APPENDIX D
SODIUM-BONDED FUEL CHARACTERISTICS

D.1 BACKGROUND

D.1.1 General Characteristics

The sodium-bonded spent nuclear fuel addressed in this environmental impact statement (EIS) is primarily from the operation of the Experimental Breeder Reactor-II (EBR-II) and Fermi-1 breeder reactors (a small percentage of the spent nuclear fuel is derived from other sources). Breeder reactors use two types of fuel: driver fuel, which is placed in the center of the reactor core, and blanket fuel, which is placed at the perimeter of the core. Driver fuel consists of highly enriched uranium alloy (alloy of uranium in zirconium or fissium[1]) fuel. (Natural uranium consists of mostly uranium-238, containing approximately 0.7 weight percent uranium-235; low-enriched uranium contains less than 20 weight percent uranium-235; highly enriched uranium contains greater than or equal to 20 weight percent uranium-235.) As a fissile material, uranium-235 is capable of undergoing fission (splitting into two major fragments called fission products) releasing energy and additional neutrons when struck by a neutron. This enriched uranium core produces the majority of the neutrons that power (drive) the reactor and breeding in the blanket, hence the name driver fuel. In the blanket region, uranium-238 from either natural uranium or depleted uranium, which has less than 0.3 weight percent uranium-235, capture neutrons to produce fissile materials, such as plutonium-239. In this manner, breeder reactors can produce (or breed) more fissile material than they consume.

The uranium in nuclear fuel is clad with a metal to protect it from chemical reactions with the coolant and to prevent the release of fission products to the coolant. Zirconium, stainless steel, and aluminum are common cladding materials. Most of the spent nuclear fuel analyzed in this EIS is clad with stainless steel.

Inside the cladding, the fuel is often in the form of a ceramic, an alloy that combines uranium with other metals such as zirconium, metallic uranium, or an oxide, carbide, nitride, or other form. The fuel can be fabricated as parallel plates, concentric tubes, bundles of rods or pins, or other designs. Each individual fuel item is referred to as a fuel element. Multiple fuel elements are typically combined into an assembly. Each assembly has mounting and lifting hardware, structures to direct coolant, and in some cases the capability to install neutron absorbing material and instrumentation. Most of the fuel elements addressed by this EIS are uranium alloy rods or pins. In order to improve the transfer of heat from the uranium matrix where the heat is generated to the cladding, the gap between the fuel and the cladding has been filled with a small amount of metallic sodium.

Usually a number of fuel assemblies make up a reactor core. Blanket assemblies placed around the reactor driver core for breeding or shielding are similar in design to driver fuel. An axial blanket may be placed above and below the reactor core and a radial blanket may be placed at the perimeter of the reactor core.

D.1.2 Recent Spent Nuclear Fuel Management Actions

In 1992, the Department of Energy (DOE) decided to phase out defense-related spent nuclear fuel reprocessing. Subsequently, the Department began to establish programs to manage DOE spent nuclear fuel

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[1]*Fissium is a mixture of noble metals (molybdenum, ruthenium, rhodium, palladium, zirconium, and niobium).*

that were no longer based on the production of strategic nuclear material. DOE identified the initial components of this plan in the *Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Programs Environmental Impact Statement* (DOE 1995) (hereafter referred to as the Programmatic Spent Nuclear Fuel EIS). The Record of Decision for this EIS (60 FR 28680) stated, in part, that DOE would consolidate the management of its aluminum-clad spent nuclear fuel at the Savannah River Site (SRS), leave the Hanford production spent nuclear fuel at Hanford, and would consolidate nonaluminum-clad fuel at the Idaho National Engineering and Environmental Laboratory (INEEL). This Record of Decision was amended in March 1996 (61 FR 9441). The amended Record of Decision leaves all Fort St. Vrain spent nuclear fuel at the storage site in Colorado, all but sodium-bonded spent nuclear fuel at Hanford, and places restrictions on shipment schedules.

However, in the Programmatic Spent Nuclear Fuel EIS Record of Decision, DOE made no decisions on the technologies it would apply to the management of spent nuclear fuel at the designated storage sites. The Record of Decision stated that the selection of spent nuclear fuel stabilization technologies and the preparation of spent nuclear fuel for ultimate disposition would be the subject of site-specific and fuel-type-specific evaluations prepared in accordance with the National Environmental Policy Act (NEPA) and tiered from the Programmatic Spent Nuclear Fuel EIS (DOE 1995).

D.2 INVENTORY OVERVIEW

This EIS addresses a variety of spent nuclear fuel types that have one common characteristic, the presence of metallic sodium (or sodium and potassium). As a result of research, development, and demonstration activities associated with liquid metal fast breeder reactors, DOE has approximately 60 metric tons of heavy metal of spent nuclear fuel that contains metallic sodium. This EIS addresses a range of technologies that may be used to treat and manage this spent nuclear fuel for disposal. Based on composition, there are five broad categories of spent nuclear fuel to be considered: EBR-II driver spent nuclear fuel, EBR-II blanket, Fermi-1 blanket, Fast Flux Test Facility fuel, and miscellaneous spent nuclear fuel. While there are variations within each category, they may generally be described as follows:

EBR-II driver – This spent nuclear fuel is stainless steel clad highly enriched uranium in a uranium alloy, typically either fissium or zirconium. There are some variations in the specific cladding alloys, the enrichments, fuel compound alloy, dimensions, and burnup within this category. Also, there are small amounts of fuel experiments that use a different uranium compound, for example uranium carbide. This uranium carbide fuel type was added to the miscellaneous group.

EBR-II blanket – This spent nuclear fuel consists of stainless steel clad depleted uranium in a uranium metal form. There are various blanket designs: upper and lower axial, and inner and outer radial blankets. The primary difference between these blankets is dimension and burnup.

Fermi-1 blanket – This spent nuclear fuel consists of stainless steel clad depleted uranium in a uranium-molybdenum alloy. There are various blanket designs: upper and lower axial, and inner and outer radial blankets. The primary difference between these blankets is dimension, elements per assembly, and burnup. Fermi-1 blankets are similar to EBR-II blankets in enrichment, but differ in dimension (Fermi-1 elements are larger), burnup, and form (uranium metal versus uranium-molybdenum alloy).

Fast Flux Test Facility – This group of fuel includes both irradiated and fresh driver fuel. The fuel is either uranium zirconium or plutonium/uranium zirconium, with some containing plutonium/uranium carbide and nitride. This fuel is stainless steel-clad with various levels of enrichment.

Miscellaneous – This group includes experimental spent nuclear fuel from experiments irradiated in the Engineering Test Reactor and the Annular Core Research Reactor at Sandia National Laboratories/New Mexico, Oak Ridge National Laboratory fast reactor spent nuclear fuel, sodium research experiment spent nuclear fuel at SRS, and Westinghouse Atomic Power Division test reactor experiment at INEEL. There are small quantities of experimental fuel that have metallic sodium or potassium. This type of fuel is highly diverse and differs in cladding, uranium compound, enrichment, and burnup.

