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UC-2050

Pacific Northwest National Laboratory

Operated by Battelle for the
U.S. Department of Energy

U.S. Graphite Reactor D&D Experience

S.M.K. Garrett
N. C. Williams

February 1997

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Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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CONTENTS

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

APPENDIX E

APPENDIX F

APPENDIX G

1.0 INTRODUCTION

This report describes the results of the U.S. Graphite Reactor Experience Task for the Decommissioning Strategy Plan for the Leningrad Nuclear Power Plant (NPP) Unit 1 Study. The work described in this report was performed by the Pacific Northwest National Laboratory (PNNL) for the Department of Energy (DOE).

1.1 Objective

The objective of the U.S. Graphite Reactor Experience Task was to review available literature on decontamination and decommissioning (D&D) of U.S. graphite reactors and document the results of the review. The results will be incorporated in a document to be developed by Brookhaven National Laboratory relating world-wide graphite reactor D&D experience. The Decommissioning Strategy for Leningrad NPP Unit 1 will incorporate lessons learned from the D&D of other graphite-moderated reactors.

1.2 Background

There are 16 graphite-moderated reactors in the U.S. that have been included in this study. All have undergone shutdown and have some level of deactivation. Five of the reactors have also undergone some level of decommissioning. Other small graphite reactors (e.g., the Standard Pile, CP-1, and CP-2) have been dismantled in the U.S., but no information was found on them and they are not included in this report. The small graphite reactors left out of the study are believed nonrepresentative of the D&D that would be needed on the larger graphite reactors.

Nine of the reactors investigated are plutonium production reactors at the Hanford Site in Richland, Washington. Although the Hanford Site Reactors are a different design from the RBMK reactors, much of their D&D should be relevant to that of the RBMKs. The Hanford Site reactors are named B, C, D, DR, F, H, KE, KW, and N. None of the Hanford Site reactors have undergone decommissioning, but all have undergone some level of deactivation. Two of the reactors (the C and N reactors) have decommissioning or deactivation work ongoing. The first eight reactors listed are single-pass water-cooled graphite reactors used exclusively for plutonium production. The ninth reactor, N, was a dual purpose, multi-pass water-cooled reactor.

Two of the reactors investigated were commercial reactors that have undergone D&D. Fort Saint Vrain was a 330-MWe high temperature gas-cooled reactor (HTGR) owned by the Public Service Company of Colorado. The Fort Saint Vrain decommissioning to green field started in 1992 and has recently (1996) been completed. Green field decommissioning is the removal of all contamination and structures at a site.

Peach Bottom Unit 1 (referred to simply as Peach Bottom) was the other commercial reactor investigated. Peach Bottom was a 40-MW prototype HTGR owned by the Philadelphia Electric Company. The Peach Bottom Unit was mothballed, that is, the containment area and the spent fuel buildings have been isolated in an exclusion area. All contamination outside the exclusion area and accessible areas within the exclusion area have been decontaminated. Decommissioning took place from 1974 to 1977.

The Hallam Nuclear Power Reactor was a 254-MW(t) sodium-cooled reactor that was owned by the Atomic Energy Commission (AEC). The Hallam reactor was shut down in 1964, and entombment was completed in 1968.

The remaining four reactors investigated under this task were all small research reactors. The ORNL Graphite Reactor was shut down in 1963 and is currently open for public viewing as a National Historic Landmark. Little information was found in the documentation on the ORNL Graphite Reactor, but several options were considered for decommissioning. The Sodium Reactor Experiment was a 20-MW system that was mothballed immediately after shutdown and then decommissioned later to green field. The Oak Ridge National Laboratory (ORNL) Molten Salt Reactor Experiment (MORE) was an 8-MW, fluid-fuel reactor that operated for four years and has not been decommissioned. The Ultra-High Temperature Reactor Experiment (UHTREX) at Los Alamos, New Mexico, was a 3-kW, graphite-moderated, helium-cooled system. UHTREX was decommissioned to green field.

Two other reactors were identified during the study, but little or no information was found on their D&D. These were the TRIGA Mark II Berkeley Research Reactor and the Brookhaven Graphite Research Reactor. The Brookhaven reactor has not been decommissioned.

1.3 Document Overview

The main report (Sections 2.0 through 6.0) provides an overview of the D&D experiences for U.S. graphite-moderated reactors. Section 2.0 describes in general the activities performed from shutdown through decommissioning of nuclear facilities. Section 3.0 describes the shutdown experience for the reactors investigated in this study. Section 4.0 provides information on the deactivation and Section 5.0 on the decommissioning of the reactors investigated. Section 6.0 provides general conclusions based on the literature review performed.

The appendices provide the detailed information for each of the reactors investigated. Appendix A gives details for the Hanford Site Reactors, Appendix B for Fort Saint Vrain, and Appendix C for Peach Bottom. Appendix D describes the information found for the smaller research reactors.

2.0 GENERAL DECONTAMINATION AND DECOMMISSIONING OF NUCLEAR REACTORS

Decontamination and decommissioning is usually performed on nuclear reactors after a safe shutdown and a surveillance and maintenance period. The description that follows is compiled from the *Decommissioning Handbook* (DOE/EM-0142P) and addresses shutdown, surveillance, maintenance, and D&D. The definitions provided below draw from DOE's terminology. Other countries and other agencies may use other terms or have different meanings for the same terms. This report uses the meanings presented below.

2.1 Safe Shutdown

Safe shutdown is performed at the end of a nuclear reactor's operating life and involves cleaning the process systems and removing all process materials. At the end of safe shutdown, some residual sludge and residues and hazardous materials that are part of the physical plant would remain in the facility.

The general activities of safe shutdown are as follows:

- Nuclear fuel is removed.
- Process systems are emptied and flushed.
- Filters and other such equipment that contain radioactive or hazardous contamination are removed and disposed of, as was done during operations.

2.2 Deactivation

Deactivation is performed to remove the conditions that present potential human health and environmental threats and to reduce surveillance and maintenance requirements. Deactivation is required only if a facility is to go into a period of waiting before D&D is to be performed.

Deactivation includes contamination removal, surfaces stabilization, repairs, surveys, building and systems isolation, shutdown and deactivation, sealing of openings, and varmint control. Once deactivation is complete, the facility then enters a surveillance and maintenance mode.

2.3 Surveillance and Maintenance

After safe shutdown and deactivation are completed, a facility may go into a period of waiting before D&D is performed. Surveillance and maintenance are done on the facility during the waiting period to ensure that workers will be safe and that process equipment does not fail and release any residual material.

Surveillance and maintenance should be done on a facility for the entire period between safe shutdown/deactivation and the beginning of D&D. During the surveillance and maintenance period, records should be kept on the facility's equipment that has deteriorated with time so that personnel performing D&D would be informed of potential hazards.

2.4 Decontamination and Decommissioning

Decontamination and decommissioning are performed to remove radioactive and hazardous materials so there are no risks to humans and the environment. D&D consists of four stages: assessment, development, operation, and closeout.

2.4.1 Assessment Stage

During the assessment, it is decided what is to be done. The assessment stage results in definition of the final goal of D&D, performance of initial characterization surveys, evaluation of risks, and selection of a D&D alternative.

Assessment consists of two phases: characterization and decision-making. Characterization is performed to determine the physical, hazardous, and radiological properties of a facility in enough detail to support the decision-making phase. Once characterization is complete, the decision-making phase begins, during which D&D alternatives are analyzed to determine the best approach. Three alternatives, with possible combinations and variations, are generally evaluated during the decision-making phase:

- SAFESTOR - A facility is placed in safe storage for a period of time before decommissioning is performed.
- ENTOMB - Radioactive contaminants are encased in a structurally long-lived material.
- DECON - Equipment, structures, and portions of the facility and site with radioactive contamination are removed.

SAFESTOR and ENTOMB involve continued surveillance and maintenance, which are continued in the ENTOMB alternative until radioactive levels allow for free release.

The D&D alternatives are evaluated taking the following into account: regulatory requirements, land use plans, financial requirements, disposal options, risks, and technology alternatives. Regulatory requirements may include the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); the Environmental Protection Agency (EPA) Guidance in Conducting Remedial Investigations and Feasibility Studies under CERCLA (EPA 1988); and Nuclear Regulatory Commission (NRC) regulations requiring a decommissioning plan at least 5 years before decommissioning (Regulatory Guide DG-1005; NRC 1989). Local and state regulations may also apply.

Land-use plans address how the facility/facility site will be used in the future. Possible land-use scenarios range from totally restricted (to continue to be used as a nuclear site) to complete restoration of the area for unlimited use.

2.4.2 Development Stage

In the development stage, planning needed to carry out the alternative selected in the assessment stage is performed. Detailed engineering, cost estimating, and task scheduling are performed. The Decommissioning Plan is prepared, based on the technologies and methodology resulting from the detailed tasks.

During detailed engineering, appropriate actions are designed to accomplish D&D. Exposures, criticality, safeguards and security, and the results from the assessment stage are considered during the engineering task.

Preparation for physical decommissioning is performed during the development stage. Coordination with various organizations is implemented, documentation is planned (e.g., Characterization Plan, Decommissioning Plan, Progress Reports, Security Plan, Final Survey Report), public involvement is initiated, the project organization is defined, and permits are applied for. Training is also defined and initiated.

2.4.3 Operations Stage

Operations is the performance of physical decommissioning. The key aspects of decommissioning operations include operations on contaminated materials, onsite storage of materials awaiting disposal or processing, and packaging of materials for transport.

Operations include site preparation prior to and after a facility is decommissioned. For example, staging areas for material storage may be required prior to shipment.

2.4.4 Closeout Stage

The purpose of the closeout stage is to verify that the site meets the release criteria established for the project. Closeout consists of surveys, verification, and documentation. Planning for closeout should be performed during the development stage to ensure regulatory buy-in early in the project. Such planning includes the survey plan for the closeout survey and identification of an independent verifier.

