REED COLLEGE RESEARCH REACTOR DECOMMISSIONING COST ESTIMATE

February 2018

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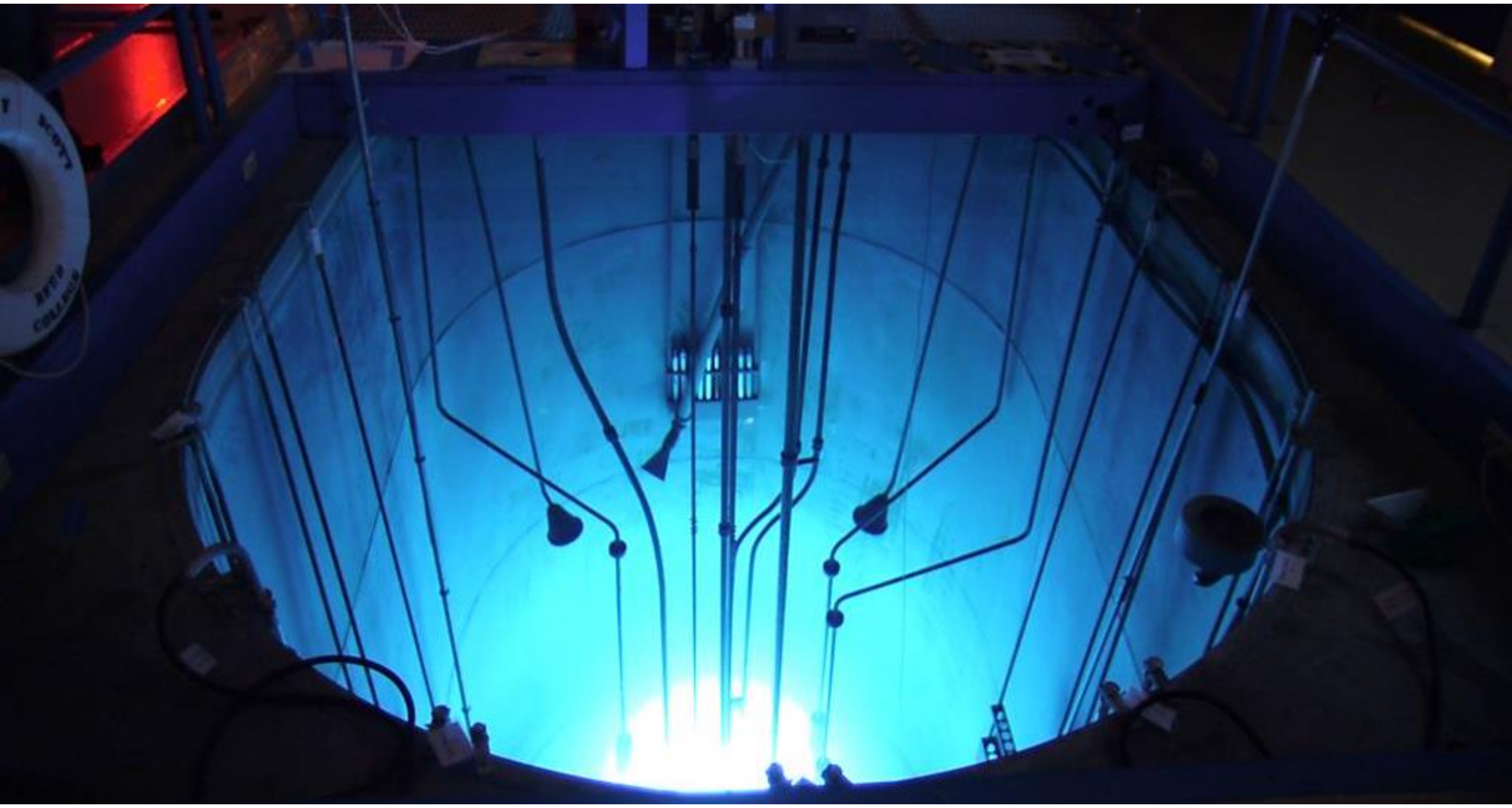

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EXECUTIVE SUMMARY

At the request of Reed College, NV5/Dade Moeller performed this Decommissioning Study to provide cost estimates and to evaluate alternatives for the eventual decommissioning the Reed Research Reactor (RRR) facility located in Portland, Oregon.

This study uses information from a variety of sources, including the previous study performed by Reed College in 2010, several U.S. Nuclear Regulatory Commission (NRC) guidance documents and reports, and the decommissioning plans, cost estimates, and experience from other university research reactors. Wherever possible, current RRR-specific information and current decommissioning cost factors were used, particularly those related to low-level radioactive waste handling and disposal.

This study presents alternative decommissioning strategies: one called DECON, where the facility is qualified for unrestricted release within a couple of years after permanent cessation of reactor operations; and one called SAFSTOR, where the facility is placed in a secure mode for several decades after permanent cessation of reactor operations to allow time for additional radioactive decay before final decommissioning. Due to the uncertainties associated with SAFSTOR, the DECON strategy is likely to be preferred for RRR decommissioning.

In order to provide a frame of reference, three additional reactor decommissioning cost estimates are shown in Table E-1. The University of Illinois shows actual costs for their decommissioning project. This was included as it was completed approximately 10 years ago and indicates recent experience. The Oregon State University number is included as it is the baseline reactor used by the NRC for these estimates. The Oregon State University reactor is approximately four times larger than RRR. The University of Kansas Training Reactor was a similar size reactor with a similar use profile and was used as a base case for this report.

Table E-1: Decommissioning Cost Estimate Summary

Estimate Description	Cost – 2018 Dollars	Cost Including Standby
DECON	$3,000,000	$4,400,000
2010 Estimate	$2,850,000	$4,190,000
SAFSTOR – 25 years	$5,147,500	N/A
SAFSTOR – 100 years	$4,253,650	N/A
University of Illinois – Actual Costs	$4,300,000	N/A
University of Kansas	$1,030,000	N/A

It should be noted that SAFSTOR only delays the DECON option. At some point, the RRR will have to be decommissioned. The SAFSTOR estimates include the DECON cost without escalation, but does include the five years of standby time.

This study includes estimated costs (in 2018 dollars) and a schedule duration estimate for decommissioning planning, removal, and disposal of irradiated and radioactively contaminated structures and materials, final radiological surveys to demonstrate compliance with radiological criteria for unrestricted release, facility demolition, and site restoration.

The costs associated with reactor fuel removal and transport from the RRR to U.S. Department of Energy (DOE) facilities are excluded, since that function is typically funded by DOE and is performed before decommissioning commences. The RRR fuel is owned by the DOE. DOE is willing to take the fuel upon reactor shutdown; however, the State of Idaho has currently placed a moratorium on receipt of fuel shipments. Decommissioning cannot proceed until the fuel is removed from the reactor and shipped to DOE. Cost for surveillance and maintenance of the reactor facility will continue until such time as the reactor can be defueled and the fuel shipped.

There are four major risks, as discussed in Section 5.1.2, associated with decommissioning at this time:

1. As noted above, the DOE cannot currently receive fuel even if the budget for receipt of fuel is approved.
2. The State of Oregon may take longer than two years to approve the decommissioning plan and final status survey plan.
3. The NRC may take longer than two years to approve the decommissioning plan.
4. Soil and or ground water contamination may be found under the reactor building.

ACRONYMS

CFR	Code of Federal Regulations
Ci	curie
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
FTE	full-time equivalent
KUTR	University of Kansas Training Reactor
kW	kilowatt
LLRW	low-level radioactive waste
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
mrem	millirem
N/A	not applicable
NRC	U.S. Nuclear Regulatory Commission
RCT	radiological control technician
RRR	Reed Research Reactor
SAR	Safety Analysis Report
μCi	microcurie

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1.0 INTRODUCTION

This Decommissioning Study consists of assessing the various decommissioning alternatives and estimated costs related to decommissioning the Reed Research Reactor (RRR). This evaluation is based on information contained in the 2007 Safety Analysis Report (SAR) (Reed, 2007) submitted to the U.S. Nuclear Regulatory Commission (NRC) as part of the relicensing application, on other documents supplied by Reed College, interviews with Reed College personnel, and field verification of pertinent data and information.

This review is required in part by 10 CFR 50.75, “Reporting and Recordkeeping for Decommissioning Planning,” and 10 CFR 50.82, “Termination of License” (NRC, 2017). There are multiple guidance documents available to assist with cost estimating. The most germane, NUREG/CR-1756 (NRC, 1983), is no longer in print or available from the NRC. As a replacement, the NRC has published NUREG-1757, Volumes 1, 2, and 3, *Consolidated Decommissioning Guidance*, (NRC 2006a, 2006b, and 2006c), which supersedes a number of previously issued NRC regulatory guidance documents, and NUREG-1537, *Guidelines for Preparing and Reviewing Applications for the Licensing of Non-Power Reactors* (NRC, 1996). These guidance documents provide NRC-accepted methodologies for licensees to use in demonstrating compliance with applicable sections of Title 10 of the Code of Regulations (CFR), which are enforced by the NRC. It is noted that NUREG-1757 specifically does not apply in total to 10 CFR 50 licensees such as the RRR; however, parts of NUREG 1757 are applicable such as the radiological criteria. The applicable radiological criteria are reflected where appropriate.

1.1 OBJECTIVES OF THE STUDY

The primary objectives are to identify the alternatives available to Reed College with regards to decommissioning and to estimate the associated costs. Note that the removal of reactor fuel is done before commencement of decommissioning operations; therefore, this task is not included as part of decommissioning costs.

There are two decommissioning alternatives to be considered for the RRR:

> DECON – in this alternative, the RRR would proceed into decommissioning mode after the fuel is removed and shipped for long-term storage or disposal. During DECON, all radioactive material is removed and shipped for disposal, and final release surveys are performed to allow the site to be used for any purpose Reed College chooses. The primary advantages are that costs are estimated for the disposal pathways and labor using current information and the costs of long-term stewardship are avoided. The primary disadvantages are there may be more low-level radioactive waste volume and activity to dispose of under this scenario because additional time for radioactive decay is not provided.
>
> SAFSTOR – in this alternative, the RRR is put is a safe shutdown configuration, the fuel is removed and shipped for disposal, and the facility is put in a cold, dark, and dry condition while the majority of the remaining radioactive constituents allowed to decay for a period of time pending ultimate demolition and removal. The primary advantage to this alternative is the reduction in radioactive inventory to be disposed as low-level radioactive waste (LLRW). The disadvantages are the long-term stewardship cost, the potential for significant increase

in labor cost, the potential for loss of (or having to use costlier) radioactive waste disposal options, potentially resulting in a significant increase in disposal cost.

