TECHNICAL CONSIDERATIONS IN CHARACTERIZING AND CLASSIFYING A DECOMMISSIONED REACTOR VESSEL

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ABSTRACT

This paper discusses background material related to the Pathfinder decommissioning, and emphasizes the technical considerations taken into account during the characterization and classification of the decommissioned Pathfinder reactor vessel. The second half of this paper emphasizes the details of meeting 10 CFR 71 packaging requirements.

INTRODUCTION

The Pathfinder Atomic Power Plant, built and operated by Northern States Power Company (NSP), is located near Sioux Falls, SD. The plant's 66 MWe nuclear reactor first went critical in 1964. After several years of subcritical and low power testing, the plant went into commercial operation in 1966. After a short history of limited power operations, the reactor underwent its final shutdown on September 16, 1967.

After establishing that the plant required structural and design upgrades, NSP made an economic decision in 1968 to keep the nuclear reactor permanently shutdown. NSP began to repower the Pathfinder Plant with gas-fired boilers in 1968. The reactor was defueled, then placed in SAFSTOR (i. e., mothballed) during 1969 and 1970. Its 10 CFR 50 (Code of Federal Regulations) operating license was surrendered for a by-product material possession license under the provisions of 10 CFR 30. Following conversion, Pathfinder was placed back into commercial operation as a fossil-fueled peaking plant. It continues to operate to this day.

The present phase of Pathfinder decommissioning began in the late 1980's when NSP examined the feasibility of completing work while low-level radioactive waste (LLW) disposal sites were available and disposal costs were relatively low. Following NSP's decision to demolish the unused nuclear portions of the site, NSP conducted several conferences with the US Nuclear Regulatory Commission (NRC) to discuss the proposed project. In Jan 1990, an NSP decommissioning team headed by Project Manager Al Kuroyama arrived on site; and in July 1990 began to dismantle nuclear portions of the plant. Except for hiring contractors and laborers when expertise or resources were not available within the company, NSP managed and conducted the decommissioning.

The scope of the present phase of decommissioning includes:

a. The reactor building, the reactor vessel and the contents of the reactor building.

b. The fuel handling building and its contents.

c. The fuel transfer vault between the reactor building and the fuel handling building.

Radioactive material and residual contamination contained in the operating, fossil-fired plant was not included in the scope of this project.

The Pathfinder reactor vessel was lifted out of the reactor building on May 14, 1991. NSP applied for and was granted a Certificate of Compliance by the NRC for shipping the reactor vessel as a Type A package. Between May and August, NSP prepared the package for its cross-country trip. And on August 7, 1991, the vessel was shipped in one piece to a commercial disposal facility near Richland, WA.

VESSEL REMOVAL CONSIDERATIONS

During the SAFSTOR decommissioning program, the nuclear steam supply system (NSSS) was dismantled to the extent necessary to render it inoperable and incapable of being restored to service. All nuclear fuel was removed from the reactor and shipped off-site. The reactor vessel was drained and connected to a vacuum pump to remove all residual water from non-drainable cavities. The control rods and blades were placed in the vessel for disposal, and the reactor vessel was filled with gravel. The internals were left in place. The vessel head was reinstalled and bolted to the vessel using studs and nuts.

Two vessel removal alternatives were considered:

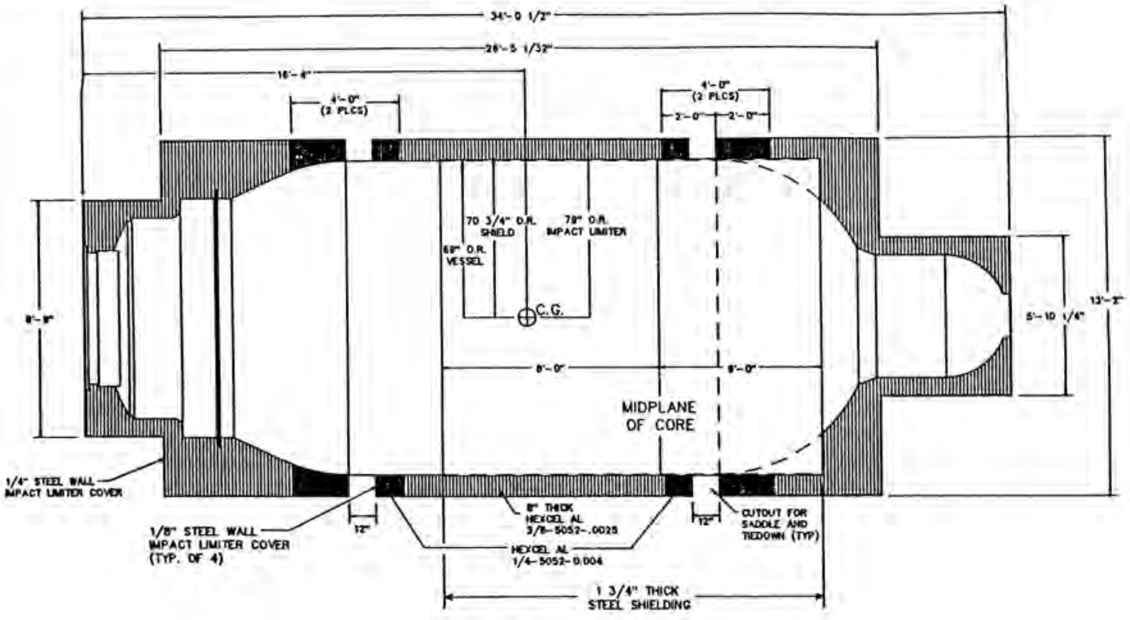
a. One-piece removal and disposal.

