories.

The several operating contracts at Hanford were consolidated in 1987, and Westinghouse Hanford Company assumed management of the reactors, reprocessing plants, and the FFTF. Battelle expanded its management of research and development activities.

It should be noted that these changes in contractors did not result in significant disruption of activities, since in every case the great majority of employees merely transferred to the new operating contractor with no change in responsibilities or employment status. However, the contractor changes complicate the task of tracing project documentation.

3.4 REFERENCES


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4.0 DESCRIPTION OF HANFORD PROCESSES AND FACILITIES

This section presents a brief description of the Hanford facilities that were involved in incidents described in Section 2 and Appendix A.

4.1 PRODUCTION-ONLY REACTORS

The eight production-only reactors were all generally similar, but represented two generations of design evolution. Six reactors were originally planned, but only three (B, D, and F) were built initially, going into service in late 1944 and early 1945. Three additional reactors of similar design (H, DR, and C) were added in 1949, 1950, and 1951, respectively. Two larger reactors (KW and KE), representing second generation plants, began operation in 1955. Some design data for these reactors are given in Table 4-1. Operating dates for these plants are given in Section 3.

4.1.1 Reactor Description

All eight of the production reactors were graphite-moderated, water-cooled reactors, with coolant water drawn from the Columbia River, pretreated, and discharged back to the river via retention basins after a single pass through the reactor. Because of this once-through design, the reactors operated at low pressure and with a maximum outlet temperature of 95 °C.

The basic reactor design consisted of a large stack of graphite blocks forming an approximate cube about 30 ft on each side, surrounded by a 5-ft-thick layer of shielding. Several thousand 1.75-in.-diameter channels (2,004 in the case of the small reactors and 3,220 in the K Reactors) traversed the reactor from front to rear. Each fuel channel was lined with an aluminum process tube* into which a number of short, aluminum-clad metallic uranium fuel elements were charged. The fuel elements were supported and centered by two ribs formed into the bottom of the process tube, leaving a narrow annular space around the element for cooling water to flow. Cooling water was delivered by 10 electrically driven pumps to a system of risers and crossheaders distributing flow to each process tube. Fittings were provided at the front and rear face for fuel charge and discharge, and elevators at each face permitted access to all tube rows. Aluminum spacers or "dummies" were charged at each end of each fuel column to fill out the portion of the process tubes penetrating the reflector and shield. A simplified cutaway view of a production reactor is shown in Figure 4-1.

The first reactors were controlled by nine horizontal control rods (HCR) inserted into channels from one side of the stack and by 29 vertical safety rods (VSR) entering from the top. The number of HCRs and VSRs was increased in later reactors, including H and C, to give a wider range of control. The HCRs were used for operating control of power level and power distribution, while the VSRs were held outside the reactor to be inserted rapidly to shut down the reactor in an emergency. For a backup shutdown system in case the

*The K Reactors were later retubed with zirconium alloy process tubes.
Table 4-1. Reactor Core Data for Hanford Production Reactors.

<table>
<thead>
<tr>
<th>Graphite stack dimensions (core and reflector) (ft)</th>
<th>B</th>
<th>D</th>
<th>F</th>
<th>DR</th>
<th>H</th>
<th>C</th>
<th>KE</th>
<th>KW</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>33.5</td>
<td>33.5</td>
<td>39</td>
</tr>
<tr>
<td>Height</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>41</td>
<td>41</td>
<td>33</td>
</tr>
<tr>
<td>Width</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>41</td>
<td>41</td>
<td>33</td>
</tr>
<tr>
<td>Weight of graphite (tons)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderator</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1200</td>
<td>1700</td>
<td>1700</td>
<td>800</td>
</tr>
<tr>
<td>Reflector</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Lattice pitch (in.)</td>
<td>8.37</td>
<td>8.37</td>
<td>8.37</td>
<td>8.37</td>
<td>8.37</td>
<td>8.37</td>
<td>7.50</td>
<td>7.50</td>
<td>8.0 x 9.0</td>
</tr>
<tr>
<td>Material of process tubes</td>
<td>Al</td>
<td>Al</td>
<td>Al</td>
<td>Al</td>
<td>Al</td>
<td>Al</td>
<td>Al/Zr</td>
<td>Al/Zr</td>
<td>Zr-2</td>
</tr>
<tr>
<td>Number of horizontal control rods</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>20</td>
<td>84</td>
</tr>
<tr>
<td>Number of vertical safety rods</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>45</td>
<td>44</td>
<td>41</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>Number of ball channels</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>45</td>
<td>45</td>
<td>51</td>
<td>51</td>
<td>107</td>
</tr>
</tbody>
</table>
Graphite Reflector and Core

Detail of Graphite Stacking

Horizontal Control Rods

Vertical Safety Rods

Concrete Shielding

Front Face with Coolant Tubes

Charge Elevator

Control Room

Figure 4-1. Simplified Cutaway View of Hanford Production Reactor.
VSRs failed to function, the reactors were at first provided with a borated water injection system, which could rapidly fill the VSR channels with neutron absorbing solution. Later, when the reactor temperatures were raised to a level where borated water injection was not feasible, this system was replaced by one that would fill the VSR channels with borated steel balls.

Because the early reactors were required to operate with natural uranium, they had to be designed to provide maximum reactivity. This requirement dictated a high ratio of moderator atoms to fuel atoms. These reactors were therefore somewhat over-moderated, giving them a positive void coefficient of reactivity and a positive moderator temperature coefficient of reactivity. In addition, the number of control rods was insufficient to provide enough reactivity range to overcome xenon poisoning, which was a phenomenon not foreseen when the reactors were designed. These factors greatly complicated reactor control, as described in Section 4.1.4. Each process tube had a flow monitor gage at its inlet and a temperature monitor at its outlet. These were connected to reactor shutdown "scram" circuitry, so that improper conditions on a single coolant channel could shut down the reactor. Nuclear instrumentation in the biological shields and reflectors monitored the intensity of the neutron chain reaction, while bulk coolant flow and temperature measurements monitored total power.

4.1.2 Early Problem Areas

Several unforeseen problems arose in operation of the reactors. The two most significant, in that they threatened the operability of the reactors, were xenon poisoning and graphite expansion and distortion.

Xenon Poisoning--A few hours into the initial power run of B Reactor on September 27, 1944, operators noted that the power level began to decline. After about 14 hours, the reactor had shut itself down. It was first thought that coolant water had leaked into the pile, but that was found not to be the case.

A few hours after the shutdown, reactivity began to increase, and after about 12 hours the reactor power had regained its former level, but again declined. The physicists quickly deduced that a strongly neutron-absorbing fission product poison was responsible for the problem and identified it as $^{135}$Xe from the observed decay period.

In order to operate the reactor at power, it was necessary to load fuel into additional fuel channels, including channels that had not originally been connected to the coolant system. Full loading was not achieved until late December. Fortunately, the reactor had been conservatively designed with redundant channels, providing space for the additional fuel necessary to accommodate $^{135}$Xe poisoning. It was necessary to develop a complex startup procedure, including the use of temporary poison, to provide control from startup to equilibrium conditions. The startup procedure is described in more detail in Section 4.1.4.

Graphite Expansion--After about a year of operation, it was observed that graphite distortion was taking place from irradiation effects. Graphite block growth threatened to distort process tubes and rod channels and make the
reactors inoperable. The B Reactor was placed on standby in March 1946 to extend its life and assure some production capability in later years, while a program was undertaken to solve the problem. It was found that elevating the graphite temperature would anneal the radiation damage, partially reversing the distortion. The reactors originally operated with an inert helium atmosphere within the graphite moderator. The addition of \( \text{CO}_2 \) to the helium reduced heat transfer from the graphite sufficiently to raise its temperature and ameliorate the distortion. By late 1948, the reactors were operating with a 100% \( \text{CO}_2 \) atmosphere. Still later, as higher reactor power levels further increased graphite temperatures, the helium atmosphere was restored. These higher temperatures permitted continued reactor operation as long as their production was required.

4.1.3 Reactor Power Levels

The first reactors had a design thermal power rating of 250 MW. It was found that they were capable of operating safely at much higher power, given sufficient cooling. A number of design improvements were made over the years, including improved fuel metallurgy to minimize swelling and an annular fuel element design to increase the area available for coolant flow and improve fuel-to-water heat transfer. In 1956 and 1957, the coolant systems of the six smaller reactors were upgraded, greatly increasing coolant flow capability. As a result of all of these changes, power levels of these reactors were increased to just over 2000 MW, or more than eight times their initial rating. The larger K Reactors, which were initially rated at 1850 MW, were operated at up to 4400 MW.

The increased power level, along with increased fuel irradiation time, permitted greatly increased plutonium production. A side effect, however, was to increase the number of fuel element clad failures. No fuel elements failed in the reactors for about the first three years of operation (until May 1948). From 1951 to 1964, an average of about 140 fuel element failures occurred each year. The large number of fuel failures, together with techniques implemented for rapid discharge of failed fuel, contributed to a number of the incidents reported in Section 2 and the appendixes.

4.1.4 Hanford Production Reactor Control

Many of the production reactor incidents reported relate to control or reactivity anomalies or to problems with poison elements or poison splines. These situations arose as a consequence of the reactors' somewhat complex startup control requirements. This complexity was required to cope with xenon poisoning, a phenomenon that was not anticipated, and therefore not provided for, when the reactors were designed. A further complicating factor was the substantial positive graphite moderator temperature coefficient of reactivity.

The production reactors were controlled primarily by withdrawing or inserting HCRs containing neutron-absorbing material, to increase or decrease reactivity and thereby speed up or slow down the nuclear chain reaction. When the reactors were operating at a steady power level in a state of equilibrium, little or no control rod movement was required. However, reactor startup required rather complex operations.
A cold reactor would be brought to criticality and its power ramp-up started by first withdrawing the VSRs, followed by appropriate withdrawal of the HCRs. Because the reactors had a positive graphite moderator temperature coefficient of reactivity, the reactivity increased as the temperature of the reactor increased and it was necessary to begin reinserting the HCRs to avoid an excessive rate of power rise.

An even greater, although slower, transient reactivity effect was due to $^{135}$Xe, a high-yield fission product with an enormously high neutron absorption cross-section. Approximately 5.9% of uranium fissions produce an atom of $^{135}$Xe. Most of the xenon is not produced directly, but results from the radioactive decay of $^{135}$I, which has a half-life of 6.7 hours. The xenon itself decays with a half-life of 9.2 hours. Thus, if a reactor has been shut down for a few days, there is essentially no $^{135}$I or $^{135}$Xe present. When the reactor is started up, $^{135}$I is produced, decaying to $^{135}$Xe, so that the $^{135}$Xe concentration builds up slowly. After some hours, the $^{135}$Xe concentration reaches an equilibrium level, where its rate of production is balanced by its combined removal by neutron absorption and radioactive decay.

When a production reactor was started up after being shut down for a day or more, the net effect of the temperature and xenon transients was first to increase reactivity as the reactor heated up. However, as $^{135}$Xe accumulated, its effect outweighed the temperature coefficient, and reactivity would begin to decrease. "Turnaround" was the point at which control rod insertion to compensate for reactivity gains ceased and rod withdrawal began.

The total reactivity worth of the HCRs of the production reactors was not sufficient to both hold down the initial reactivity gain prior to turnaround following a long shutdown and to then maintain criticality when xenon built up. The addition of supplemental temporary neutron absorbing material, in the form of poison slugs replacing fuel in selected tubes, or, later, the use of poison splines inserted into selected tubes from the front face of the reactor, was necessary to provide sufficient control. After turnaround, the supplemental poison was removed. This required a brief shutdown in the case of the poison slugs, but was done with the reactor operating in the case of the splines.

When a reactor was shut down, xenon would continue to be generated from the decay of $^{135}$I, so the $^{135}$Xe concentration would first increase, reaching a peak several hours after shutdown, and then decrease, as the xenon continued to decay. As a result, if a reactor was to be restarted after a shutdown from power operation, it was necessary either to restart within about an hour or to wait at least 10 to 12 hours. This requirement led to techniques for quick failed-fuel discharges and restarts, which sometimes contributed to operating incidents. This quick discharge procedure was discontinued in 1958.

The N Reactor was provided with sufficient reactivity control that the use of temporary poison was not required.
4.2 N Reactor

Unlike the earlier reactors, N Reactor was planned as a dual-purpose reactor, to provide both plutonium production and electricity generation. The N Reactor is a graphite-moderated, pressurized light-water cooled reactor, designed for economic and efficient production of plutonium at up to 4000 MW of thermal power while supplying byproduct steam for the production of up to 850 MW of electricity. The reactor core is an 1,800-ton graphite cuboid approximately 33 ft square at the face and 39 ft long. The approximately 400 tons of reactor fuel is contained within 1,003 zirconium alloy pressure tubes that penetrate the core horizontally from front to rear. The fuel is slightly enriched metallic uranium, metallurgically bonded to a zirconium alloy cladding. The fuel is in the form of two concentric tubes which, with the pressure tube, provide an inner coolant passage and two annular coolant passages. The fuel pieces are supported and centered by spring clips or feet welded to the cladding. The pressure tubes provide the primary coolant pressure boundary that is provided by the reactor vessel in a commercial light-water cooled reactor.

Because of its dual-purpose mission, the N Reactor operates at an outlet coolant temperature of 525 °F and a pressure of 1600 psi, both much higher that the earlier production reactors. The primary coolant carries the heat generated in the fuel to six steam generator cells. The steam produced in the secondary coolant system is piped to an adjacent site for generation of electricity by the Washington Public Power Supply System. A portion of the steam is used to drive the reactor coolant pumps and a plant service generator for onsite AC electric power. Backup cooling systems and standby power sources are provided to assure safety and continuity of operation. Primary and secondary coolant systems are separate closed systems, providing protection against release of radioactivity to the Columbia River.

The N Reactor is controlled by 84 horizontal neutron-absorbing rods which enter the core from both sides, providing a much greater range of control than was available for the earlier production reactors. These rods also serve as the primary safety control, with each rod provided with a nitrogen-pressurized hydraulic accumulator for rapid insertion on a scram signal. An independent boron carbide ball safety system is provided to ensure safe shutdown of the reactor in case the safety rods fail to operate. The boron balls are stored in hoppers above the reactor and can be dropped by gravity to fill 107 vertical channels in the core graphite. Both the rod and ball safety systems independently provide sufficient reactivity control to maintain the reactor safely shut down.