The other objective of the study is to generate cost estimates for each of the two decommissioning alternatives. Best estimates, based on historical and industry data, have been used to develop these numbers. Contingency numbers have been specified as directed by the NRC.

1.2 FACILITY DESCRIPTION

The RRR is owned and operated by Reed College, a private undergraduate educational institution located in Portland, Multnomah County, Oregon. The reactor was obtained in 1968 through a grant from the U.S. Atomic Energy Commission and is currently operated under NRC License R-112 and the regulations in Chapter 1 of 10 CFR. The facility supports education and training, research, and public service activities. The reactor is in the Psychology Building, in an area constructed for that purpose, near the southeast corner of the Reed College campus in southeast Portland. The licensee controls access to Reed College facilities and infrastructure. City and college maps are supplied in Chapter 2, *Site Characteristics* (Reed, 2007). Latitude and longitude, building plans, universal Transverse Mercator coordinates, population details, and other relevant information is provided in Chapter 2 (Reed, 2007). The campus has approximately 1,300 students while the city of Portland has approximately 639,000 residents.

The operations boundary of the reactor facility encompasses the reactor room and control room. The site boundary encompasses the entire building and 250 feet (76 m) from the center of the reactor pool, including the Psychology and Chemistry Buildings.

1.2.1 Reactor Description

The RRR TRIGA® reactor is a water-moderated, water-cooled thermal reactor operated in an open below-ground, water-filled tank. The reactor is fueled with heterogeneous elements clad with aluminum or stainless steel, consisting of nominally 20% enriched uranium in a zirconium hydride matrix. In 1968, the RRR TRIGA® was licensed to operate at a steady-state thermal power of 250 kW. In 2007, Reed College applied for a renewal of the Operating License (NRC,2011). This was granted by the NRC in April 2012 (NRC, 2012). An application was made concurrently with the license renewal application to operate up to a maximum steady-state thermal power level of 500 kW. This upgrade allocation was withdrawn in 2010 during the NRC license renewal review process. Reactor cooling is by natural convection. The 250 kW-core consists typically of 79 fuel elements, each containing as much as 39 grams of ^{235}U. There are currently 101 fuel elements in the RRR inventory. The reactor core is in the form of a right circular cylinder of about 9 inches (23 cm) radius and 15 inches (38 cm) depth, positioned with axis vertical on one focus of a 10-foot (3 m) by 15-foot (4.6 m) tank with a 5-foot (1.5 m) radius on each long end. Criticality is controlled, and shutdown margin is assured, by three control rods in the form of aluminum or stainless-steel clad boron carbide or borated graphite. A sectional view of a typical TRIGA® reactor is shown in Figure 1-1.

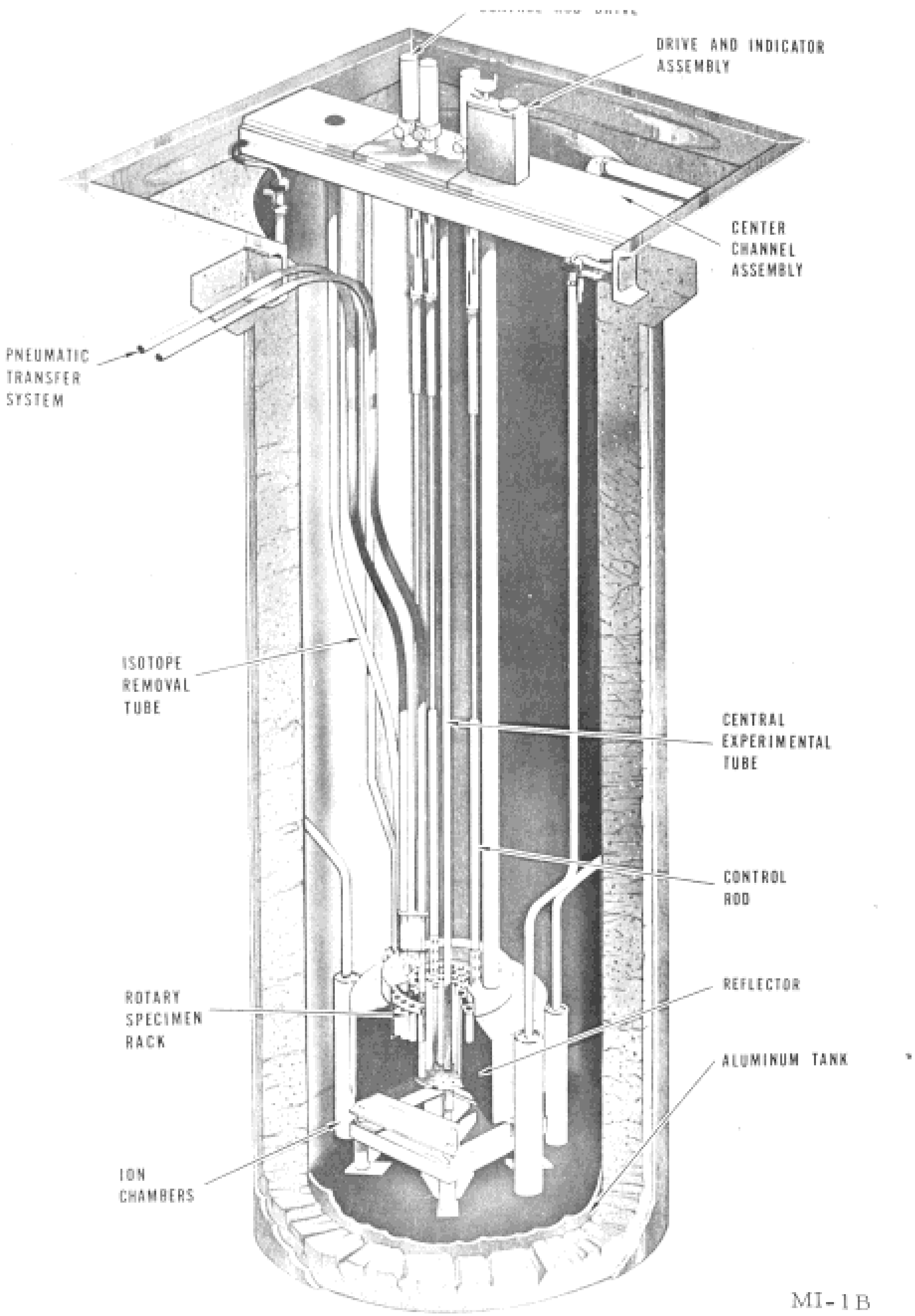


Figure 1-1: Cutaway View of a Typical TRIGA Reactor

1.2.1.1 Reactor Tank

The reactor core is located at the bottom of a below grade aluminum tank, which is 10 feet (3 m) wide and 15 feet (4.6 m) long with a 5-foot (1.5 m) radius at each end. The tank is 25 feet (7.6 m) deep and is bolted at the bottom to a 24 inch (61 cm) thick poured concrete slab. The tank has a minimum wall thickness of 0.25 inches (0.64 cm) and is surrounded by approximately 2.5 feet

(0.76 m) of concrete. A 2-inch (5 cm) by 2-inch (5 cm) aluminum channel used for mounting the neutron detectors and underwater lights is welded around the top of the tank. The top of the tank is surrounded by a steel frame 11 feet (3.4 m) wide and 16 feet (4.9 m) long, which is fabricated of 10-inch (25.4 cm) structural-steel channel and is recessed in the top of the shield structure. The tank is filled with demineralized water to a depth of 24.5 feet (7.5 m), providing approximately 20 feet (6 m) of shielding water above the top of the core.

1.2.1.2 Center-Channel Assembly

Support for the various irradiation facilities, the control rod drive mechanisms, and the tank covers is provided by the center-channel assembly at the top of the reactor tank (Figure 1-1). This assembly consists of two 8-inch (20 cm) structural-steel channels with six 16-inch (41 cm) wide by 0.625-inch (1.59 cm) thick steel cover plates bolted end-to-end to the flanges of the channels with socket-head screws. The assembly has the shape of an inverted U, is 11 feet (3.3 m) long, and is positioned directly over the center of the reactor. The assembly is attached by two steel angle brackets at each end to the 10-inch (25.4 cm) steel channels that form the recessed frame around the top of the tank. Each angle bracket is attached to each channel with four 1/2-13 by 1.5 inch (3.8 cm) stainless steel machine bolts. The brackets are made of 6-inch (15 cm) by 6-inch (15 cm) steel angle, 0.5 inches (1.3 cm) thick and 6 inches (15 cm) long. The channel assembly is designed to support a shielded isotope cask, weighing 4.5 tons (4,100 kg), placed over the specimen-removal tube.

1.2.1.3 Reactor-Tank Covers

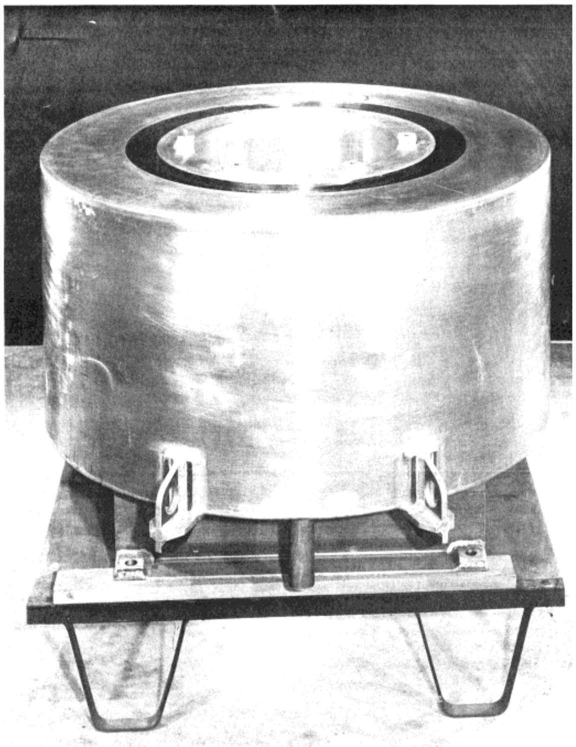
The top of the reactor tank is closed at one end by four hinged covers that are flush with the floor. The covers are made of aluminum grating formed from 0.1875-inch (0.77 cm) by 1.5-inch (3.8 cm) aluminum bars. A sheet of 0.25 inch (0.635 cm) thick plastic is inserted in the bottom of each grating section to limit the entry of foreign matter into the tank while still permitting visual observation of the reactor.