b. Segmentation of the vessel and internals and transport for disposal in shielded shipping containers.

The segmentation alternative would require extensive remote tooling and individual segment handling to cut and load the shipping casks for disposal. The cutting process would generate large quantities of smoke and debris which would require extensive contamination control measures such as control access tents, high efficiency particulate air (HEPA) filters and remote handling devices. There would have been additional exposure to workers owing to the extensive time required to segment, load and ship each piece. The selected alternative of one-piece shipment did not require extensive tooling, handling contamination controls or high worker radiation exposure. However, there were considerable costs associated with building and certifying the package which was shipped.

The vessel and internals package contained 2.08×10^{13} Bq (562 curies) of radioactivity as activated and contaminated material. This number of curies did not warrant the effort to segment and package the vessel and internals. Based on the vessel activation and shielding analysis, the vessel and internals qualified as Low Specific Activity material and the package qualified as a Type A container.

To prepare the vessel for shipment, the it was filled with grout to fix the gravel in place; attached piping was cut off and openings were sealed; then the vessel was lifted from the reactor cavity, moved through the open reactor building dome and laid on its side within a temporary enclosure. Once the



TOTAL WEIGHT = 582,000 LBS.

Fig. 1. Pathfinder vessel transport package.

vessel was removed from the reactor building and enclosed in a tent, any remaining attachments were cut away. The external asbestos insulation was removed and the vessel certified clean of asbestos. A cylindrical steel shield was welded to the vessel shell. An impact limiter consisting of Hexcel and wood was installed on the vessel shell surface to protect the vessel a postulated transportation accident. The outer 6 mm (1/4 inch) shell protected the package during normal conditions of transport. The vessel package was lifted horizontally and placed on saddles installed on a flatbed railcar for transport to the US Ecology, Inc. disposal facility near Richland, WA.

When fully prepared, the vessel package weighed 2.63×10^5 kg (290 tons), not including tie-downs or other supports. The package was transported by rail from the Pathfinder site to Richland, WA. The Type A container package was shipped in an exclusive use vehicle (railcar) as part of a special train. A special train was used because the package was high and wide, not because of nuclear concerns. The reactor vessel package was unloaded from the railcar and transported a short distance to the disposal site.

PACKAGE DESCRIPTION

The Pathfinder package is shown on Fig. 1, and is based on TLG Engineering, Inc. Drawing No. N04-22B-001, Pathfinder Vessel Transport Package. The package was essentially a cylindrical container and consisted of the reactor vessel, internals, gravel, grout, steel shielding and impact limiter. The internal steel components of the package were neutron activated and included a variety of radionuclides, primarily cobalt-60 (Co-60), iron-55 (Fe-55), nickel-63 (Ni-63) and nickel-59 (Ni-59). A small amount of surface contamination existed on the interior surfaces of the vessel, but was generally bound to the surfaces by the grout.

The total radioactivity was 2.08×10^{13}Bq (562 Curies). However, the majority of the package source term consisted of activated base metal that was not readily dispersible. The remaining source term was estimated to be 3.52×10^9Bq (95 millicuries) consisting of a thin corrosion film that was bound to the surfaces of the Pathfinder vessel and internals and was further bound by the grout. The maximum specific activity of the package was approximately 9.18×10^6Bq (0.248 millicuries) per gram. Since this value is less than 1.11×10^7Bq (0.3 millicuries) per gram, the package qualified as a Low Specific Activity (LSA) package. In accordance with 10 CFR 71.52, the package was exempt from the additional requirements for Type B packages, and qualified as a Type A package. If analysis had shown the package to be Type B, NSP would probably have considered alternate methods for disposing of the vessel.