Table D–1 provides a summary of all DOE sodium-bonded spent nuclear fuel. It should be noted that the inventories reported in Table D–1 include 0.4 metric tons of heavy metal of EBR-II driver fuel and the 1.2 metric tons of EBR-II blanket fuel that are being treated as part of the electrometallurgical treatment demonstration program.

Table D–1 Overview of Sodium-Bonded Spent Nuclear Fuel Categories

Fuel Type	*Storage Volume (cubic meters)* [a]	*Total End of Life Fissile Mass (kilograms)*	*End of Life Mass Metric Tons of Heavy Metal*
EBR-II Driver	58 [b]	2,030	3.1
EBR-II Blanket	13	285	22.4
Fermi-1 Blanket	19	130	34.2
Fast Flux Test Facility	8 [b]	175	0.3
Miscellaneous	3 [b]	60	0.1
Total	**101**	**2,680**	**60**

[a] Volume refers to canister storage volume.
[b] A larger volume per unit mass for the driver fuel is required for the criticality control.
Source: ANL 1999.

By any measure, the majority of the spent nuclear fuel consists of EBR-II driver, EBR-II blanket, and Fermi-1 blanket fuel. **Table D–2** provides a summary of the fraction of spent nuclear fuel in each category by a variety of different measures. As shown, the percentages vary considerably depending upon the measure used for comparison.

Table D–2 Comparison of Sodium-Bonded Spent Nuclear Fuel by Different Measures

Fuel Type	*Storage Volume (percent)*	*Total End of Life Fissile Mass (percent)*	*End of Life Mass Metric Tons of Heavy Metal (percent)*
EBR-II Driver	58	75	5
EBR-II Blanket	13	11	37
Fermi-1 Blanket	19	5	57
Fast Flux Test Facility	8	7	0.5
Miscellaneous	3	2	less than 0.1
Total [a]	**100**	**100**	**100**

[a] Values may not add to exactly 100 percent due to rounding.

The radionuclide inventory of the spent nuclear fuel varies widely due to differences in the construction, function and operational history of the spent nuclear fuel. Therefore, radionuclide inventory estimates were developed for EBR-II driver fuel (including a separate estimate for the experimental driver fuel), EBR-II blanket, Fermi blanket, and Fast Flux Test Facility experimental fuel (SAIC 1999). **Table D–3** provides a summary of plutonium and sodium content for each fuel type.

Table D–3 Plutonium and Sodium Content in Sodium-Bonded Fuel

Spent Nuclear Fuel Type	*Plutonium Mass (kilograms)*	*Sodium Mass (kilograms)*
EBR-II Driver	19	83
EBR-II Blanket	250	176
Fermi-1 Blanket	7	365
Fast Flux Test Facility	3	7
Miscellaneous	0.10	31
Total	**279.10**	**662**

Table D–4 provides a list of principal radionuclide isotopes for each of the fuel types.

For each fuel type, principal radionuclide inventories were determined by considering all isotopes that, as a whole, contribute greater than 99.99 percent of the total dose in a case of accidental release. The dose estimates associated with each isotope intake were based on the effective committed dose equivalent factors provided in Federal Regulatory Guidance Report No. 11 (EPA 1988). Next, the list of isotopes was adjusted to include those isotopes with a boiling point less than 1,400° C (2,550° F), which is the maximum melt and dilute process temperature, and then isotopes of interest like hydrogen-3 (tritium), krypton-85, iodine-129, and uranium isotopes were added. The values in Table D–4 reflect the inventory of each isotope as of January 2000 (Liaw 1998).

The following sections provide a more detailed description of each category of spent nuclear fuel.

D.3 EBR-II SPENT NUCLEAR FUEL

D.3.1 Reactor Background

EBR-II was a research and test reactor at Argonne National Laboratory-West (ANL-W) used to demonstrate the engineering feasibility of a sodium-cooled, liquid metal fast breeder reactor with a steam electric power plant and integral fuel cycle. It achieved initial criticality in September 1961 and continued to operate until September 1994. During its operation, numerous fuel designs were tested in EBR-II. The reactor operating power level was 62.5 megawatts-thermal.

D.3.2 Description of EBR-II Spent Nuclear Fuel

The EBR-II reactor consisted of an enriched driver core surround by depleted blanket assemblies. The reactor originally had an upper and lower axial blanket above and below the driver core, as well as a radial blanket around the perimeter of the driver core. It later operated with a radial blanket only. In addition, various experimental assemblies where placed into the core for testing. The following sections describe the driver fuel (including experiments) and blanket assemblies.

Table D–4 Principal Radionuclide Activities per Kilogram of Heavy Metal [a]

Elements	Isotope	EBR-II Driver [b]	EBR-II Radial Blanket [c]	EBR-II Exp. Driver Fuel	Fermi-1 Blanket	FFTF Driver
Tritium	H-3	1.23	0.00712	1.16	0.0000756	1.90
Carbon	C-14	0.000199	0.0000597	0.000954	1.05×10^{-8}	0.000674
Iron	Fe-55	4.87	0.0901	5.11	0.0000269	9.89
Cobalt	Co-60	0.481	0.0159	2.09	0.0000888	0.586
Nickel	Ni-63	0.229	0.00306	0.152	0.0000482	0.0491
Krypton	Kr-85	18.9	0.0520	16.5	0.000663	23.9
Strontium	Sr-90	197	0.807	171	0.0163	241
Yttrium	Y-90	197	0.807	171	0.0163	241
Ruthenium	Ru-106	1.51	0.135	2.67	7.02×10^{-10}	3.95
Rhodium	Rh-106	1.51	0.135	2.67	7.02×10^{-10}	3.95
Cadmium	Cd-113M	0.0464	0.000712	0.0511	2.86×10^{-6}	0.0659
Antimony	Sb-125	2.96	0.0231	2.98	2.92×10^{-6}	4.72
Tellurium	Te-125M	1.23	0.00951	1.23	1.20×10^{-6}	1.89
Iodine	I-129	0.0000735	1.44×10^{-6}	0.0000685	1.26×10^{-8}	0.0000898
Cesium	Cs-134	1.76	0.0134	1.93	6.66×10^{-9}	4.19
	Cs-137	221	1.73	199	0.0243	272
Barium	Ba-137M	209	1.64	188	0.0230	257
Cerium	Ce-144	2.96	0.0627	5.55	6.60×10^{-12}	9.88
Praseodymium	Pr-144	2.96	0.0627	5.55	6.60×10^{-12}	9.88
Promethium	Pm-147	82.6	0.407	80.2	0.0000810	128
Samarium	Sm-151	5.34	0.100	5.00	0.00131	6.49
Europium	Eu-154	0.567	0.00734	0.628	7.70×10^{-7}	0.969
	Eu-155	3.81	0.0481	3.97	0.0000671	5.28
Thorium	Th-228	0.0000514	1.55×10^{-7}	0.0000561	1.32×10^{-10}	0.0000739
Uranium	U-234	0.0404	1.33×10^{-6}	0.0371	3.20×10^{-8}	0.0407
	U-235	0.00131	3.77×10^{-6}	0.00120	7.48×10^{-6}	0.00123
	U-236	0.00121	4.24×10^{-6}	0.00104	1.09×10^{-7}	0.00141
	U-238	0.000111	0.000327	0.000120	0.000331	0.000117
Neptunium	Np-237	0.000289	8.37×10^{-6}	0.000287	2.28×10^{-7}	0.000401
Plutonium	Pu-238	0.166	0.00939	0.233	3.34×10^{-6}	0.304
	Pu-239	0.269	0.753	1.61	0.0134	0.739
	Pu-240	0.00911	0.0518	0.754	0.0000112	0.123
	Pu-241	0.00222	0.210	14.4	3.54×10^{-7}	1.60
Americium	Am-241	0.000391	0.0163	0.359	3.46×10^{-8}	0.0516
Americium	Am-242M	3.313×10^{-7}	0.000169	0.00218	7.84×10^{-14}	0.000140
Total	**Ci/kg [d]**	**957**	**7.18**	**884.1**	**0.0959**	**1,240**
Total heavy metal mass	metric tons	3.1	22.4	0.2 [e]	34.2	0.25