1.2.1.4 Reflector Platform

The reflector platform is a square, all-welded aluminum-frame structure. It rests on four legs that are held down by aluminum anchor bolts welded to the bottom of the aluminum tank.

1.2.1.5 Reflector

The reflector surrounding the core (Figure 1-2) consists of a ring-shaped block of graphite having an inside diameter of approximately 18 inches (46 cm), a radial thickness of 12 inches (30 cm), and a height of 22 inches (56 cm). Water is kept from contact with the graphite by a welded aluminum container which encases the entire reflector. Provision for the isotope-production facility (rotary specimen rack) is made in the form of a ring-shaped well in the top of the reflector. The rotary specimen rack mechanism does not penetrate the sealed reflector assembly at any point. The reflector assembly rests on the reflector platform. Support is provided by two aluminum channels welded to the bottom of the reflector container.



(MI-3) Fig. 3-1. Reflector assembly

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Figure 1-2: Reflector and Reflector Plate

1.2.1.6 Grid Plates

The top grid plate (Figure 1-3) is made of aluminum and is 19.44 inches (49.35 cm) in diameter and 0.75 inches (1.9 cm) thick. This plate provides accurate lateral positioning of the core components. It rests on six pads welded to the top of the reflector container. Two stainless steel dowel pins, which fit tightly in the pads and loosely in the grid plate, orient the grid plate.

The bottom grid plate (Figure 1-3), in addition to providing accurate spacing between the fuel-moderator elements, carries the entire weight of the core. This plate is of aluminum and is 16 inches (40.6 cm) in diameter and 0.75 inches (1.9 cm) thick. It is supported by six L-shaped lugs welded to the underside of the reflector container. Two stainless steel dowel pins, which fit tightly in the lugs and loosely in the plate, orient the grid.

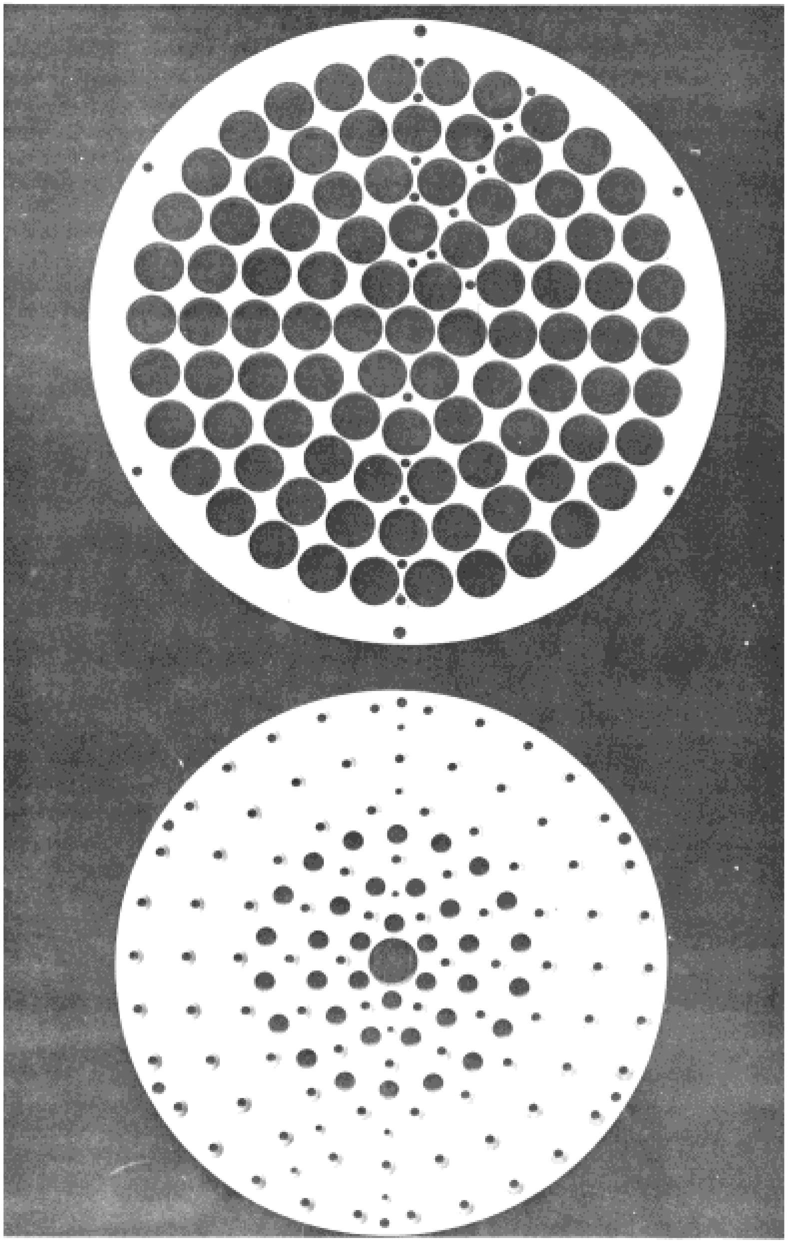

Figure 1-3: Upper and Lower Grid Plates

1.2.2 Reactor Coolant System

During full power operation, the nuclear fuel elements in the reactor core are cooled by natural convection of the primary tank water. To remove the bulk heat to the environment, the primary water is circulated through a heat exchanger where the heat is transferred to a secondary cooling loop. A cleanup loop maintains primary water purity with a filter and demineralizer to minimize corrosion and production of long-lived radionuclides that could otherwise occur. The primary coolant provides shielding directly above the reactor core.

1.2.3 Secondary Cooling System

The secondary cooling system provides the interface for heat rejection from the primary coolant system to the environment. The secondary system is an open system, with the secondary pump discharging through a primary-to-secondary heat exchanger, then through a forced-draft cooling tower.

1.2.4 Experimental Facilities

Standard experimental facilities at the RRR TRIGA®, as supplied by the vendor (General Atomics), include the central thimble, rotary specimen rack, and pneumatic specimen tube. Samples can also be lowered into the pool near the core for individually designed in-pool irradiations.

1.2.4.1 Central Thimble

The reactor is equipped with a central thimble for access to the point of maximum flux in the core. The central thimble consists of an aluminum tube that fits through the center holes of the top and bottom grid plates terminating with a plug below the lower grid plate. The tube is anodized to retard corrosion and wear. The thimble is approximately 20 feet (6.1 m) in length, made in two sections, with a watertight tube fitting. Although the shield water may be removed to allow extraction of a vertical thermal-neutron and gamma-ray beam, four 0.25-inch (6.3 mm) holes are located in the tube at the top of the core to prevent expulsion of water from the section of the tube within the reactor core.

1.2.4.2 Rotary Specimen Rack

A 40-position rotary specimen rack is in a well in the top of the graphite radial reflector. A rotation mechanism and housing at the top of the reactor allows the specimens to be loaded into indexed positions and allows rotation of samples for more uniform exposure across a set of co-irradiated samples. Although the rotary specimen rack would allow for large-scale production of radioisotopes, it is primarily used for neutron activation analysis on about 200 samples per year.

1.2.4.3 Pneumatic Specimen Tube

A pneumatic transfer system, permitting applications with short-lived radioisotopes, rapidly conveys a specimen from the reactor core to a remote receiver. The in-core terminus is located at location F-5 in the outer ring of fuel element positions.

2.0 REGUALTORY REQUIREMENTS

This section provides a summary of the most relevant regulatory requirements that control the decommissioning process.

2.1 NUCLEAR WASTE POLICY ACT

The Nuclear Waste Policy Act of 1982 provided for the development of repositories for the disposal of high-level radioactive waste and spent nuclear fuel and established a program of research, development, and demonstration regarding the disposal of high-level radioactive waste and spent nuclear fuel. This Act created a fund supported by the utilities that was supposed to result in the opening of Yucca Mountain (or a similar repository) for the disposal of spent nuclear fuel. Utility fuel would have priority over research reactor fuel such as that in use at RRR. The RRR fuel is owned by the U.S. Department of Energy (DOE) and, historically, it was intended to be returned to DOE after the RRR permanently ceases reactor operations so Reed College would not be responsible for its final disposal.

However, the only repository for DOE research reactor fuel is at the Idaho National Laboratory. Currently, the State of Idaho has placed a moratorium on any further fuel receipts of research reactor fuel until DOE has a path forward for disposal of the used fuel. Without a national repository such as Yucca Mountain, such a path forward is not being developed. If this situation persists, there will be an impact on research reactors since at shutdown there may be no provisions for shipping the fuel to DOE and the individual reactors may need to develop and maintain facilities to safely, and securely, store the fuel

2.2 LOW-LEVEL RADIAOCTIVE WASTE POLICY ACTS

The Low Level Radioactive Waste Policy Act of 1980 implemented Congress's belief that commercially-generated LLRW (i.e., radioactive waste that is not generated by DOE activities) could best be managed on a regional basis and set up the framework for interstate compacts that would be ratified by Congress. To encourage the development of new sites, the compacts would be allowed to exclude or limit waste from generators located in states that are not parties to those compacts (called "nonparty" or "out-of-compact" states). At that time, only three commercial LLRW disposal sites existed in the United States in Nevada, South Carolina, and Washington. These three states soon formed compacts with their neighboring states (called the "sited" compacts). Because of the lack of progress toward establishing new LLRW disposal sites, Congress passed the Low Level Radioactive Waste Policy Amendments Act of 1985 to create penalties for delays and allowed the sited compacts to ban importation of out-of-compact waste at the end of 1995.

The state of Oregon is part of the Northwest Compact, which allows the RRR to send its waste to the U.S. Ecology Site near Richland, Washington. This greatly reduces the uncertainty surrounding waste disposal pathways and helps minimize transportation costs. The U.S. Ecology Site is licensed to receive all demolition waste except for the fuel and any highly radioactive reactor components, which would be classified as greater than Class C waste by the NRC. There is no disposal pathway for either of these classes of waste.