VESSEL AND INTERNALS

The major components of the reactor vessel and internals are shown in Fig. 2. The reactor vessel was fabricated from 75 mm (3 inch) thick carbon steel ASME A212 Grade B plate with integrally bonded (Lukens clad) 304L stainless steel cladding. The flanges and nozzle forgings conformed to the ASTM A105 Grade II and were weld overlaid with stainless steel having a chemistry similar to Type 304 except that maximum free carbon content at the clad surface was below 0.050 per cent. The overlay was stabilized with a small amount of niobium.

The vessel head was fabricated from the same carbon and stainless steel cladding materials as the vessel shell. The head was secured to the vessel flange by the original 48 head studs and nuts.

The vessel internals were all fabricated from Type 304L stainless steel with the exception of the boiler boxes which were Zircaloy-2. The other principal contents of the vessel were the control rods and blades that were disposed of in the reactor vessel. These components were fabricated from boron stainless steel and contained boron pellets.

At the recommendation of the Atomic Energy Commission at the time of the initial Pathfinder decommissioning, the vessel was filled with 6 mm (1/4 in) diameter pea gravel. The pea gravel apparently filled all cavities uniformly with the exception of one area at the side of the vessel. At this location there was a "hot spot" with a radiation reading of about 6.0 m Sv (600 mR/hour), whereas all other areas at the same elevation were about 1.5 mSv (150 mR/hour). To stabilize the gravel and to fill the apparent void spot, the vessel was pumped full with a grout. Other than the filling of the apparent void, no direct credit was taken for the shielding effectiveness of the grout in the shielding analysis.

SHIELDING, IMPACT LIMITER AND TIE-DOWNS

Based on the shielding analysis of the vessel package with a 40 per cent void fraction in the gravel (no credit for the grout), 50 mm (2 in) of steel shielding were added to the vessel package to meet the US Nuclear Regulatory Commission (NRC) and the US Department of Transportation (DOT) transport regulations. The shielding was made up from a 44 mm (1-3/4 in) thick shell plate welded to the vessel shell outside diameter, extending 0.9 m (3 ft) below the elevation of the core bottom and five feet above the elevation of the core top. Figure 1 shows the shield extending 1.8 m (6 ft) below and eight feet above the core midplane. The remaining 6mm (1/4 in) of steel shielding was fabricated in a cylindrical shape to form the outer shell for the Hexcel and wood impact limiters. The 50 mm (2 in) of steel shielding was sufficient to reduce the external exposure rate to less than 0.1 mSv (10 mRem/hr) at two meters (without credit for the grout), assuming a 40 percent void fraction in the gravel.

The impact limiter was used to absorb the energy of impact from the postulated one foot drop during normal conditions of transport. The impact limiter was fabricated from wood or pre-crushed Hexcel (TM of the Hexcel Corporation, Dublin, CA); a honeycomb configuration of aluminum bonded to the vessel surface. Two types of Hexcel were used; a low density Hexcel configuration bonded to the vessel shell region extending over the entire length of the vessel. In the region where the 0.3 m (12 in) wide vessel support saddles were located (at the vessel upper and lower shell spring lines), a higher density Hexcel was used to compensate for the loss of low density Hexcel in that area. The Hexcel was bonded to the vessel, and then covered by a 6 mm (1/4 in) thick steel cylindrical plate to protect the Hexcel from inadvertent damage. The minimum Hexcel thickness was .2 m (8 in) located at the center region of the shell, surrounding the 44 mm (1-3/4 in) thick shielding section. The Hexcel thickened to approximately 0.28 m (11 in) for the remaining region of the vessel shell. Rounded and hard-to-fabricate areas were surrounded by wood which was cut and pieced into restricted spaces.

The tie-downs used for the package shipment consisted of two 10 cm (4 inch) steel bands. The bands were attached to the support saddles. The vessel rested on the two circumferential saddles located at the vessel shell spring lines. There were no direct attachments to the vessel shell or Hexcel material for vessel tie- down except for a circumferential weld of the shield to the vessel.

PACKAGE WEIGHT AND DIMENSIONS

The overall package weight of the vessel, internals, gravel, grout, shield, and impact limiter was 2.63×10^5kg (580,000 lbs, or 290 tons). Since the saddles and tie-downs were not attached to the package directly, no additional weight was included. The weights of the individual major components are shown in Table I.