For refueling, both the front and rear ends of the reactor pressure tube to be recharged are manually prepared by the removal of nozzle end caps and the installation of a tip-off fitting on the rear face and a charging adapter on the front. A monotube containing the fuel load for a designated reactor process tube is placed on the charging machine, which is mounted on a movable work platform. The charging machine aligns the monotube with the proper reactor pressure tube and inserts it through a barrier wall and into the charging adapter. The charge is then hydraulically driven into the reactor pressure tube, displacing the old charge. The discharged fuel, guided by the tip-off fitting, drops into a water-filled catch basin, from which it is transported underwater to storage basins.
As indicated in Table 4-1, N Reactor contained less graphite than the earlier reactors. The N Reactor was designed to be undermoderated so that it would have negative coolant and void coefficients of reactivity. This was accomplished by using graphite of a lower density and leaving more void volume in the core. This design also afforded an additional safety feature by providing space for steam discharge in case of a pressure tube failure. N Reactor also exhibited a graphite distortion problem, with the graphite blocks first shrinking and later expanding. Measures were developed, to extend reactor life including special fuel loadings to control flux distributions. It is estimated that N Reactor could continue to operate for at least 10 more years from the present.

N Reactor was first made critical on December 31, 1963. However, full power operation in the production-only mode was not achieved until December 1964. The electricity generation feature was added later, and first electrical production was on April 8, 1966. N Reactor operated safely and successfully until January 1987, when it was placed on standby to add a number of safety enhancements recommended by a series of review teams following the Chernobyl reactor accident of April 1986. Although the safety enhancement program was successful and largely completed, the DOE decided in late 1988 not to restart N Reactor but to place it on cold standby, which is its present status.

4.3 REPROCESSING FACILITIES AND WASTE DISPOSAL

Processing irradiated fuel for recovery of plutonium, and later other products, represents an undertaking equivalent to reactor operation. The highly radioactive nature of the fission products requires that all operations be carried out by remote control behind thick shielding. Equipment maintenance and repair must also be done remotely. The pyrophoric and toxic character of uranium and plutonium and the potential for inadvertent nuclear criticality add to the difficulties and hazards.

4.3.1 Bismuth Phosphate Process

The bismuth phosphate process was selected for the first processing plants because it was further developed than other approaches. It also had the advantage of flexibility and fairly straightforward scale-up from laboratory results. Other, more efficient processes were developed later. Each of the original processing plants was designed to include a separation building, where the bismuth phosphate process would be performed; a concentration building, where the plutonium would be separated from the phosphate carrier and other gross impurities; a ventilation building for disposal of hazardous gases from the process building; and a waste storage area, where the highly radioactive residues of the process would be stored for later treatment. A single isolation plant was constructed to perform the final plutonium purification process and prepare the plutonium product to be shipped to Los Alamos for reduction to metal.

The bismuth phosphate process consisted first of dissolving the fuel, including its aluminum jacket, in concentrated nitric acid. The plutonium was then separated from the other constituents by a series of precipitation and
dissolution steps. The process took advantage of the fact that plutonium can exist in different valence states, with tetravalent plutonium phosphate essentially insoluble and hexavalent plutonium phosphate soluble in appropriate carrier solutions. By successive oxidations and reductions combined with dissolutions and precipitations, the plutonium was separated from the bulk of the uranium, aluminum and fission products of the fuel. Bismuth was added as a carrier to increase the efficiency of the precipitation steps by forming a coprecipitate with plutonium. Final decontamination of the plutonium was accomplished in a separate concentration building by coprecipitation with lanthanum fluoride.

The separation buildings (221T, U, and B) were massive concrete structures more than 800 ft long, 65 ft wide and 80 ft high. A row of 40 concrete cells, typically 15 ft square and 20 ft deep ran the length of the building. Each cell was separated from its neighbors by 6 ft of concrete and covered by concrete blocks 6 ft thick. Along one side of the cell row and separated from it by 7 ft of concrete were three levels of operating galleries. The entire area above the cells was enclosed by a single gallery, or canyon, 60 ft high and running the length of the building. Once operation started, access to the canyon was only by a remotely operated crane, so that all equipment had to be designed for maximum reliability and easy interchangeability.

Since most of the fission products were removed in the separation building, the concentration buildings (224-T, U, and B) were much smaller, involved less shielding, and permitted direct maintenance. The single isolation building, 231-W, purified the plutonium by precipitating plutonium nitrate with hydrogen peroxide.

The offgases from the dissolver included nitrogen oxides, iodine, and the noble gases krypton and xenon. The nitrogen oxides were removed in scrubbing towers. During early operation, iodine was allowed to be released through tall stacks. In 1948, however, water filters were added, and in 1950, these were replaced by silver-nitrate-coated filters. These filters absorbed essentially all of the iodine, greatly reducing radioactive releases. The noble gases were released through the stacks after dilution with large volumes of air.

4.3.2 Solvent Extraction Processes

The bismuth phosphate process served the early needs of the project adequately. However, the large number of batch operations, the large quantities of radioactive waste to be disposed of, the absence of a process for recovering uranium, and the significant amount of plutonium unrecovered (about 5%) were limitations that were not desirable for long-term operation. As research continued, solvent extraction processes were developed that eliminated these deficiencies.

The solvent extraction processes are based on the fact that both uranium and plutonium can be put in valence states in which they are soluble in appropriate organic solvents, while in other valence states they are not. Since plutonium is more easily reduced than uranium, the solvent extraction processes have the ability to recover plutonium and uranium separately.
Because the organic and aqueous phases can be readily mixed and separated, the processes lend themselves to a continuous, multi-stage operation in extraction columns. By successive oxidations, reductions, extractions, and back-extractions, highly purified uranium and plutonium products are obtained.

The REDOX process used hexone (methyl isobutylketone) as solvent to extract hexavalent uranium and plutonium from the nitric acid dissolver solution. The organic product, after scrubbing to remove fission products that had been extracted, was then contacted with a reducing solution which removed the plutonium. The uranium was then stripped from the organic phase in a separate column.

Additional decontamination and treatment steps were required to provide products of the required purity and chemical form. A final plutonium purification was accomplished using an ion exchange process. Plutonium was absorbed onto an organic ion exchange resin in the extraction section of the contactor. Impurities were then removed from the plutonium-loaded resin by scrubbing with concentrated nitric acid, and purified plutonium was recovered in the stripping section with dilute nitric acid.

Although the REDOX process was a marked improvement over the precipitation process, the use of hexone as an extractant had several disadvantages. These included a flammability hazard because of hexone's low flash point and solvent losses because of its appreciable solubility in water and its instability in contact with concentrated nitric acid. The PUREX process, which uses a solution of tributyl phosphate (TBP) in purified kerosene (NPH) as extractant, overcame these difficulties.

In the PUREX process, the acid solution from the dissolver is treated with nitrite ion to put plutonium into the tetravalent state, which is the oxidation state most easily extractable with TBP. Both uranium and plutonium are then extracted preferentially from fission products and other metal ions in an extraction column. After scrubbing to remove more impurities, the organic product from the first column is contacted with a nitric acid solution containing a reducing agent. Plutonium is reduced to the relatively inextractable trivalent state and is stripped from the organic phase. Additional decontamination and treatment steps are used to obtain the final products.

4.3.3 Plutonium Finishing Plant (Z Plant)

The original processing facilities produced a purified plutonium nitrate product that was shipped offsite for reduction to metal. The Plutonium Finishing Plant (PFP), or Z Plant, was constructed and added to over a period of years to provide an onsite capability to produce other forms of plutonium, particularly plutonium metal and plutonium oxide, and to recover plutonium from sources such as scrap and waste solutions. The PFP currently can perform the following types of operations:

- Plutonium Handling--Reclaim and ship (onsite or offsite), assay, store, repackage
- Plutonium Reclamation—Reclaim from scrap material and waste solutions
- Plutonium Conversion—Convert plutonium solutions into oxide or metal
- Decontamination and Decommissioning—Decontaminate and package equipment and facilities for final disposal.

The first major structure of this complex was the 234-5Z Building, which began operation in July 1949. The original installation included the remotely operated mechanical A (RMA) line to convert plutonium nitrate solutions to plutonium oxide or metal. The 234-5Z facility also included analytical and developmental laboratories and storage vaults for a variety of plutonium forms packaged in metal containers. Other facilities added or removed over the years included:

- Recuplex waste recovery facility: Completed in 1955 and operated until 1962, when an inadvertent criticality (incident S-10) occurred. The Recuplex facility was then replaced by the safe-geometry Plutonium Reclamation Facility
- Remote Mechanical C (RMC) line: Completed in 1960 to convert plutonium nitrate solutions to plutonium metal and fabricate plutonium metal components
- Plutonium Reclamation Facility (PRF): Completed in the 236-Z Building in 1964 to recover and purify plutonium from aqueous fuel solutions and from various scrap materials
- Waste Treatment Facility: Completed in the 242-Z Building in 1964 to reduce the amount of plutonium disposed of as waste

Currently active facilities in the Z Plant include the RMC line, laboratories and storage facilities in the 234-5Z Building; the PRF and scrap treatment facilities in the 236-Z Building; and other storage and support facilities.

4.3.4 UO₃ Plant

Building 224-U was completed in 1944 as part of the U Plant complex but was found not to be needed. In 1951, 224-U was converted to the UO₃ Plant, to receive an impure uranyl nitrate hexahydrate (UNH) solution from REDOX and prepare a pure UO₃ product. An adjacent building, 224-UA, was constructed in 1957 with additional calciners to increase the UO₃ Plant capability. The UO₃ Plant now receives UNH from the PUREX facility via truck and produces a pure UO₃ powder for shipment offsite.
4.3.5 TBP Plant

The TBP Plant was completed in 1951 to recover uranium from the process wastes of the original bismuth phosphate process. The TBP Plant used a solvent extraction process with tributyl phosphate in kerosene as the solvent, to extract and purify the uranium. The plant was shut down in 1957 after completing its mission.

4.3.6 Waste Storage Tanks

Neutralized high-level radioactive liquid wastes from the various processing plants is stored in large single-shell and double-shell tanks in several "tank farms" in the 200 East and 200 West areas. One hundred and forty-nine single-shell tanks ranging in capacity from 55,000 gal to 1,100,000 gal were constructed between 1943 and 1964. These tanks are in the form of upright cylinders with mild steel walls and bases contained within reinforced concrete shells. The tank tops are ellipsoidal concrete domes covered with 6 to 9 ft of earth. These tanks are monitored by means of a constant surveillance system, including leak detection wells as well as liquid level, temperature and other measuring gages. A number of these tanks developed leaks, beginning in the mid 1950s. In consequence, all single-shell tanks are now inactive and all excess liquid has been or is in process of being removed.

The waste-storage function is now performed by 28 double-shell tanks of 1,000,000 gal capacity or more which were put into service between 1971 and 1986. These consist of carbon steel tanks inside carbon steel lined concrete shell. These tanks are covered by at least 6.5 ft of soil and are fully monitored. No leaks have been observed from any of the double-shell tanks.

4.4 REFERENCES


5.0 REFERENCES

The following pages include reference information for the incidents described in this report. The incident column identifies the incident or incidents described in each report.

The letters "RD" following a report number indicate that the report, as reviewed, was in draft form. The notation "Del" following a report number indicates that deletions were made in the report before its public release to conform to current classification or Privacy Act requirements.

References to Periodical and Unnumbered Reports. Some of the references are not numbered reports. They are gathered at the end of the references list under the following categories:

IR - Special investigative reports followed by a number indicating the year of issue or of the event.

NS - Nuclear Safety magazine, followed by the volume and number of the issue being referenced.