2.5 Lessons Learned

The following lessons learned were identified for a particular decommissioning project. However, they are applicable to future decommissioning projects and are, therefore, included here. Before the following lessons were learned, they caused grave delays for the project:

- Set acceptable levels of residual surface contamination radiation in soil, air, and water.
- Obtain permits and approvals early.

- Get prior commitment of the waste disposal site for acceptance of all expected waste forms.
- Anticipate that meeting the regulatory requirements (e.g., RCRA, CERCLA, SARA (EPA) will add years to the D&D schedule.

3.0 GENERAL SHUTDOWN EXPERIENCE

The major activity of shutdown is defueling. All but one of the reactors investigated defueled at shutdown. Fuel was left in the ORNL reactor temporarily at shutdown. Reactors were defueled with control rods in place with cooling water supplied. Cooling water was removed after defueling. Control rods were generally left in place after defueling.

All but the two commercial reactors investigated went into surveillance and maintenance before decommissioning. Shutdown included preparing for deactivation when decommissioning did not immediately follow shutdown. For the original eight Hanford Site reactors, shutdown included removing all radiation source material from the reactor areas, deactivating operable systems, and performing radiation surveys. For N Reactor, which went into cold standby, maintenance was also performed during shutdown to prepare for future restart. Reactor-related equipment was removed for many of the non-Hanford reactors at shutdown.

4.0 GENERAL DEACTIVATION EXPERIENCE

Deactivation is the stage where surveillance and maintenance are reduced and conditions that present potential health and environmental threats are removed. Deactivation is performed only if there is to be a surveillance and maintenance period between shutdown and decommissioning.

Very little on deactivation is found in the literature. The test reactor's documentation did not contain any information regarding deactivation; deactivation may have been performed at shutdown. The two commercial reactors studied went directly from shutdown to decommissioning and, therefore, did not undergo deactivation. The reactors at the Hanford Site underwent some deactivation after shutdown and have recently started undergoing another phase of deactivation in preparation for long-term storage.

Early deactivation of the original eight reactors at the Hanford Site included shutdown and isolation of operating systems that had been left operational at shutdown. Early deactivation also included ancillary facilities demolition. Current deactivation of the original eight reactors includes radiation and hazardous material cleanup and demolition of the reactor buildings up to the shield walls surrounding the reactor blocks. The reactor block will be stabilized for long-term storage, the shield walls will then be extended to a level above the reactor block, and a new roof will be installed.

N Reactor, the ninth reactor at the Hanford Site, is currently undergoing deactivation. N Reactor deactivation includes the shutdown and isolation of operating systems and facilities, the cleanup of radioactive and hazardous materials, the cleanup and stabilization of N Basin, and the environmental stabilization of ancillary facilities. Although decommissioning is to follow deactivation for the ancillary facilities, the decommissioning will take over 20 years. Therefore, the ancillary facilities will have surveillance and maintenance performed before decommissioning is completed.

5.0 GENERAL DECOMMISSIONING EXPERIENCE

Of the 15 reactors investigated in this study, only four have undergone decommissioning. Fort St. Vrain and the Sodium Reactor Experiment were decommissioned to green field or near-green field conditions; Peach Bottom was moth-balled; and the Ultra-High Temperature Reactor Experiment was cleaned for reuse. The remaining 11 reactors (the nine at the Hanford Site and the two at Oak Ridge National Laboratory) have not undergone decommissioning. The Brookhaven Graphite Research Reactor, for which very little information was found, has also not been decommissioned.

Fort St. Vrain has recently completed decommissioning. The reactor core vessel was flooded to minimize exposure. Technologies used during decontamination included grit blasting, high-pressure water, and hand methods. Dismantling technologies included plasma arc cutting, diamond wire abrasive method, oxylance process, long-handled tooling, and hydraulically operated shears and clamp system.

The Sodium Reactor Experiment was decontaminated using foam, sandblasting, scabbling, and a hoe ram. The reactor vessel was dismantled using underwater cutting with a rotating mast manipulator. Explosive cutting and large impact hammers were also used.

Peach Bottom used arc gouging and grinding for some of the decontamination.

The plans for decommissioning the remaining 12 reactors are as follows:

- The eight original Hanford Site reactors are slated for one-piece removal and disposal of the reactor blocks after a 75-year wait. B Reactor, the first of the original reactors, is a National Historic Landmark and may be made into a museum instead of being decommissioned.
- For N Reactor at the Hanford Site, decommissioning options are being investigated. No decision has been made.
- The ORNL Graphite Reactor is a National Historical Landmark. It is open to the public for viewing. No decommissioning is planned.
- The ORNL Molten Salt Reactor Experiment decommissioning options have been studied. No written documentation was found regarding a final decision for decommissioning.

6.0 CONCLUSIONS

Most of the U.S. graphite reactors have undergone shutdown and some deactivation. Of the 15 reactors investigated in this study, only four have undergone decommissioning.

In the past, DOE has usually shut down its reactors and then performed some deactivation and minimal maintenance. More recently, DOE has decided to put many of its reactors into long-term safe storage and has started to decrease the footprint of the structures to be maintained. Construction has been started for low-maintenance structures to isolate the reactor cores and provide safety for workers. The new structures, which will replace the existing structures, will be relatively low cost compared to upgrading the present structures for long-term storage.

There is much less experience with commercial graphite-moderated reactors. Only two of the 15 reactors investigated were commercial. In one case, full decommissioning was accomplished as soon as possible after shutdown. The other reactor was mothballed and the remainder of the facility released for other use as soon as possible after shutdown. In both cases, unknown future regulations and waste disposal site options resulting in potentially higher costs probably played a factor in the decisions.

Meeting regulatory requirements is time-consuming and must be planned for in the early stages of decommissioning. Federal, State, and local regulations affect all aspects of D&D, ranging from analysis of final land-use options and public involvement requirements to documentation and permitting requirements. Consider the following two examples of regulations driving schedules:

- The NRC, in the past, required a decommissioning plan at least 5 years before decommissioning was to start.

- A Record of Decision (DOE) took 7 years after submittal of the Environmental Impact Statement for the original eight reactors at the Hanford Site.

Obtaining permits and approvals early is necessary to avoid delays once the work has started.

Much of the documentation reviewed concentrated on what was done instead of how it was done. However, the technologies documented for use in D&D of U.S. graphite reactors are standard D&D tools. The most exotic technology proposed is a transport vehicle for one-piece transport of reactor blocks at the Hanford Site. This transport vehicle (or set of vehicles) would carry the 8,100- to 11,000-tonne reactor blocks up to 15 miles for final disposal.

Technologies for shutdown appear to be the normal techniques and tools used during operation. Only the RO-7 (Eberline) system was mentioned for characterization, while decontamination included hand methods (e.g., wipes), vacuums, filters, foam, high-pressure water, brushes, fixatives, sand and grit blasting, grinding, and scabbling. The most exotic demolition/dismantling technology is the rotating mast manipulator with a plasma arc cutting system. Other dismantling/demolition techniques mentioned in the readings include hydraulically operated shears and clamp systems, scissors, abrasive wheel saw, plasma arc cutting, diamond wire abrasive cutting, oxylance process, arc gouging and grinding, explosives, large-impact hammer, and hydraulic hoe ram. A few material-handling/packaging technologies are also mentioned in the literature: crushing with high-efficiency particulate filters on the crushing vacuum, grout, long-handled grasping tools, flat beds, and various cranes.

C Reactor at the Hanford Site is a large-scale demonstration site for innovative technologies. The plan is to test 20 innovative technologies in the areas of characterization, decontamination, segmentation, health and safety, facility stabilization, and waste minimization. Some of the technologies currently planned for testing include temporary power and lighting, radiation mapping system, gamma ray imaging, battery-operated shears, lightweight diamond chain saw, asphalt emulsion remover, pipe cutting/removal system, sealed seam sack suits, self-contained air-cooled respirator/suits, spray-on stabilizer, light ablation, concrete shaving, and laser cutting.

In general, D&D of graphite reactor facilities is similar to D&D of other facilities. The major difference is that the reactor block requires special considerations in dismantling and handling (e.g., because of high dose rates) and decommissioning (e.g., one-piece transport of a 8,100- to 11,000-tonne block). The planned final disposition for a reactor block depends on the final land/facility use planned. Final disposition then determines if something needs to be done to the reactor block. For instance, entombment would require very little work on the reactor block, whereas total dismantlement would require the reactor block to be removed from the site.

APPENDIX A

HANFORD REACTORS

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The Hanford Site was selected for the location of the first, full-scale plutonium production plants in the world in 1942. The Hanford Site is located in south-central Washington State on the Columbia River with onsite waste disposal located approximately 8 to 22 kilometers from the reactors. The area is semi-arid, receiving less than 17.8 cm of rain per year.

Nine plutonium-producing reactors were constructed and operated on the Columbia River at the Hanford Site between 1943 and 1987. One was a dual-purpose reactor (N Reactor), which was designed to supply steam for the production of electricity as a by-product. The other eight reactors (B, C, D, DR, F, H, KE, and KW Reactors) were all similar in design and are in a short-term safe storage condition. The record of decision for the eight reactors is for long-term storage (SAFESTOR) followed by one-piece removal of the reactor cores for burial onsite. C Reactor is scheduled to be the first of the original eight reactors to be dismantled, but will not be totally dismantled for up to 75 years. N Reactor, which was shut down in 1987, is being deactivated and its potential dispositioning is being analyzed.

In general, the Hanford Site is cleaning up auxiliary facilities and waste sites and leaving the reactor buildings for later decommissioning. Since shutdown, all of the reactors have been in short-term safe storage and have been monitored. Planning began in 1974 to decommission support facilities in the reactor areas. Work began in 1976 with 25 auxiliary buildings decommissioned between 1976 and 1988. Work was also initiated during the same time-frame to clean up fuel storage pools.

Current plans are to prepare the original eight reactors for long-term storage (SAFESTOR) by the end of FY 2007. Work has started at the C Reactor to place the reactor in SAFESTOR.