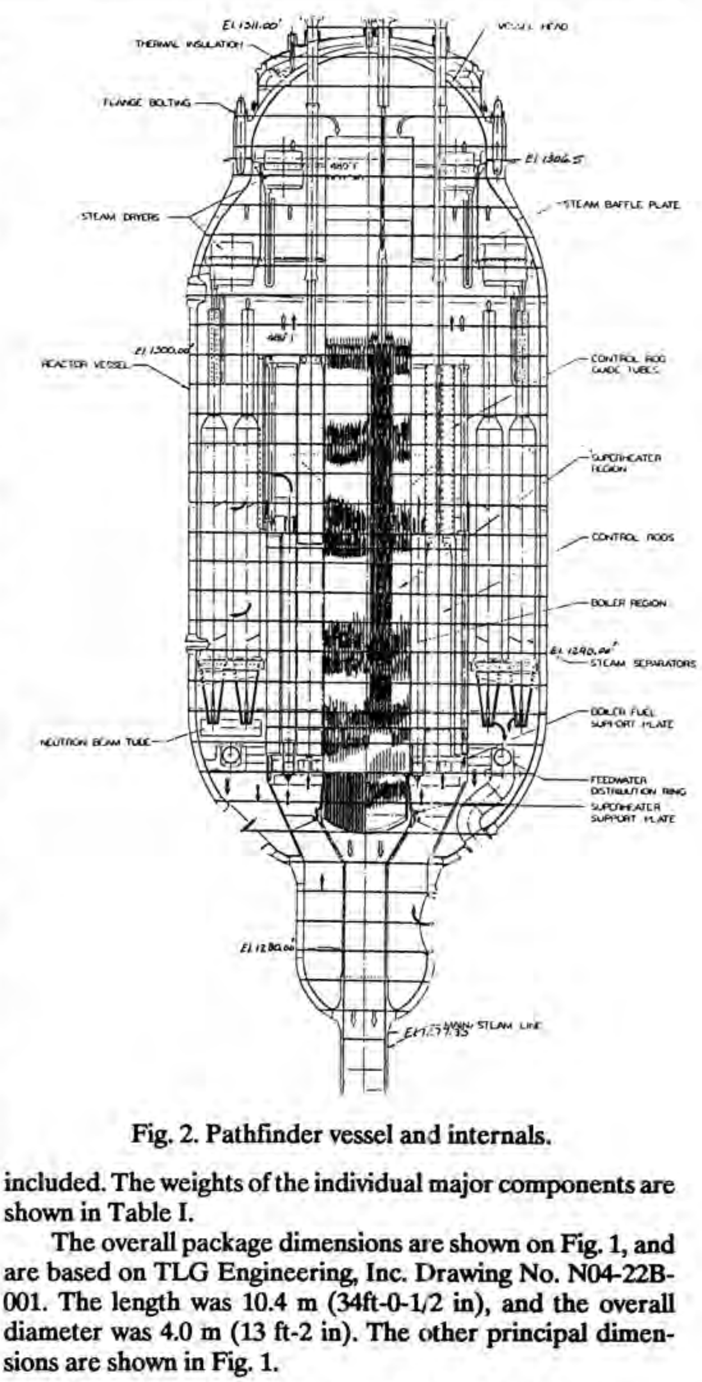


Fig. 2. Pathfinder vessel and internals.

The overall package dimensions are shown on Fig. 1, and are based on TLG Engineering, Inc. Drawing No. N04-22B-001. The length was 10.4 m (34ft-0-1/2 in), and the overall diameter was 4.0 m (13 ft-2 in). The other principal dimensions are shown in Fig. 1.

DETAILS OF CERTIFYING THE REACTOR VESSEL

The remainder of this paper summarizes some of the technical details involved in certifying the Pathfinder reactor vessel as a Type A package. The data presented follows the format contained in Reg Guide 7.9, "Standard Format and Content of Part 71 Applications for Approval of Packaging of Type B, Large Quantity, and Fissile Radioactive Material," (1).

Total Curie Content

The Pathfinder package contained both activated and contaminated materials. The reactor vessel and internals activated inventory constituted most of the radioactivity of the package. The total activation inventory as shown by analysis

TABLE I

Pathfinder Package Calculated Weights

Component	Calculated Weight (lbs)	Calculated Weight (kgs)
Reactor Vessel	154,000	6.99×10^4
Vessel Internals	43,000	1.95×10^4
Shielding/Impact Limiter	63,000	2.86×10^4
Gravel and Grout	320,000	14.51×10^4
Gross Weight	580,000 290 tons	26.3×10^4

was 2.08×10^{13}Bq (562 curies), consisting primarily of Co-60, Fe-55, Ni-59 and Ni-63. In addition, approximately 3.52 x 10^9Bq (95 millicuries) of the same radionuclides was present in the form of surface contamination on the interior surfaces of the internals. Table II lists the major components of the vessel and internals and their activity (in Curies) by radionuclide.

The principal radionuclide of interior surface contamination was Co-60 based on data taken of scraping samples from the feedwater system piping attached to the vessel. This sample point was judged to be a conservative representation of the vessel source of surface contamination. The individual quantities of surface contamination are not shown on Table II because the amounts are so small relative to the activation inventory.