UND - Other unnumbered reports, followed by a number indicating the year of issue.
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<tr>
<td>HW-77552</td>
<td>Report of Accidental Whole Body Radiation Exposure Exceeding 3 Rems in a Calendar Quarter (Also identified as IR-63-20).</td>
<td>W. J. Ferguson</td>
<td>05/06/63</td>
<td>B-7</td>
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<tr>
<td>HW-77749-Del</td>
<td>Irradiation Processing Department Monthly Report, May 1963 (HAN-85394-Del)</td>
<td></td>
<td>06/14/63</td>
<td>KE-9</td>
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<tr>
<td>HW-78633</td>
<td>Investigation of Unusual Incident - Inadvertent Tripping of No. 3 Primary Pump at 165-KW</td>
<td>J. C. McLaughlin</td>
<td>04/24/63</td>
<td>KW-7</td>
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<tr>
<td>HW-79073</td>
<td>Environmental Effects of a Fuel Element Failure</td>
<td>R. B. Hall</td>
<td>09/27/63</td>
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<tr>
<td>HW-79802-RD</td>
<td>Unusual Incident - Power Level Rate of Rise, 105-DR Processing</td>
<td>A. E. Brown</td>
<td>11/27/63</td>
<td>DR-11</td>
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<td>HW-80387</td>
<td>Investigation Report - Exceeding Reactor Operating Limits</td>
<td>R. E. Dunn</td>
<td>11/26/63</td>
<td>C-6</td>
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<tr>
<td>HW-82143</td>
<td>Investigation of Mischarging Incident at H Reactor, April 1964</td>
<td>R. S. Bell</td>
<td>05/15/64</td>
<td>H-14</td>
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<tr>
<td>HW-82352</td>
<td>Investigation Report, H Reactor Mischarging Incident</td>
<td>A. P. Vinther</td>
<td>05/01/64</td>
<td>H-14</td>
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<td>HW-83000</td>
<td>Hanford Laboratory Operations Monthly Report, June 1964</td>
<td></td>
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<td>HW-83102-Del</td>
<td>Chemical Processing Division Monthly Report, June 1964</td>
<td></td>
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<td>HW-83457</td>
<td>Report of Accidental Plutonium Deposition Pt1-The Accident and Related Actions Pt2-Conclusions and Recommendations (Also identified as IR-64-37).</td>
<td>O. J. Wick</td>
<td>08/07/64</td>
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<tr>
<td>HW-84619</td>
<td>Summary of Environmental Contamination Incidents at Hanford, 1958-64</td>
<td>G. E. Backman</td>
<td>04/12/65</td>
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<tr>
<td>PNL-SA-7471</td>
<td>In Vivo Measurement of AM 241 in an accidentally Exposed Subject</td>
<td>H. E. Palmer</td>
<td>10/81</td>
<td>S-22</td>
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<tr>
<td>RHO-ST-1</td>
<td>Status of Liquid Waste Leaked from the 241-T-106 Tank</td>
<td>D. J. Brown, et al</td>
<td>02/87</td>
<td>S-20</td>
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<tr>
<td>RL-GEN 1300-6</td>
<td>Hanford Atomic Products Department Monthly Report, June 1967</td>
<td>W. J. Ferguson</td>
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<td>N-3</td>
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<tr>
<td>RL-NRD-150-1</td>
<td>N Reactor Monthly Report, January 1965</td>
<td></td>
<td>02/65</td>
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<tr>
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<td>Report of the Investigation of 241-S Tank Farm Contamination Occurrence at Hanford Reservation Richland, WA 11/14/73</td>
<td>P. S. Holsted et al</td>
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<td>R. D. Freeburg et al</td>
<td>01/78</td>
<td>N-14</td>
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<td>TID-5360</td>
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<td>D. F. Hayes</td>
<td>08/56</td>
<td>Several</td>
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<tr>
<td>TID-26431</td>
<td>Report of the Investigation of the 106-T Tank Leak at the Hanford Reservation</td>
<td></td>
<td>07/73</td>
<td>S-20</td>
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<tr>
<td>UNI-138</td>
<td>Annual Operating Report, Calendar Year 1972</td>
<td></td>
<td>02/15/74</td>
<td>W-10,11,12</td>
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<td>N Reactor ACRS Briefing Report, 1968 through 1976</td>
<td></td>
<td>06/87</td>
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<td>UNI-1961</td>
<td>Abnormal Occurrence 81-01. Loss of Instrument Air to N Plant Auxiliary Building December 1, 1981</td>
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<td>UO-73-017</td>
<td>DUN Unusual Occurrence Report - Fire in Relay Panel PR-39, Reactor Power Setback Controls, 6/12/73, Final Report</td>
<td></td>
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<td>UNI Unusual Occurrence Report - Delayed Detection of Fuel Failure, 12/07/73, Final Report</td>
<td></td>
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<td>UNI Unusual Occurrence Report - Failure to Clear Personnel From Zone 1 Prior to the Commencement of Charge Discharge, 1/18/85, Final Report</td>
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<td>02/05/85</td>
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<td>T. P. Vander</td>
<td>02/06/87</td>
<td>S-27</td>
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<td>C. L. Owen</td>
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<td>S-28</td>
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<td>Operational Accidents and Radiation Exposures within the USAEC 1943-1975</td>
<td></td>
<td>Fall 1975</td>
<td>Several</td>
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### Reference Data Base

**Hanford Process Review**

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<tr>
<td>WASH-1521</td>
<td>Radioactive Waste Evaporator and Auxiliaries</td>
<td>U.S. AEC, Richland, WA</td>
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| IR-80-1 | Report of Investigation of the February 27, 1980 B Plant Trench Accident | | 04/80 | S-23 |
| IR-86 | DOE Review Team Report to Manager, RL on CV-3 Valve and Related Problems with the N Reactor Primary System. | | 01/86 | N-17 |
| NS-2-4 (2) | Redox Multipurpose Dissolver Accident, Nuclear Safety Vol.2, No.4, P.136 | J. C. Bresee | 06/61 | S-9 |
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<tr>
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<td>J. R. Cartmell</td>
<td>12/06/68</td>
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APPENDIX A