[a] Activities are in curies per kilogram of heavy metal, as of January 1, 2000.
[b] Inventory of Mark III driver fuel is bounding fuel for all EBR-II driver fuel type.
[c] Representative for all EBR-II blanket fuel.
[d] Curie per kilogram of heavy metal.
[e] EBR-II experimental driver fuel mass is a subset of EBR-II driver fuel.

D.3.2.1 Driver Fuel

Standard Driver Fuel

The driver fuel contains highly enriched uranium (enrichment of up to 78 weight percent). When the fuel is "spent," the enrichment (ratio of uranium-235 to total uranium) ranges between 55 percent and 76 percent.

Each driver fuel element has a metal rod (also called a fuel pin) about 36 centimeters (14 inches) long and less than 0.5 centimeters (0.2 inches) in diameter. A typical EBR-II driver fuel pin is a metal alloy of 90 percent uranium and 10 percent zirconium. This fuel pin and a small amount of metallic sodium were loaded into a 73.7-centimeter (29-inch) long stainless-steel tube (cladding) and welded shut, as shown in **Figure D–1**. This unit of fuel is called an "element." Sixty-one (in some 91) fuel elements were put together in a stainless-steel hexagonal "can" to make a fuel assembly approximately 2.3 meters (92 inches) long and 5.8 centimeters (2.3 inches) across. A typical fresh (unirradiated) driver fuel assembly contains 4.5 kilograms (9.9 pounds) of uranium and a typical irradiated fuel assembly contains 4.1 kilograms (9.0 pounds).

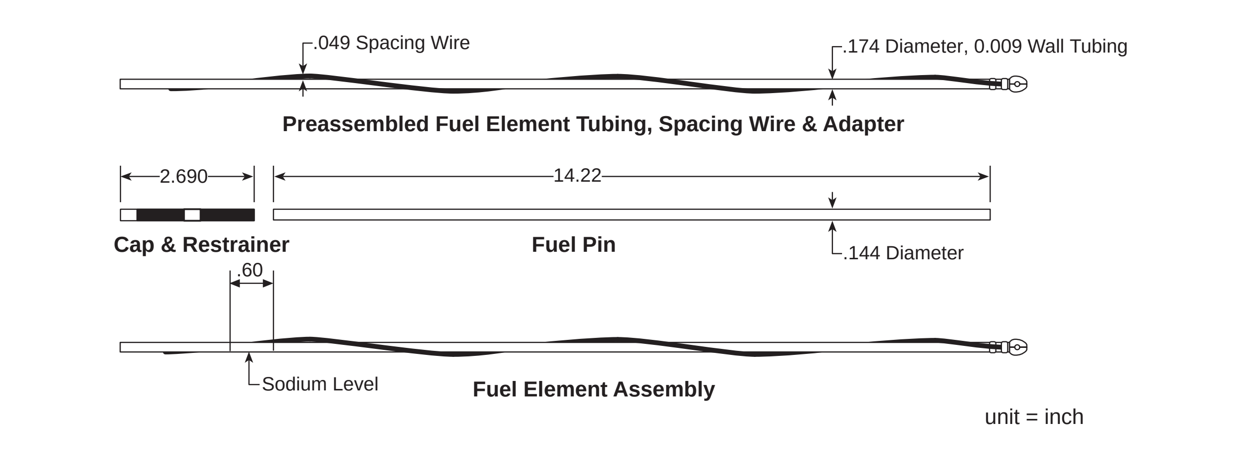

Figure D–1 Typical EBR-II Driver Element

The sodium inside driver and blanket elements improves the heat transfer from the fuel to the reactor coolant through stainless steel cladding. When the driver fuel is irradiated in the reactor for some period of time, the metallic pin swells until it reaches the cladding wall. Pores form throughout the fuel pin as it swells under pressure from the gaseous fission products. As these pores expand and connect to one another, the fission gases escape to a plenum in the fuel element just above the metallic fuel pin. As the gas escapes, the liquid sodium flows into these tiny pores, much like a sponge. As more pores form and grow, others are closed off from the fuel pin surface, including those containing sodium. Between 20 and 40 percent of the available sodium flows into the fuel pores and is inseparable from the uranium except by dissolving or melting the fuel. Further, during reactor operations, cesium-137 (an abundant radioactive fission product) dissolves in the sodium. Cesium, a reactive metal with chemical properties similar to sodium, remains with the sodium until the spent nuclear fuel is treated.

There have been numerous different fuel assemblies used in the EBR-II reactor, including a variety of experimental fuel. The types of standard spent nuclear fuel include Mark-I/IA, Mark-II/IIA, Mark-IIC/IICS, and Mark-III/IIIA. These different fuel types are quite similar, but differ in terms of dimensions, enrichment, fuel alloy, and cladding material. **Table D–5** shows the range of properties for EBR-II fuel, experimental fuel, and blanket elements.