A.1 Hanford Decommissioning History

The original eight reactors, which are similar in design, construction, and radiological condition, have been considered as a group in evaluating D&D alternatives. All eight of the reactors were defueled after final shutdown and all radioactive source material was removed from the reactor areas. All operable systems were deactivated and routine radiation surveys have been made during their short-term storage. For years, minimal funding was allocated to maintain the reactor buildings and equipment, resulting in facility exteriors in poor condition. After a recent fatal accident, increased funding allowed the exteriors to be greatly improved.

Decommissioning work on the original eight reactors and their associated facilities began in 1976. Large-area, surface contamination monitors, remotely operated sand blasters, arc-saws, concrete scabblers, low-temperature decontamination fluids, in situ electro-polishing, high pressure water jets, and explosive cutting and demolition techniques were all used to decommission the auxiliary buildings.

Various D&D alternatives were analyzed in an Environmental Impact Statement for the original eight reactor buildings: no action, immediate one-piece removal, safe storage followed by either one-piece removal or dismantlement, and in situ decommissioning. The Record of Decision, which was finalized approximately seven years after the Environmental Impact Statement was issued, placed the reactors in long-term safe storage and recommended waiting for approximately 75 years before removing the cores in one piece and moving them for onsite burial.

Current plans are to place seven of the original eight reactors in long-term storage (SAFESTOR) starting with C Reactor. In order to minimize future surveillance and maintenance, most of the reactor building is to be decontaminated and dismantled, leaving only the area directly around the core. The area directly around the core will be built up to above the core and a new long-life roof will be placed over the top. Lessons learned during the decommissioning work at C Reactor will be applied at the other reactors.

B Reactor, the first full-scale plutonium production reactor, is the original reactor at the Hanford Site. It is a National Historical Facility that may be turned into a museum and not placed in SAFESTOR.

N Reactor, the ninth reactor constructed at the Hanford Site, is different than the other eight reactors in design. N Reactor and its auxiliary facilities are currently undergoing deactivation. Decommissioning of the auxiliary facilities is to start immediately after the completion of deactivation. The final disposition of the reactor building is being analyzed; however, the core construction is different enough from the original eight reactors that one-piece removal and burial may not be feasible.

The remainder of this Appendix discusses the original eight reactors and the N Reactor.

A.2 Original Eight Hanford Reactors

This section covers the physical characteristics of the reactors, the circumstances of their shutdown, and their current status.

A.2.1 Physical Characteristics

There are only minor differences among the original eight reactors in terms of design, construction, and radiological condition. The reactor buildings, with dimensions approximately 76 x 70 x 29 meters, are constructed of reinforced concrete and concrete block. The lower reinforced concrete walls around the reactor block range in thickness from 0.9 to 1.5 meters. Lighter concrete or corrugated asbestos cement was used above the reactor block.

The roofs are primarily precast concrete slab or poured insulated concrete. The total volume of concrete in each reactor building is estimated as 330 m^3, excluding the reactor block itself.

Each of the reactor buildings contains a reactor block, a reactor control room, a spent-fuel discharge area, a fuel storage basin, a ventilation and recirculation system, inert gas systems, water cooling systems, supporting offices, and shops and laboratories.

The reactor block is the primary portion of the reactor building. The graphite moderator stack is made of graphite blocks placed in a criss-cross pattern and cored for process tubes, control rods, and other equipment. This is all encased in a single-layer thermal shield, 8 to 10 inches (20 to 25 cm) thick and constructed of cast-steel interlocking blocks. The thermal shields of the reactors each contain approximately 91 tonnes (100 tons) of lead. A biological shield, about 40 to 83 inches (102 to 211 cm) thick, surrounds the thermal shield. The biological shield is constructed of steel and masonite in the older reactors and concrete in the K Reactors. Fifty percent of the weight of the reactor block is from the biological shield. A vault-like steel outer shell encases the reactor block on the top and on four sides. The shell has gas-tight seals for the reactor block penetrations. The block, with dimensions of 14 x 12.2 x 14 meters, rests on a massive concrete base/foundation and weighs 8,100 to 11,000 tonnes. The block is separated from the foundation by a 0.635 cm thick steel membrane plate. The control rods run horizontally through the block and the safety rods run vertically from the top of the block. The emergency shutdown system, the Ball 3X system, consists of steel and boron balls that drop into the safety rod channels and shut the process down in the case of an emergency. The process tubes run horizontally from front to rear.

The KE and KW reactor blocks are approximately fifty percent larger than the older reactors. Larger fuel elements were used and required more process tubes, which are made of zircaloy-2 or aluminum. The older reactors' process tubes are all aluminum.

The KE and KW fuel storage basins are being used to store approximately 2,100 MTU of N-Reactor and 3 to 4 MTU of Sandia Pulsed Reactor fuel. The remaining fuel storage basins are empty of fuel and water. The reactor fuel storage basins were filled with water when spent fuel was stored in them. The water provided protection from radiation. The basins have capacities of 650 to 930 m^2 (7,000 to 10,000 ft^2) and are approximately 7 m (22 ft) deep. The basins contained about 6 m (20 ft) of water during operation. A basin consists of roughly 575 m^3 (750 yd^3) of concrete, with outside walls at 50 cm (20 in.) thick and the bottom at 15 cm (6 in.) thick. The basins extend 6 m below grade and vary in height from 3 to 12 m. The above-grade portion of the fuel basins is concrete block and precast concrete, with an average outside basin wall thickness of 50.8 cm. The below-grade structure is reinforced concrete columns and walls.

The cooling system of the eight water-cooled, graphite-moderated reactors includes steel external piping, carbon steel supply lines and storage tanks, aluminum or zircaloy-2 in-reactor tubes and tubing, and stainless steel effluent piping near the reactor and larger carbon steel piping/retention tanks. The water entering the cooling system was treated to minimize corrosion.

A.2.2 Shutdown

In general, the facility shutdown phase at the Hanford Site includes defueling, laying up the nonreactor systems, stabilizing contamination and decommissioning ancillary buildings, remediating the surrounding waste sites, and placing the reactor buildings in short-term safe storage. The reactors were defueled with control rods in place with cooling water supplied. Cooling water was removed after defueling.

The following describes the activities for shutdown of B and C Reactors from the B Reactor Museum Association report (on the Internet) by Michele S. Gerber, 1993. Since the original eight reactors at the Hanford Site are all similar, it is assumed that shutdown was similar for all eight reactors.

B-Reactor was shut down on February 12, 1968. At that time, it was decided that several of the systems would be kept operational for different purposes:

- the irradiated metal storage basin, in order to store existing lags from B-Pile as well as future lags from other reactor operations
- the effluent basin, lines, and outfall pipe, in order to dispose of the water running through the fuel storage basin for safety measures
- the portions of buildings that served C-Reactor and/or the 200 Area export water system
- the stack sampling equipment.

An additional diesel drive was installed on one of the raw water and one of the larger, diesel-driven export pumps excessed from another area in order to ensure an adequate export water supply to the 200 Areas. The four boilers remained operational although the output of those that had served B Reactor was transferred to supply steam for secondary coolant supply systems for the C Reactor facility.

C Reactor operation was terminated in 1969, and the reactor was placed in standby condition for restart on 18-months notice. Similar systems that were left operational at B Reactor were also left in operation at C Reactor. The following shutdown activities were similar for both C and B Reactors; they are also assumed to be similar for the other six Hanford reactor facilities.

The reactor graphite stack was emptied of fuel, dummy charges, and irradiated test samples. The uranium fuel was discharged, and the channels were then charged with poison columns. Once discharging was completed, the channels into the reactor were closed and radiation zones were posted. The rear face access was locked and tagged while the graphite temperature and wetness instrumentation remained energized for continued monitoring.

The horizontal control rods and vertical safety rods were left in the reactor but were de-energized, and all loose contamination was removed. The Ball-3X system balls were left in their hoppers and secured by lock bars. The oil in the Poison Column Control Facility sump was drained as was the water in the lines and equipment in the reactor control systems.

The process water flow was throttled down gradually and a low coolant flow was maintained until three successive weeks of graphite temperature decrease had passed. The coolant flow was then stopped, and the system, including risers, instrumentations, process tubes, valves, and water tubes were drained and some of the lines blown dry. The reactor gas system continued to operate for a week after the reactor cooling water had been shut off and the process tubes blown out. The inlet and outlet dew point readings of the gas system determined when the gas system could be shut down to ensure that the reactor would be left in a dry condition.

In the spring of 1968, the AEC reported that the shutdown procedures of B Reactor had been satisfactory despite higher than usual personnel exposure rates during the final discharge operations. The operation of the irradiated fuel storage basin was planned to continue indefinitely at the time.

A.2.3 Current Status

Currently, the eight single-pass graphite reactors are in short-term safe storage in order to contain any residual contamination and to protect workers from contamination and declining structural integrity. The safe storage measures in place are not adequate for long-term storage and the buildings are not stabilized for long-term storage.

Most of the residual radioactive material, estimated at 13,000 to 58,000 curies in 1987, present in the reactor buildings is low-level waste and is in the reactor block. Very little of the reactor block inventory is expected to be in the biological shield. What is in the biological shield is expected to be nearly all in the first layer of steel. As of 1985, half of the contamination present in the graphite was tritium, with the other half made up of carbon-14, nickel-63, cobalt-60 and chloride-36. Most of the inventory present in the thermal shield and process tubes was cobalt-60.

The fuel storage basins are in varying stages of being cleaned out and backfilled. The K basins are being used to store spent fuel. The F and H basins contain residual sludge, miscellaneous equipment, and 20 feet of backfill. B and C basins also contain residual sludge and the walls and floors have been coated with asphalt emulsion to fix surface contamination. D and DR Basins have had all material removed and the concrete has been sealed with an asphalt emulsion.