DATABASE OF INCIDENTS IDENTIFIED
APPENDIX A

DATABASE OF INCIDENTS IDENTIFIED

The following pages give summary descriptions of 125 safety-related incidents that have occurred during Hanford nuclear process operation. Incidents are arranged first by facility and then in chronological order. Incidents are described more fully in Section 2. Reporting documents are identified more completely in the Section 5.
<table>
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<tr>
<th>Event No.</th>
<th>Date</th>
<th>Type</th>
<th>Description</th>
<th>Consequences &amp; Implications</th>
<th>RTG Document</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1</td>
<td>12/22/52</td>
<td>Radiation exposure/ Personnel error</td>
<td>Seven irradiated fuel pieces from tube 2484 B were ejected inadvertently. One lodged in the rear pigtail.</td>
<td>Moderate personnel overexposure and potential for severe exposure. Procedures changed to prevent recurrence.</td>
<td>2HW-26720</td>
</tr>
<tr>
<td>B-2</td>
<td>12/10/58</td>
<td>Startup anomaly</td>
<td>Startup with safety instruments bypassed.</td>
<td>Safety violation, no incident resulted.</td>
<td>3HW-73060</td>
</tr>
<tr>
<td>B-3</td>
<td>02/26/59</td>
<td>Radiation exposure</td>
<td>Discharge of poison elements onto work platform. (Elevator was moved while charging machine was connected).</td>
<td>Maximum Dose 40 mr</td>
<td>2HW-59457</td>
</tr>
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<tr>
<td>B-4</td>
<td>09/12/59</td>
<td>Equip/Maint failure</td>
<td>Reactor scram because screen plugged with Neoprene.</td>
<td>Gasket failed after removal delayed, and faulty strainers allowed plugging. No damage resulted</td>
<td>3HW-62052</td>
</tr>
<tr>
<td>B-5</td>
<td>02/02/61</td>
<td>Operator error</td>
<td>An operator in training withdrew a control rod, causing a minor surge in reactivity. A regular operator corrected error without scram. An alarm was out of order.</td>
<td>No damage</td>
<td>3HW-73060</td>
</tr>
<tr>
<td>B-6</td>
<td>2/61</td>
<td>Radiation exposure</td>
<td>An employee entered the supply air duct while the reactor was operating. He was exposed for 1-3 minutes to a high radiation field for a total dose of about 170 mv.</td>
<td>Potential high radiation exposure</td>
<td>3HW-68718-Del</td>
</tr>
<tr>
<td>B-7</td>
<td>04/17/63</td>
<td>Radiation exposure</td>
<td>During an attempt to remove a process tube containing a ruptured fuel element, an employee did not hear the monitor's advice to withdraw and continued work until a radiation alarm sounded.</td>
<td>The worker received 5 rem of radiation for the quarter, exceeding the quarterly limit of 3 rem.</td>
<td>2HW-77552</td>
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PRODUCTION REACTOR INCIDENTS
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<tr>
<td>C-1</td>
<td>03/02/60</td>
<td>Equip/Maint failure</td>
<td>Operated for 48 h with a safety rod No damage resulted in the reactor. A sticking rod was tied out instead of clamped out, and the rope broke. A limit switch was bypassed, so reactor did not scram as it should have.</td>
<td></td>
<td>HW-64268, HW-73265-RD</td>
</tr>
<tr>
<td>C-2</td>
<td>11/09/60</td>
<td>Contamination/Personnel error</td>
<td>Personnel, truck and cask were contaminated in removing irradiated sample material from a test hole and later in transferring the material from C Reactor to the 300 Area.</td>
<td>Contamination was spread</td>
<td>HW-67432, HW-67749, HW-68039-DeL</td>
</tr>
<tr>
<td>C-3</td>
<td>04/05/62</td>
<td>Multiple fuel failures</td>
<td>Unusual multiple fuel ruptures observed after two scram-recovery startups. In one case 2 ruptures and in the other 3 ruptures and 3 incipient ruptures.</td>
<td>Attributed to flux peaking and transients caused by enriched fuel loading around an overbore pattern.</td>
<td>HW-73483</td>
</tr>
<tr>
<td>C-4</td>
<td>10/09/62</td>
<td>Coolant interrupt./Personnel error</td>
<td>During a reactor outage, two cross-headers were valleyed off in error. The next shift discovered and corrected the error.</td>
<td>No damage resulted, but the potential for damage or personnel injury or exposure existed.</td>
<td>HW-75451</td>
</tr>
<tr>
<td>C-5</td>
<td>10/20/62</td>
<td>Startup anomaly</td>
<td>High tube temperature was observed during startup. Rupture indications led to discharge of tube 3857 and nearby tubes.</td>
<td>Fuel rupture apparently caused by high rate of rise and high coolant temperature.</td>
<td>HW-75600</td>
</tr>
<tr>
<td>C-6</td>
<td>11/20/63</td>
<td>Startup anomaly</td>
<td>Reactor operating limits were exceeded during a cold startup</td>
<td>Eight tubes were discharged, but no fuel or reactor damage resulted.</td>
<td>HW-80387</td>
</tr>
<tr>
<td>D-1</td>
<td>06/17/45</td>
<td>Power anomaly</td>
<td>The reactor scrammed from 80% power level. After restart, the power level was found to be 121% of the maximum level because a power level instrument was out of calibration.</td>
<td>Potential for exceeding an operating safety limit</td>
<td>HW-7-1981</td>
</tr>
<tr>
<td>Event No.</td>
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<td>Type</td>
<td>Description</td>
<td>Consequences &amp; Implications</td>
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<tr>
<td>D-2</td>
<td>07/46</td>
<td>Radiation exposure</td>
<td>During fuel discharge, several pieces lodged on an I-beam flange because the elevator had been set too low. It took 8 h to retrieve the pieces without significant radiation exposure.</td>
<td>Potential for excessive radiation exposure. Control circuits revised to assure proper elevator positioning for fuel discharge.</td>
<td>HW-7-4542</td>
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<tr>
<td>D-3</td>
<td>09/05/46</td>
<td>Reactivity anom./Equip failure</td>
<td>Reactor power reached 140% of normal when a rod hydraulic control switch stuck in the &quot;on&quot; position while a control rod was being withdrawn. Trip points were not exceeded.</td>
<td>This was an uncontrolled reactivity increase, but safety circuits would have shut down the reactor before damage occurred. Switches were upgraded.</td>
<td>HW-7-5194</td>
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<tr>
<td>D-4</td>
<td>01/06/56</td>
<td>Startup anomaly</td>
<td>During a cold startup, the predicted criticality was in error, and a power rise to 50 MW occurred in 1.5-2 min, with an estimated rising period of 4.3 to 15.7 s.</td>
<td>No damage resulted, but prompt action by operator was required to prevent probable damage (scram trips were improperly set).</td>
<td>HW-41006</td>
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<tr>
<td>D-5</td>
<td>06/20/59</td>
<td>Fuel discharge malfunction</td>
<td>Faulty valve on flushing machine caused several fuel pieces to lodge on rear catwalk and on a concrete pad.</td>
<td>Fuel pieces dislodged and dumped into basin over 4-day period.</td>
<td>HW-73265-RD</td>
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<tr>
<td>D-6</td>
<td>06/26/59</td>
<td>Startup anomaly</td>
<td>In startup, criticality reached before prediction. 5 tubes supposed to be loaded with poison pieces actually contained regular fuel.</td>
<td>Violation of total control criteria. No damage resulted. Reactor shut down and restarted properly.</td>
<td>HW-73265-RD</td>
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<tr>
<td>D-7</td>
<td>01/15/60</td>
<td>Equip/Maint failure</td>
<td>A High-lift pump failed on 1/15/60. Pressure decreases occurred and worsened. Reactor shut down on 1/25, and debris removed from screens.</td>
<td>The pump failure was apparently caused by debris left in the casing after modification. The debris in the system resulted from the pump failure.</td>
<td>HW-64140</td>
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<tr>
<td>D-8</td>
<td>2/61</td>
<td>Reactivity anomaly</td>
<td>Mechanical failure of rear face ball valve allowed 37 poison pieces to flush. Reactor scrammed by high reactivity trip.</td>
<td>Total reactor power increased 10-15%, local tube power 50-100%. No damage resulted.</td>
<td>HW-73265-RD</td>
</tr>
<tr>
<td>D-9</td>
<td>01/22/62</td>
<td>Coolant interruption</td>
<td>Temporary loss of coolant to empty PCCF tube, because low-flow valve position completely blocked flow.</td>
<td>No damage resulted, but had the potential for high radiation exposure.</td>
<td>HW-72405</td>
</tr>
<tr>
<td>DR-1</td>
<td>10/03/50</td>
<td>Reactivity anomaly</td>
<td>During initial startup, the reactor became critical on a 13-16 s period, when VSRs were withdrawn. High reactivity resulted from miscalculation of initial loading.</td>
<td>Physics error created an unsafe situation.</td>
<td>HW-19323</td>
</tr>
<tr>
<td>DR-2</td>
<td>05/11/53</td>
<td>Radiation exposure</td>
<td>During fuel charging, irradiated aluminum spacers were flushed onto the charge elevator and inadvertently handled by 3 workers.</td>
<td>Three workers received an estimated hand dose of 100 R and whole body dose of 3.4 R.</td>
<td>HW-28062</td>
</tr>
<tr>
<td>DR-3</td>
<td>01/01/55</td>
<td>Reactivity anomaly</td>
<td>Flushing poison column while preparing for displacement discharge caused high-reactivity trip scram.</td>
<td>Power level increased from 648 MW to 658 MW. No tube boiling or reactor damage occurred.</td>
<td>HW-34373</td>
</tr>
<tr>
<td>DR-4</td>
<td>12/13/57</td>
<td>Multiple fuel failures</td>
<td>During discharge operation, a crossheader misvalving caused 5 irradiated fuel pieces to be ejected from a tube by steam pressure and lodge in the discharge area. Subsequently, fuel ruptures occurred in 8 tubes. About 150 h of shutdown resulted.</td>
<td>Some radiation exposure resulted, as well as loss of production.</td>
<td>HW-54257</td>
</tr>
<tr>
<td>DR-5</td>
<td>12/05/58</td>
<td>Startup anomaly/Fuel failures</td>
<td>Equipment malfunctions and operator error delayed charging of temporary at top of reactor.</td>
<td></td>
<td>HW-58560</td>
</tr>
<tr>
<td>DR-6</td>
<td>11/07/59</td>
<td>Power anomaly</td>
<td>Plugged sample line to flowmeter resulted in a low bulk outlet temperature reading and power indication lower than actual.</td>
<td>High tube outlet temperature indicated problem. No damage resulted.</td>
<td>HW-62802</td>
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A-6
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<th>Event No.</th>
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<th>Description</th>
<th>Consequences &amp; Implications</th>
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<tbody>
<tr>
<td>DR-7</td>
<td>12/17/59</td>
<td>Equip/Maint failure</td>
<td>After several days of abnormal temp. and flow observations and removal of a piece of wood from a high lift pump on 12/14, the reactor scrammed on a flow monitor trip. Wood and other debris was found in screens.</td>
<td>Origin of wood not determined. No damage resulted.</td>
<td>3 HW-63281 HW-73265-RD</td>
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<tr>
<td>DR-8</td>
<td>01/21/60</td>
<td>Poison element melt</td>
<td>Poison slugs partially melted and a poison column control tube failed, while attempting to replace a leaking front-face fitting during reactor operation.</td>
<td>Reactor was manually scrammed and no further damage resulted.</td>
<td>3 HW-63852 HW-67185 HW-73060 HW-73265-RD</td>
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<tr>
<td>DR-9</td>
<td>04/12/60</td>
<td>Power loss/Operator error</td>
<td>Transformer failure tripped off two high-lift pumps and turned out lights in 190-DR Bldg. Operator inadvertently shut off an additional pump, and effort to restart it caused reactor to scram.</td>
<td>No damage resulted.</td>
<td>3 HW-73265-RD</td>
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<tr>
<td>DR-10</td>
<td>07/11/61</td>
<td>Power loss/ Ball 3X scram</td>
<td>Equipment check caused loss of power to #1 bus, resulting in scrams at D &amp; DR, and a trip of the Ball 3X system at DR.</td>
<td>Residual balls in the reactor required subsequent increase in fuel enrichment.</td>
<td>3 HW-70454 HW-71294 HW-77123</td>
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<tr>
<td>DR-11</td>
<td>11/19/63</td>
<td>Startup anomaly</td>
<td>Normal rate of power rise was exceeded for a 4 min period due to inadvertent withdrawal of a control rod.</td>
<td>Showed lack of attention by control room staff. No damage or reactor scram.</td>
<td>3 HW-79802</td>
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<tr>
<td>F-1</td>
<td>10/20/48</td>
<td>Target and tube failure</td>
<td>Rupture of an Lift target slug caused violent reaction with water, rupturing tube 3169 and flooding the reactor.</td>
<td>Maximum power temporarily limited to 40 MW by low reactivity. Tritium program suspended until better target developed.</td>
<td>2 HW-11499</td>
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<tr>
<td>F-2</td>
<td>10/26/50</td>
<td>Equip/Maint failure</td>
<td>With the reactor operating, a rigging failure caused the drop of a deaerator tank through the roof of the 185F Building onto the 40 f level, where it protruded into the 190F Building tank room.</td>
<td>Reactor operation was suspended for 24 h for interim repairs. The accident had potential to disrupt reactor coolant flow.</td>
<td>2 HW-19325</td>
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<td>F-3</td>
<td>12/31/57</td>
<td>Coolant interrupt./Personnel error</td>
<td>Due to a valving error during an outage, fuel on two rows overheated. The suspect tubes were discharged and no fuel failures were found.</td>
<td>Potential for fuel damage. Some production lost by premature fuel discharge.</td>
<td>HW-54291</td>
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<tr>
<td>F-4</td>
<td>11/20/60</td>
<td>Coolant interruption</td>
<td>10 1/2 hrs after shutdown, flow to a tube was interrupted for maintenance, and the tube was without flow for 17 h before the situation was noticed and corrected.</td>
<td>No damage resulted. Time limits were not exceeded, but standard procedures were not followed.</td>
<td>HW-73265-RD</td>
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<tr>
<td>F-5</td>
<td>05/61</td>
<td>Radiation exposure</td>
<td>4 employees received significant skin and nasal contamination when a bayonet was removed from a process channel in preparation for borescoping. Zn-65 and Na-24 inhalation occurred.</td>
<td>Maximum nasal intake was 1 to 6% of MPBB. The incident showed inadequate planning and radiation monitoring.</td>
<td>HW-69835-Del</td>
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<tr>
<td>H-1</td>
<td>10/03/54</td>
<td>Startup anomaly/Fuel failures</td>
<td>During startup following repair of a water leak into the reactor graphite, a rapid power rise &amp; higher tube temps. were observed. Reactor scrammed while adjustments were being made. Restarted w/o trouble, but fuel failures observed for several days.</td>
<td>Poor monitor location, choice of control rod withdrawal patterns resulted in local overpower. 22 ruptured slugs &amp; 50 incipient ruptures occurred.</td>
<td>HW-33945, HW-34338, HW-41495, NS-4-1</td>
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<tr>
<td>H-2</td>
<td>10/23/54</td>
<td>Personnel error/Cooling loss</td>
<td>During a quick discharge of a ruptured fuel slug, a rear crossheader was valved off instead of to a drain, stopping flow to 92 tubes for about 2 1/4 h. This resulted in overheating and probable boiling in all 92 tubes.</td>
<td>No fuel or reactor damage resulted. Fuel in 3 tubes was discharged for examination. Disciplinary action was taken for failure to follow procedures.</td>
<td>HW-33839, HW-34353</td>
</tr>
<tr>
<td>H-3</td>
<td>10/31/55</td>
<td>Irradiated fuel fire</td>
<td>A test fuel element failed in the test loop. Cooling was removed while attempting to discharge the element, and when cooling resumed, the element partly burned.</td>
<td>Some contamination occurred from discharge of about 1 Ci up the stack. Disciplinary action was taken for failure to follow procedures.</td>
<td>HW-39974, HW-40115, HW-43064, HW-43557, HW-54636, HW-73265-RD, TID-5360</td>
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<tr>
<td>H-4</td>
<td>07/17/56</td>
<td>Radiation exposure</td>
<td>Irradiated fuel pieces were discharged out of a tube onto the discharge elevator during startup preparations.</td>
<td>The rear face crew evacuated in time to prevent overexposure. Operating procedures were revised as a result.</td>
<td>HW-45189</td>
</tr>
<tr>
<td>H-5</td>
<td>09/29/57</td>
<td>Startup anom./Multiple fuel failure</td>
<td>During startup, a temperature map at 900 MW showed maldistribution. Power increased to 1200 MW &amp; reactor scrapped due to low flow.</td>
<td>Ruptured fuel found in 3 tubes, 1 tube ruptured, causing water leak into reactor. ATTRIBUTED to improper control rod modernment &amp; failure to take action when problem first was noted.</td>
<td>HW-52918 HW-53001-RD HW-53481 HW-73265-RD</td>
</tr>
<tr>
<td>H-6</td>
<td>05/05/58</td>
<td>Reactivity anomaly</td>