2.3 RADIOLOGICAL CRITERIA FOR LICENSE TERMINATION

Since the RRR is licensed by the NRC, radiological criteria for terminating its license are specified in 10 CFR 20, Subpart E. The criteria used for license termination are largely dependent upon the future use scenario for the facility. For example, if a restricted use scenario is chosen, it is possible that a 100 mrem/year dose distinguishable from background to the average member of a critical group would be an acceptable endpoint for residual radioactivity after institutional controls are no longer in effect (as specified in 10 CFR 20.1403, "Criteria for license termination under restricted conditions"). However, it is unrealistic for Reed College to request license termination using these criteria, considering the restrictions that would be required for approval. The federal limit for unrestricted release is a 25 mrem/year dose distinguishable from background to the average member of the critical group (as specified in 10 CFR 20.1402, "Radiological criteria for unrestricted release”). NUREG-1757, Volume 1, provides screening values for building surfaces, materials, and soils, which can be used for this purpose (NRC, 2006a)

Reed College does not possess a radioactive material license from the State of Oregon. However, Reed College should anticipate satisfying Oregon requirements for license termination. Unlike the NRC, Oregon has not established specific numerical dose criteria for license terminations. Currently, radiological release criteria are specified for each license termination on a case-by-case basis. If unrestricted (or free release) is chosen, it is likely that the State of Oregon will apply a level that is much lower than the NRC criteria, closer to levels that are indistinguishable from background; in any case, not more than a few mrem/year of additional dose to the average member of a critical group. The amount of remediation required to meet these endpoints could be significantly different if it is discovered there have been leaks to the soil. Barring that, there is likely to be little difference as both scenarios will require removal of radioactive components and fuel. Another consideration is the potential difference in the volume of activated concrete shielding that would be sent to an LLRW disposal site. However, since both NRC and the State of Oregon require that residual radioactivity levels be reduced to those as low as reasonably achievable (dose limits notwithstanding), there is likely to be little or no difference in the volume of activated concrete shielding sent to an LLRW disposal site. This report assumes that all contaminated material above background levels is removed from the facility.

2.4 RADIONUCLIDES OF CONCERN

Based on the reactor design and material descriptions in the safety analysis report (Reed, 2007), Table 2-1 shows a list of radionuclides expected during decommissioning, their source and potential impact.

Table 2-1: Isotopes of Concern

Isotope	Source	Impact	Comments
Tritium (^{3}H)	Primary Coolant	Minimal	Not currently detectable in primary coolant.
^{55}Fe	Rebar	Hard to detect radionuclide.	Will be evaluated based on surrogates such as ^{152}Eu and ^{154}Eu.
^{59}Fe	Rebar	Minimal	Short half-life. Will decay while waiting for fuel offload.
^{60}Co	Stainless Steel pins and bolts	Small volume, high dose rate. Easily found and removed	Highest exposure potential during decommissioning. Decay in place before fuel offload will reduce impact.
^{152}Eu	Concrete	Likely activation product to be present in concrete	If detectable, assume that portion of concrete is rad waste.
^{154}Eu	Concrete	Likely activation product to be present in concrete	If detectable, assume that portion of concrete is rad waste.
Fission Products	Fuel, Fission Chamber	None	Both should be shipped with the fuel.

2.5 OTHER REQUIREMENTS FOR LICENSE TERMINATION

In 10 CFR 50.82(b), license termination requirements are specified for non-power reactor licensees, particularly the requirements for proposed decommissioning plans specified in 10 CFR 50.82(b)(4).

Within two years following permanent cessation of operations, and in no case later than one year prior to expiration of the operating license, a licensee must apply for license termination.

10 CFR 50.75 specifies requirements for reporting and recordkeeping for decommissioning planning. 10 CFR 50.75(d) specifies that decommissioning reports for non-power reactors must contain a cost estimate for decommissioning the facility, indicate which method or methods will provide financial assurance for decommissioning funds, and describe the means of adjusting the cost estimate and associated funding level periodically over the life of the facility. In 10 CFR 50.75(f)(4), the factors to be considered in submitting preliminary decommissioning plans for non-power reactor licensees are specified, including the decommissioning alternative anticipated to be used, major technical actions necessary to carry out decommissioning safely, the current situation with regard to disposal of high-level and low-level radioactive waste, residual radioactivity criteria, and other site-specific factors which could affect decommissioning planning and costs. 10 CFR 50.75 also specifies the recordkeeping requirements for information important to the safe and effective decommissioning of the facility, including records of spills or other unusual occurrences, as-built drawings of the facility, cost estimates performed for the decommissioning funding plan, and other records of the licensed site area and licensed activities.

3.0 FACILITY OPERATING HISTORY AND RADIOLOGICAL CHARACTERIZATION

In December 2017, NV5/Dade Moeller project staff visited Reed College and the RRR for a project kick-off meeting, a tour of the facility, direct observation of areas and equipment relevant to this study, and interviews with reactor operations staff. Representative operating and license records have been provided to NV5/Dade Moeller for review. This information included the NRC license (License Number R-112) and license amendments, technical specifications, NRC inspection reports, reactor operating procedures, radiation safety procedures, facility annual reports [including information about reactor operations (e.g., unscheduled shutdowns, anomalies, facility modifications and maintenance activities other than preventive), approved experiments, licensing and regulatory activities, radiological investigation reports, facility radiation monitoring and contamination surveys, personnel radiation exposure monitoring, radioactive waste disposal, radioactive effluent releases, and environmental radiation monitoring], facility and equipment descriptions and diagrams, and previous decommissioning cost estimates.

There have been no recorded discharges of liquid effluents to the sanitary sewer. The secondary cooling water was historically discharged to the pond near the RRR facility; that practice has been discontinued. Annual summaries of airborne effluents typically show only releases of ^{41}Ar and ^{16}N in average concentrations equivalent to less than 20% of the constraint dose limit of 10 mrem per year to any member of the public in an uncontrolled area. For example, the 2017 annual summary of environmental radiation monitoring shows the average off site dose was not detectable above background levels. The 2017 annual summary of radioactivity concentrations in environmental samples to be non-detectable compared to background concentrations (Reed, 2017).

After reviewing all of the information that Reed College provided, it can be concluded that the facility has a clean operating history with no significant spills of long-lived radioactive materials inside the facility or releases to the environment resulting in any radioactive contamination of soil or groundwater. Therefore, after removal of the reactor fuel, the reactor core and in-tank structures, tank liner, activated shielding materials, and LLRW generated during decontamination and demolition of building and equipment system components (especially those involved in processing and conveying primary coolant and handling reactor room air), it is unlikely that there would be any residual long-lived radioactive contamination that would require additional remediation.

Since 1992, the reactor operated with a total utilization of about 1,500 megawatt-hours through the end of 2017 (Reed, 2017). Future utilization is projected at about 160 hours per year at 250 kW (about 40 megawatt-hours per year).

4.0 DECOMMISSIONING ALTERNATIVES

Each of the identified decommissioning alternatives is discussed below along with assumptions for cost estimating associated with each alternative.

4.1 DECON

The DECON alternative, as defined by the NRC, is

> *… the alternative in which the equipment, structures, and portions of a facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations.* (NRC, 1983)

4.1.1 Period 1: Preparations

In anticipation of the cessation of RRR operations, detailed preparations are undertaken to provide a smooth transition from operations to site decommissioning. Through implementation of a staffing transition plan, the organization required to manage the intended decommissioning activities is assembled from available staff and outside resources. Preparations include the planning for permanent defueling of the reactor, revision of technical specifications applicable to the operating conditions and requirements, a characterization of the facility and major components, and the development of a decommissioning plan.

When Reed College intends to begin planning for decommissioning (which must be no later than the timeframe specified in 10 CFR 50.82, as described in Section 2.5), their representatives should meet with NRC staff to identify any site-specific issues, discuss the NRC's expectations, review the agency's checklist for decommissioning and license termination, and develop a preliminary schedule for Reed College and NRC staff activities. This discussion should help Reed College develop a decommissioning plan with the level of specificity necessary for submission to NRC with the request for license termination.

After the reactor has permanently ceased operations and has been defueled, radiological characterization of activated shielding materials and potentially contaminated building surfaces and building systems will help to refine the decommissioning plan and cost estimates.

4.1.2 Period 2: Decommissioning Operations

This section provides a brief description of major decommissioning activities and requirements of DECON, including decontamination, disassembly and disposal, quality assurance, environmental surveillance, essential systems and services, final radiological surveys, and license termination.

4.1.2.1 Decontamination

Decontamination is necessary to remove the radioactive contamination from selected systems and components. The objectives of the decontamination effort are twofold: first, to reduce the radiation levels throughout the facility to minimize personnel exposure during disassembly; and second, to attempt to clean as much material as possible to unrestricted levels, thereby permitting salvage of valuable material and reducing the quantities of material that must be packaged and shipped to an LLRW disposal site.

4.1.2.2 Disassembly and Disposal

Disassembly of the reactor is started after the reactor is defueled, systems and components are decontaminated, and temporary shielding is installed where a comprehensive radiation survey indicates the need. The exact component removal sequence within a given system or work area is dictated by the component's accessibility and the anticipated personnel exposures during removal. When possible, items that contribute significantly to the general level of exposure in the work area are either removed first or are temporarily shielded while the work goes on. Systems are unbolted at flanges when possible and cut into manageable sections, using an appropriate cutting device (plasma-arc torch, oxyacetylene torch, or power hacksaw). Piping is cut into lengths compatible with standard B-25 shipping boxes. Similarly, tanks and the reactor tank liner are cut into plate segments appropriately sized. In this study, all initially contaminated materials are assumed to remain contaminated to greater than unrestricted-use levels, even after decontamination, and are packaged for disposal as radioactive waste.

Packaging of radioactive materials for disposal is accomplished in accordance with U.S. Department of Transportation (DOT) regulations published in 49 CFR 173–178, and with NRC regulations published in 10 CFR 71. Shipping of packaged contaminated materials from the RRR to a LLRW processing or disposal facility is accomplished using a licensed radioactive waste broker or a trucking company that specializes in transporting radioactive materials. The volume of materials to be transported and the number of shipments required are estimated in Section 6.0 of this report.

The TRIGA® reactor is constructed almost entirely of aluminum. As such, there will be minimal activation of the core support structure and the reflector. Any activation is expected to be short lived and will decay prior to decommissioning. Once the fuel is removed, the remaining portions of the core will be removed and packaged in B-25 boxes or disposal. The only high activity waste expected is the ^{60}Co in the stainless steel pins and bolts. These are expected to be small sources and will be easily shielded. They should not exceed the shipping criteria for standard waste containers, such a “B25” box.

Remaining contaminated equipment is removed and packed in B-25 boxes. Larger contaminated equipment will be size reduced to fit in the B25 boxes. Activated or contaminated concrete is removed by cutting sections with concrete saws and the slabs packaged in B-25 boxes for disposal.

Sources such as the start–up sources and other sources used in support of reactor operations will be packaged in a 55-gallon drum for disposal or transferred to another licensee.

4.1.2.3 Quality Assurance

An extensive quality assurance program is carried on throughout the decontamination effort to assure that all applicable regulations are met, that the work is performed according to plan, that the work does not endanger public safety, and that decommissioning staff are safe.