Argonne National Laboratory has performed radionuclide projections individually for all of its spent nuclear fuel elements with the ORIGEN-RA depletion code and created a database containing inventory projections for all sodium-bonded spent nuclear fuel at ANL-W (Liaw 1998). The radionuclide inventory for a typical standard driver and experimental driver fuel element is presented in Table D–4. The driver fuel inventory is based on an average of the Mark-III elements, which are expected to have the highest inventory of the driver fuel. The EBR-II experimental driver inventory is based on the average of the experimental fuel elements that have not been processed. There may be individual elements with inventories that exceed this basis, but these inventories are well above the average for all driver assemblies.

Table D–5 Description of Unirradiated Typical EBR-II Driver and Blanket Fuel Elements

Property	*Standard Driver Fuel*	*Experimental Driver Fuel*	*Axial Blanket*	*Radial Blanket*
Element Description:				
Cladding material	SS-304L, SS-D-9, SS-316, SS-HT-9	SS-316, SS-HT-9, and SS-D-9	SS-304	SS-304
Clad outside diameter (inches)	0.179 – 0.23	0.17 - 0.29	0.38	0.49
Clad thickness (inches)	0.009 – 0.015	0.012 - 0.022	0.022	0.018
Element length (inches)	18 – 30	24 - 30	22	62
Fuel elements (or rods) per assembly	61 – 91	61	19	19
General Composition:				
Uranium alloy composition	U–5F [a] U–10Zr [b]	U–10Pu–10Zr [c] Pu/U-Carbide	Uranium metal	Uranium metal
Uranium-235 enrichment (percent)	67-78	Up to 93	0.2	0.2
Burnup (atom percent)	Up to 10	Up to 18	0.014	0.2
Sodium (g/element)	1.0 – 2.0	1.0 – 2.0	~ 3	~ 20

SS = Stainless steel.

[a] An alloy of 95 weight percent uranium and 5 weight percent fissium. Fissium consists of molybdenum, ruthenium, rhodium, palladium, zirconium, and niobium.

[b] An alloy of 90 weight percent uranium and 10 weight percent zirconium.

[c] An alloy of 80 weight percent uranium, 10 weight percent plutonium, and 10 weight percent zirconium.

Experimental Fuel

EBR-II has irradiated various types of different experimental driver fuel in support of its own and other liquid metal fast breeder reactor fuel development programs. Over 3,000 of these fuel elements still exist. Some of these experiments investigated the use of different fuel compositions including uranium-plutonium-zirconium alloy, plutonium-carbide, uranium-carbide and uranium-oxide. Table D–5 provides the range of data applicable for experiments. While the quantity of experimental spent nuclear fuel is relatively small, it is significant because of the associated potential unique requirements. Before this fuel can be treated, the carbide and oxide forms of the fuel may have to be reprocessed and converted to metallic forms.

D.3.2.2 Axial and Radial Blanket

The blanket assemblies were made from depleted uranium, a type of uranium in which most of the fissile uranium-235 has been removed, leaving 99.7 percent uranium-238. This type of uranium will fission, but not readily, and cannot be used alone to power a nuclear reactor. Early in EBR-II's history, the blanket assemblies surrounded or "blanketed" the reactor core to demonstrate the breeding of plutonium-239, another fissile material. However, in 1967 the breeding experiment was completed and the job of reconfiguring the reactor for its role as an irradiation test facility began. By 1972, the final blanket assemblies had been moved well away from the core and replaced by a thick ring of stainless-steel reflector assemblies. In this configuration, the blanket assemblies provided shielding to protect structural materials from radiation emanating from the core.

Blanket assemblies are similar to the driver assemblies except that the individual blanket pins are larger. The blanket pins, made entirely from depleted uranium, are 1.1 centimeters (0.4 inches) in diameter, with three to five pins placed end-to-end to make a sodium-bonded blanket element 140 centimeters (55 inches) long. Since the blanket pins are a larger diameter and longer length, 19 blanket elements comprise a blanket assembly containing approximately 47 kilograms (103 pounds) of uranium. On average, about 99 percent of the uranium remains in the spent blanket assemblies with the remaining 1 percent having been converted to fission products and transuranic elements. The principal isotopes contributing to the activity of the axial and radial blanket assemblies are given in Table D–4.

Some of the EBR-II blanket assemblies have been in the reactor since it began operation more than 30 years ago. With the shutdown of EBR-II, these assemblies were unloaded from the reactor. In preparation for interim storage in the Radioactive Scrap and Waste Facility, they were cleaned to remove the few grams of sodium coolant that had adhered to the external surface as they were pulled out of the reactor.

D.3.2.3 Storage

Most of the fuel from the last seven years of EBR-II operation is presently stored in three different facilities at ANL-W: the Fuel Conditioning Facility, Hot Fuel Examination Facility, and Radioactive Scrap and Waste Facility. Previously, the spent nuclear fuel was shipped to the Idaho Nuclear Technology and Engineering Center (INTEC) (formerly Idaho Chemical Processing Plant) for reprocessing. However, INTEC ceased accepting the fuel in 1991 when a new uranium-zirconium alloy fuel, which could not be dissolved with INTEC's existing Chemical Processing Plant, went into full use at EBR-II. More than 6 metric tons (6.6 tons) of EBR-II fuel were processed at INTEC. When DOE stopped processing at INTEC in 1992, elements from some 500 EBR-II spent driver fuel assemblies of earlier design were left in storage pools located at INTEC. The spent nuclear fuel generated after shipments to INTEC ceased was stored at ANL-W in several facilities (Fuel Conditioning Facility, Hot Fuel Examination Facility, and Radioactive Scrap and Waste Facility).

D.4 FERMI-1 BLANKET

D.4.1 Reactor Background

The Enrico Fermi Atomic Power Plant[2] was designed and built at Monroe Beach, Michigan (30 miles southwest of Detroit) to demonstrate the feasibility of the fast breeder reactor for electric power production. Fermi-1 was a sodium cooled, fast reactor. Information was provided by Argonne National Laboratory, based upon EBR-I and EBR-II, to assist in the design of the Fermi-1 reactor. The reactor achieved initial criticality in 1963 and operated until September 1972. Fermi-1 was licensed for operation at a power level of 200 megawatts-thermal.

On October 5, 1966, Fermi-1 experienced a coolant blockage caused by a detached piece of zirconium liner. As a result, melting occurred in two subassemblies and the reactor was shutdown for three years and nine months. On July 18, 1970, the second Fermi-1 reactor core achieved criticality. New fuel and some of the

[2]The original name of the plant was the Enrico Fermi Atomic Power Plant. The numeral "1" was added to the name in 1969 after Detroit Edison Company began construction of Fermi-2. The plant is also known as Fermi, Fermi-1 or Enrico Fermi-1 (EF-1).

original fuel was used for the second core. Termination of reactor operations in 1972 was not due to mechanical or technical problems, but rather due to lack of adequate financial support.