<td>Attempts to clear a stuck dummy poison element in a PCCF tube by opening charging machine caused water to boil out of tube, producing rapid local reactivity surge. Action was repeated &amp; reactor scrapped.</td>
<td>No damage resulted</td>
<td>HW-56005 HW-73060 HW-73265-RD</td>
</tr>
<tr>
<td>H-7</td>
<td>10/20/59</td>
<td>Startup anomaly</td>
<td>During startup, operating personnel concluded actual power was higher than indicated power (800 MW). An instrument malfunction indicating lower than actual flow was corrected.</td>
<td></td>
<td>HW-73265-RD</td>
</tr>
<tr>
<td>H-8</td>
<td>03/11/60</td>
<td>Power failure</td>
<td>H Reactor was operating with only 1 Secondary backup cooling source of power (from F Area) while system functioned &amp; no other source of power was off-line for maintenance. Multiple component failures in F Area cut off power to H area, causing scram.</td>
<td></td>
<td>HW-64676 HW-66364 HW-66767 HW-73060 HW-73265-RD</td>
</tr>
<tr>
<td>H-9</td>
<td>04/13/60</td>
<td>Equip/Maint failure</td>
<td>A tube fitting on the H-1 loop failed because of poor installation experimental equipment, and a personnel error during switch and slight contamination. Calibration. Failure to turn off line heaters resulted in their failure.</td>
<td>Damage only to</td>
<td>HW-64966 HW-73265-RD</td>
</tr>
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<tr>
<td>H-10</td>
<td>10/04/60</td>
<td>Fire/Personnel injury</td>
<td>A controlled burn of waste in the H Reactor containment burial ground practices and poor caused drums of flammable substance records resulted in to erupt, setting fire to a utility personnel injury and pole and injuring a fireman. property damage.</td>
<td>2 HW-67034</td>
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<tr>
<td>H-11</td>
<td>01/10/61</td>
<td>Fuel discharge accident</td>
<td>Charging machine interlock bypassed to permit charging to proceed while access door was being repaired. 2 tubes above platform level were discharged onto platform. Elts. cooled by intermittent fog-spray until removal operations completed on 1/14.</td>
<td>No damage resulted.</td>
<td>3 HW-68213</td>
</tr>
<tr>
<td>H-12</td>
<td>01/16/61</td>
<td>Coolant interruption</td>
<td>The reactor was shut down because of a leak on a front-face process tube assembly. Maintenance supervisor valved off tube and replaced fitting before safety evaluations were completed. Tube was discharged successfully.</td>
<td>No damage resulted, although it could have if flow reestablishment had been delayed.</td>
<td>3 HW-73265-RD</td>
</tr>
<tr>
<td>H-13</td>
<td>07/10/62</td>
<td>Partial ECS trip</td>
<td>The high tank, part of the last ditch cooling system, was tripped briefly due to an electrical malfunction while testing a pump with the reactor shut down.</td>
<td>The reactor was adequately cooled at all times.</td>
<td>3 HW-74511</td>
</tr>
<tr>
<td>H-14</td>
<td>04/17/64</td>
<td>Startup anomaly</td>
<td>A block of tubes containing target elements was mischarged, causing a reactivity discrepancy during startup. All 171 tubes that had been mischarged were recharged properly.</td>
<td>No damage resulted, but substantial cost and production loss were incurred.</td>
<td>2 HW-82143</td>
</tr>
<tr>
<td>KE-1</td>
<td>12/13/57</td>
<td>Control rod damage/Personnel error</td>
<td>An HCR being repaired during reactor operation was partially inserted into the reactor for convenience. Since it was uncooled, the tip melted.</td>
<td>The reactor had to be shut down to remove the damaged rod.</td>
<td>3 HW-54291</td>
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<tr>
<td>KE-2</td>
<td>06/28/59</td>
<td>Equip/Maint failure</td>
<td>A faulty flow indicator scrammed the reactor and opened the dump valve on the KER-1 loop, causing rapid loop depressurization. A second fault caused the valve to close and cycle to be repeated.</td>
<td>No damage resulted</td>
<td>HW-55900 HW-61447-RD HW-73265-RD</td>
</tr>
<tr>
<td>KE-3</td>
<td>01/31/60</td>
<td>Equip/Maint failure</td>
<td>KER-2 Loop rapid depressurization resulted from a valve failure. Although boiling occurred during the transient, no overheating resulted.</td>
<td>No fuel or tube damage resulted</td>
<td>HW-64443</td>
</tr>
<tr>
<td>KE-4</td>
<td>03/19/60</td>
<td>Power &amp; Equip/Maint failure</td>
<td>A faulty circuit breaker (due to improper repair) opened a path to ground, tripping off a 13.8 KV bus and removing power from 2 of 5 primary pumps, scramming the reactor on a low-flow trip.</td>
<td>No damage resulted</td>
<td>HW-64624 HW-64767 HW-73265-RD</td>
</tr>
<tr>
<td>KE-5</td>
<td>08/05/60</td>
<td>Startup anomaly</td>
<td>Faulty instrument readings and misuse of instruments resulted in excess power on startup. Reactor scrammed by flow monitor trip.</td>
<td>No damage resulted</td>
<td>HW-66454 HW-73060 HW-73265-RD</td>
</tr>
<tr>
<td>KE-6</td>
<td>01/19/61</td>
<td>Equip/Maint failure</td>
<td>Failure of a front-face thermocouple in KER-1 loop removed loop cooling, causing a reactor scram.</td>
<td>Fuel elements were apparently undamaged and were not discharged.</td>
<td>HW-68229</td>
</tr>
<tr>
<td>KE-7</td>
<td>01/12/63</td>
<td>Equip/Maint failure</td>
<td>Complete failure of the front-face nozzle of tube 1162 scrammed reactor on low-flow trip. Apparently a spline inserter had been left on the tube and was struck by the C platform.</td>
<td>No fuel was ejected. Nozzle was replaced and operational changes recommended.</td>
<td>HW-76354 HW-76431</td>
</tr>
<tr>
<td>KE-8</td>
<td>03/26/63</td>
<td>Cooling interruption/Operator error</td>
<td>Error in valving during an outage resulted in complete cooling flow stoppage to reactor for 2 to 4 min.</td>
<td>If the interruption had continued for a few more minutes, fuel failure would have occurred.</td>
<td>HW-77209</td>
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<tr>
<td>KE-9</td>
<td>05/12/63</td>
<td>Fuel failure</td>
<td>After failure of an experimental fuel element, about 1 lb of U was missing after fuel discharge.</td>
<td>This was the largest release of fission products to the river to that date. Dose to offsite persons was calculated to be a small fraction of limits.</td>
<td>HW-77749-0el</td>
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<td>HW-79073</td>
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<td>KW-1</td>
<td>01/05/55</td>
<td>Fuel melt</td>
<td>On initial reactor startup, a calibration plug was left in place, causing melting of fuel &amp; tube 4669. Because a flow instrument was misadjusted, the reactor did not scram on a low tube flow trip, but did scram from a tube-row pressure fluctuation.</td>
<td>Reactor was down for 9 weeks for repair.</td>
<td>HW-34403</td>
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<td>WASH-1192</td>
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<td>KW-2</td>
<td>08/21/55</td>
<td>Power &amp; Equip/Maint failure</td>
<td>BPA system frequency surge caused 4.16 kV system to trip, scrambling reactor. Two emergency 4.16 kV generators started but tripped off by malfunction, shutting off low-lift pumps. Water was automatically supplied from KE crosstie, causing KE to scram.</td>
<td>No damage resulted</td>
<td>HW-39501</td>
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<td>HW-73265-RD</td>
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<td>KW-3</td>
<td>02/05/58</td>
<td>Cooling anomaly</td>
<td>Low flow was found on 6 crossheaders in preparing for startup. This was caused by erroneously valuing off pressure monitoring lines following charge-discharge.</td>
<td>No damage resulted, and startup proceeded.</td>
<td>HW-54983</td>
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<tr>
<td>KW-4</td>
<td>04/29/59</td>
<td>Fuel fire</td>
<td>Fuel rupture in poison spline tube required discharge of tube and its charge. A portion of tube broke, but was held in the air by the spline, causing a brief fire before the rest of the tube could be discharged.</td>
<td>About 5 Ci radioactivity released, 1.3 Ci up the stack. Slight contamination &amp; temporary evacuation of reactor building.</td>
<td>HW-63076</td>
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<td>HW-84619</td>
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<td>KW-5</td>
<td>05/20/59</td>
<td>Startup anomaly, Equip/Maint failure</td>
<td>Reactor scrambled on high tube outlet temperature during startup. Power level indicator found to be low (by more than a factor of 2) because of faulty flow measurement and an inoperative temperature indicator.</td>
<td>Power was more than twice indicated level. No damage resulted.</td>
<td>HW-60594, HW-73265-RD</td>
</tr>
<tr>
<td>KW-6</td>
<td>03/08/61</td>
<td>Operator error/Power anomaly</td>
<td>Reactor operator attempted to shut down the reactor by further inserting 2 partially inserted half rods. This increased reactivity, causing the reactor to scram on high tube temperature.</td>
<td>No damage resulted. Procedures were revised to prevent recurrence.</td>
<td>HW-68939-RD, HW-73060, HW-73265-RD</td>
</tr>
<tr>
<td>KW-7</td>
<td>04/24/63</td>
<td>Partial ECS trip</td>
<td>Inadvertent shutdown of a primary pump during an outage caused automatic activation of emergency steam turbine pumps and the ECS backup diesel system.</td>
<td>No damage resulted. Procedures were revised to prevent recurrence.</td>
<td>HW-78633</td>
</tr>
<tr>
<td>KW-8</td>
<td>02/11/66</td>
<td>Test fuel failure</td>
<td>A test fuel element containing sintered uranium oxide fuel failed, releasing radiation to the river.</td>
<td>Up to 600 Ci I-131 released to the river.</td>
<td>HW-60594, HW-73265-RD</td>
</tr>
<tr>
<td>KW-9</td>
<td>06/19/68</td>
<td>Fuel jacket melt</td>
<td>Tube 3560 flow stoppage caused multiple fuel jacket melts. Flow was blocked by a thermocouple bulb that lodged in the tube inlet venturi.</td>
<td>Fuel jackets on most of the elements in the tube melted, and about 20 Ci of I-131 were released to the river. Operation resumed 7/28.</td>
<td>DUN-5000, DUN-5001, DUN-SA-112, WASH-1192</td>
</tr>
<tr>
<td>N-1</td>
<td>01/25/65</td>
<td>Equip/Maint failure</td>
<td>An RV-2 valve opened due to leakage through a pilot valve, partially depressurizing the primary coolant system and scramming the reactor.</td>
<td>The injection pumps started as designed, and pressure and level recovered to normal post-scram levels in about 2 minutes.</td>
<td>RL-NRD-150-1, RL-NRD-660-1</td>
</tr>
<tr>
<td>N-2</td>
<td>01/24/66</td>
<td>Personnel error</td>
<td>The GSCS system dumped from recirculation to once-through cooling when a draftsman updating wiring diagrams moved a loose wire.</td>
<td>Reactor was shut down manually and the system was returned to normal.</td>
<td>RL-NRD-150-1, RL-NRD-660-1</td>
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<td>N-3</td>
<td>06/21/67</td>
<td>Fire &amp; Equip/Maint failure</td>
<td>A fire started in SG cell 3 caused by igniting of oil that had leaked from the pump lubrication system.</td>
<td>The fire was extinguished 2 by the fog spray system, but extensive cleanup was required.</td>
<td>DUN-2872, DUN-2874, IR-67, RL-GEN-1300-6, WASH-1192</td>
</tr>
<tr>
<td>N-4</td>
<td>01/70</td>
<td>Personnel error</td>
<td>An out-of-service control rod was left partly in the reactor without cooling for 26-day operating period.</td>
<td>Rod tip damaged and replaced.</td>
<td>DUN-6594, DUN-7545, UNI-785</td>
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<tr>
<td>N-5</td>
<td>01/29/70</td>
<td>Control anomaly</td>
<td>During a startup, HCRs failed to respond to manual controls. Oper. shut down reactor using scram button. A failed surge suppressor had tripped circuit breaker supplying control power. The surge suppressor was the wrong type for this application.</td>
<td>No damage resulted</td>
<td>DUN-6594, DUN-7545, UNI-785</td>
</tr>
<tr>
<td>N-6</td>
<td>09/30/70</td>
<td>Equip/Maint fail. Control mal.</td>
<td>A reactor scram was caused by flow transient produced by trip of No. 6 primary pump drive turbine. Rod safety system failed to respond due to electrical malfunction believed related to maint. error.</td>
<td>Ball safety system responded automatically to shut down reactor safely with no damage. Rod scram circuitry &amp; procedures revised to prevent recurrence.</td>
<td>DUN-7060, DUN-7342, DUN-7436, DUN-7545, NS-12-6, UNI-785</td>
</tr>
<tr>
<td>N-7</td>
<td>07/01/71</td>
<td>Control anomaly</td>
<td>During modification, 2 scram circuits found to have been interconnected for an extended period, negating redundancy requirements.</td>
<td>Problem corrected and testing procedures tightened.</td>
<td>DUN-7436, DUN-7867, UNI-785</td>
</tr>
<tr>
<td>N-8</td>
<td>06/27/72</td>
<td>Radioactivity release</td>
<td>A pipe leak released 90,000 gal of decontamination liquid containing about 35 Ci, including 26 Ci Co-60, to ground.</td>
<td>Ground contamination resulted, and the potential for greater contamination existed from failure to monitor the tank level.</td>
<td>UD-72-006</td>
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A-14
<table>
<thead>
<tr>
<th>Event No.</th>
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<th>Consequences &amp; Implications</th>
<th>Reporting RTG Document</th>
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</thead>
<tbody>
<tr>
<td>N-9</td>
<td>10/23/72</td>
<td>Equip/Maint failure</td>
<td>The ECS tempered-water tank was nearly emptied by inadvertent discharge through the pump jacket cooling water system. This was not detected for several hours because of instrument failure.</td>
<td>No damage. However, reactor operated while tempered ECS water was not available.</td>
<td>UNI-785 UO-72-025</td>
</tr>
<tr>
<td>N-10</td>
<td>05/23/73</td>
<td>Equip/Maint failure</td>
<td>During a steam generator inspection, numerous metal fragments were found. These were found to be from stellite bushings of CV-3 and PCSV-202 valves.</td>
<td>All CV-3 and PCSV-valves overhauled.</td>
<td>UNI-138 UNI-785 UO-73-016</td>
</tr>
<tr>
<td>N-11</td>
<td>06/12/73</td>
<td>Fire</td>
<td>During scheduled summer maintenance outage, a fire occurred in relay panel PR-39, which houses the reactor power setback circuits. An overheated relay coil ignited the plastic dust cover.</td>
<td>Reactor was in a safe controlled shutdown condition. To prevent similar occurrences, damaged relays were replaced with a different type.</td>
<td>UNI-138 UNI-785 UO-73-017</td>
</tr>
<tr>
<td>N-12</td>
<td>12/07/73</td>
<td>Fuel, &amp; Equip/Maint failure</td>
<td>Reactor was shut down because of general fuel failure indications, with no specific tube identified. It was found that the tube 2350 sample line valve had been left closed following maintenance preventing detection.</td>
<td>Failed fuel element lost 1.6 lb of U, &amp; about 220 Ci of I-131 entered primary coolant system. No significant dose resulted. Maintenance &amp; monitoring procedures were tightened.</td>
<td>UNI-138 UO-73-053</td>
</tr>
<tr>
<td>N-13</td>
<td>07/29/77</td>
<td>Power failure</td>
<td>All 4160 V power was lost during outage, due to incorrect installation of a design change.</td>
<td>No damage resulted.</td>
<td>UNI-785 UO-77-026</td>
</tr>
<tr>
<td>N-14</td>
<td>12/16/77</td>
<td>Radiation exposure</td>
<td>Irradiated fuel was flushed from tube 2158 onto the C elevator during an attempted charge operation. The primary loop had not been depressurized due to a series of errors.</td>
<td>4 workers exposed to 5, 6, 11, and 15 rem.</td>
<td>AO-77-002 DOE/EV 0091/1 RLO-78-1</td>
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<tr>
<td>N-15</td>
<td>12/01/81</td>
<td>Personnel error</td>
<td>In isolating instrument air dryer for maint., personnel failed to open a bypass line. This shut off all instrument air to N Reactor service bldgs. Flow transient scrammed reactor. Makeup flow was low because of lack of instrument air.</td>
<td>No damage resulted &amp; ECCS 2 was not called upon. However, numerous mandatory requirements were not followed.</td>
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<tr>
<td>N-16</td>
<td>01/18/85</td>
<td>Radiation exposure</td>
<td>Fuel was discharged while personnel were in the rear pipe space. Workers had attempted to leave, but found the door locked. The operator, thinking they had left, resumed fuel discharge.</td>
<td>The workers were able to leave by another exit. Exposures were within limits, but potential for overexposure existed. Procedures were revised to prevent recurrence.</td>
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<tr>
<td>N-17</td>
<td>11/10/85</td>
<td>Equip/Maint failure</td>
<td>Because of error in vendor's manual, flapper retention bolts on CV-3 valves were under-torqued, resulting in a valve failure and debris in primary coolant system.</td>
<td>Some damage to steam generators. Valve would not have functioned if called on.</td>
<td></td>
</tr>
<tr>
<td>R-1</td>
<td>04/06/62</td>
<td>Power failure</td>
<td>The first total loss of all power to the Hanford 100 Area.</td>
<td>All reactors shut down safely, and backup cooling systems operated. No damage resulted.</td>
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PRTR INCIDENTS