Outside the reactor buildings, there were many ancillary facilities, most of which have undergone D&D. Although very little is to be found in the literature regarding the D&D of ancillary facilities, there are a few examples:

- Retention basins were used for temporary storage of reactor cooling water before discharging it to the river. The basins had been filled with uncontaminated soil in the 1980s. Since then, the basins have been dismantled using oxy-fuel cutting for dismantlement and abrasive blasting for decontamination of the steel structures.

- A Main Pump House facility has been decontaminated and dismantled. The structure was a reinforced concrete foundation with an above-grade structure consisting of a steel framework with transite siding and a transite roof.

- A Filter House/Pumproom made of reinforced concrete below-grade with transite-covered structural steel above-grade was decontaminated and demolished. Voids below-grade were filled, backfilled, and graded.

A.2.4 Deactivation

The following is a generalization from the B Reactor Museum Association report (on the Internet) by Michele S. Gerber, 1993. Since the original eight reactors at the Hanford Site are all similar, it is assumed that deactivation was similar for all eight reactors.

The systems left operational after shutdown were shut down and drained in the deactivation phase. The raw water system, the fire and sanitary water systems, the solids feed system, the heating and air conditioning systems, the exhaust system, and the fresh air breathing system were all shut down and all moisture was removed. The platforms, cranes, cables, and hoists were lowered into their down positions. The monorail and associated equipment were left in place for use in the irradiated fuel storage basin. The top of the reactor itself was vacuumed, wiped with solvent to remove oils, and cleaned with a solution to decontaminate traffic areas to less than 1,000 counts per minute (c/min) smearable and equipment to less than 3,000 c/min smearable. Acid/detergent solutions were used to decontaminate the area. Finally, the decontamination system was drained, neutralized, and flushed. All areas and equipment that could not be decontaminated to levels less than 200 c/min smearable and less than 1 mrem/hr at 1 foot were posted as radiation zones. Any radioactive sources removed from the reactor area were buried.

All accessible areas of C Reactor were found to be within acceptable criteria for release from radiation zone status except for areas posted in 1971. Areas with high radiation that were left posted included the Ball-3X tunnel, the discharge area, the inner rod room, the X levels, the storage tank for irradiated 3-X balls, and the shielding cave.

A.2.5 SAFESTOR

The original eight reactors have been in short-term storage since initial deactivation was completed. During short-term storage, very little has been done to maintain the facilities. The result is that the outside structures are in relatively poor condition.

The Record of Decision by DOE-HQ calls for the eight single-pass reactors to be placed in safe storage for 75 years, followed by removal and disposal of the reactor blocks in one piece. The reactor blocks are to be disposed of in the 200 Area burial ground at the Hanford Site. The C Reactor is to be the first of the reactors to be placed in interim storage. All support structures around the reactor block are to be removed, except for the shield walls. The walls will then be extended to reach above the reactor block and a stainless steel roof is to be installed. All penetrations will be filled with concrete. Entry access will remain to the reactor area for surveillance purposes.

As part of the activities to place the reactor block in interim safe storage, the structure will be decontaminated, hazardous material will be removed, and the reactor block will be stabilized prior to the support structures being removed. Innovative stabilization technologies, including polyurea and other spray-on techniques, are being investigated.

Several studies were performed in analyzing the safe storage options. One option considered was the installation of a removable steel barrier, with a berm covering the barrier. This option required materials in the facility to be removed, the building decontaminated, and the building razed prior to the barrier and berm installation. Example activities include removal of salvageable and contaminated material and equipment, shipment of contaminated material to the 200 Area for disposal, decontamination of the fuel storage basins (filling them with clean dirt), decontamination of rooms and equipment, preparation of the block for storage, and razing of the building. The barrier that would be placed over the reactor block would be a dome consisting of ½-inch (1.27 cm) cor-ten steel over a bolted steel frame. Once the dome was in place, earth (70,000 yd^3 (53,500 m^3)) and gravel would be mounded to 2.4 m (8 ft) above the dome peak. A security door would be installed at the base of the mound.

Another study examined the use of the existing reactor buildings for long-term storage, with major maintenance activities such as replacing the roofing every 20 years. Inspections would be required every 5 years, with minor repairs and routine rad surveys done on a routine basis. This option would require extensive modifications to the facility to strengthen the superstructure, stripping the facility of unnecessary equipment, and sealing the building against the elements.

A third option considered removing all the reactor buildings (as in the first option) and then wrapping the reactor block in 1/4-inch (0.6-cm) spray-applied fiberglass reinforced plastic. An earthen berm would then be placed over the reactor.

A.2.6 Decommissioning

None of the reactors at the Hanford Site have undergone decommissioning. However, several decommissioning options have been investigated for the reactors as part of the Environmental Impact Statement for the original eight reactors. The options included immediate one-piece removal, immediate dismantlement, safe storage followed by one-piece removal, safe storage followed by dismantlement, and in situ decommissioning. The Record of Decision is for safe storage of the reactor blocks for 75 years, with one-piece removal of the reactor blocks and burial of the blocks in the 200 Area of the Hanford Site.

The dismantlement option would be performed by stripping the equipment off the reactor; removing the control rods, process tubes, gun barrels, and experiment hole assemblies; removing the top of the biological shield; removing the top and sides of the thermal shield; removing the graphite blocks; and removing the remaining biological shield. Flame cutting, arc saws, plasma arc torch, explosive cutting, and other available techniques would be used to dismantle the reactor block. Once the reactor block is removed, miscellaneous systems and equipment and the outlet cooling water piping would be removed. The building would be decontaminated and then demolished to 6 ft (1.8 m) below-grade and backfilled.

The one-piece removal option includes the activities for decontaminating and demolishing the building, but the reactor block is transported as one unit to the burial ground. This option appeared to be best in terms of occupational dose, cost, and population dose over 10,000 years. Compared to the safe storage followed by one-piece removal option chosen in the Record of Decision, the option of safe storage followed by dismantlement had 10 times the dose, a 10-percent increase in cost, and the same population dose.

The in situ decommissioning option is defined as filling in and around the structure and then capping the mound. This option would take 98,000 m^3 of grout and 1.6-million m^3 of fill material, taking up to 3.3 times more land than either the one-piece removal or dismantlement options. The advantage would be that any nearby waste sites would also be covered by the mounded cover.

An offsite burial option was also considered. However, the transportation costs are increased substantially with offsite burial. The probabilities of public exposure and a transportation accident also increase. The offsite burial option would also eliminate the one-piece removal from consideration since the size of the block would make it impossible to satisfy the Department of Transportation requirements for transport.

C Reactor will be the first of the eight original reactors to be placed in interim safe storage. Innovative technologies will be demonstrated as part of the decommissioning work at C Reactor. Successfully proven technologies will be used for the remainder of the work at C Reactor and at the other seven older reactors. Innovative technologies are currently being defined and procured for characterization, decontamination, dismantlement, health and safety, stabilization, and waste minimization. A minimum of 20 innovative technologies are to be demonstrated. The following technologies being investigated for possible demonstration:

- temporary power and lighting
- three characterization technologies
- battery-operated shears
- lightweight diamond chain saw
- asphalt emulsion remover
- pipe cutting/removal system (lightweight)
- two personal protection suits
- spray-on strippable coatings
- light ablation
- laser ablation
- concrete shaving
- process to free release structural steel
- waste segregating/sorting technology
- radioactive waste decontamination and conversion system
- laser cutting

The activities to place the reactor block in interim safe storage are listed in the "105 C Reactor Interim Safe Storage Project, Integrated D&D and Construction Schedule". The general activities listed in the schedule are as follows:

- Mobilization

    - ensure that all required utilities and services are in place and available
    - install temporary facilities

- Decontamination and demolition (external to shield walls)

    - establish waste processing area
    - reduce source term
    - decontaminate the facility
    - remove facility utilities
    - remove roof
    - remove exterior structure
    - demolish structural steel
    - demolish reinforced concrete

- Interim safe storage structure construction

    - D&D of area above shield walls
    - construct safe storage enclosure

  - install safe storage systems (e.g., electrical, ventilation, remote monitoring system, perimeter fence/lighting)
  - backfill and grade area

- Demobilization
  - remove temporary facilities
  - switch over power.

A.2.7 Surveillance and Maintenance

No documentation was found regarding the surveillance and maintenance of the eight original Hanford reactors. Minimal surveillance and maintenance have been performed during short-term safe storage since shutdown, resulting in facilities in poor condition. After the reactors are placed in long-term safe storage, minimal surveillance and maintenance will be required. Inspections will be performed on a 5-year basis with maintenance as required. The roof will have a 50-year life and should require no major work for 20 years.

A.3 N Reactor

The following discussion of N Reactor discusses its physical characteristics, circumstances of its shutdown, and its current status.

A.3.1 Physical Characteristics

The N Reactor Area, designated 100-N, is 90 acres with over 250 buildings and structures. Current surveillance and maintenance of the area costs approximately $8 million per year. Surveillance and maintenance after deactivation is expected to cost about $2 million per year.

N Reactor produced electricity as well as plutonium. It used a closed-loop recirculation cooling system instead of the "single-pass" type of the older reactors. The reactor building, designated 105N, contains the reactor block, fuel storage basins, equipment rooms, control rooms, and safety systems. The building shares a wall and a confinement system with 109N, which houses the electric steam generators. N Reactor used a confinement system versus the containment system used by commercial reactors. Air pressure is used to control air flow from clean to dirty areas. The 105N roof is primarily pre-cast concrete slabs or poured insulating concrete.

The reactor is graphite-moderated, negative-void coefficient, and light-water-cooled, with horizontal pressure tubes. The reactor block consists of a graphite core (12 x 10 x 10 meters high of interlocking graphite blocks) and reflector, surrounded by a cast iron thermal shield, an aluminum reflector sheet, and a massive biological shield with a steel outer casing. The block rests on a base of massive concrete pillars and a foundation. Unlike the older reactors, the thermal and biological shields are not tied into the reactor core structure.