D.4.2 Blanket Description

The reactor had two different blanket designs: axial blanket assemblies above and below the core, and radial blanket assemblies surrounding the core. The core assemblies (25.69 percent enriched fuel) were not bonded with sodium and are not part of the scope of this EIS. All blanket assemblies contain depleted uranium and contain a sodium bond between the uranium and the cladding. **Figure D–2** shows the radial blanket assembly. The inner and outer radial blanket assemblies had the same design and only differed in their placement in the reactor. The axial assemblies are similar, except they are shorter and have fewer, larger diameter pins. **Table D–6** provides data on both the axial and radial assemblies.

Table D–6 Description of Fermi-1 Blanket Elements and Assemblies

Property	***Axial Blanket***	***Radial Blanket***
Element Description:		
Cladding material	Stainless steel 304	Stainless steel 304
Clad outside diameter (inches)	0.443	0.443
Clad thickness (inches)	0.010	0.010
Uranium length (inches)	14	65
Fuel elements (pins or rods) per assembly	16 in upper blanket 16 in lower blanket	25
Assembly Description:		
Cross-section shape	Square	Square
Outside dimension (inches)	2.646	2.646
Wall thickness (inches)	0.096	0.096
Number of assemblies	403 [a]	559
General Composition:		
Uranium alloy composition	U–2.75 Mo [b]	U–2.75 Mo [b]
Uranium-235 enrichment (percent)	0.35	0.35
Sodium (grams/element)	5.5	20.7

[a] Includes both upper and lower axial blankets.
[b] An alloy of 97.25 percent depleted uranium and 2.75 percent molybdenum.

D.4.3 Storage

After the Fermi-1 reactor was permanently shutdown, the blanket assemblies were placed into 14 canisters and transported to INTEC in 1974 and 1975 in 14 shipments. The 14 canisters are made of stainless steel with a carbon steel basket inside. The canisters are 3.4 meters (11 feet, 2.5 inches) long and 65 centimeters (25.5 inches) in diameter. The canisters were filled with helium and seal welded. Twelve of the canisters contain the radial blanket assemblies and two of the canisters contain the shorter axial blanket assemblies.

D.5 FAST FLUX TEST FACILITY AND OTHER MISCELLANEOUS FUEL

As shown in Table D–2, the majority of the spent nuclear fuel addressed by this EIS is EBR-II driver, EBR-II blanket, or Fermi-1 blanket. However, there are small quantities of other spent nuclear fuel that also contain metallic sodium that are included in the scope of this EIS. These miscellaneous materials are described below.

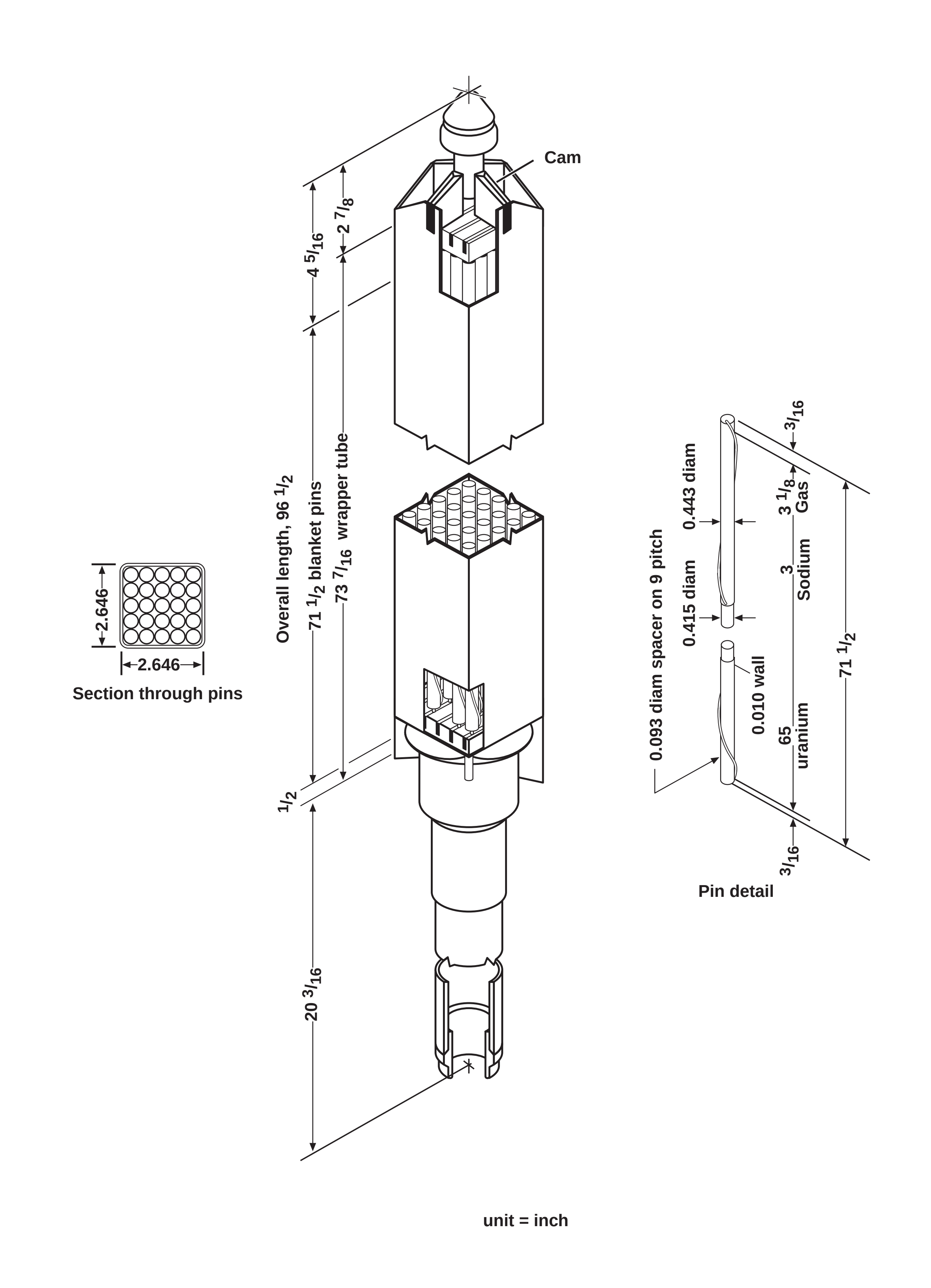

Figure D–2 Fermi-1 Radial Blanket Assembly

D.5.1 Fast Flux Test Facility

Background – The Fast Flux Test Facility, located on the Hanford Site near Richland, in southeastern Washington State, is a 400-megawatt thermal nuclear test reactor cooled by liquid sodium. It was built in 1978
and achieved initial criticality in 1980. The Fast Flux Test Facility was built to test plant equipment and fuel for the U.S. Government's liquid metal reactor development program. Although the facility is not a breeder reactor, this program demonstrated the technology of commercial breeder reactors. It was constructed to verify the safety and optimal performance of the key reactor systems and components. It was also intended to ensure the safety and best design of mixed oxide fuel, a mixture of uranium oxide and plutonium oxide.