4.1.2.4 Environmental Surveillance

An abbreviated version of the environmental monitoring program implemented while the RRR was operating is continued during the DECON period. The purpose of the program is to identify and quantify any releases of radioactivity to the surrounding areas resulting from the DECON activities. For emergency situations involving releases from events such as fires or malicious acts that may necessitate prompt emergency action to minimize the risk to the public, additional short-term surveillance efforts are required.

4.1.2.5 Essential Systems and Services

To prevent the release of significant quantities of radionuclides (or other hazardous materials) to the environment, all or parts of certain facility systems and services must remain in place and in service until all radioactive material is either removed from the facility or secured on the site. Some systems and services are required for cleanup and disassembly activities. Others provide personnel health and safety protection. These systems and services include those for normal and emergency electric power, Reactor Room and Stack Ventilation, HVAC, demineralized water, service water, compressed air (control and service), communications, fire protection, security, and radiation protection. As dismantlement and decontamination are completed in areas within the facility, the essential systems and services in these areas are deactivated and, if contaminated, removed as required. Continuous service to the remaining work areas is maintained as long as necessary.

4.1.2.6 Radiological Surveys and License Termination

After removal of all LLRW and completion of decontamination and demolition activities, radiological surveys must be performed to demonstrate compliance with radiological criteria for unrestricted release. These are not the final status surveys although in most cases will use similar criteria and methods to demonstrate that there is no residual activity in the facility.

Following building demolition and prior to site remediation, a final status survey must be completed along with an independent survey commissioned by the NRC. These radiological surveys must be performed according to a site-specific NRC-approved final status survey plan, which is prepared using guidance provided in NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM).* The MARSSIM process includes negotiation with stakeholders (including the State of Oregon) on acceptable release limits. Typically, the final status survey report is submitted to the NRC with an application for license termination. Before approving the license termination, the NRC usually requires an independent confirmatory survey (which historically has been at no cost to university licensees). Upon license termination, the site is released for unrestricted use.

4.1.3 Period 3: Site Restoration

This study assumes that the building will not be demolished. The complete removal of the reactor and ancillary systems will result in significant building damage. An alternative path where the reactor portion of the building is removed could be considered.

4.2 SAFSTOR

The SAFSTOR decommissioning alternative, as defined by the NRC, is

> *... a method of decommissioning in which a nuclear facility is placed and maintained in a condition that allows the facility to be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use.* (NRC, 1983)

4.2.1 SAFSTOR Activities and Requirements

Activities at the RRR during the SAFSTOR period would include routine inspection, preventive and corrective maintenance on safety systems, and a regular program of radiation and environmental monitoring. Action is initiated immediately to correct any unusual or potentially unsafe conditions detected by the surveillance program. In addition to the routine tasks, a comprehensive inspection of the facility should be performed annually by qualified third-party inspectors. The SAFSTOR period lasts until final disposition of the facility. The length of this period is determined by a cost-benefit analysis that balances the costs of surveillance and maintenance against the decreased decontamination costs and land use values, as well as by societal or regulatory issues.

An alternative SAFSTOR process would require that the reactor tank be filled with concrete and the rest of the building surveyed for free release and repurposing. This alternative process would need to be approved by the State of Oregon and it would imply the need for future remediation of the concrete monolith. Because of potential regulatory uncertainties, this alternative process is not evaluated in this report.

4.2.1.1 Deferred Decontamination Activities and Manpower Requirements

Deferred decontamination achieves the degree of decontamination necessary for termination of the amended NRC license through radioactive decay after some period of SAFSTOR. Following the SAFSTOR period, the facility and site must be shown to have residual radioactivity levels low enough to permit unrestricted use. The same basic operations performed during DECON are assumed to have been performed during deferred decontamination. The radioactive corrosion products on the inner surfaces of the piping, tanks, and equipment consist mostly of ^{60}Co. It is unlikely that the residual radioactivity on all surfaces will decay to levels that permit unrestricted use before 50 years have elapsed. This generally means that, regardless of the SAFSTOR period, all of the systems will have to be disassembled to make measurements on the interior surfaces of the systems to determine whether the material can be released or must be handled as LLRW.

Operations such as reactor defueling and shipment of spent fuel are performed during preparations for SAFSTOR and are not required during deferred decontamination. These activities are replaced by extensive training and familiarization of the decommissioning staff with the facility, since the staff is not likely to consist of personnel from the operations staff after an extended period of safe storage.

Additional effort is required to restore the services needed for decontamination throughout the facility and to remove the various locks, welded closures, and barricades that were installed to secure the facility during preparations for safe storage. Significant reductions in radioactive waste volumes are expected with time as the radioactive decay processes decrease the radionuclide quantity in the stored wastes.

4.2.1.2 Work Schedule Estimates

Since the same basic efforts are required to decontaminate the facility regardless of when the decontamination takes place, the work hour estimates presented in Section 5.2 of this report are assumed to be valid for deferred decontamination. Operations such as reactor defueling and fuel shipment are replaced by familiarization of the workforce with the facility, through training, and by restoring essential services and un-securing the facility.

4.2.1.3 Deferred Decontamination Staff Requirements

The management and support staff requirements are the same for deferred decontamination as they are for DECON. However, fewer decommissioning workers may be required because the radiation dose rates are lower when decontamination is deferred and less LLRW will need to be packaged for shipment. Since the occupational radiation dose is lower because of radioactive decay, the extra workers that might be needed to meet the occupational dose limits during DECON are not needed for deferred decontamination.

According to the sensitivity analysis in NUREG/CR-1756, Addendum (NRC, 1983), for the reference TRIGA® research reactor, it is concluded that if DECON is deferred for 100 years, there would be a 67% savings for LLRW disposal costs (primarily due to the reduction in volume of contaminated equipment and decontamination wastes), but only a 14% savings for the total decommissioning costs (in constant dollars). If DECON is deferred for any shorter amount of time, there would be less savings for LLRW disposal (due to the shorter radioactive decay period) with little change in the other cost categories. This analysis did not evaluate the opportunity costs for deferring potential beneficial reuses of the site. According to NUREG/CR-3474 (NRC, 1984), 20 years after shutdown, the dominating radionuclides in the activated concrete are ^{3}H and ^{152}Eu, with ^{152}Eu being the most significant contributor to radiation dose. In the activated steel rebar, the dominating radionuclides at that time are ^{55}Fe and ^{60}Co, with ^{60}Co being the most significant contributor to radiation dose.

There are potentially significant unquantifiable factors associated with deferring DECON for decades. Among these factors are the potential unavailability of LLRW disposal sites (due to lack of disposal capacity and/or access for Oregon waste generators) and potential changes in legal and regulatory requirements.

4.2.1.4 Site Restoration

Site restoration, following decontamination, will be the same as for the DECON method.

4.3 COLD SHUTDOWN (STANDBY)

Although this is not a formal decommissioning mode, it is a very likely scenario given the lack of a path forward on fuel disposal. This option can be used in conjunction with either of the alternatives listed above. In this option, the RRR would be permanently shut down and Reed College would apply to the NRC for a possession only license. Staffing would be adjusted to a lower level. It is noted that even in a possession-only license, there must be a qualified reactor operator on staff.

5.0 COST ESTIMATE

The previous cost estimates performed for the RRR do not have sufficient detail to use a basis for this estimate. In the absence of other data, comparisons can be made to the actual costs of decommissioning of similar sized reactors.

5.1 FINANCIAL COMPONENTS OF THE COST MODEL

The following sections define the financial elements to be considered in developing the cost analysis.

5.1.1 Contingency

A 25% contingency figure is included in the cost estimate as recommended by the NRC. Since this is only a recommendation, it may be adjusted by Reed College based on the college's experience in capital projects. However, as discussed below, there are elements of risk associated with decommissioning and adequate contingency needs to be provided.

5.1.2 Financial Risk

NV5/Dade Moeller has provided what we believe to be a conservative estimate of the cost of decommissioning for the RRR. Our estimate is based on comparison to the decommissioning costs of similar types and sizes of research reactors, and the NRC model for decommissioning. The volume of contaminated concrete has been conservatively estimated based on reactor description. It is possible the volume can be reduced. There is a trade-off though between cost of disposal and labor costs of performing radiation surveys and sampling for release.

It is difficult to predict what may happen during the course of decommissioning as well; there are unforeseen issues and delays which impact the costs. For example, the total cost for decommissioning the Ford Nuclear Reactor was $14.5 million over a six-year period—versus the initial estimate of $9.8 million over a two-year period—because more extensive radioactive contamination than initially anticipated was encountered.

NV5/Dade Moeller has identified four major project risks. As the project progresses, additional risks may be identified.

1. The DOE cannot currently receive fuel even if the budget for receipt of fuel is approved. Until the legal issues with the State of Idaho are resolved, fuel shipments are on hold. There is no projected resolution to this in sight. In addition, DOE has notified other licensees that fuel receipt will not occur until sometime after 2020. With a two-year budget cycle on top of that, the earliest expected fuel shipment date would be 2022. This situation puts decommissioning of the RRR on indefinite hold unless Reed College wishes to explore on-site dry cask storage of the reactor fuel. Dry cask storage of TRIGA® fuel has not been done to date making this a difficult item to estimate from a cost and schedule perspective because

Reed College would have to get a dry cask design certified and licensed, which is both time consuming and expensive.

2. The State of Oregon may take longer than two years to approve the decommissioning plan and final status survey plan. Delay costs are $255,000 per year which is based on the same calculation as the stand-by time. State delay costs should come out of the contingency fund since it is assumed that this delay would occur after the fuel is scheduled for shipment.

3. The NRC may take longer than two years to approve the decommissioning plan. NRC delay costs should come out of the contingency fund since it is assumed that this delay would occur after the fuel is scheduled for shipment. NRC delay costs would be calculated on the same basis as the stand-by time.

4. Soil and or ground water contamination may be found under the reactor building. NV5/Dade Moeller does not believe this is likely based on the design and operating history, however, there is a possibility of this happening. If more extensive contamination than anticipated is found, there will be additional remediation cost and schedule impacts, which would come from the contingency fund. The cost of this clean-up is difficult to estimate without knowing the nature and extent of the contamination.

5.1.3 Site-Specific Considerations

As a basis for the cost estimates, NV5/Dade Moeller considered information from decommissioning previous research and test reactors. The RRR is similar to the University of Kansas Training Reactor (KUTR) in terms of reactor size (KU, 1992a). The Oregon State Reactor is much larger but is used as the basis for the decommissioning estimate in NUREG/CR-1756, *Technology Safety and Costs of Decommissioning Reference Nuclear Research and Test Reactors,* (NRC, 1982). For this study, when RRR-specific characterization data were not available, information from KUTR was used as appropriate, because of the similarity of reactor size. Where appropriate, additional scaling factors for size are also used and are explained.