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<tr>
<th>Event No.</th>
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<tbody>
<tr>
<td>PRTR-1</td>
<td>11/09/61</td>
<td>Coolant Interruption</td>
<td>During low-flow shutdown conditions, a vapor lock in the primary coolant pump interrupted primary coolant flow for about 3h. The reactor had been shut down for 9 days.</td>
<td>No damage resulted</td>
</tr>
<tr>
<td>PRTR-2</td>
<td>09/29/65</td>
<td>Fuel and tube failure</td>
<td>A light-water cooled test loop in the heavy water moderated PRTR ruptured, contaminating the heavy-water with light water and fission products (from an intentionally defected test fuel element).</td>
<td>No significant radiation exposure but program was delayed for an extended period as a result. Cost of recovery was $895K</td>
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A-16
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<thead>
<tr>
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<tbody>
<tr>
<td>L-1</td>
<td>01/23/49</td>
<td>Chemical explosion</td>
<td>A chemical explosion in a pump stand in the hydromechanical laboratory damaged the REDOX demo unit, injuring a maintenance employee.</td>
<td>Building was modified to increase personnel protection</td>
<td>HW-12391-E</td>
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<td>HW-12666-E</td>
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<td>HW-13190-E</td>
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<td>HW-42068-RD</td>
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<td>UND-68-1</td>
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<td>L-2</td>
<td>11/16/51</td>
<td>Nuclear criticality/Subsequent fire</td>
<td>Rapid withdrawal of the safety rod from a partially filled spherical homogenous reactor experiment resulted in a prompt criticality. Total energy release was about 3 MW-s.</td>
<td>Radiation dose in the control room measured up to 600 mrem. Extensive contamination. During decontamination, a fire caused further damage. The facility was abandoned and later removed.</td>
<td>HW-22936</td>
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<td>HW-23034</td>
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<td>HW-23140</td>
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<td>HW-24327</td>
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<td>TID-5360</td>
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<td>WASH-1192</td>
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<tr>
<td>L-3</td>
<td>03/31/59</td>
<td>Explosion in Pu hood</td>
<td>An explosion occurred in a hood in building 234-5 during machining of plutonium.</td>
<td>Potential for injury and contamination spread.</td>
<td>HW-59717</td>
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<td>NS-2-4</td>
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<td>TID-5360</td>
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<tr>
<td>L-4</td>
<td>02/12/63</td>
<td>Radiation contamination</td>
<td>Widespread contamination resulted from a glove-box explosion in the Pu lab.</td>
<td>12 employees had detectable skin contamination and 14 had measurable deposition of Pm 147.</td>
<td>HW-76596</td>
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<td>IR-63</td>
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<td>WASH-1192</td>
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<td>L-5</td>
<td>07/10/64</td>
<td>Pu contamination</td>
<td>A Pu coupon being compressed in a hydraulic press ruptured and a fragment penetrated a hood glove and penetrated an employee's upper arm. It was surgically removed.</td>
<td>The residual contamination was estimated to be 270% of the MPBB</td>
<td>BNWL-138</td>
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<td>HW-83457</td>
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<td>NS-6-4</td>
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<td>WASH-1192</td>
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<tr>
<td>L-6</td>
<td>08/23/65</td>
<td>Pu contamination</td>
<td>An explosion of acetone vapor during cleaning of equipment blew out a side of a Pu glove box and 2 gloves, contaminating 3 workers. The workers were given DTPA treatment.</td>
<td>Final contamination levels were less than 10% of MPBB.</td>
<td>BNWL-CC-249</td>
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<td>NS-7-4</td>
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<tr>
<td>L-7</td>
<td>11/19/68</td>
<td>Radiation exposure</td>
<td>Pu contamination of a hood in the Z plant analytical lab went undetected over a shift change, allowing spread to other parts of the facility.</td>
<td>Surveys of 14 residences conducted, but no off-plant contamination found.</td>
<td>ARH-310 (Section J)</td>
</tr>
<tr>
<td>L-8</td>
<td>03/13/79</td>
<td>Pu contamination</td>
<td>A PuO2 Storage container ruptured from internal pressure while being placed in storage.</td>
<td>About 1 mCi of PuO2 was released to the atmosphere. No excessive exposure of any employee or to public. Cost of decontamination was about $725,000.</td>
<td>BNWJ-1017 DOE-EV-0091</td>
</tr>
<tr>
<td>L-9</td>
<td>10/20/86</td>
<td>Safety Violation</td>
<td>Criticality safety specification violated. Package for disposal found to contain 600 g Pu plus moderator.</td>
<td>Contents adjusted. Could 2 have led to inadvertent criticality.</td>
<td>UO-86-007</td>
</tr>
<tr>
<td>S-1</td>
<td>03/46</td>
<td>Radiation exposure</td>
<td>While attempting to unplug a radioactive waste line with compressed air, an employee was sprayed with radioactive waste. He received a dose of about 2 rep to the face and 5 rep to the hands and internal deposition of 0.1 uCi.</td>
<td>Unsafe action by employee resulted in contamination, with potential for excessive exposure. Procedures were changed to prevent recurrence.</td>
<td>HW-7-3751</td>
</tr>
<tr>
<td>S-2</td>
<td>12/02/49</td>
<td>Radiation Release</td>
<td>A planned release of 4000 to 8000 Ci of 1-131 occurred over a 12-h period by processing fuel cooled for only 16 days instead of the usual 90-120 days, (the &quot;Green Run&quot;).</td>
<td>Excessive iodine levels, both onsite and offsite, persisted for several days.</td>
<td>HW-15593 HW-16015 HW-17003 HW-17381</td>
</tr>
<tr>
<td>S-3</td>
<td>02/28/52</td>
<td>Plutonium contamination</td>
<td>An employee punctured a glove and received a puncture wound on his left hand from a wire brush while performing maintenance in a Pu hood. Later, urine samples indicated Pu deposition.</td>
<td>Surveys indicated internal deposition was initially above MPBB.</td>
<td>HW-38428</td>
</tr>
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<tr>
<td>S-4</td>
<td>12/52</td>
<td>Radiation release</td>
<td>Process tank coil and jacket failures contaminated swamps near the REDOX facility, resulting in contamination of waterfowl to levels up to 250 mrem/h.</td>
<td>Inadequate control of environmental contamination.</td>
<td>ARH-780 HW-26376-Del HW-26720 HW-60807</td>
</tr>
<tr>
<td>S-5</td>
<td>02/16/55</td>
<td>Plutonium inhalation</td>
<td>Two employees grossly contaminated with plutonium, apparently from careless removal of protective clothing and/or by improperly fitted mask in centrifuge repair at 224-T bldg.</td>
<td>Internal deposition estimated at 290% and 80% of MP8B for the two employees.</td>
<td>HW-35540 HW-36034 HW-38427 TID-5360</td>
</tr>
<tr>
<td>S-6</td>
<td>02/27/56</td>
<td>Pu Contamination</td>
<td>An instrument line blowback contaminated the PUREX pipe gallery. Contamination spread to other parts of the facility and to the roof and the surrounding area through unfiltered exhaust ducts.</td>
<td>Significant contamination resulted from instrumental failure. Some parts of facility posted to limit access following cleanup.</td>
<td>HW-43073</td>
</tr>
<tr>
<td>S-7</td>
<td>06/18/56</td>
<td>Pu leak</td>
<td>A Pu solution leak entered the 233-S building air supply and contaminated the building and 3 employees.</td>
<td>The employees received estimated Pu deposition of 1.2, 1.7 and 7.8 times MP8B.</td>
<td>HW-43964 HW-43990 HW-44008 TID-5360 WASH-1192</td>
</tr>
<tr>
<td>S-8</td>
<td>02/13/58</td>
<td>Chemical explosion</td>
<td>A silver reactor used to absorb radioactive iodine from dissolver offgas vapors exploded, apparently due to unstable products formed from reaction of ammonia with silver salts.</td>
<td>No injury or detectable contamination spread. $76,000 cost.</td>
<td>HW-55223 UND-68-1</td>
</tr>
<tr>
<td>S-9</td>
<td>04/17/60</td>
<td>Uranium fire</td>
<td>An uncontrolled chemical reaction occurred in a REDOX dissolver when undisolved fuel was left partially uncovered and exposed to the atmosphere for two days.</td>
<td>Equipment damaged, but no environmental contamination or injury.</td>
<td>HW-64991 HW-65022 HW-66850 HW-67164 NS-2-4 TID-5360 UND-58-1 UND-68-1 WASH-1192</td>
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<tr>
<td>S-10</td>
<td>12/60</td>
<td>Radiation exposure</td>
<td>An employee using a fresh air mask ingested 5000 microcuries of uranium because the mask was not properly adjusted and the air supply line was blocked by condensate.</td>
<td>Potential for serious injury. However, the ingested U was rapidly eliminated. No detectable U after 1 wk.</td>
<td>HW-67954, HW-67985</td>
</tr>
<tr>
<td>S-11</td>
<td>04/07/62</td>
<td>Nuclear criticality</td>
<td>A nuclear excursion occurred in the Recuplex operation at the 234-5 building in a transfer tank, resulting from a Pu solution overflow.</td>
<td>Individual exposure up to 110 rem occurred.</td>
<td>HW-75546, HW-77295, HW-77345, HW-84619, NS-4-4, TID-5360, UND-62-1, UND-68-1, WASH-1192</td>
</tr>
<tr>
<td>S-12</td>
<td>11/06/63</td>
<td>Fire</td>
<td>A fire occurred in the REDOX concentration (233-S) facility, when a valving error permitted a concentrated sodium dichromate solution to enter the ion exchange resin bed. The resulting reaction ruptured a gasket and started a fire in flammable material.</td>
<td>Damage and contamination required approximately 6 week shutdown, costing about $397,000. Operation was then resumed without the ion exchange contactor.</td>
<td>BWI-10011, HW-84619, NS-5-4, NS-9-5, TID-5360, WASH-1192</td>
</tr>
<tr>
<td>S-13</td>
<td>06/12/64</td>
<td>Radiation release</td>
<td>Two cooling water swamps at the PUREX facility were contaminated by an estimated 10,000 Ci of Zr, Nb, Ce and Ru by failure of a cooling coil in a sampling tank.</td>
<td>Loss of control of radioactive material due to a design deficiency. Prompt action was taken to kill algae in the swamps and cover the contaminated ditches.</td>
<td>ARH-780, HW-83000, HW-83102-Del, HW-84619</td>
</tr>
<tr>
<td>S-14</td>
<td>01/28/65</td>
<td>Waste Tank Instability</td>
<td>A sudden steam eruption occurred from waste tank 105A. Investigation found that the steel tank liner had buckled severely due to high pressure in liquid that had leaked and accumulated between the liner and the concrete tank shell.</td>
<td>Minor contamination, but concern for potential tank failure. After thorough analysis, tank continued in use until taken out of service in 1968.</td>
<td>ARH-78</td>
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<tr>
<td>S-15</td>
<td>09/11/67</td>
<td>Radiation exposure</td>
<td>Four employees received radiation exposures from a supposedly empty fuel canister containing four irradiated fuel elements.</td>
<td>Exposures ranged from less than 25 mR to 360 mR. The potential for very high exposure existed.</td>
<td>ARH-30</td>
</tr>
<tr>
<td>S-16</td>
<td>11/14/67</td>
<td>Radiation exposure</td>
<td>A worker contaminated the cuff of his sleeve and received radiation exposure to his hand in placing a screw cap on a shielded sample carrier.</td>
<td>Some contamination spread and possible localized extremity exposure up to 370 rem.</td>
<td>ARH-233 WASH-1192</td>
</tr>
<tr>
<td>S-17</td>
<td>06/18/68</td>
<td>Radiation exposure</td>
<td>Radioactive liquid was sprayed onto the knee of an operator's coveralls during removal of an obstruction from the F-26 PUREX sampler visor.</td>
<td>Maximum localized radiation to knee was estimated at 30 rads.</td>
<td>ARH-723</td>
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<tr>
<td>S-18</td>
<td>03/22/70</td>
<td>Radioactive release</td>
<td>An instrument line failure released a strontium solution, and approximately 1,000 Ci of Sr90 leaked through floor drains and the chemical sewer to a ditch and pond.</td>
<td>Potentially serious environmental spread and localized WASH-1192 extremity exposure up to 370 rem.</td>
<td>ARH-1503-Del ARH-1648 WASH-1192</td>
</tr>
<tr>
<td>S-19</td>
<td>04/18/70</td>
<td>Radiation Exposure</td>
<td>A maintenance employee received about 2500 rem to the hands when he attempted to hook up an unloading line to a waste cask.</td>
<td>Erythema appeared on both hands following the exposure.</td>
<td>IR-70 WASH-1192</td>
</tr>
<tr>
<td>S-20</td>
<td>04/20/73</td>
<td>Ground Contamination</td>
<td>Approximately 115,000 gal of high level radioactive waste solution leaked to the ground from a tank in the 200W area over a 7-wk period because of failure of personnel to review liquid level and radiation level reports.</td>
<td>Approximately 40,000 Ci Cs-137, 14,000 Ci Sr-90, 4 Ci Pu-239 and various amounts of other material leaked.</td>
<td>ARH-2874 RHO-ST-1 TID-26431 WASH-1192</td>
</tr>
<tr>
<td>S-21</td>
<td>11/14/73</td>
<td>Radiation release and exposure</td>
<td>Feed solution being pumped from one tank to another in the 200W tank farm sprayed out onto the ground because the line became plugged with salt.</td>
<td>16 employees received a total of 3.5 R exposure from the incident. There were no injuries, property damage or offsite contamination.</td>
<td>ARH-2907 ARH-2935 RLD-74-1 WASH-1192</td>
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<tr>
<td>S-22</td>
<td>08/30/76</td>
<td>Explosion/Radiation contamination</td>
<td>An ion exchange column in an Americium process glove box exploded, resulting in acid burns and severe contamination to the process operator, and lesser contamination of others.</td>
<td>Operator was hospitalized for several months and remained under medical observation until his death from unrelated causes 11 y later.</td>
<td>BNWI-1006 BNWI-1007 DOE-EV-0080 PNL-SA-7401 PNL-SA-7471 RPD-26-1</td>
</tr>
<tr>
<td>S-23</td>
<td>2/27/80</td>
<td>Crane accident</td>
<td>A 32-ton cover block fell 19 ft into the 221-B hot pipe trench when the remote crane operator moved a supporting cover block.</td>
<td>Damage of $1,174,000. Localized contamination but no external release. Facility able to continue operation.</td>
<td>IR-80-1</td>
</tr>
<tr>
<td>S-24</td>
<td>10/09/80</td>
<td>Pu contamination</td>
<td>A container of scrap material ruptured during a repackaging operation, contaminating several individuals and the facility.</td>
<td>No serious injuries resulted, and doses were within annual limits. Decon. cost was $654,000.</td>
<td>DOE/EV-0091 IR-80-2</td>
</tr>
<tr>
<td>S-25</td>
<td>04/02/82</td>
<td>Radiation Release</td>
<td>A misrouting of dilute nitric acid solution at the PUREX plant resulted in a 2,500-gal spill and spread of radioactivity into other areas of the building.</td>
<td>No radiation exposure above DOE limits resulted, and no release to the environment.</td>
<td>IR-82</td>
</tr>
<tr>
<td>S-26</td>
<td>01/29/85</td>
<td>Pu Contamination</td>
<td>A Pu glove-box worker received a puncture wound which was contaminated with Pu and Am. To remove contamination, tissue was surgically excised and DTPA treatments were given.</td>
<td>Final contamination level after treatment was less than the MPBB of Pu and Am.</td>
<td>IR-85</td>
</tr>
<tr>
<td>S-27</td>
<td>2/27/86</td>
<td>Safety Violation</td>
<td>In the PUREX Plant a concentrated plutonium nitrate solution was transferred to a tank that was connected to a non-geometrically favorable tank.</td>
<td>Several procedural violations could have resulted in a single-contingency criticality. Procedures and training were tightened.</td>
<td>UO-86-008</td>
</tr>
<tr>
<td>S-28</td>
<td>9/29/86</td>
<td>Safety Violation</td>
<td>In the Plutonium Finishing Plant, a concentrated plutonium nitrate solution was transferred to a tank that was connected to a non-geometrically favorable tank.</td>
<td>Several procedural violations could have resulted in a single-contingency criticality. Shutdown ordered for evaluation of all chemical processing operations.</td>
<td>UO-86-053</td>
</tr>
</tbody>
</table>
APPENDIX B