The Fast Flux Test Facility successfully tested advanced nuclear fuel, materials, and safety designs. It also produced a large number of different medical isotopes, and made tritium for the U.S. fusion research program. Its operation also demonstrated the reactor's inherent safety features—most notably its ability during an emergency to remove reactor decay (residual) heat without pumps or any other mechanical system, simply based on its design. By contrast, current conventional water reactors require complex safety cooling and backup systems to remove their decay heat.

Description – Under normal operating conditions of the Fast Flux Test Facility, mixed oxide fuel with an enrichment of 20 to 30 percent plutonium was fabricated and inserted in the reactor core. However, the Fast Flux Test Facility also tested a number of experimental fuel types. The material included in the scope of this EIS is the sodium-bonded experimental fuel that was irradiated. **Table D–7** provides data on the sodium-bonded Fast Flux Test Facility spent nuclear fuel addressed by this EIS.

Storage – The Fast Flux Test Facility sodium-bonded spent nuclear fuel is currently in dry storage at the facility. The facility has no major vulnerabilities.

Inventory – There are just over 1,600 Fast Flux Text Facility rods (approximately 300 individual rods or elements and six assemblies consisting of 217 rods each) which are sodium-bonded totaling 0.32 metric tons of heavy metal. (Of this fuel, 0.07 metric tons of heavy metal, consisting of approximately 100 rods or elements and one assembly, are unirradiated fuel.) The radionuclide inventory of this spent nuclear fuel is presented in Table D–4.

D.5.2 Miscellaneous Fuel

Sandia National Laboratory Experiments

Background – A series of debris bed experiments were conducted at the Sandia National Laboratory's Annular Core Research Reactor from 1977 to 1985. These experiments were part of a program to study the "coolability" of debris beds that might be formed during reactor accidents. In the event of a severe accident in a sodium-cooled fast reactor, molten core materials may interact with liquid sodium and thus result in rapid quenching, freezing, and fragmentation. This fragmented debris may settle on horizontal surfaces within the reactor vessel to form debris beds. If the beds are subcritical, the debris will be heated by the radioactive decay of retained fission products. The possibility of damage to the pressure vessel and the containment, which prevent or mitigate the release of fission products as a consequence of the accident, depends on the extent to which natural cooling of the debris can be relied to remove decay heat from the bed. The debris bed experiments were the first "coolability" experiments to be conducted in-pile, using internally heated uranium dioxide and sodium.

Table D–7 Description of the Fast Flux Test Facility Sodium-Bonded Spent Nuclear Fuel

Property	*Fast Flux Test Facility Spent Nuclear Fuel*
Element Description:	
Shape	Round rod
Cladding material	Stainless steel 316 Stainless steel D9 Stainless steel HT9
Clad outside diameter (inches)	0.23 to 0.38
Clad thickness (inches)	0.022
Element length (inches)	93 to 120
Fuel pins or rods per assembly	217
Sodium (grams/element)	9 to 40
General Composition:	
Uranium alloy composition	Uranium-10 Zirconium [a] Uranium-10 Plutonium-10 Zirconium Plutonium/Uranium Carbide
Uranium-235 enrichment (percent)	0.2 to 24
Typical burnup (megawatt days/metric ton uranium)	68,000 to 140,000
Assembly Description:	
Rods per assembly	217
Assembly shape	Hexagon
Assembly width (inches)	4.567 flat to flat
Assembly height (inches)	144

[a] An alloy of 90 weight percent uranium and 10 weight percent zirconium.

Description – Each experiment consists of either a single or double containment within a helium chamber in the experiment section. Older experiments had a single containment, while newer ones were doubly contained. The uranium dioxide fuel, sodium, thermocouples, and in newer experiments, the insulated crucible are within the inner containment vessel. The uranium dioxide used in the experiments was produced by Los Alamos National Laboratory. The fuel was not irradiated prior to use in these experiments, nor was it melted during the experiments.

Figure D–3 provides a cut-away view of a typical debris bed experiment. As shown, these experiments are considerably different than the arrangement of sodium-bonded spent nuclear fuel. The fuel is just a small portion of the overall experiment structure. The fuel bed is held in a tantalum-tungsten alloy crucible with zirconia insulation. Each of the experiments is 10 centimeters (4 inches) in diameter and 50 centimeters (20 inches) long.

Storage – The seven debris bed experiments are stored dry at Sandia National Laboratories/New Mexico in Tech Area 5. The experiments are presently stored in seven “Dense Packs,” a set of underground storage holes in Tech Area 5. There are no known vulnerabilities with this storage.

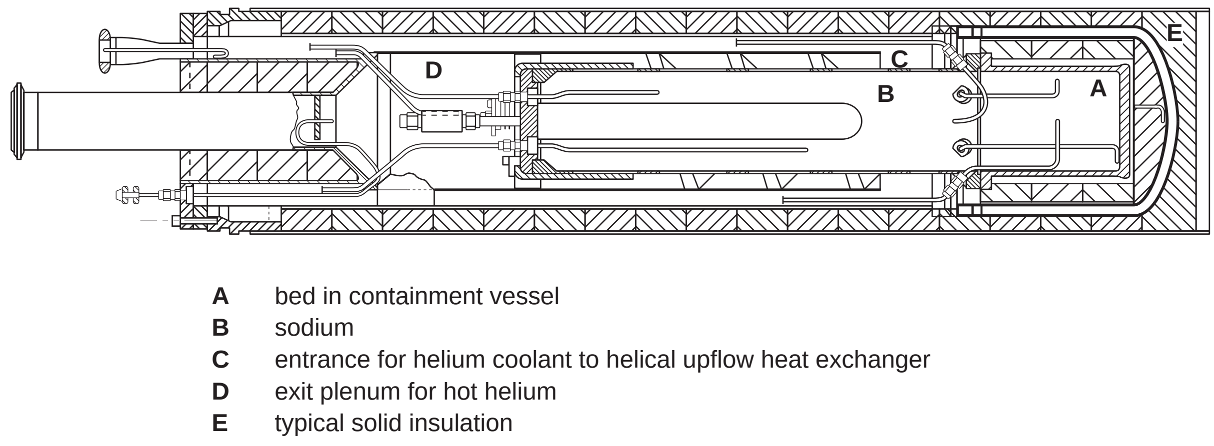

Figure D–3 Typical Debris Bed Experiment

Inventory – The seven debris bed experiments have a total mass of 650 kilograms (1,433 pounds), of which only 34 kilograms (75 pounds) is highly-enriched uranium (93 percent uranium-235) and 20 kilograms (44 pounds) is metallic sodium. The sodium is interdispersed within the fuel debris. The burnup on this spent nuclear fuel is minor since the fuel had not been irradiated prior to these experiments.