5.1.4 Assumptions

This current study makes the following assumptions for decommissioning the RRR in the future:

1. Any changes in legal and regulatory requirements will not significantly affect RRR decommissioning activities.
2. The DOE will honor its commitment to receive the reactor fuel and control rods by resolving the current legal issues between the DOE and the State of Idaho.
3. Currently available LLRW disposal facilities through the Northwest Compact will be available to accept RRR decommissioning wastes.
4. Any changes in projections for the RRR and facility utilization will not significantly affect decommissioning waste characteristics or volumes.
5. Additional radiological characterization of RRR decommissioning wastes will not significantly increase LLRW disposal volumes.
6. RRR operations will not cause releases to the environment that require remediation of soil or groundwater.

5.2 DECON ALTERNATIVE COST ESTIMATE METHODOLOGY

Generally, the NV5/Dade Moeller cost estimate is based on data generated from the decommissioning experience at the KUTR (KU, 1992b), modified for RRR, and updated with current information for LLRW packaging, transportation, treatment, and disposal provided by a LLRW broker/processor and LLRW disposal facilities in Richland, Washington.

As a baseline, by NRC requirements, for a possession only license there must be a qualified reactor operator on staff. For example, staffing could include:

FTE	Position
0.25	Reactor Director
1.0	Reactor Supervisor
0.1	Facility Manager
0.1	Radiation Safety Officer
0.1	Facility Engineer

Salaries (including benefits) for these staff have been calculated using current labor rates. Staff salaries are expected to escalate at 3% per year. This level of staffing is approximately $140,000 per year. This is equal to a blended hourly rate of about $43 per hour. For planning purposes, a conservative blended rate of $50 per hour will be used to maintain a possession only license.

In addition to the staffing shown above, there are ongoing costs to maintaining the facility. Reed College has estimated the additional costs for utilities, building maintenance, custodial services, inspections, and supplies are approximately $115,000 per year. This will escalate at approximately 3% per year.

Reed College should plan on this for a minimum of 5 years at the possession only staffing once the decision is made to permanently shut down the RRR.

A baseline labor cost of $255,000 per year for standby time will be used in all scenarios to account for staff time and maintenance costs while waiting for items such as approval to ship the fuel, approval from the NRC and the State of Oregon on the decommissioning plan, and for any other significant delay period. The $255,000 value is based on an approximate $140,000 per year staff costs and the maintenance costs of $115,000 described above. These costs are escalated as appropriate to account for the standby time.

The following sections describe the basis and results of the DECON alternative cost estimation. A summary of the methods used to estimate costs for each cost component of the DECON alternative are summarized in Section 5.2.12.

5.2.1 Basis of the DECON Alternative Cost Estimate

The 2010 RRR cost estimate shows a very simple model for decommissioning. Volumes are estimated for waste disposal and a time estimate of one year is used. There is no documented basis provided for either of these numbers.

For this analysis, NV5/Dade Moeller calculated radioactive waste volumes consistent with the facility design and experience at the KUTR (KU, 1992a) and used current waste disposal costs. Since Reed College uses a radioactive waste broker, we concluded that transportation costs are included in the waste disposal fee charged. Decommissioning time estimates for decontamination and demolition were made based on historical and industry knowledge regarding the actual time needed for these types of projects. Required staffing was also estimated from industry data. The total estimated duration for the RRR decommissioning was 60 days.

For this analysis, personnel costs assume that Reed College would have two FTE employees on site at all times during the decommissioning schedule. Based on the labor cost discussed in Section 5.2, this works out to a total of $55,000 (rounded to $60,000 for the cost estimate) for the 60-day project. It should be noted that all stand-by time and preparatory time prior to the start of decommissioning is captured in the $255,000 per year described above. All costs shown below will be for the contractor only. For decommissioning and demolition activities where the crew is contractor staff, a blended rate of $85 per hour is used. If an activity is craft specific, such as final status surveys which is essentially all radiological control technician (RCT) time, then that craft hourly rate is used versus the blended rate. For purposes of the analysis, it was assumed that Reed College would be providing the engineer, the Radiation Safety Officer, and the administrative support, so those personnel were not included in the blended contractor labor rate.

For material and equipment estimating, an average value of $85 per hour was used per unit of equipment needed. This was then applied to the expected schedule duration to estimate the cost.

5.2.1.1 DECON Alternative Project Planning

Project planning is a Reed College activity and is a schedule duration estimate; it is not intended to imply a full-time commitment for an entire planning crew. As a result, an estimate of 480 man-hours to complete the demolition planning is considered to be realistic. This planning will also be conducted during the standby period and as such is included there rather than as a separate line item. This is consistent with the KUTR cost estimate which showed all of these planning costs to be a University of Kansas expense (KU, 1992b).

No material or equipment cost is incurred during planning.

5.2.1.2 DECON Alternative Document Preparation

This phase includes preparation of documents such as the project management plan, work procedures, budgets, survey plans, and the final reports. There was a total cost at KUTR of $36,000 (KU, 1992b) which has been escalated for Reed College to $50,000. This will be a joint effort between Reed College and the Decommissioning Contractor.

5.2.1.3 DECON Alternative Mobilization and Training

Based on the crew size expected, this is estimated at 320 hours. This will be a mix of Reed College and contract personnel. Contractor labor cost is estimated to be $27,200. This is consistent with the one week of site mobilization used by the KUTR contractor.

No material or equipment cost incurred here.

5.2.1.4 DECON Alternative Facility Preparation

In this phase, temporary ventilation will be installed as necessary, hazardous materials will be removed, clean equipment and debris will be removed, a baseline survey will be performed, and unnecessary utilities will be isolated. This will require a mix of Reed College and contractor personnel. Set-up time at the KUTR project took a total of 8 days. The RRR timeline is extended to 12 days to account for building modification, ramp construction, and other impacts due to the below grade reactor location. Contractor labor cost is estimated to be $65,280.

This phase includes removal of the primary coolant and preparing it for disposition. Disposition/disposal of the reactor coolant is part of the overall waste management process.

As noted in Section 3.0, there is historical evidence of secondary water disposal into the on-campus lake. During the baseline survey process, sediment samples will be taken near the outfall f this piping system. The piping will be identified and sampled/surveyed as well. This is considered a Reed College activity and will be completed using existing site resources. It is estimated that 10 samples, at approximately $200 per sample, will be required for a total cost of $2,000.

Equipment and material cost was estimated at $8,160 based on needing equipment for removal of debris, survey and removal of hazardous material, and acquisition and installation of temporary ventilation systems.

5.2.1.5 DECON Alternative Reactor Component Removal

In this phase, the reactor tank and internals are removed. This includes the associated systems like the Reactor Water Cleanup System. The KUTR timeline showed 13 days of work for component removal (KU, 1992a). The RRR tank is significantly larger, resulting in a 20-day estimate for removal. Contractor labor cost is estimated to be $108,800.

Equipment and material cost of $13,600 was estimated primarily for the equipment needed to remove the reactor tank and internals and to package them for disposal. The packaging and waste disposal costs are covered in the waste section.

5.2.1.6 DECON Alternative Concrete Radiological Characterization

In this phase, the concrete structure around the reactor tank will be characterized. Radiological surveys and sampling will be done with the intent of segregating as much concrete for clean debris disposal as possible versus declaring all of the concrete as LLRW. Initial Micro-R meter readings will be taken with a meter calibrated to a low energy gamma emitter, such as ^{241}Am. Any area with detectable radiation above background will be isolated and automatically disposed of as LLRW. Areas where the levels are at background will be sampled to determine if activated material is in the concrete. Negative sample results will be used to justify disposal of the material as clean debris. This phase is estimated to take 5 days. Note that concrete coring at the KUTR was performed in an earlier phase. Contractor labor cost is estimated to be $27,200. Material and equipment cost is estimated at $6,800 which will include sample analysis.

5.2.1.7 DECON Alternative Concrete Removal

This phase includes the removal of the concrete structure around the reactor tank, including the base mat. Since the concrete structures are below grade, preparations for this phase will include creating access to the outside of the concrete vessel. A total of 20 days is allotted to this effort resulting in a cost of $108,800. Note that in this case, all hours are assigned to the contractor even though Reed College staff will be onsite and providing work control and direction.

Equipment cost is estimated at $13,600 based on the acquisition of the concrete cutting equipment and the leasing of the machines, cranes and hoists for lifting the concrete blocks, and other material handling equipment needed.

5.2.1.8 DECON Alternative Facility Decontamination

Following concrete and contaminated system removal, there may be residual contamination that must be removed prior to conducting final status surveys. It is expected that appropriate work controls will be employed to minimize this effort, but it will still be necessary to some extent. A total of 5 days and 160 man-hours are allocated for this effort. This is a mix of Reed College and contractor personnel. Estimated contractor labor cost is $27,200.

Equipment cost for decontamination is based on the cost for removal and packaging for disposal. It is assumed that contaminated items will be removed and disposed as waste. Estimated cost is $3,400.

5.2.1.9 DECON Alternative Final Status Surveys

Once the reactor and support systems have been demolished and removed and all contaminated material removed as described in Sections 5.2.17 and 5.2.18, the building structure will be ready for the final status survey as described in the decommissioning plan and as agreed to with the State of Oregon and the NRC. The reactor building is considered to be a single Class 1 site for MARSSIM (NRC, 2000) purposes.[1] It should be noted that as long as it is less than 2,000 square meters, the size of the footprint is not considered when designing the survey. The exterior areas can be considered to be a single Class 3 survey Area. A total of 5 days (40 hours) of RCT time will be required for a cost of $16,320.

Equipment and material cost is based on leasing of RCT survey equipment and on analysis cost of samples. Total cost is estimated to be $5,440.

5.2.1.10 DECON Alternative Building Restoration

Following approval of the results of the final status survey, the building is ready for repair and restoration. This restoration is outside the scope of the decommissioning plan since Reed College has not determined a path forward for that portion of the building. However, the building will likely

[1] MARRSIM Class 1 is any area where there is a potential for residual radioactive material exceeding the design concentration guideline level. It is also any area that has been radiologically remediated. Class 3 areas are defined as areas adjacent to Class 1 or Class2 areas and areas where there is minimal probability of residual radioactive material.

need enough repair to make it weather tight. An estimate of $100,000 is included to account for the minimum repair.