Decay Heat Generation

The total amount of decay heat generation for the vessel and internals package was calculated from the activation analysis to be 4.67 watts. This amount of decay heat was insignificant, and was not considered further in the analysis.

Thermal Evaluation

Since the package did not contain spent fuel, the release of fission products from a fuel source due to excessive temperatures did not need to be considered. Furthermore, since the decay heat generation was conservatively calculated to be 4.67 watts, there was no significant internal thermal gradients that would lead to differential thermal expansion that would, in turn, result in stresses that might be considered in evaluating the structural integrity of the package. For a worst case analysis, a scenario was evaluated for the situation where the vessel and interior concrete was initially at a temperature of 311°K (100°F) and the vessel instantaneously cooled to 233°K (-40°F) (the maximum range of hot and cold environments specified in 10 CFR 71). In this case the vessel would shrink onto the interior concrete surface and stop further deformation. This was a self equilibrating phenomenon typical of thermal stress situations. For this worst case scenario, the calculated stress in the vessel wall was 1.65×10^8Pa (23.9 ksi) which was less than the 1.5 Sm allowable for membrane plus bending stress of 1.85×10^8Pa (26.81 ksi). The self equilibrating effect of this phenomenon, coupled with the thermal conductivity effects of the concrete heating the steel and relieving the stress condition was evidence that there would be no significant vessel damage.

Containment

The decommissioning team identified the package containment for normal conditions of transport. Use of the term containment was predicated on the fact that the package source term consisted of activated base metal and a thin internal corrosion film on the surfaces of the well confined internal structural components. In addition, the grout pumped into the vessel under pressure also served to bind the surface contamination within the interior of the reactor vessel. The package contained no free-standing pools of contaminated liquids, no explosive mixtures or potential aerosol particles that could be considered radiological hazard.

The exterior of the containment boundary was a steel structure which contained no valves or leak test ports. Leak test criteria or leak rate limits were not applicable to this package as a quantitative measure of containment integrity. Analysis showed that there would be no rupture of the vessel due to normal conditions of transport from either structural or thermal stresses, and consequently there would be no release of activated or contaminated radioactive material.

Containment Boundary

The containment boundary consisted of the reactor vessel, vessel head and the nozzle closure plates welded to the nozzle openings. The upper closure head contained 20 control rod drive nozzles, one liquid level and one instrumentation nozzle. The lower hemispherical head contained three pump suction nozzles and one feedwater nozzle. The lower cylinder assembly (part of the lower hemispherical head) contained three pump discharge nozzles and one steam outlet nozzle extending through the bottom of the cylinder assembly. There was a liquid level nozzle and an instrument nozzle connected to the shell of the vessel.

Welding and weld examination complied with the requirements of NUREG/CR-3019. Specifically, Section VIII, Division 1, Part UW, of the 1989 edition of the ASME code, including July 1989 addendum, was be followed in the welding of the vessel closures.

Single fillet welds were used for the closure welds on the RPV nozzle capping rather than the double fillets or groove welds used by the ASME code. Considering the nature of the material inside the package, and the negligible potential internal and external pressures, the use of the single fillet welds was justified. The welds were done under an approved quality assurance program as explained below.

Closure

The closure head was bolted closed with 48 closure studs and nuts designed to contain pressure and radioactivity during reactor power operation. The closure studs were analyzed for stress loadings for normal conditions of transport, and shown not to exceed yield stresses for the one-foot drop case. In addition, the Hexcel outer shell was welded closed and could not be inadvertently opened.

Requirements for Normal Conditions of Transport

The limit for radioactive material releases is defined in 10 CFR 71.51(a)(1) for normal conditions of transport. This regulation requires that there would be no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of 10^{-6} A2 per hour, no significant increase in external radiation