The fuel storage basin, called N Basin, is unlined concrete and holds 1-million gallons of water. The basin is 45.7 x 15.2 x 7.3 meters, with approximately 182 m^3 of hardware and 2 m^3 of sediment in the basin. The basin area is ventilated with high-efficiency particulate air (HEPA) filters and other filtration. The N Basin is currently undergoing deactivation, with completion scheduled for the end of FY 1997. At the end of deactivation, the N Basin will be dry with a seal coating applied. All hardware and sediment will be removed from the N Basin with the sediment placed in a repository within the basins.

A.3.2 Present Status

As of 1995, contaminated liquid, sediment, and equipment were still present at N Reactor. Loose surface contamination was also present and there were unsealed penetrations to the environment. Many of the support systems were still active, but unneeded. Small amounts of irradiated fuel fragments were suspected to be in the N Basin.

The radioactive inventory for N Reactor includes carbon-14, chlorine-36, cobalt-60, cesium-137, and uranium-238. The hazardous inventory includes mercury, friable asbestos, polychlorinated-biphenyls (PCBs), cadmium, and irradiated lead. At the end of deactivation, much of the radioactive and hazardous inventories will have been cleaned with most of the remaining inventory contained in the 105N Building.

A.3.3 Shutdown

On February 16, 1988, the Department of Energy Hanford Site Manager announced that N Reactor would be placed in "cold standby" (shutdown of the reactor with the capability of restarting within a three-year period). During the following two-and-a-half years, the reactor fuel was removed, process cooling tubes were inspected, most of the plant piping systems were drained, and after modifying and aligning over 4,000 valves, warm dehumidified air was circulated throughout the piping systems for corrosion protection. Most of the reactor instrumentation lines were blown dry, large diesel engines were preserved with special oil, and thousands of electrical lockouts were made. In October 1990, the effort to place N Reactor in cold standby was declared complete.

The fuel was initially stored in the N Basin. Irradiated fuel was later sent to the K Basins (Fuel Storage Basins at the KE and KW Reactors) and nonirradiated fuel was sent to the 300 Area (fuel preparation area) for storage.

Sixty systems were used during reactor operations. The only systems remaining in operation after shutdown was completed were the passive confinement, radiation and environmental monitoring, fuel storage basin recirculation system, criticality monitoring, fire protection, and air systems. Most of the piping systems were drained, dried, and subjected to a controlled atmosphere to limit corrosion. Some of the systems so treated, which were from 182N and the 105N/109N Confinement Zone I, are

- primary cooling system
- emergency cooling system
- high-pressure injection system
- graphite and shield cooling system
- low-pressure injection
- reactor decontamination
- confinement and fog sprays
- filtered water
- fuel ruptures detection
- horizontal control rods
- circulating raw water system
- demineralized water system.

It should be noted that confinement boundaries were maintained and the fire system remained in service at the end of shutdown.

HEPA filters were installed wherever air from the primary air system was vented into the Confinement Zone I area. Airborne releases have charcoal and HEPA filters.

A.3.4 Deactivation

Deactivation is the orderly isolation and shutdown of operating systems and buildings. Deactivation work started in the 100N Area with the receipt of the cease-preservation directive issued by DOE on September 20, 1991. Ongoing deactivation includes N Basin stabilization and environmental stabilization of ancillary facilities. Deactivation is to occur prior to decommissioning. N Basin stabilization is to be completed in FY 1997, and ancillary buildings are to be deactivated through 2018.

DOE has established the following criteria for the completion of N Reactor deactivation:

- Complete and document the final deactivation/shutdown of the 100 N Area.
- Place facilities at the 100 N Area in a safe condition and in compliance with regulatory requirements.

- Assess compliance with environmental, health and safety regulation requirements.
- Ensure that facilities and required systems are structurally sound to permit deferred final decommissioning.

At the end of deactivation, the N Reactor facilities are to be in compliance. Major compliance requirements for the N Reactor Area are as follows:

- maintenance for facilities to be radiologically and environmentally safe and for meeting habitability requirements
- maintenance of boundaries that isolate contaminated equipment, rooms, or facilities to prevent the spread of contamination, cross-contamination, or environmental interchange
- radiation zone reduction
- temperature control
- reduction of routine access to process facilities to absolute minimum
- minimization of surveillance to meet requirements
- maintenance of fire protection as required
- identification or classification and disposal of all unneeded N Reactor assets for use by others
- disposal of all non-essential N Reactor Area records
- maintenance of two warehouses until all equipment and material are removed from them.

The general 100 N Area deactivation plan comprises the following steps:

- Shut down and isolate operating systems and facilities.
- Clean up radioactive and hazardous waste.
- Clean out and stabilize the N Basin.
- Environmentally stabilize facilities.

The deactivation plan calls for existing equipment to be restarted to support deactivation. Then, equipment fluids, hazardous substances, and unattached equipment and material are to be removed, characterized, packaged, and transported for use, reuse, recycling, or disposal. Basins and tanks are to be drained. Any water and residuals are to be shipped to the 200 Area for disposal.

N Basin. Prior to stabilizing N Basin, non-essential materials were removed from work areas, and the work areas were decontaminated. Appropriate equipment maintenance was performed and other needed equipment was fabricated for deactivation. Finally, water clarity was established using a back-washable steel mesh filter.

Since the deactivation of N Basin is ongoing, some of the activities that follow may have been completed at the time of the writing of this report. N Basin has been inspected for irradiated fuel fragments, which are to be removed, packaged, and then stored in the fuel storage basin. Contaminated water is to be removed, pretreated using a 4-micron filter, and then shipped to the Effluent Treatment Facility for final treatment. Contaminated sediment is to be moved using vacuuming and centrifuging to a central repository (North Cask Pit) within the storage basin for storage. Hardware, irradiated fuel spacers, and pieces of lithium targets that are in the Basin are also to be removed and packaged. The packages will be transported to the 200 Area for storage or disposal. The N Basin walls and cubicles will be cleaned using high-pressure water and then stabilized with a seal coating. Once the material and water are removed from the N Basin, the permanent radiation zones will be decontaminated or stabilized to fix loose contamination; temporary radiation zones will be decontaminated and removed.

The final steps of deactivation will include de-energizing unneeded support systems, performing structural repairs, and sealing building penetrations to the outside. Routine surveillance and maintenance will be performed until decommissioning starts.

Hardware in the N Basin includes fuel storage canisters (comprising the majority of the hardware), miscellaneous hardware items, and irradiated materials. Canisters are to be cleaned underwater with brushes and/or high-pressure water, removed, and then drained until there is no water dripping; then, they will be crushed with a HEPA vacuum on the crushing chamber and packaged. Contaminated hardware also may be cut to smaller size underwater and cleaned underwater. Hardware with a high exposure rate may be cleaned underwater and resurveyed. Other high-exposure-rate hardware and irradiated hardware are to be cut underwater, placed in a steel basket in a larger steel pipe, and grouted underwater. The grouted package will then be removed from the water and rinsed. The high-exposure-rate hardware will be handled and processed with long-handled grasping tools, fuel baskets, RO-7 detectors with underwater probes, bridge cranes, load cells, flat beds, a 60-ton crane, a fill hose, a 7-ton crane, a grout miser truck, grout supply pumping and piping, hoses, grout, contamination control sleeving, underwater cameras, communication equipment, rinse water, a low-pressure delivery system, a long spray wand, fixatives, application equipment, and a low-boy trailer.

Ancillary Facilities. The deactivation of the ancillary buildings is being performed in four phases:

- removal of assets, dangerous material, and waste
- asbestos removal, radioactive decontamination and stabilization, structural stabilization
- isolation, shutdown, and deactivation of operating systems

- securing of facility from intrusion of animals and unauthorized persons.

The general plan for removal of assets and dangerous materials and waste is as follows:

- Remove and package waste, debris, and fixtures.
- Stabilize surface contamination by decontaminating, coating, and/or isolating the area.

The plan for surface stabilization is to remove or confine contamination. The usual techniques for removal of contamination are vacuuming and wiping with damp rags. Sandblasting, grinding, scabbling, and high-pressure water may also be used.

A.3.5 SAFESTOR

The Record of Decision has not been made for N Reactor. Decontamination and decommissioning of the ancillary buildings are expected to be completed in 2018. Surveillance and maintenance will continue for the N Reactor building.

A.3.6 Decommissioning

Decommissioning of the N Reactor Area consists of removing the reactor core and dismantling the ancillary buildings. Differences in the size and configuration of the N Reactor block from the original eight reactors require extensive engineering studies for decommissioning. Dismantling of the buildings will progress after deactivation as time and money permit.

There are four stages to dismantling the ancillary buildings:

- removal of all asbestos and other hazardous materials - This step should be minimal as much of this step was performed during deactivation.
- demolition of the building
- segregation of the waste
- filling of foundation voids and grading of site.

A.3.7 Surveillance and Maintenance

Deactivated facilities in the N Reactor Area are inspected quarterly while active facilities are inspected daily. Routine maintenance and vermin and weed control are done as necessary.

APPENDIX B

FORT SAINT VRAIN

APPENDIX B

FORT SAINT VRAIN

The 330-MWe high-temperature gas-cooled reactor (HTGR) at Fort Saint Vrain is owned by the Public Service Company of Colorado. It was constructed in 1968 with initial fuel loading in 1973. The reactor was operated from 1974 through August 1989, when it was permanently shut down.

After shutdown and prior to decommissioning, the reactor had to be defueled, requiring 1,482 irradiated fuel blocks and other greater-than-class-C reactor components to be stored. The plan was to send the fuel to the Idaho National Engineering Laboratory (INEL), with an onsite installation as a backup choice. The onsite facility, the Independent Spent Fuel Storage Installation (ISFSI), was used until the permanent storage facility, the irradiated Fuel Storage Facility (IFSF), was available for storing spent fuel. The fuel was to be removed completely by August 1992, and in the process minor components were permitted to be removed.

The Fort Saint Vrain fuel is permanently stored at the IFSF, a dry storage facility at the ICPP at INEL. The fuel is stored in carbon steel canisters and cooled by forced-flow, single-pass air systems. Fuel blocks are cooled with helium and stored for 100 days to allow decay. They are then transferred into a fuel shipping cask unique to the Fort Saint Vrain facility.