5.2.1.11 DECON Alternative Demobilization

Demobilization of the decommissioning contractor is dependent on the amount of equipment used. Since minimal equipment will be required, demobilization is expected to take two days and cost $10,880. This is consistent with the KUTR timeframe.

5.2.1.12 DECON Alternative Methodology Summary

Table 5-1 summarizes the costs using this estimating method.

Table 5-1: DECON Activity Summary

Activity ID	Activity Description	KUTR Activity Duration (Days)	KUTR Cost	RRR Activity Duration Estimate (Days)	Activity Cost[1]	Equipment Costs	Comments
1	Planning	N/A	N/A	30	N/A	N/A	Included as a Reed College task. Will be conducted during the standby period while preparing for fuel offload. Not included in duration
2	Document Preparation	N/A	$36,000	N/A	$50,000	N/A	Includes project management plan, work plan, procedures, and final reports
3	Mobilization and Training	5	$15,100	5	$27,200	N/A	None
4	Facility Preparation	8	$17,100	12	$65,280	$8,160	None
5	Reactor Component Removal	13	$65,400	20	$108,800	$13,600	Includes auxiliary systems such as reactor water cleanup.
6	Concrete Characterization	N/A	N/A	5	$27,200	$6,800	Will be used to reduce volume of contaminated concrete disposed
7	Concrete Removal	10	$37,500	20	$108,800	$13,600	KUTR was above grade. Additional time added here for below grade demolition
8	Facility Decontamination	N/A	N/A	5	$27,200	$3,400	Included as a contingency.
9	Final Status Surveys	N/A	N/A	8[2]	$16,320	$5,440	The KUTR release pre-dates MARSSIM so is not directly comparable.
10	Demobilization	2	$4,000	2	$10,880	N/A	None
Total		**46**	**$175,100**[3]	**77**	**$491,680**	**$51,000**	

[1]Contractor man-hours are estimated on a crew size of 8, at an average rate of $85 per hour.
[2]This task is for RCTs only, three RCTs at $85 per hour.
[3]The total KUTR cost was $490,000 including undistributed costs, waste disposal, and contingency of 10% (KU, 1992b).

5.2.1.13 Total DECON Alternative Cost Estimate

Table 5-2 combines the cost as summarized above, the Reed College labor costs, and the waste disposal cost. The waste disposal cost estimates shown are developed in Section 6.0.

Table 5-2: DECON Cost Estimate Summary

Cost Element	Cost
Contractor Labor	$490,000
Reed College Labor	$60,000
Equipment	$51,000
LLRW Packaging, Shipping, and Disposal	$1,600,000
Subtotal – Direct Cost	**$2,201,000**
Reed College Project Oversight (10% of Direct Costs)	$220,100
Contingency (25% of Direct Costs)	$550,250
Total	**$2,971,350 or ~$3,000,000**

5.2.2 Comparison to KUTR Actual Costs

As noted above, the KUTR actual costs were $490,000, including all waste disposal. The University of Kansas building was not removed during the KUTR removal, which is consistent with the plan for the RRR. The primary difference in the cost estimate is the waste disposal cost. The KUTR waste was disposed of for approximately $80 per cubic foot. The RRR estimate was performed at $1,000 per cubic foot, or over a factor 10 increase. Other significant increases were for building preparation which includes building modification to allow construction of a ramp to the bottom of the RRR reactor pad. In addition, the reactor tank is larger which will increase the demolition time. The larger tank also increases the volume of waste. The KUTR waste volume was calculated at approximately 360 cubic feet, where RRR is estimated to be over 1,440 cubic feet, or approximately four times the volume. Notwithstanding the differences related to waste, the KUTR decommissioning provides a reliable baseline for the estimated decommissioning of the RRR.

5.3 SAFSTOR COST ESTIMATE

According to the sensitivity analysis in the Addendum of NUREG/CR-1756 (NRC, 1983), for the reference TRIGA® research reactor, it is concluded that if DECON is deferred for 100 years, there would be a 67% savings for LLRW disposal costs (primarily due to the reduction in volume of contaminated equipment and decontamination wastes), but only a 14% savings for the total decommissioning costs (in constant dollars). If DECON is deferred for any shorter time, there would be less savings for LLRW disposal (due to the shorter radioactive decay period) with little change in the other cost categories, except for the future cost of money. This analysis did not evaluate the opportunity costs for deferring potential beneficial reuses of the site. According to NUREG/CR-3474 (NRC, 1984), 20 years after shutdown, the dominating radionuclides in the activated concrete are ^{3}H and ^{152}Eu, with ^{152}Eu being the most significant contributor to radiation dose. In the activated steel rebar, the dominating radionuclides at that time are ^{55}Fe and ^{60}Co, with ^{60}Co being the most significant contributor to radiation dose.

There are potentially significant unquantifiable factors associated with deferring DECON for decades. Among these factors are the potential unavailability of LLRW disposal sites (due to lack of disposal capacity and/or access for State of Oregon waste generators) and potential changes in legal and regulatory requirements.

For the RRR, it is estimated that the savings will be significantly less than those discussed above. Because the amount of activated material is already small, the reduction of waste volume by radioactive decay will not be too significant. The expected dose rates in the tank once the fuel is removed should be well within occupational exposure restrictions; thus, there may be little labor cost benefits from allowing a radioactive decay period.

5.3.1 25 Year SAFSTOR Alternative Cost Estimate

If decommissioning is delayed for only 25 years, there will still be roughly the same amount of activated concrete and rebar as this is only two half-lives for ^{152}Eu and five half-lives for ^{60}Co. There will likely be no savings in decommissioning costs since the amount of contaminated material to be disposed will be significantly reduced. There will also be 25 years of surveillance costs. These are not as high as the minimum safe operating costs and are estimated at 25% of that cost, or $50,000 per year. Table 5-3 shows a summary of the estimated SAFSTOR alternative costs for delaying decommissioning by 25 years.

Table 5-3: 25 Year SAFSTOR Cost Estimate

Cost Element	Cost[1]
Labor	$490,000
Reed College Labor	$60,000
Equipment	51,000
LLRW Packaging, Shipping, and Disposal	$1,600,000
Subtotal – Direct Cost	**$2,201,000**
Reed College Oversight (10% of Direct Costs)	$220,100
Contingency (25% of Direct Costs)	$550,250
Surveillance Cost: $25,000 per year × 25 years	$625,000
Total	**$3,596,350 or ~$3,600,000**

[1]Costs are in 2018 dollars and are not escalated to account for the cost of money in 25 years.

5.3.2 100 Year SAFSTOR Analysis Cost Estimate

After 100 years, there is a 67% is savings in LLRW costs due to reduced radioactive waste volumes. There will be a significant savings in labor costs since there will be less radioactive was to handle. This is estimated to be approximately 25% and is primarily achieved in the areas where activated concrete would need to be removed using wire saws versus conventional demolition techniques. The total surveillance cost goes up because of the length of time needed for the alternative. Table 5-4 shows a summary of the estimated SAFSTOR alternative costs for delaying decommissioning by 100 years.

Table 5-4: 100 Year SAFSTOR Cost Estimate

Cost Element	Cost[1]
Labor	$370,000
Reed College Labor	$60,000
Equipment	$51,000
LLRW Packaging, Shipping and Disposal	$530,000
Subtotal – Direct Cost	**$1,011,000**

Cost Element	Cost[1]
Reed College Oversight (10% of Direct Costs)	$101,110
Contingency (25% of Direct Costs)	$252,750
Surveillance Cost: $25,000 per year × 100 years	$2,500,000
Total	**$3,863,850 or ~3,900,000**

[1]Costs are in 2018 dollars and are not escalated to account for the cost of money in 100 years.

6.0 RADIOACTIVE WASTES

After removal of the reactor fuel (including control rods), which will be done before commencement of decommissioning operations, the primary coolant will be sampled and released in accordance with the State of Oregon discharge permit. The primary sources of radiation from neutron activation will need to be removed for disposal as LLRW. These activated items include the reactor core structure, graphite moderator and dummy fuel elements, and all other in-tank structures and components. Lower levels of neutron activation products are expected in the aluminum tank wall and portions of the reinforced concrete shielding surrounding the reactor tank. Equipment directly involved in radioisotope production and experiments handling radioactive materials need to be surveyed and either decontaminated or disposed of as LLRW. Additional LLRW will include contaminated portions of building equipment systems, especially those involved in: (1) processing and conveying the primary coolant (i.e., reactor tank water) and its demineralizer resins (including filters, holding tanks, pumps and piping), and (2) handling reactor room air (including fume hoods, filters, fans, and ducts). Additional LLRW will be generated during the decontamination and demolition of other building equipment systems and building materials.

For purposes of this estimate, the cost per cubic foot of using the Reed College waste broker of $1,000 per cubic foot is used. It is possible to achieve a cost savings if Reed College requires the demolition contractor to ship directly to U.S. Ecology without using the broker. The B25 Shipping containers are approximately $600 each. Drums are estimated at $75 each.

Besides LLRW generated during decommissioning activities, accountable sealed radioactive sources and other small check sources will need to be sent to authorized storage or LLRW disposal facilities. A summary of the radioactive waste disposal cost estimates is provided in Table 6-2. Table 6-1 lists the sources that will need special handling and disposition

Table 6-1: Accountable Radioactive Sources

Serial Number	Principal Nuclide	Activity (µCi)	Activity (Ci)	Disposal Option
06-03	^{92}Ir	99,400	0.099	U.S. Ecology
06-26	^{239}Pu	7,500,000	7.5	8-PuBe neutron sources. Will need appropriate packaging but can go to U.S. Ecology
06-40	^{241}Am	44,000	0.044	Surface Moisture Gauge – Return to manufacturer; transfer to another licensee; dispose at U.S. Ecology
07-01	^{137}Cs	900,000	0.9	Shepherd Calibrator: Transfer to another licensee
10-01	^{60}Co	400,000	0.4	Solid inside pipe: Send to U.S. Ecology
12-02	^{226}Ra	UNK	UNK	10-12 mR/hour: Send to U.S. Ecology
86-20	^{233}U	20 mg	N/A	U.S. Ecology
86-36	^{226}Ra	2,000	0.002	U.S. Ecology
86-39	^{238}Pu	30,000	0.03	U.S. Ecology
86-40	^{241}Am	30,000	0.03	U.S. Ecology

Serial Number	Principal Nuclide	Activity (µCi)	Activity (Ci)	Disposal Option
96-03	^{137}Cs	10,000	0.01	U.S. Ecology
96-04	^{137}Cs	100,000	0.1	U.S. Ecology

Table 6-2: Radioactive Waste Summary

Description	LLRW Volume Generated (ft³)	LLRW Disposal Volume (ft³)	LLRW Disposal Cost ($) at U.S. Ecology, Richland
Concrete Base Mat (Note 1)	503	540	$540,000
Concrete Reactor Tank (Note 2)	739	810	$810,000
Equipment and decontamination waste (Note 3)	25	25	*
Sealed sources	<1	8	$8,000
Special Sources (Note 4)	5	80	$80,000
Containers – B25	—	30	$9,600
Containers – Drums	—	12	$900
Aluminum Tank (Note 5)	25.9	25.9	*
Reflector	14.4	14.4	*
Core Support Structure	10	90	$90,000*
Totals	**2,299**	**2,312**	**$1,538,500 or $1,600,000**

*These items can all go into a single B25 Box.