TABLE II

Estimated Inventory of Radionuclides on January 1, 1990

Component	H3	C14	Fe55	Co60	Ni59	Ni63	Nb94	Tc99	Eu152	Eu154	Others	Total Curies
Superheater baffle	0.08	0.03	4.63	34.81	0.19	22.24	--	--	0.03	--	--	62.0
Superheater fuel insul, tubes	0.15	0.06	8.88	66.71	0.36	42.61	--	--	0.05	--	--	118.8
Superheater support plate	--	--	--	--	--	--	--	--	--	--	--	< 0.01
Superheater control rods	--	--	0.07	0.49	--	0.31	--	--	--	--	--	0.9
Boiler fuel boxes	0.01	0.05	0.83	7.62	0.04	4.49	--	--	--	--	1.33	14.4
Boiler shroud	0.23	0.09	14.51	78.09	0.59	70.88	--	--	--	--	--	164.4
Boiler hold down structure	0.02	--	0.92	6.93	0.04	4.43	--	--	--	--	0.01	12.3
Boiler CR tubes/ remain. struct.	0.01	--	0.74	5.58	0.03	3.56	--	--	--	--	--	9.9
Boiler element poison shims	0.03	0.01	1.88	14.14	0.08	9.03	--	--	0.01	--	--	25.2
Boiler control blades	0.11	0.04	6.47	48.61	0.26	31.05	--	--	0.04	--	--	86.6
Instrumentation/sample holders	--	--	0.48	3.58	0.02	2.29	--	--	--	--	0.01	6.4
Boiler grid plate	0.07	0.02	3.82	28.69	0.15	18.33	--	--	0.02	--	--	51.1
Steam separators & supports	0.01	--	0.72	3.89	0.03	3.53	--	--	--	--	--	8.2
Feedwater ring & supports	--	--	0.02	0.13	--	0.11	--	--	--	--	--	0.3
Vessel cladding	--	--	0.10	0.52	--	0.47	--	--	--	--	--	1.1
Vessel	0.01	--	0.46	0.16	--	0.11	--	--	--	--	--	0.7
Total by isotope (curies)	0.74	0.31	44.52	299.95	1.78	213.44	< 0.01	< 0.01	0.15	< 0.01	1.36	562.2
Percent of total by isotope	0.13%	0.05%	7.92%	53.35%	0.32%	37.96%	< 0.01%	< 0.01%	0.03%	< 0.01%	0.24%	

levels, and no substantial reduction in the effectiveness of the packaging.

Activated Materials

Nearly the entire source term was comprised of activated carbon steel, stainless steel and Zircaloy-2 components that made up the Pathfinder package. The radionuclides were dispersed in matrices of component alloys which were stable under the conditions of normal transport. Therefore, the activated radionuclides were contained within the metallic alloys under these conditions.

Corrosion Product Layer

The corrosion product layer was a thin, tenacious surface deposit which occurred on components that were in contact with the primary coolant. To evaluate the potential for release of this material, the 3.52×10^{9} Bq (95 millicuries) was divided by the allowable A2 value for the principal radionuclides of Co-60, Ni-63, Ni-59 and Fe-55 to compare the potential release to the 10^{-6} A2 limit. Accordingly, for the mixture of radionuclides:

$$F1 + F2 + F3 + \ldots Fn \leq 1 \qquad \text{(Eq. 1)}$$

$$F\,\text{Co-60} = 5.17 \times 10^{-2}\ \text{Ci} / (7\ \text{Co-60/A2}) = 7.39 \times 10^{-3}\ \text{Ci} \qquad \text{(Eq. 2)}$$

$$F\,\text{Ni-63} = 4.23 \times 10^{-2}\ \text{Ci} / (100\ \text{Ni-63/A2}) = 4.23 \times 10^{-4}\ \text{Ci} \qquad \text{(Eq. 3)}$$

$$F\,\text{Ni-59} = 1.30 \times 10^{-4}\ \text{Ci} / (900\ \text{Ni-59/A2}) = 1.44 \times 10^{-7}\ \text{Ci} \qquad \text{(Eq. 4)}$$

$$F\,\text{Fe-55} = 9.45 \times 10^{-4}\ \text{Ci} / (1000\ \text{Fe-55/A2}) = 9.45 \times 10^{-7}\ \text{Ci} \qquad \text{(Eq. 5)}$$

$$F\,\text{avg} = 7.81 \times 10^{-3}\ \text{Ci} \qquad \text{(Eq. 6)}$$

Therefore,

$$\text{A2 Quantity} = 9.50 \times 10^{-3}\ \text{Ci} / 7.81 \times 10^{-3}/\text{A2} = 1.22 \times 10^{-6}\ \text{A2} \qquad \text{(Eq. 7)}$$

The package was designed not to be breached. However, even in the most extreme case if all the surface contamination were instantaneously released from the package, the dispersal would be only slightly above the A2 limit. Obviously, this was a highly conservative case and actual dispersal would be much lower. As noted earlier, within the vessel, the interior of the vessel cavities was filled with a grout to stabilize the pea gravel and to further bind the surface contamination to the vessel internals. The likelihood of all the surface contamination being released instantaneously was remote.

Pressurization of Containment Vessel

No gases or vapors were available to form an explosive gas in the reactor vessel. Therefore, containment pressurization was not possible.

Shielding Evaluation

The shielding around the Pathfinder package met the requirements set by 10 CFR 71 during normal conditions of transport. The controlling factor for shielding was to show that the exposure rate at two meters from the package was be less than 0.1 mSv (10 mRem/hr), and at the surface of the package was less than 2.0 mSv (200 mRem/hr).