The ISFSI was designed, licensed, and built in 7 months at the reactor site after difficulties arose involving the use of the IFSF. Approximately $25M was required to build the ISFSI, versus $2.5M per month plus delayed D&D costs due to project delay. The ISFSI is a Modular Dry Vault Storage (MDVS) facility. The MDVS design has had commercial scale operating experience since 1971 in the United Kingdom. The MDVS concept was submitted to the Nuclear Regulatory Commission as a general Topical Report for irradiated light water reactors and was approved in March 1988. The fuel is stored in individual vault storage tubes within a concrete structure. Integral air flow ducts are used for a natural thermal buoyancy cooling system. A removable shield plug is used to close each storage tube. The Fort Saint Vrain MDVS was a six-vault module, each with 45 individual storage containers. One fuel storage container held six fuel blocks and also served as a shipping container.

With no fuel pool, the irradiated hardware packaging was processed in a hot cell. To use available casks and liners for transportation of the components, control rods were cut using an abrasive grinding wheel. Because of sparking hazards with the grinding wheel, several other cutting methods were considered, including shears, scissors, a round blade, various torches, and an improved abrasive wheel saw. The hydraulically operated shear was used due to its low cost and availability.

B.1 Physical Characteristics

The fuel blocks are hexagonal graphite blocks containing fuel rods in closed-ended channels. Helium coolant channels also pass through the blocks. The fuel rods, which are a blend of coated fuel particles and a coke filler, are inserted into the graphite blocks. The reactor core is surrounded by graphite side reflectors and metal clad reflector blocks on top, all of which are greater-than-class-C material.

The interior of the prestressed concrete reactor vessel has a 1.9 cm (3/4-inch) steel liner and is 22.9 m (75 ft) high and 9.4 m (31 ft) in diameter. The vessel is divided by a steel-lined concrete core support floor, 8.8 m (29 ft) in diameter, and 1.5 m (5 ft) thick. An upper cavity formed by this support floor houses the graphite prismatic core and over 5,000 graphite reflector blocks, of which 1,500 contain nuclear fuel. The lower cavity houses 12 once-through steam generator modules and four helium circulators.

Almost all of the radioactivity is contained within the reactor vessel. The major isotopes of concern are iron-55, tritium, and cobalt-60. There has been no carry-over to the secondary side of the plant and only minimal contamination of systems in direct support of the reactor vessel and helium cleanup systems.

B.2 Decommissioning

Decommissioning versus safe storage was considered for the Fort Saint Vrain reactor, and decommissioning for unrestricted release was the chosen option. The decommissioning plan was submitted in 1990 and approval was received in 1992.

A two-phase decommissioning strategy was incorporated. The first phase included the decommissioning plan, initial site characterization, low-level radioactive waste arrangements, defueling, and removal and disposal of the control rods. Initial characterization took 9 months and approximately 20,000 person-hours. The activities included background determination, steam system characterization, auxiliary systems characterization, structural and environmental characterization, and development of isotopic scaling factors. Radiation levels that were As Low As Reasonably Achievable (ALARA) were accomplished for the decommissioning activities through temporary and permanent shielding, contamination control, mockup training, engineering controls, worker awareness, integrated work package reviews, communication, special instrumentation, video camera usage, robotics application, and project committee. (See NUREG/CP-0143 for more details.)

Phase two of decommissioning encompassed the physical activities of dismantlement and decommissioning. Phase two started in August 1992 and was scheduled for completion in 1996. The initially removed graphite core components had contact dose readings of 1600 R/h. These components were packaged in boxes or liners and transported offsite for burial. The steam generator was removed, in parallel with the graphite core components, using plasma arc cutting. Penetrations were sealed at this time. A specialty engineered shield water system was then put in place. Around 325,000 gallons of water were flooded into the pressurized reactor core vessel. This system maximized worker exposure reduction, airborne contamination control, and work plan flexibility. Water was recycled through the core cavity, and depth visibility up to 18.3 m (60 ft) was maintained.

Using the diamond wire abrasive method, a horizontal cut was made in the reactor vessel, and the vessel was cut vertically into 12 pie-shaped wedges. The wedges were further segmented in tents on the operating deck. A specially designed rotary work platform was used to allow access for top head liner and internal core component removal using an air contamination control system that allowed workers on the platform to work without respirators. The head liner, consisting of carbon steel plates and mineral wool insulation, was cut using an oxylance process. The remaining graphite components were then removed (up to 300 R/h). Systems used in removing the final components included underwater plasma arc system, long-handled tooling, and hydraulically operated shear and hydraulically operated inner diameter clamp system. Once removed, the components were packaged within hot cells. After the lower plenum floor was removed, the area was decontaminated with grit blasting, high-pressure water and hand methods.

APPENDIX C

PEACH BOTTOM

APPENDIX C

PEACH BOTTOM

Unit 1 at Peach Bottom was the first prototype HTGR in the U.S. It is owned by the Philadelphia Electric Company and was operated from January 1967 through October 1974.

The plan as of July 1974 for final configuration of Unit 1 was that all residual activity would be contained within containment and spent fuel buildings with 99% of the 3 megacuries contained in the reactor vessel. The vessel would be accessible only by removing the concrete missile shields, the refueling flanges, and the refueling shield plugs. Piping and equipment were to be removed and transferred to Units 2 or 3 or shipped offsite. Defueling would start shortly after shutdown and take 20 to 40 weeks to complete. During defueling, decommissioning of systems and components not affecting nuclear safety could be initiated. Once the fuel was accepted at the fuel reprocessing facility, the exclusion area's accessible areas (i.e., noncontrolled areas), all contaminated areas outside the exclusion area, and all equipment and piping outside the exclusion area were to be decontaminated. The equipment and piping were also to be removed. Near the end of decontamination activities, the radioactive waste facility was to be drained, partially dismantled, and decontaminated.

Several changes were made to the Peach Bottom Operating License in 1975. The irradiated fuel elements were to be enclosed individually in hermetically sealed 1/16-inch thick, steel-lined aluminum canisters before leaving the containment building. The irradiated fuel had to be stored vertically in canisters in an underwater rack in the spent fuel storage pool, having a square array of at least 13.3 cm (5.25-inch) pitch. Provisions were to be made available to cover a faulty canister. Lastly, no more than seven elements could be located anywhere other than in the reactor, new or spent fuel shipping containers, or spent fuel storage pool at any time.

C.1 Shutdown

Shutdown occurred in August 1974. Immediately after shutdown, defueling was initiated and was completed in July 1975. During defueling, 804 fuel elements were canned and stored in the spent fuel pool and 513 dummy elements were inserted into the core to maintain lateral support of the core. Other components, including three hexagonal reflector elements and one control rod guide, were removed. In June 1975, spent fuel shipments were started to Aerojet Nuclear Company (now EG&G) in Idaho for long-term storage. The shipments were expected to be completed in late 1976; however, the necessity of obtaining overweight permits to transport the fuel caused considerable delay in shipping the fuel from the site.

Over the next several months, primary coolant systems, the helium purification system, and all nuclear auxiliary systems were removed from service. The reactor access nozzles were sealed as in full power operations before the end of 1975. By October 1975, all oil systems, the steam generators, and the chilled water systems were drained. In addition, the control rod accumulators were depressurized; all moving equipment, including the helium purification system and primary coolant system, was shut down; and the plant cleanup operations were completed.

C.2 Decommissioning

Several options were considered for the final end-state of the Peach Bottom reactor, including total removal of all facilities, entombment, and mothballing. Mothballing was chosen. Mothballing is the reduction of a controlled access area to include only the reactor containment vessel and spent fuel building. All other areas and facilities are decontaminated and removed. The maximum level of dose allowed at the facility fence was <0.04 mR/h. Mothballing leaves the site unmanned except for semiannual inspections.

The Decommissioning Plan and Safety Analysis Report were submitted in August 1974. The plan identified four phases of decommissioning: 1) remove all fuel from reactor and degas the purification system, 2) ship all spent fuel from the Peach Bottom site and remove the contaminated systems, 3) perform final lay-up of containment and removal of the radioactive waste system and components, and 4) maintain unmanned status with responsibility under the Part 50 Possession Only License for periodic inspections of the facilities within the newly established exclusion area.

The site preparation prior to decommissioning included several activities: determining the site office; providing health physics, safety and mock up training; installing electric power supplies; erecting the scaffolding and the refueling floor and steam generator control tents; installing atmosphere control system; installing shielding; and removing ducting and steam generator insulation.

Decommissioning activities involved preparing and receiving approval of the decommissioning plan and safety analysis report, defueling and shipping offsite all fuel and source materials, removing liquids/pressurized gases and flammable materials from the containment vessel, cutting and capping containment penetrations and vents to the atmosphere, decontaminating and retiring major equipment, removing and burying the fission product traps as well as delay beds and contaminated materials, completing the closure of the primary system, and releasing the control room and labs for unrestricted use. Following the shipment of all the fuel, the fuel pool was drained and the pool water was processed through the radioactive waste system and then released.

Component removal site work began with establishment of restricted access areas and installation of controlled atmosphere tents to retain relative humidity at <30%. A mockup room was established to test and develop the tooling and to train operators under simulated working conditions. Primary circuit ducting samples were removed by trepanning, and steam generator access was achieved by a combination of arc gouging and grinding. Steam generator tubing and other samples were removed by internal cutting and side grinding. Throughout the component removal phase, strict health physics, safety, and quality assurance programs were implemented.

APPENDIX D

HALLAM NUCLEAR POWER REACTOR

APPENDIX D

HALLAM NUCLEAR POWER REACTOR

The following write up is taken from the *U.S. DOE Decommissioning Experience - Selected Projects* by E.G. DeLaney and J.R. Mickelson.