Notes:

1. This is assumed to be the entire reactor base mat. Concrete segregation is likely cost and labor prohibitive.
2. This the concrete reactor tank to a height of six (6) feet. Sampling and surveys of the concrete can result in significant waste disposal cost savings.
3. For equipment and decontamination wastes, the current study uses approximately the same estimated volume as the 2010 Cost Estimate. Most of this will need to be packaged in drums or B25 boxes. Disposal cost is based on volume of the container versus volume of the waste.
4. Special sources are those shown in Table 6-1. An estimated 10 drums will be required to adequately package and transport these items.
5. This assumes the entire tank is cut up and shipped as LLRW.

6.1 PRIMARY COOLANT OPTIONS

As noted previously, the cost estimates for the primary coolant are based on release to the sanitary sewer. The primary coolant currently meets drinking water standards and so should be releasable. However, either the State of Oregon or the City of Portland could decide that the coolant needs to be disposed of in a controlled manner. One option would be to treat it at the Perma Fix Environmental Facility in Richland, Washington. Perma Fix can provide tanker trucks for transporting the water to their facility. For bulk water similar to this, processing is available for approximately $10 per gallon. It is estimated to take 2 tankers for the water and it is a 460-mile round trip from Richland to Reed College. At an estimated $2.30 per mile, each shipment will incur approximately $1,100 in transportation charges. This is a total of approximately $250,000 for processing and shipping. This value is a significant portion of the contingency and it is recommended that Reed College consider adding it as a contingent line item.

6.2 SOLID WASTE COST SAVING OPPORTUNITIES

There are options available for cost savings, reducing the volume of waste, direct contracting with U.S. Ecology, and taking advantage of low activity shipping options.

6.2.1 Solid Waste Volume Reduction

As noted in Section 5.2.1.6 regarding concrete characterization, it was assumed that the entire base mat and a minimum of 6 feet of the walls would need to go as solid waste. Reed College can choose to characterize all of the concrete and segment for waste disposal. Only those pieces that have detectable radioactivity would be shipped.

6.2.2 Direct Contracting with U.S. Ecology

The current estimate was based on the rate that the broker quotes for taking and disposing of radioactive waste in a drum. Reed College could include shipping directly to U.S. Ecology as part of the decommissioning contractor's scope. Reed College already has a site use permit, so would only need the contractor to package and ship the waste. This could result in a 50% minimum reduction in waste disposal costs.

6.2.3 Low Specific Activity Shipping

The waste from the RRR will most likely meet the DOT definition of Low Specific Activity waste (DOT, 2017). Given that, the concrete blocks could be wrapped and shipped on an exclusive-use vehicle and take advantage of the Excepted Packaging requirements. This could save in excess of $10,000 just in packaging costs. Since U.S. Ecology charges over $13,000 per package, there will be significant cost savings by reducing the number of packages as well.

7.0 SCHEDULE ESTIMATE

To comply with the NRC's timeliness requirements, unless NRC approves an alternate schedule, decommissioning must be completed within 24 months of NRC's approval of the decommissioning plan.

The schedule duration assumptions listed in Table 5-1 are based on a similar reactor decommissioning project at the University of Kansas. Although completed in the early 1990s, the schedule durations for a reactor similar in size and operating history still form a valid basis for comparison. The University of Kansas decommissioning took approximately 6 weeks. Note that this duration was after the fuel had been removed and the reactor coolant was removed. A conservative estimate for the RRR would be 2 months, based primarily on needing additional time to perform sub-grade demolition. In developing a schedule, the schedule for the final status survey can be time-phased and conducted for selected areas in parallel with the ongoing decommissioning activities. This helps ensure there is adequate time to interface with the NRC and Oregon State stakeholders regarding license termination and clearance criteria. The schedule durations as shown assumes that the NRC has approved the decommissioning plan. It may take Reed College 18 to 24 months of work to get this plan prepared, submitted, and approved. During this time, many of the pre-decommissioning activities can be completed such as procedure development, fuel removal and shipment to DOE, and any radioactive waste not directly associated with decommissioning can be disposed.

8.0 SUMMARY

Table 8-1 shows the overall decommission alternative cost estimate summaries from this study. The 2010 estimate is shown (escalated to 2018 dollars for comparison). The KUTR decommissioning report showed a total of $490,000 (KU, 1992b).

As can be seen below, the current DECON cost estimate is approximately the same as the escalated costs from the 2010 study. The significant increase in waste disposal costs are off by the shorter time period planned for the decommissioning efforts. This is due in part to reducing labor costs for the length of the decommissioning schedule from 1 year to three months, and through reductions in amount of radioactive waste to be shipped for disposal.

Included for reference only are the actual costs for the University of Illinois Decommissioning Project (UIC, 2012). Although the reactor was larger, the concrete volume and building footprint are similar. This project was completed in 2012, which makes it one of the more recently completed projects. It should be emphasized that standby time was not included. The reactor had been shut down for over 10 years before decommissioning began. This easily would have added over a million dollars to the overall cost.

Table 8-1: Decommissioning Cost Estimate Comparison

Estimate Description	Cost – 2018 Dollars	Cost Including Standby	Comments
DECON	$3,000,000	$4,400,000	None
2010 Estimate	$2,850,000	4,190,000	2010 escalated at 3%. Burial ground charges actually went up much more than 3%. Using 2018 rates, the estimate would be over $400,000 higher (Reed, 2010).
SAFSTOR – 25 years	$5,147,500	N/A	No need for standby time in SAFSTOR
SAFSTOR – 100 years	$4,253,650	N/A	No need for standby time in SAFSTOR
University of Illinois Actual Costs	4,300,000	N/A	Included for comparison only. Larger reactor and facility. Did not include planning, standby, or preparatory costs. No escalation assumed (UIC, 2012)
University of Kansas	$1,030,000	N/A	Escalated from 1993 to 2018. 1993 cost was $490,000. (KU, 1992b)

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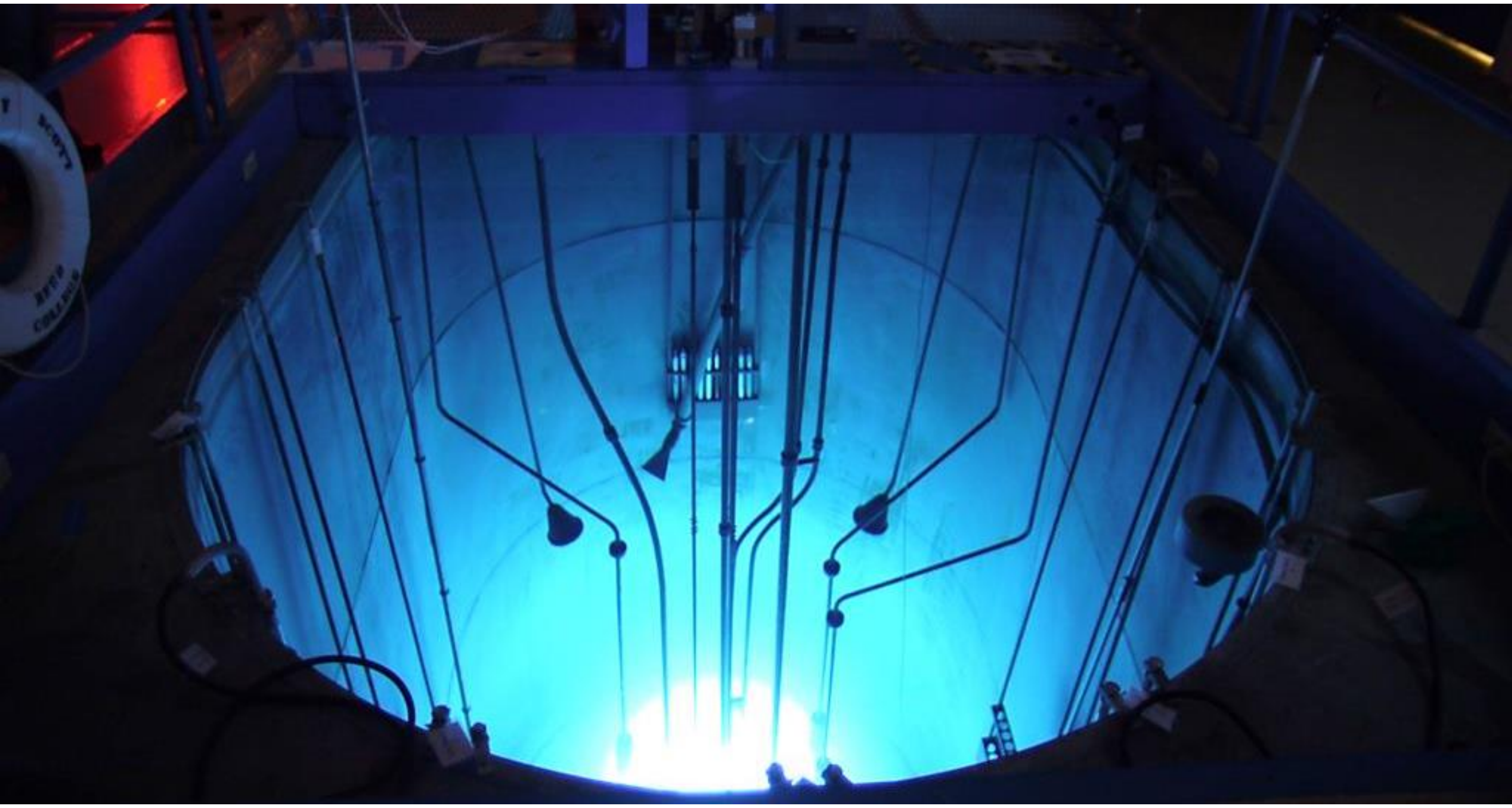

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