Shielding Design Features: Shield Description

The shielding used for the Pathfinder package consisted of a 44 mm (1-3/4 in) thick steel cylindrical shell welded to the vessel exterior shell, and a 6 mm (1/4 in) thick steel shell welded around the exterior of the Hexcel impact limiter. The length of the 44 mm (1-3/4 in) thick shield extended .9 m (3 ft) below the bottom of the core elevation and 1.5 m (5 ft) above the top of the core elevation. The overall length of the 44 mm (1-3/4 in) shield was 4.3 m (14 ft) The extension above and below the core shielded the contribution from the core internals at the upper and lower regions of the core. There was a 3 mm (1/8 in) thick shield covering the radial regions where the vessel support saddles and lifting sling points were located. The thinner shielding in these areas was to ensure impact loads would not be transmitted to the vessel shell.

In addition, the Pathfinder vessel was filled with 6 mm (1/4 in) diameter pea gravel at the time of initial decommissioning. The pea gravel filled the vessel cavity with the apparent exception of one point at elevation 393 m (1289.5 ft) on the northwest side of the vessel. Based on measurements made at the side of the vessel there appeared to be a void of approximately 150 mm (6 in) diameter, with an exposure rate reading of 6.0 mSv (600 mR/hr). All other exposure rates was approximately 1.5 mSv (150 mR/hr) at the same elevation. The pea gravel void fraction was assumed to be 40 percent based on a correlation between calculated and measured exposure rates. In addition, no credit was taken for the grout fill material to be added prior to shipment for its shielding effectiveness other than filling in the apparent void with grout.

Shield Effectiveness

The combination steel shield and gravel materials were sufficient to reduce the calculated core axial centerline exposure rate at two meters from the package surface to approximately .084 mSv (8.4 mR/hr). The contact exposure rate (at one centimeter from the surface) was 0.275 mSv (27.5 mRem/hr). These exposure rates were below the 10 CFR 71.47(c) limit of 0.1 mSv (10 mR/hr) at two meters.

NSP made dose rate measurements at the outer surface of the vessel in the reactor cavity. The measurements were taken from the basement of the reactor building recording dose rate and elevations vertically upward. The measurements were made on the outer surface of the .13 m (5 in) thick asbestos insulation. The results of the measurements showed that the contact readings were all within the 10 CFR 71 limits of 2.0 m Sv (200 mR/hr), ranging from a few mSv (mR/hr) to about 0.8 mSv (80 mR/hr) except for a band at the core beltline region that read between 1.0 to 2.0 mSv (100 to 200 mR/hr). One hot spot, had a reading of 6.0 mSv (600 mR/hr) as noted earlier was located on the northwest side of the vessel at an elevation of 393 m (1289.5 ft). This hot spot appeared to be a void in the gravel fill, and the grout fill was expected to shield the area sufficiently to meet the 10 CFR 71 limits. If grout had not filled the void, an external shield patch would have been welded to the shield cylinder.

Source Specification

The primary radiation source present within the package was the gamma ray source resulting from the neutron activation of the metal components during operation of the reactor. The dominant radiation source was from Co-60 as confirmed by a field survey spectral analysis. The contribution of other activation radionuclides were negligible.

Gamma Source

The gamma ray source was dominated by the presence of Co-60 which was derived from the Co-59 impurity through an n-gamma reaction. Co-60 has two high energy gamma rays at 1.17 MeV and 1.33 MeV. The gamma ray energy spectrum that was present at the surface of the package was the result of the attenuation of gamma rays emitted at these two source energies.

Neutron Source

The Pathfinder package did not have any neutron activity since there was no fissile material in the package. The spent antimony-beryllium source was disposed of in the reactor vessel, but the neutron activity was negligible since the antimony-125 has a half-life of only 2.73 years and the reactor had been shut down since 1967.

Quantity of Radioactive Materials - Activation Analysis

An activation analysis was performed to determine the number of Bq of radioactive material in the vessel and internals. ORIGEN2 (2) was the point activation analysis code used for this activation analyses. The Pathfinder plant's operating history, neutron flux, materials in the vessel and internals, and location of the components with respect to the core centerline were used to develop input for the ORIGEN2 code. Where specific information was not available from Pathfinder, references from other similar reactors were used with adjustments to account for differences in plant design or configuration. The ORIGEN2 code outputs provided the Bq per gram contents for each major region of the vessel and internals. These Bq per gram quantities were then multiplied by the number of grams in each component to obtain the number of Bq in each component. The total number of Bq estimated was 2.08×10^{13} Bq (562 curies), 99 per cent of which is from Co-60, Ni-63, Fe-55 and Ni-59. The activation analysis was documented in a report entitled, "Radionuclide Inventory and Package Dose Rate for the Pathfinder Atomic Power Plant".