The Hallam Nuclear Power Reactor was a 254-MW(t) sodium-cooled, graphite-moderated power reactor located in Hallam, Nebraska. The reactor began operations in December 1962 as an Atomic Energy Commission (AEC) power reactor demonstration project.

D.1 Shutdown

The plant was shut down in September 1964. It was owned by AEC on land leased from the Consumers Public Power District (CPPD) which operated the reactor. Failure of the stainless-steel cladding of the graphite moderator elements necessitated shutting down the plant.

D.2 Decommissioning

Entombment was the method of disposition agreed to by the AEC and CPPD. The entombment project requirement was to leave the Hallam Reactor Site safe from a radiation standpoint, requiring no further AEC licensing for use or access.

The operating crew of the facility carried out the decontamination and partial dismantlement work, with assistance from outside contractors. To prepare for entombment, all fuel and bulk-sodium were shipped offsite. All other contaminated or irradiated material was subsequently disposed of by either shipment to approved offsite burial grounds or storage in underground structures on the site that were later entombed. The reactor vessel was used as containment for about 200 irradiated items. The vessel and the reactor cavity liner were then isolated and sealed. The annular space around the loading-face shield and pipe trenches was filled with concrete to the floor level. A rectangular 1.25 cm thick steel plate was then fitted and welded over this area. Finally, the reactor building superstructure was removed. A layer of bituminous was used to coat the isolation structure, followed by 60 cm of sand, a water impermeable 40-mL thick polyvinyl chloride sheet, 30 cm of medium-grained sand, 60 cm of fine-grained sand, and 30 cm of top soil and sod. Another structure, the radiological waste facility including an empty liquid waste tank, was left in place and isolated 3 m below grade. Above ground, this structure was left clean and empty for later unrestricted use. A total of 300,000 Ci of radioactivity, mainly activation products associated with the reactor vessel and internals, was sealed in the reactor and underground vaults.

Entombment cost was $3.5 million expended over 4 years ending in September 1968. Annual surveillance costs were $5,000 as of 1984.

APPENDIX E

VARIOUS RESEARCH REACTORS

APPENDIX E

VARIOUS RESEARCH REACTORS

E.1 Sodium Reactor Experiment

The Sodium Reactor Experiment (SRE) is a 20-MW system, located at the Atomics International Nuclear Development Field Laboratory in Santa Susana, CA. Construction of the reactor was initiated in 1955 and operation started in 1957. The reactor was shut down in 1964 and deactivated in 1967, with reactor decommissioning completed in 1982.

E.1.1 Physical Characteristics

The SRE was a high-temperature, sodium-cooled, graphite-moderated reactor. The reactor vessel was made up of several layers, including 38.1-mm thick stainless steel, 13.97-cm carbon-steel thermal rings, 6.35-mm carbon steel as the outer vessel, 30.48-cm insulation pack, 6.35-mm thick carbon steel cavity liner, and 1.22-m high-density concrete biological shield. Without the biological shield, the vessel assembly was 4.27 m in diameter and 8.84 m high.

E.1.2 Shutdown

The decided shutdown method for the reactor was mothballing. Once the irradiated fuel was encapsulated and transported to onsite storage, the facility was mothballed.

E.1.3 Deactivation

The deactivation of the reactor included removing and decladding the fuel elements prior to decommissioning. The fuel was reprocessed in a hot cell under an inert atmosphere. The fuel was disassembled, declad, cleaned, and re-encapsulated in remotely welded aluminum canisters for shipment to Savannah River for reprocessing.

E.1.4 Decommissioning

The endstate of the sodium reactor experiment was unrestricted use of the facility. The options of safe storage and entombment were considered, but dismantlement was chosen. The dismantling activities were initiated in 1974. At this time, activation products (10^4 Ci) remained in the stainless steel vessels, the vessel components, the biological shielding, and the carbon-steel containment structures. Residual primary sodium was present in the vessel and primary sodium systems. Approximately 55,000 lb of sodium was removed and shipped to Hanford for reuse.

Decontamination activities were completed prior to dismantling and removing the structures. The surfaces were generally vacuumed first. The painted/metal surfaces were then decontaminated using foam, concrete surfaces were scabbled, and surfaces with paint containing contamination were sandblasted.

The noncontaminated SRE systems and support facilities were scheduled for decommissioning and disposal first to allow for easier access in dismantling. Once the contaminated sodium was removed, the SRE peripheral systems and facilities were decommissioned and removed. A hoe-ram was used to peel off the contaminated layers of concrete. Support systems, including fuel storage cells and a fuel examination hot cell, were then removed. Next, the large components were removed as one piece, and unique approaches for transportation and disposition were used. Finally, the reactor vessel was removed using remote equipment and tooling.

For dismantling the reactor vessel, a rotating mast manipulator was designed, mated with a plasma arc cutting system, and installed in the SRE vessel to initiate remote underwater cut-up. While this manipulator was being developed, the primary and secondary sodium systems were removed and the residual sodium in the piping and components was passivated. All auxiliary systems were removed, the sodium heel was removed from the vessel and residue was passivated, the vessel was filled with water for dismantling purposes, the loading face shield was removed, and the removable internal vessel was taken out.

Early in 1977, underwater explosive cutting of piping inside the vessel was started. The concrete biological shield was removed by a combination of explosive demolition and by means of large impact hammers. Contaminated materials removed during dismantling activities were sent to the licensed burial site at Beatty, Nevada. The area was excavated to an average depth of 8 m to remove the reactor structure and other below-grade structures. Surrounding contaminated soil and bedrock were also removed.

Total waste sent to burial from SRE dismantlement was 3,850 m^3. All radioactive waste was surveyed, packaged, and shipped offsite. Liquids were evaporated and sludge solidified with concrete prior to shipment for burial. The Department of Energy (DOE) maintained radiation safety and survey according to NRC and state guidelines.

E.2 ORNL Graphite Reactor

The ORNL Graphite Reactor was operated for 20 years before it was shut down in 1963. The reactor was contaminated with uranium oxide, fission products, and plutonium.

E.2.1 Shutdown

Shutdown of the graphite reactor included sealing any openings and maintaining negative pressure inside the reactor. All pipes with possible flammable liquid/gas contamination were disconnected from the reactor and additional neutron poison (spare control rod poison sections) were added. The fuel was left in the reactor temporarily.

E.2.2 Decommissioning

Several options were considered to place the reactor in a structurally and radiologically safe condition: demolishing all structures, covering the outside shield with gunite, filling all internal voids with grout, or filling the internal voids with urethane foam. The concrete grouting approach looked best in that it provided a permanent solution and was relatively inexpensive. This approach eliminated the need to maintain negative pressure in the reactor vessel, which drops costs by $3,000/year.

E.3 ORNL Molten Salt Reactor Experiment

The molten salt breeder reactor was a 8-MW fluid-fuel reactor and was in operation between 1965 and 1969. The reactor went critical on June 1, 1965. The options for disposing the salts were studied in 1971 and the decommissioning study was initiated in 1977. The decommissioning options considered for the molten salt reactor experiment (MSRE) included entombment and complete removal of the reactor components for burial, leaving the facility available for reuse.

E.3.1 Physical Characteristics

The MSRE reactor cell is constructed as a tank within a tank. The annulus is filled with water and magnetite sand, and the cell is covered with concrete shield plugs and roof beams. The reactor vessel itself is 1.5 m (5 ft) in diameter and 2.4 m (8 ft) high. It contains the bare graphite core structure, which is 1.4 m (55 in.) in diameter and 1.6 m (64 in.) high. The reactor vessel is surrounded by a thermal shield constructed of 2.6 cm (1-in.) stainless steel plate with a 35.6 cm (14-in.) annulus filled with water and carbon steel balls. The shield interior is lined with 1.3 cm (6 in.) of high-temperature insulation forming the reactor tank furnace.

The reactor cell structure measures 7.3 m (24 ft) in diameter and 10.1 m (33 ft) high. It has a hemispherical bottom and flat top and is made of 5.1 cm (2-in.) thick carbon steel. The reactor cell vessel is enclosed by a 9.1 m (30-ft) diameter and 10.8 m (35.5-ft) high shield tank vessel made of 1 cm to 1.9 cm (3/8- to 3/4-in.) steel. This vessel also has a flat bottom which rests on a 0.8 m (2.5-ft) thick concrete foundation. The resulting annulus is about 0.9 m (3 ft) thick, filled with magnetite sand and water for shielding. A region beneath the skirt is filled only with water, and the top 1.8 m (6 ft) of the annulus is filled with a ring of magnetite concrete. Shield blocks cover the cell with an 11-gauge stainless steel seal membrane welded to the cell wall. Several other structures in the area in support of the reactor are of a standard concrete construction.

Any significant radiological hazards are confined to within the reactor and process cells. The remainder of the building remains mostly clean and open for uncontrolled access. The exceptions are a pit area above the drain tank cell and drums of contaminated soil above the reactor cell; these areas of contamination are isolated and marked.

E.3.2 Shutdown

Following reactor shutdown, the fuel salt was drained into two fuel drain tanks and a flush salt was run through the reactor and drained into the flush salt tank. All salts were allowed to freeze, the control rods were locked into the core, and instrumentation was locked out to prevent reactor restart. In 1970, the reactor system was inspected and samples were taken. Control rods were disconnected and left in the reactor cell, and the core was sealed with a 25.4 cm (10-in.) blind flange. Two freeze flanges were also removed from the drain tank cell.

A surveillance program was put into place which included periodic reheating of the fuel salt to recombine radiolytic fluorine gas. All MSRE equipment not required for the surveillance/ reheat program or for possible future operation was declared surplus. The coolant salt pump, some of the external coolant salt piping, the process computer, and a large part of the instrumentation were designated surplus and removed from the facility.