COMPILATION OF HANFORD FATALITIES, INCIDENTS COSTING MORE THAN $50,000, RADIATION OVEREXPOSURES, AND RADIATION EXPOSURE LIMITS
The Hanford Process Review has been restricted to nuclear process related incidents with significant safety or environmental implications. The DOE-RL has maintained compilations of several categories of reportable incidents at Hanford, as reported to appropriate government agencies. These incidents are summarized in this appendix, along with their corresponding incident numbers or the reasons for not including them in the present review.

B.1 HANFORD FATALITIES, 1943 TO PRESENT

There have been 44 work-related fatalities at Hanford, as summarized below. None of these are included in this review, since none relate to nuclear process operations.

### Employment Category of Fatalities

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>31</td>
</tr>
<tr>
<td>Operations</td>
<td>10</td>
</tr>
<tr>
<td>Government</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>44</strong></td>
</tr>
</tbody>
</table>

### Summary of Nonconstruction Fatalities

#### Operations

- 07/22/44 Engineer killed in vehicle accident
- 07/31/48 Driver killed in vehicle accident
- 08/31/55 Technician died of injuries from furnace explosion
- 11/25/55 Coal handler suffocated from coal pile collapse
- 08/14/61 Equipment operator killed in tractor accident
- 12/08/64 Track maintenance man killed by locomotive
- 12/05/71 Security patrolman electrocuted by fallen wire
- 07/18/74 Clerk killed in fall
- 08/22/78 Equipment operator crushed by crane
- 10/23/79 Patrolman died during physical test

#### Government

- 08/10/46 Pilot killed in airplane crash
- 11/22/48 Analyst died after vehicle accident

#### Other

- 07/28/81 Contractor employee died in bunker collapse
Reportable incidents involving more than $50,000 in property damage or loss are listed below along with their treatment in the current review.

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
<th>Loss or cost</th>
<th>Incident number</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/23/49</td>
<td>Hexone-nitric acid explosion</td>
<td>$125,000</td>
<td>L-1</td>
<td>2</td>
</tr>
<tr>
<td>12/04/51</td>
<td>Fire during cleanup from criticality</td>
<td>50,000</td>
<td>L-2</td>
<td>1</td>
</tr>
<tr>
<td>01/28/52</td>
<td>Warehouse fire</td>
<td>270,000</td>
<td>n.i.²</td>
<td></td>
</tr>
<tr>
<td>05/16/54</td>
<td>Fire starting in janitors' closet</td>
<td>62,000</td>
<td>n.i.²</td>
<td></td>
</tr>
<tr>
<td>01/05/55</td>
<td>Reactor fuel and tube melt</td>
<td>550,000</td>
<td>KW-1</td>
<td>1</td>
</tr>
<tr>
<td>02/13/58</td>
<td>Chemical explosion in silver nitrate vessel</td>
<td>76,000</td>
<td>S-8</td>
<td>3</td>
</tr>
<tr>
<td>08/08/58</td>
<td>Turbogenerator disintegration in test</td>
<td>90,000</td>
<td>n.i.²</td>
<td></td>
</tr>
<tr>
<td>04/17/60</td>
<td>Fire in fuel dissolver</td>
<td>250,000</td>
<td>S-9</td>
<td>2</td>
</tr>
<tr>
<td>11/06/63</td>
<td>Fire in REDOX facility</td>
<td>397,000</td>
<td>S-12</td>
<td>2</td>
</tr>
<tr>
<td>01/22/64</td>
<td>Tunnel collapse during backfilling</td>
<td>66,000</td>
<td>n.i.²</td>
<td></td>
</tr>
<tr>
<td>04/17/64</td>
<td>Reactor misloading requiring reload</td>
<td>51,000</td>
<td>H-14</td>
<td>2</td>
</tr>
<tr>
<td>11/03/64</td>
<td>Fire damage aquatic laboratory</td>
<td>317,000</td>
<td>n.i.²</td>
<td></td>
</tr>
<tr>
<td>07/31/65</td>
<td>Explosion in oil-fired boiler</td>
<td>75,000</td>
<td>n.i.²</td>
<td></td>
</tr>
<tr>
<td>08/23/65</td>
<td>Plutonium contamination from glovebox explosion</td>
<td>77,000</td>
<td>L-6</td>
<td>2</td>
</tr>
<tr>
<td>09/29/65</td>
<td>Tube failed in test reactor</td>
<td>895,000</td>
<td>PRTR-2</td>
<td>1</td>
</tr>
<tr>
<td>06/21/67</td>
<td>Oil fire in reactor heat exchanger cell</td>
<td>185,000</td>
<td>N-3</td>
<td>2</td>
</tr>
<tr>
<td>06/22/68</td>
<td>Reactor fuel and tube melt</td>
<td>66,000</td>
<td>KW-9</td>
<td>1</td>
</tr>
<tr>
<td>01/02/69</td>
<td>Flood damage</td>
<td>51,000</td>
<td>n.i.²</td>
<td></td>
</tr>
<tr>
<td>03/22/70</td>
<td>Strontium-90 release</td>
<td>95,000</td>
<td>S-18</td>
<td>2</td>
</tr>
<tr>
<td>11/14/73</td>
<td>Waste overflow in tank farm</td>
<td>264,000</td>
<td>S-21</td>
<td>3</td>
</tr>
<tr>
<td>03/06/75</td>
<td>Chain hoist failure</td>
<td>71,000</td>
<td>n.i.²</td>
<td></td>
</tr>
<tr>
<td>10/15/75</td>
<td>Damage to hoist</td>
<td>64,000</td>
<td>n.i.²</td>
<td></td>
</tr>
<tr>
<td>08/30/76</td>
<td>Americium contamination from glovebox explosion</td>
<td>500,000</td>
<td>S-22</td>
<td>1</td>
</tr>
<tr>
<td>Date</td>
<td>Description</td>
<td>Loss or cost</td>
<td>Incident number</td>
<td>Category</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------------------------</td>
<td>--------------</td>
<td>-----------------</td>
<td>----------</td>
</tr>
<tr>
<td>03/24/78</td>
<td>Compressors failed during testing</td>
<td>100,000</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>04/09/78</td>
<td>FFTF damage during installation</td>
<td>1,088,000</td>
<td>n.i.(^3)</td>
<td></td>
</tr>
<tr>
<td>11/21/78</td>
<td>Fuel truck fire</td>
<td>243,000</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>01/06/79</td>
<td>Chiller damaged during repair</td>
<td>51,000</td>
<td>n.i.(^4)</td>
<td></td>
</tr>
<tr>
<td>03/13/79</td>
<td>Rupture of PuO(_2) storage container</td>
<td>725,000</td>
<td>L-8</td>
<td>2</td>
</tr>
<tr>
<td>02/19/80</td>
<td>Compressor damage, run without oil</td>
<td>223,000</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>02/27/80</td>
<td>Cover block dropped on pipe trench</td>
<td>1,174,000</td>
<td>S-23</td>
<td>1</td>
</tr>
<tr>
<td>10/09/80</td>
<td>Plutonium scrap container ruptured</td>
<td>654,000</td>
<td>S-24</td>
<td>2</td>
</tr>
<tr>
<td>04/11/81</td>
<td>Wind damage to temporary building</td>
<td>141,000</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>08/03/81</td>
<td>Contamination from pump reversal</td>
<td>209,000</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>03/31/82</td>
<td>Fire in exhaust duct</td>
<td>339,000</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>04/02/82</td>
<td>Radioactivity spill and contamination</td>
<td>241,000</td>
<td>S-25</td>
<td>3</td>
</tr>
<tr>
<td>03/03/83</td>
<td>Dump of cadmium nitrate solution</td>
<td>250,000</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>01/09/84</td>
<td>Cooling pond dike break</td>
<td>87,000</td>
<td>n.i.(^4)</td>
<td></td>
</tr>
<tr>
<td>01/09/84</td>
<td>Fire in soiled laundry, smoke damage</td>
<td>86,000</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>01/11/85</td>
<td>Contamination blown from diversion box</td>
<td>160,000</td>
<td>n.i.(^4)</td>
<td></td>
</tr>
<tr>
<td>02/06/90</td>
<td>Contamination from cask filter disassembly</td>
<td>76,000</td>
<td>n.i.(^4)</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Rounded to the nearest $1,000.
\(^2\) Not included in incident review because not related to nuclear processes.
\(^3\) Not included in incident review because construction-related, not process related.
\(^4\) Not included in incident review because deemed to be of lesser safety significance.
### B.3 RADIATION OVEREXPOSURES AT HANFORD

#### B.3.1 Whole Body Penetrating Exposures

There have been 17 reported operational exposures greater than 5 rem per year and/or 3 rem per quarter. Their treatment in the process review is shown below.

<table>
<thead>
<tr>
<th>Date</th>
<th>Annual dose (rem)</th>
<th>Description</th>
<th>Incident number</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947</td>
<td>6</td>
<td>Worker in fuel prep. No details available</td>
<td>n.i.</td>
<td>2</td>
</tr>
<tr>
<td>4/54</td>
<td>14</td>
<td>Worker in radiometry lab, no identified cause</td>
<td>n.i.</td>
<td>2</td>
</tr>
<tr>
<td>04/07/62</td>
<td>110</td>
<td>Recuplex Criticality</td>
<td>S-11</td>
<td>1</td>
</tr>
<tr>
<td>04/07/62</td>
<td>43</td>
<td>Same as above, second individual</td>
<td>S-11</td>
<td>1</td>
</tr>
<tr>
<td>04/07/62</td>
<td>19</td>
<td>Same as above, third individual</td>
<td>S-11</td>
<td>1</td>
</tr>
<tr>
<td>04/63</td>
<td>5.9</td>
<td>5 rem exposure during tube removal</td>
<td>B-7</td>
<td>2</td>
</tr>
<tr>
<td>12/66</td>
<td>5.1</td>
<td>Normal work at N Reactor</td>
<td>n.i.</td>
<td>2</td>
</tr>
<tr>
<td>12/68</td>
<td>5.04</td>
<td>Normal work in fuel storage area</td>
<td>n.i.</td>
<td>2</td>
</tr>
<tr>
<td>12/68</td>
<td>5.4</td>
<td>Normal work in fuel storage area</td>
<td>n.i.</td>
<td>2</td>
</tr>
<tr>
<td>06/69</td>
<td>8</td>
<td>Overexposure from x-ray machine</td>
<td>n.i.</td>
<td>3</td>
</tr>
<tr>
<td>12/70</td>
<td>5.1</td>
<td>Normal work at 100-N area</td>
<td>n.i.</td>
<td>2</td>
</tr>
<tr>
<td>07/77</td>
<td>8</td>
<td>No specific incident identified</td>
<td>n.i.</td>
<td>2</td>
</tr>
<tr>
<td>10/77</td>
<td>4.6</td>
<td>Probable source liquid waste tank cars</td>
<td>n.i.</td>
<td>2</td>
</tr>
<tr>
<td>12/16/77</td>
<td>17.6</td>
<td>Accidental fuel discharge</td>
<td>N-14</td>
<td>1</td>
</tr>
<tr>
<td>12/16/77</td>
<td>13.5</td>
<td>Same as above, second individual</td>
<td>N-14</td>
<td>1</td>
</tr>
<tr>
<td>12/16/77</td>
<td>8.4</td>
<td>Same as above, third individual</td>
<td>N-14</td>
<td>1</td>
</tr>
<tr>
<td>12/16/77</td>
<td>8.2</td>
<td>Same as above, fourth individual</td>
<td>N-14</td>
<td>1</td>
</tr>
</tbody>
</table>

1List does not include four nonoperational overexposures of construction employees during radiography.
2Not included in incident listing because no specific incident was identified as causing the overexposure.
3Not included in incident listing because not related to nuclear process operations.
B.3.2 Extremity Overexposures at Hanford

There have been 12 reported operational extremity exposures greater than 75 rem in a year or 25 in a quarter. Their treatment in the incident review is given below.

<table>
<thead>
<tr>
<th>Date</th>
<th>Exposure</th>
<th>Location</th>
<th>Description</th>
<th>Incident number</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/11/53</td>
<td>430</td>
<td>hands</td>
<td>Handled irradiated aluminum spacers</td>
<td>DR-2</td>
<td>2</td>
</tr>
<tr>
<td>05/11/53</td>
<td>300</td>
<td>hands</td>
<td>Same as above, second individual</td>
<td>DR-2</td>
<td>2</td>
</tr>
<tr>
<td>05/11/53</td>
<td>300</td>
<td>hands</td>
<td>Same as above, third individual</td>
<td>DR-2</td>
<td>2</td>
</tr>
<tr>
<td>03/64</td>
<td>57</td>
<td>thumb</td>
<td>Irradiated wire stuck in glove</td>
<td>n.i.¹</td>
<td>¹</td>
</tr>
<tr>
<td>09/65</td>
<td>80,000</td>
<td>hand</td>
<td>Repairing x-ray spectrometer unit</td>
<td>n.i.²</td>
<td>²</td>
</tr>
<tr>
<td>11/14/67</td>
<td>370</td>
<td>wrist</td>
<td>Contamination on coverall cuff</td>
<td>S-16</td>
<td>3</td>
</tr>
<tr>
<td>02/69</td>
<td>60</td>
<td>hand</td>
<td>Backup from cesium-144 cask</td>
<td>n.i.¹</td>
<td>¹</td>
</tr>
<tr>
<td>08/69</td>
<td>1,700</td>
<td>fingers</td>
<td>From x-ray spectroscopy unit</td>
<td>n.i.²</td>
<td>²</td>
</tr>
<tr>
<td>04/18/70</td>
<td>2,500</td>
<td>hands</td>
<td>Hooking up line to waste cask</td>
<td>S-19</td>
<td>1</td>
</tr>
<tr>
<td>02/72</td>
<td>74</td>
<td>hand</td>
<td>Repair of contaminated valve</td>
<td>n.i.¹</td>
<td>¹</td>
</tr>
<tr>
<td>02/72</td>
<td>29</td>
<td>hand</td>
<td>Preparing strontium-90 Sources</td>
<td>n.i.¹</td>
<td>¹</td>
</tr>
<tr>
<td>06/83</td>
<td>35</td>
<td>hand</td>
<td>Manipulator maintenance</td>
<td>n.i.¹</td>
<td>¹</td>
</tr>
</tbody>
</table>

¹Not included in incident review because exposure did not exceed annual limit of 75 rem.
²Not included in incident review because not related to nuclear process operations.
B.3.3 Internal Deposition Above Limits at Hanford

There have been 19 reported internal radioactivity depositions greater than 50% of a maximum permissible body burden (MPBB) reported at Hanford, of which 8 were greater than one MPBB. All were plutonium depositions except the August 30, 1976, glovebox explosion, which was an americium deposition. The treatment of these depositions in the incident review is given below.