The radionuclide inventory for these experiments was modeled as the EBR-II driver spent nuclear fuel on a heavy metal basis (see Table D–4). This is considered conservative because of the very low fuel burnup and the long cooling time (1977 to 1985, depending upon the experiment).

Westinghouse Atomic Power Division

Background – When the Engineering Test Reactor at INEEL was being taken to power, the activity of the primary reactor water rose abruptly. Within a few minutes after the rise began, the reactor received a slow setback which reduced power. Water chemistry analysis indicated a rupture in an experiment capsule. A small crack was found in one of the Westinghouse Atomic Power Division experiments (WAPD-49-AQ). There were 15 other similar experiment capsules in the reactor at the time. All of these capsules were removed from the reactor.

Description – The capsules have an overall length of 94.6 centimeters (37.25 inches) and are about 12.7 centimeters (5 inches) in diameter. Thirty centimeters (12 inches) of each capsule holds the fuel sample assembly. Each fuel sample assembly holds four fuel pins, each having a length of 14 centimeters (5.5 inches) and diameter of 0.9 centimeters (0.34 inches). The fuel pins contain uranium dioxide pellets (18 percent enriched). The oxide pellets have either one or two sheaths. The sheaths are made of either 304 stainless steel or zircaloy. The fuel pins that have two sheaths have a mixture of sodium and potassium between them. **Figure D–4** show the typical Westinghouse Atomic Power Division capsule arrangement.

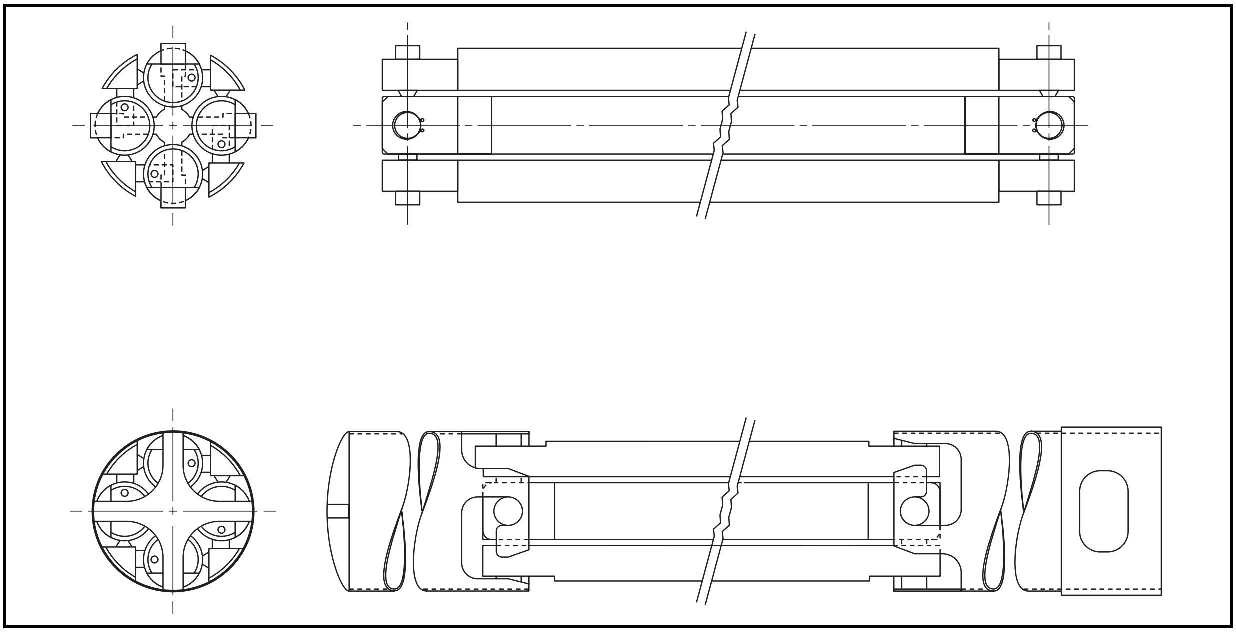

Figure D–4 Diagram of the Westinghouse Atomic Power Division Capsule

Storage – The Westinghouse Atomic Power Division spent nuclear fuel is currently stored in INTEC-603. There are a total of 22 experiments (i.e., pins). There are 4 experiments stored each in five aluminum cans and two capsules in the final can.

Inventory – The total inventory of the Westinghouse Atomic Power Division spent nuclear fuel is 6.6 kilograms (14.5 pounds) of uranium, at 18 percent enrichment. A radionuclide inventory of the Westinghouse Atomic Power Division spent nuclear fuel will be scaled conservatively from the EBR-II driver fuel inventory (see Table D–4) based upon heavy metal. This scaling approach is conservative because the experiments are fabricated with plutonium and uranium, have a lower enrichment, and have a lower burnup.

Oak Ridge National Laboratory Fast Reactor Spent Nuclear Fuel

Background – On August 12, 1998, the fuel elements were being sheared in half when a "sparkler-like reaction" was observed, lasting less than 30 seconds. This observed reaction was suspected of being an indication of sodium bonding on the spent nuclear fuel. This has not yet been confirmed. This spent nuclear fuel is included in this listing of sodium-bonded spent nuclear fuel in the event that it does prove to be sodium-bonded.

Description – The spent nuclear fuel is considered to be experimental EBR-II spent nuclear fuel elements. They are reported to be a uranium-carbide composition with stainless steel cladding. Figure D–1 shows the general configuration of EBR-II fuel, including experimental fuel. Table D–5 provides data on experimental EBR-II spent nuclear fuel.

Storage – This spent nuclear fuel is currently stored at the Oak Ridge National Laboratory in Building 3525, the Irradiated Fuel Examination Laboratory. The Irradiated Fuel Examination Laboratory is a two-story brick structure which contains hot cells. Disassembly and examination of fuel and components continue to be the mission of the facility. There are no identified vulnerabilities associated with this facility.

This spent nuclear fuel is stored in 4 containers in Building 3525. The containers are about 1.3 centimeters (0.5 inches) in diameter by 107 centimeters (42 inches) long.

Inventory – This spent nuclear fuel contains a total of 0.38 kilograms (0.84 pounds) of uranium, 0.35 kilograms (0.77 pounds) of which is uranium-235. Therefore, the enrichment is over 90 percent. This spent nuclear fuel also contains a total of 0.091 kilograms (0.20 pounds) of plutonium, 0.084 kilograms (0.18 pounds) of which is plutonium-239 or plutonium-241.

The radionuclide inventory for this small amount of material can be approximated by scaling the experimental spent nuclear fuel inventory (see Table D–4) based on heavy metal. This scaling approach is appropriate since this is an EBR-II experimental fuel.