An estimate was also prepared of the surface contamination source term contribution to the gamma dose rate. Samples from the feedwater system piping to the reactor vessel were collected by Battelle Pacific Northwest Laboratories in 1980 and analyzed for surface contamination levels. The major constituents were Co-60, Ni-63, Fe-55 and Ni-59 as expected. Applying these measured interior surface contamination levels to the surface areas of each component of the vessel and internals showed the total inventory of surface contamination to be 3.52×10^9Bq (95 millicuries). The contribution of this internal surface contamination to the overall package dose was negligible.

Model Specification: Description of the Shielding Configuration

The concentric geometry of the Pathfinder vessel and internals lent itself to the use of cylindrical geometry for modeling. Vessel internals were represented by homogenized cylinders of the component materials and activation curies, radiating to its outer neighboring cylinder. In turn, each cylinder represented self-shielding to its interior cylinder neighbor reducing the contribution to dose reaching the vessel exterior.

In addition, the 50.5 m^3 (66 yd^3) of pea gravel added at the time of initial decommissioning provided internal shielding. However, the density of the gravel was affected by the void fraction assuming uniform void fraction distribution within the vessel. The gravel void fraction was estimated to be 23.4 percent, and is conservatively assumed to be 40 percent for this analysis.

An external steel shield was provided to reduce the external dose rates to meet 10 CFR 71 limits. The cylindrical shield extended from a point 0.9 m (3 ft) below the bottom of the core to a point 1.5 m (5 ft) above the top of the core. The extension above and below the core region was included to shield from the axial contribution at the top and bottom of the core region.

Two dose points were considered. The first was at the vessel outer wall core midplane region at a distance of one centimeter from the surface. This point was chosen to correlate the measured dose rates to the calculated dose rates to confirm the calculational assumptions of distribution and gravel void fraction. The second dose point was also at the core midplane, but at a distance of two meters from the package outer surface. This latter dose point was selected to evaluate the dose limits in accordance with 10 CFR 71.

Acceptance Test and Maintenance Program

The Pathfinder package was designed to be a one time use package for the disposal of the reactor vessel and internals. Following is a description of the acceptance tests required to place the package on a railcar for transport. No long term maintenance program was required since this was a one time shipment.

Acceptance Tests

Acceptance tests for the Pathfinder package included tests for shielding and containment integrity, and a visual inspection of each stage of the package preparation. Pressure tests and leak tests were not required.

Visual Inspection

Prior to the attachment of the Hexcel impact limiter material, the vessel exterior surface was visually checked for nozzle cover plate weld integrity, cylindrical shield weld integrity, head closure bolt damage. After attachment of the Hexcel material but before cover shell welding, a visual inspection of the Hexcel condition was performed. Any damage to the Hexcel material was evaluated as to its importance to the impact limiter performance. If deemed unacceptable, that portion of the Hexcel was repaired or replaced as necessary. Upon application of the Hexcel cover shell and final welding, a visual inspection was made of the cover condition.

If the inspection revealed any defects, then they were evaluated as to their significance to the shipping package. Any modifications to the package design was reviewed before proceeding, if required. All inspections and repairs were appropriately documented with Quality Control inspection reports.

Prior to leaving the Pathfinder site, an inspection of the package was made to verify that it was prepared in accordance with all requirements. The overall package was visually inspected for any defect or unusual condition.

Other Tests

The package contained no removable closures, and no pressure tests were required.

Structural tests included nondestructive tests of new welds and closure integrity including the shield to vessel weld. Nondestructive tests included liquid penetrant or magnetic particle examination weld integrity inspections. These inspections were made in accordance with the NSP QA program. NDE inspections of welds were made in accordance with ASME Section VIII, Division 1, and were included a 10% magnetic particle (MT) or liquid penetrant (PT) test.

No leak, thermal acceptance or component tests were required; nor was a maintenance program required.

Tests for Shielding Integrity

Radiation and contamination surveys were performed prior to shipment of the package to ensure the external dose rate and contamination levels are in accordance with 10 CFR 71. The acceptance limits were:

1. The acceptance limit for surface contamination were in accordance with 10 CFR 71.87(i)(1) or (i)(2), as applicable.
2. The acceptance criteria for external radiation dose for an open vehicle were in accordance with 10 CFR 71.47(b), (c) and (d).

REFERENCES

1. NRC Regulatory Guide 7.9, "Standard Format and Content of Part 71 Applications for Approval of Packaging of Type B, Large Quantity, and Fissile Radioactive Material", Revision 1, January 1980.
2. A. G. CROFF, "A User's Manual for the ORIGEN2 Computer Code", ORNL/TM-7175, Oak Ridge National Laboratory (July 1980).