<table>
<thead>
<tr>
<th>Date</th>
<th>Deposition (%MPBB)</th>
<th>Description</th>
<th>Incident number</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/47</td>
<td>85</td>
<td>Routine examination. No known cause</td>
<td>n.i.(^1,2)</td>
<td></td>
</tr>
<tr>
<td>02/28/52</td>
<td>120</td>
<td>Puncture wound in glovebox work</td>
<td>S-3</td>
<td>3</td>
</tr>
<tr>
<td>05/52</td>
<td>80</td>
<td>Routine examination, no known cause</td>
<td>n.i.(^1,2)</td>
<td></td>
</tr>
<tr>
<td>09/53</td>
<td>75</td>
<td>Routine examination, no known cause</td>
<td>n.i.(^1,2)</td>
<td></td>
</tr>
<tr>
<td>02/16/55</td>
<td>290</td>
<td>Centrifuge repair</td>
<td>S-5</td>
<td>1</td>
</tr>
<tr>
<td>02/16/55</td>
<td>80</td>
<td>Same as above, second individual</td>
<td>S-5</td>
<td>1</td>
</tr>
<tr>
<td>06/18/56</td>
<td>780</td>
<td>Plutonium leak entered building air supply</td>
<td>S-7</td>
<td>1</td>
</tr>
<tr>
<td>06/18/56</td>
<td>170</td>
<td>Same as above, second individual</td>
<td>S-7</td>
<td>1</td>
</tr>
<tr>
<td>06/18/56</td>
<td>120</td>
<td>Same as above, third individual</td>
<td>S-7</td>
<td>1</td>
</tr>
<tr>
<td>03/58</td>
<td>90</td>
<td>Puncture wound in glovebox</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>12/59</td>
<td>65</td>
<td>Multiple depositions from glovebox work</td>
<td>n.i.(^1,2)</td>
<td></td>
</tr>
<tr>
<td>01/62</td>
<td>50</td>
<td>Multiple depositions from minor incidents</td>
<td>n.i.(^1,2)</td>
<td></td>
</tr>
<tr>
<td>07/10/64</td>
<td>270</td>
<td>Plutonium coupon ruptured, fragment in bicep</td>
<td>L-5</td>
<td>1</td>
</tr>
<tr>
<td>11/66</td>
<td>55</td>
<td>Residual plutonium from unreported puncture</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>03/67</td>
<td>50</td>
<td>Puncture wound during decontamination</td>
<td>n.i.(^2)</td>
<td></td>
</tr>
<tr>
<td>07/68</td>
<td>55</td>
<td>Multiple intakes</td>
<td>n.i.(^1,2)</td>
<td></td>
</tr>
<tr>
<td>04/69</td>
<td>50</td>
<td>Multiple intakes</td>
<td>n.i.(^1,2)</td>
<td></td>
</tr>
<tr>
<td>08/30/76</td>
<td>16,000</td>
<td>Americium from glovebox explosion</td>
<td>S-22</td>
<td>1</td>
</tr>
<tr>
<td>01/85</td>
<td>160</td>
<td>Puncture wound in glovebox</td>
<td>S-26</td>
<td>2</td>
</tr>
</tbody>
</table>

\(^1\)Not included in incident listing because no specific incident was identified.

\(^2\)Not included in incident listing because deposition was less than one MPBB.
B.3.4 Occupational Whole-body Radiation Exposures
Limits established by the DOE and its Predecessor Agencies

Whole-body radiation exposure limits applicable to Hanford operations are summarized in the following table. Radiation exposure limits were first given in terms of Roentgens, a measure of radiation field intensity. During the 1950s, the exposure unit was changed to the Roentgen Equivalent, Man (rem), which takes into account the differing effectiveness of different types of radiation on human tissue.

Initially, limits were applied to daily exposure. These were gradually replaced by weekly, quarterly, and annual limits, generally with the effect of reducing overall exposure limits.

### Occupational Whole-Body Dose Equivalent Limits.

<table>
<thead>
<tr>
<th>Year</th>
<th>Day</th>
<th>Week</th>
<th>13 Weeks</th>
<th>Year</th>
<th>Avg Year</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947</td>
<td>0.1 R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NCRP NBS Hdbk #18</td>
</tr>
<tr>
<td>1950</td>
<td>0.3 R</td>
<td>3.9 R</td>
<td></td>
<td></td>
<td></td>
<td>NBS Hdbk #47 AEC (DBM)</td>
</tr>
<tr>
<td>1952</td>
<td>3.9 R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AEC (DBM)</td>
</tr>
<tr>
<td>1954</td>
<td>0.3 R (Max)</td>
<td>3.0 R</td>
<td>15 rem</td>
<td></td>
<td></td>
<td>NCRP NBS Hdbk #59</td>
</tr>
<tr>
<td>1958</td>
<td>0.3 rem</td>
<td>3.0 rem</td>
<td>12 rem (Max)</td>
<td>5 rem</td>
<td></td>
<td>NCRP NBS Hdbk #59</td>
</tr>
<tr>
<td>1960</td>
<td>3 rem</td>
<td></td>
<td></td>
<td></td>
<td>5 rem</td>
<td>FRC Report #1</td>
</tr>
<tr>
<td>1974</td>
<td>3 rem</td>
<td>5 rem</td>
<td></td>
<td></td>
<td></td>
<td>NCRP #39</td>
</tr>
<tr>
<td>1989</td>
<td></td>
<td>5 rem</td>
<td></td>
<td></td>
<td></td>
<td>DOE Order 5480.11</td>
</tr>
</tbody>
</table>
GLOSSARY

ACRONYMS

ACRS  U.S. Advisory Committee on Reactor Safeguards
AEC  U.S. Atomic Energy Commission
BPA  Bonneville Power Administration
CPS  Criticality Prevention Specification
DOE  U.S. Department of Energy
DOE-RL  U.S. Department of Energy-Richland Operations Office
DTPA  Diethylene triamine pentacetate
DUN  Douglas-United Nuclear Corporation
ECCS  Emergency Core Cooling System
ECS  Emergency Cooling System
EDF  Emergency Decontamination Facility
ERDA  U.S. Energy Research and Development Administration
FERTF  Fuel Element Rupture Test Facility
FFT  Fast Flux Test Facility
FRC  Federal Radiation Council
GE  General Electric Corporation
HCR  Horizontal control rod
HEDL  Hanford Engineering Development Laboratory
HHRE  Hanford Homogenous Reactor Experiment
LP  Low pressure (mercoid switch)
MPBB  Maximum permissible body burden
MPL  Maximum permissible limit
PCCF  Poison Column Control Facility
PFP  Plutonium Finishing Plant
PRF  Plutonium Reclamation Facility
PRTR  Plutonium Recycle Test Reactor
RMA  Remote Mechanical A
RMC  Remote Mechanical C
SMR  Standardized mortality ratio
TBP  Tributyl phosphate
UNH  Uranyl nitrate hexahydrate
VLP  Very low pressure (mercoid switch)
VSR  Vertical safety rod

DEFINITIONS OF TERMS

Backup Ball Safety System or Ball Safety System. A system to shut down a reactor by release of neutron-absorbing balls, allowing them to fall by gravity into vertical channels in the reactor graphite. This system provided a backup shutdown mechanism in case the rod system failed, was slow to react, or was inadequate to shut down the nuclear reaction.

Bayonet. A cylindrical shielding piece to be inserted into the front or rear of a dry tube to provide radiation shielding.

Beta radiation. A relatively non-penetrating form of radiation released in the fission process and by some fission products.
GLOSSARY (cont.)

DEFINITION OF TERMS (cont.)

C Elevator. The charge elevator, located at the front face of a reactor to provide access to the process tubes for fuel charging and other operations.

Canyon jumper. A piping system to transport liquids from one side of the main gallery, or canyon, in a processing facility to the other.

Chelating agent. A chemical, usually a form of DTPA (diethylene triamine pentacetate), used to solubilize radioactive contaminants and promote their elimination from the body.

Cold Startup. A startup or restart of a production reactor after the xenon transient has passed its peak poisoning effect. See also "hot startup."

Criticality. The condition in which a system has achieved a self-sustaining nuclear chain reaction. See also "prompt criticality" and "supercriticality."

Crossheader. A horizontal pipe supplying or discharging cooling water from a row of process tubes through pigtail connectors to each tube.

D Elevator. The discharge elevator, located at the rear face of a reactor to provide access for fuel charge-discharge and other operations.

Discharge chute. A device attached to the rear or discharge end of a process tube to guide discharged fuel into the spent fuel storage basin.

Displacement discharge. A method of discharging a poison column or fuel column by pushing the column of elements out with a new column of elements fed into the charge end.

Dummy. An aluminum piece of the size and shape of a fuel element or poison element, used to fill the inlet and outlet end portions of a process channel (the portions penetrating the shield) so that the fuel and poison elements are confined within the reactor core. Also called a "spacer."

Emergency Cooling System. A backup cooling system available to provide adequate post-shutdown cooling in case of complete failure of the main cooling system.

Erythema. Abnormal redness of the skin due to capillary congestion. Specifically, erythema caused by excessive radiation exposure.

Flush discharge. A method of discharging a poison column by opening the discharge valve and allowing the coolant flow to carry the poison elements out of the tube (as opposed to displacement discharge). Not used for fuel element discharge.

Flux. See "neutron flux."
GLOSSARY (cont.)

DEFINITION OF TERMS (cont.)

**Flux monitor.** Instrumentation to measure the neutron flux within a reactor. Safety instrumentation may respond to aberrations in local neutron flux, distribution of neutron flux, or rate of change of neutron flux. See also "period."

**Gunbarrel.** A steel sleeve occupying the rear portion of a process tube.

**Hexone.** Methyl isobutylketone, a solvent used in the REDOX solvent extraction process to separate and purify uranium and plutonium from other constituents of spent nuclear fuel.

**High-lift pump.** A pump providing a high pressure differential, used to pump primary coolant through the reactor.

**Horizontal control rods.** Neutron absorbing rods inserted horizontally into one or both sides of a reactor to control the rate of the nuclear reaction and the distribution of power level within the reactor.

**Hot startup.** A quick restart of a production reactor before the post-shutdown xenon transient has built up to the point that there is insufficient reactivity to restart.

**Last ditch cooling system.** Another designation for the emergency cooling system.

**Low-lift pump.** A high capacity pump providing a relatively low pressure differential, used to provide feed for the high lift pumps.

**LP switch.** A switch to initiate appropriate safety action if the primary coolant system pressure drops below a preset level.

**Manhattan Project.** The war-time project to develop an atomic bomb, managed by the U.S. Army's Manhattan Engineering District.

**Maximum permissible body burden.** The amount of a radioactive material a worker could accumulate internally before exceeding permissible radiation exposure limits to critical organs.

**Maximum permissible limit.** A term used to designate internal radioactivity limits before adoption of the MPBB.

**Minimum outage.** A refueling or other reactor outage accomplished quickly enough to permit restart before the xenon poisoning effect reached a level that would prevent an immediate restart.

**Monotube.** A charging device in the shape of a reactor process tube, holding the fuel and/or poison elements to be charged into a single process channel.
GLOSSARY (cont.)

DEFINITION OF TERMS (cont.)

Overbore pattern. The presence of overbored channels in the reactor graphite to accommodate larger diameter process tubes.

Panellit Gage. A pressure-indicating gage monitoring the coolant inlet pressure on a process tube, as a measure of coolant flow. The panellit gages on the production reactors were part of the reactor safety system.

Period. A measure of the exponential rate of rise (or decay) of the power or neutron flux level of a reactor. The time for the power or flux to increase or decrease by a factor of e, approximately 2.718.

Pigtail. A coiled connector section on the inlet and outlet of each process tube of the production reactors to accommodate expansion and contraction.

Pile. A nuclear reactor or reactor-like test assembly, so-called because the initial reactors were assembled as a stack or pile of graphite blocks.

Poison Control Column Facility. A facility for improving control of a reactor by equipping selected process tubes so that poison elements could be charged and discharged during reactor operation.

Poison element or slug. A cylinder of lead-cadmium alloy used as a neutron absorber to reduce reactivity or suppress the flux level in a region of the reactor.

Poison spline. A narrow strip or spline of neutron absorbing material, inserted into a process tube along with fuel elements. Unlike the poison slugs, poison splines were intended to be inserted or removed with the reactor operating.

Poppy. A radiation survey meter emitting an audible popping noise to indicate the intensity of a radiation field.

Prompt critical. The condition of a nuclear assembly in which the neutron chain reaction becomes self-sustaining on prompt neutron emission alone, without regard to that small fraction of neutrons that are emitted after an appreciable delay. Prompt criticality produces a very rapid rate of power increase.

Rad. A radiation exposure unit based on the energy deposition in any medium. Equal to 100 ergs/g.

Radiolytic degradation. Deleterious chemical reactions produced in materials exposed to nuclear radiation.

Rem. Roentgen equivalent man; a radiation exposure unit that takes into account the relative biological effects of the radiation.
GLOSSARY (cont.)

DEFINITION OF TERMS (cont.)

_Ren_. Roentgen equivalent physical; a radiation exposure unit based on the amount of energy deposited in soft tissue.

_Rising period_. See "period."

_Roentgen (R)_._ A radiation exposure unit based on the amount of energy deposited in air.

_Safety rods_. Control rods held outside a reactor during operation and equipped with a rapid insertion mechanism to provide a rapid shutdown capability, either by automatic safety circuitry or by operator action.

_Scram_. A sudden reactor shutdown produced by insertion of the safety rods or activation of the ball safety system.

_Secondary cold startup_. A cold startup taking place while xenon levels are still appreciable. Reactivity patterns were particularly difficult to predict under such conditions.

_Stack_. The graphite assembly of a reactor.

_Subcritical_. the reactor condition in which sufficient neutron absorbing material is present to prevent the nuclear reaction from becoming self-sustaining.

_Tipoff fitting_. A device attached to the rear end of a process tube during charge-discharge operations to guide the discharged fuel into the spent fuel basin.

_Total control limit_. A requirement placed on the amount of control capability of the control and safety systems to ensure the ability to shut down the reactor and maintain a safe shutdown state under any conditions.

_Trip_. The automatic actuation of a safety device.

_Vertical safety rods_. See "safety rods."

_VLP switch_. A very low-pressure switch, designed to initiate appropriate safety action in case the primary coolant system pressure drops below a preset limit.

_Zircaloy_. An alloy of zirconium, used in reactor process tubes and fuel cladding.

_Zone temperature monitoring system_. A system of temperature monitoring devices located throughout the reactor cooling system to provide a display of power distribution and initiate automatic control action as appropriate.
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