Sodium Research Experiment at SRS

Background – The Sodium Research Experiment was a sodium-cooled, graphite-moderated reactor owned by the Atomic Energy Commission and Southern California Edison, Co. The Sodium Research Experiment achieved initial criticality in 1957 and was last operated in 1964. The Sodium Research Experiment operated at 20 megawatts-thermal until it was shut down in February 1964 for modification to permit an increase in power level to 30 megawatts-thermal. In December 1966, deactivation was announced.

Description – The Core I Sodium Research Experiment fuel was an unalloyed, uranium metal matrix, with a 2.8 percent uranium-235 enrichment stainless steel type 304 cladding, and sodium-potassium bonding. The Core I fuel contained seven rods per assembly. Core I was removed in 1959 after an incident resulted in the overheating and failure of one or more fuel in a number of fuel assemblies. The 26 undamaged fuel assemblies were shipped to Oak Ridge National Laboratory and were reprocessed. The assemblies that had damaged rods, along with miscellaneous fuel pieces retrieved from the reactor, were packaged into stainless steel canisters.

Core II assemblies were a thorium – 7.6 percent uranium alloy with a 92.3 percent uranium-235 enrichment, stainless steel type 304 cladding and sodium-potassium bonding. Core II fuel contained only five rods per assembly. Each rod contained 12 fuel slugs. Each fuel slug was 1.9 centimeters (0.75 inches) in diameter and 15.2 centimeters (6 inches) long. **Figure D-5** shows the typical assembly. The Core II fuel assemblies were removed from the reactor and placed into storage in 1964. This fuel was declad by Atomics International and shipped to SRS for reprocessing in 1976 and 1977.

In addition to the typical fuel, the Sodium Research Experiment also contained several types of experimental fuel. The experimental fuel addressed by this EIS is a uranium carbide fuel with a 9.8 percent uranium-235 enrichment, and stainless steel type 304 cladding.

Storage – The uranium carbide spent nuclear fuel addressed by this EIS is currently stored in the Receiving Basin for Offsite Fuel at the SRS. The Sodium Research Experiment spent nuclear fuel is stored in a can 8.9 centimeters (3.5 inches) in outer diameter and 366 centimeters (12 feet) long.

Inventory – This spent nuclear fuel contains a total of 43 kilograms (95 pounds) of uranium, 4.2 kilograms (9 pounds) of which is uranium-235. Therefore, the enrichment is 9.8 percent. This spent nuclear fuel also contains a total of 0.016 kilograms (0.035 pounds) of plutonium.

The radionuclide inventory for this small amount of material can be approximated by scaling the experimental spent nuclear fuel inventory (see Table D–4) based on heavy metal. This scaling approach is appropriate since this is a very small quantity of spent nuclear fuel with a burnup lower than the EBR-II spent nuclear fuel.

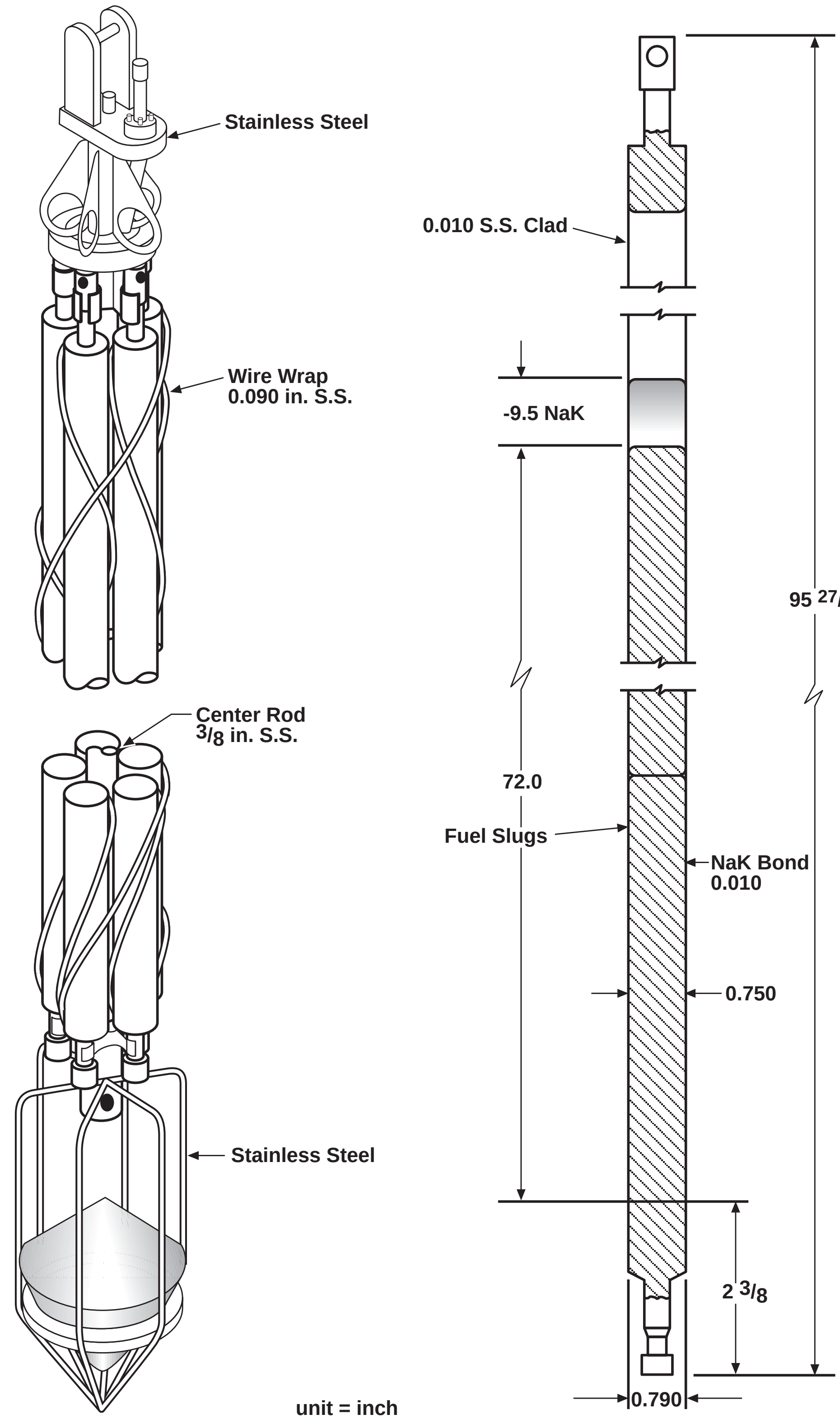

Figure D–5 Sodium Research Experiment Fuel Rod and Assembly Configuration

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