E.3.3 Decommissioning

The three alternatives studied for disposal of the fuel and flush salts were 1) entombment, 2) shipment to the Waste Isolation Pilot Plant (WIPP), and 3) storage. Entombment would require special permission for permanent, nonretrievable disposal of transuranic wastes in a near-surface site. Disposal of salt wastes at WIPP reflects the current national strategy for disposal of remotely handled transuranic waste (salts) and spent fuel. Shipment to WIPP is relatively expensive due to the extensive handling and transportation activities involved. The decision to process the salt prior to disposal was also studied. The viability of this alternative was found to depend on whether approval could be obtained to dispose of the salt as is or whether volume reduction/conversion to a more stable form would be required.

The cell decommissioning options included 1) entombment, 2) equipment removal and cell decontamination for reuse, and 3) complete cell dismantling and removal for disposal. The choices available for the reactor building were to clear the building for reuse or dismantle it. For the other buildings, the maintenance for reuse was weighed against dismantling the buildings. Generally, the costs of decommissioning the site facilities were insignificant compared to the costs of disposing of the salts and decommissioning the cells.

E.4 Ultra-High Temperature Reactor Experiment (UHTREX), Los Alamos, NM

The ultra-high temperature reactor experiment (UHTREX), a 3-kW graphite-moderated and helium-cooled system, was constructed in New Mexico in the late 1960s. The reactor was operated approximately 1 year before being shut down in February 1970.

E.4.1 Physical Characteristics

The UHTREX facility consisted of a main reactor building, a neutralization/pump station, stack, heat exchanger pump, heat dump building, filter pit, and contaminated waste lines. The main reactor building housed the reactor, the primary cooling system, a gas cleanup system, and other related equipment, such as the fuel-handling system. The reactor core rotated, allowing for refueling during operations.

The reactor vessel was a spherical carbon steel vessel, 4 m deep with a minimum wall thickness of 4.5 cm. The inner core consisted of dense carbon and graphite, weighing approximately 100 tonnes.

E.4.2 Shutdown

The reactor was shut down and defueled in February 1970. Some of the reactor-related equipment was removed at this time; the remaining equipment was secured in controlled areas. The reactor room, fuel discharge room, and hot cell rooms were locked and posted. The rest of the facility continued to be used.

E.4.3 Decommissioning

Planning for decommissioning included characterizing the facility, estimating the costs of decommissioning, preparing environmental documentation, establishing a system to track costs and work progress, and preplanning to correct health and safety concerns in the facility. Characterization of the reactor prior to decommissioning showed that most of the residual radioactivity resided in the reactor vessel, recuperator, heat exchanger, primary loop, gas cleanup system, and fuel loading system. The primary contaminants included Sr-90, Cs-137, Co-60, and U-235. Forty-eight tonnes of uncontaminated lead also required disposal.

An Action Description Memorandum (ADM) was submitted in accordance with the National Environmental Policy Act (NEPA) in support of categorical exclusion for the facility decommissioning activities. The memorandum assessed the potential environmental impact of decommissioning, described the D&D activities, and pledged adherence to the Laboratory Environmental Impact Statement. A Memorandum to File was also submitted to comply with regulations. This document summarized the decommissioning plan and referenced the Project Management Plan and ADM in support of approval. A Readiness Review meeting was then held to ensure that all NEPA documentation, cost and schedules, Quality Assurance Program, and Health, Science, and Environment programs were in place, and that the scope of the work and cleanup criteria were well defined.

Decommissioning of the UHTREX facility was initiated in 1988 and was to be done in a safe and cost-effective manner in accordance with DOE Order 5820.2A, Chapter 5. Surveillance and maintenance were to be eliminated and approximately 1,115 m^2 of the facility was made available for other uses. Steps taken to decommission the reactor included removing contaminated components and equipment, decontaminating accessible surfaces, removing hazardous materials, removing excess reactor-related peripheral structures that were decaying and that represented an environmental and safety liability, removing reactor-related systems that would not have future use, and removing uncontaminated reactor support equipment. Two-man hand saws were used in dismantling the components in temporary wood and plastic enclosures. Minor maintenance such as repairing the roof was also performed. Decommissioning was completed in September 1990 and the facility was released to DOE for reuse. The total decommissioning cost came to $2.9M.

The other buildings were decommissioned using a backhoe and wrecking ball. The neutralization/pump station was completely removed, and the excavation was backfilled and revegetated. The heat dump building and heat exchanger were removed, and the excavation was backfilled and covered with asphalt. The filter pit was emptied, decontaminated, backfilled, and covered with asphalt; ducting was excavated and removed; and the stack was removed with the base covered with asphalt.

Lessons learned from the decommissioning activities at UHTREX included several points:

- There should have been 100% scanning. There were instances of hot spots that were not detected until the final survey of the site. These would have been easily determined with a gas-flow proportional counter.
- Radionuclides should have been identified at the beginning of the activities and core samples should have been taken of activated surfaces.
- A gas explosion occurred during torch cutting because stagnant water and contaminated rags caught fire due to slag from the torch cutting.

APPENDIX F

APPLICABLE REGULATIONS

APPENDIX F

APPLICABLE REGULATIONS

Following is a list of the regulations cited for N Reactor deactivation in the N Reactor Deactivation Program Plan (December 1993), Attachment 3, "Legal and Regulatory Drivers." Memorandums, letters, and regulations that appear to deal with reporting systems only are not cited below.

- Public Law 101-189 - Defense Authorization Act, Section 3156 (b) Closure Report
- National Environmental Policy Act of 1969, as amended [42 U.S.C. 4321 et seq]
- DOE 2250.1C - Cost and Schedule Control Systems Criteria
- RL 5700.1A - Quality Assurance
- 40 CFR 61.9 - National Emissions Standards for Radionuclide Emissions from DOE Facilities
- 40 CFR 6.302g (16 USC 661 et seq) - Fish and Wildlife Coordination Act
- Clean Water Act (PL 92-500)
- 40 CFR 264 (42 USC 6901) - Resource Recovery and Conservation Act
- 29 CFR 1910 (29 USC 651) - Occupational Safety and Health Act of 1976
- Toxic Substance Control Act (15 USC 2601)
- WAC (Ch 10.105D) - Model Toxics Control Act
- RCW (Ch 173-340) - Model Toxics Control Act and Clean Up Regulations
- WAC (Ch 173-303) - Dangerous Waste Regulations
- RCW (Ch 70.105) - Hazardous Waste Management Act
- RCW (Ch 70.95) - Solid Waste Management Recovery and Recycling Act
- WHC (Ch 173-304) - Minimum Functional Standards for Solid Waste Handling
- WAC (173-480) - Washington Standards for Protection Against Radiation
- National Pollution Discharge Elimination System Permit Program (Ch 173-200)
- WAC (Ch 173-201) - Water Quality Standards for Waters of the State of Washington
- WAC (173-480) (Ch 70.94 RCW) - Washington Clean Air Act
- RL 4330.2 - Water Treatment Plants and Distribution Plants
- DOE 4330.4A - Maintenance Management Program

- DOE 5400.1 - General Environmental Protection Plan
- DOE 5400.3 - Hazardous and Radioactive Mixed Waste Program
- DOE 5400.4 - Comprehensive Environmental Response, Compensation, and Liability Act Requirements
- DOE 5400.5 - Radiation Protection of the Public and Environment
- DOE 5480.3 - Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes
- DOE 5480.6 - Safety of the Department of Energy Owned Nuclear Reactors
- DOE 5480.7 - Fire Protection
- DOE 5480.11 - Radiation Protection for Occupational Workers
- RL 5480.11A - Requirements for Radiation Protection
- DOE 5480.19 - Conduct of Operations Requirements for DOE Facilities
- RL 5630.1A - Control and Accountability of Nuclear Materials at Richland Operations Office
- DOE 5632.6 - Physical Protection of DOE Property and Unclassified Facilities
- DOE 5700.6C - Quality Assurance
- DOE 5700.7B - Work Authorization System
- DOE 5820.2A - Radioactive Waste Management
- DOE 6430.1A - General Design Criteria
- 10 CFR 20 - Standards for Protection Against Radiation
- 10 CFR 50.48 - Fire Protection
- 10 CFR 50, Appendix R - Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979
- 10 CFR 50.59 - Changes, Tests and Experiments
- 10 CFR 50.70 - Inspections
- 10 CFR 50.71 - Maintenance of Records, Making of Reports
- 10 CFR 50, Appendix I - Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low As is Reasonably Achievable" for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents
- 10 CFR 51 - Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions

- 10 CFR 73 - Physical Protection of Plant and Materials
- Hanford Federal Facilities Agreement and Consent Order, May, 1989, As Amended
- 42 USC 7401 - Clean Air Act
- 40 CFR 52 - Primary and Secondary Ambient Air Quality Standards
- 40 CFR 61 - National Emissions Standards for Hazardous Air Pollutants
- RLIP 5480.11 - Radiation Protection for Occupational Workers
- 40 CFR 268 (42 USC 6901) - Resource Recovery and Conservation Act of 1976
- DOE 5440.10 - National Environmental Policy Act Compliance Program
- 41 CFR 109 - DOE Property Management Regulations (43.51)
- DOE-RL - Property Management Instructions (109-43.51)
- RL 1324.1A - Records Disposition
- DOE 1324.2A - Records Disposition
- DOE 1324.5 - Records Management Program
- 10 CFR 1021 - Proposed NEPA Implementation Procedures
- RCW 90.76 REGS WAC 173-369 - Washington Underground Storage Tank Act
- DOE 5480.4 - Environmental Protection, Safety, and Health Protection Standards
- RL 5480.4B - Environmental Protection, Safety, and Health Protection Standards for RL
- DOE 5480.5 - Safety of Nuclear Facilities
- DOE 5481.1B - Safety Analysis and Review System
- SEN 15-90 - National Environmental Policy Act
- 10 CFR 20.106 - Radioactivity in Effluents to Unrestricted Areas

Three other regulatory requirements that appeared in other N Reactor documentation are:

- Safe Drinking Water Act
- WDOH - requires a Radioactive Air Emissions Notice of Construction permit
- Liquid Effluent Discharge Permits for sanitary waste disposal and filter backwash pond that are still operating.

APPENDIX G

REFERENCES

APPENDIX G

REFERENCES

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