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ISSUES RELATING TO SPENT NUCLEAR FUEL STORAGE ON THE OAK RIDGE RESERVATION

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ABSTRACT

Currently, about 2800 metric tons of spent nuclear fuel (SNF) stored in the United States, 1000 kg of SNF (or about 0.03% of the nation's total) are stored at the U.S. Department of Energy (DOE) complex in Oak Ridge, Tennessee. However small the total quantity of material stored at Oak Ridge, some of the material is quite singular in character and, thus, poses unique management concerns. The various types of SNF stored at Oak Ridge will be discussed including:

High-Flux Isotope Reactor (HFIR) and future Advanced Neutron Source (ANS) fuels. The HFIR and ANS fuel designs consist of a large number of involute plates arranged in two concentric cylinders. The HFIR fuel assembly contains about 9.4 kg of ^{235}U in a matrix that is not amenable to disassembly in order to meet the currently planned 700-g/package fissile mass limit for final disposal in the geologic repository.

Material Testing Reactor (MTR) fuels, including Bulk Shielding Reactor (BSR) and Oak Ridge Research Reactor (ORR) fuels. This SNF is in storage at the BSR pool and poses minimal management concerns.

Molten Salt Reactor Experiment (MSRE) fuel. This SNF is stored predominately as uranium tetrafluoride (UF_4) in a lithium fluoride/beryllium fluoride/zirconium fluoride ($LiF/BeF_2/ZrF_4$) mixture in three Hastelloy™ N™ storage tanks. The predominant fissile isotope present is ^{233}U, but ^{235}U and ^{239}Pu are present in smaller quantities in the fuel. Some migration of fissile material has occurred and is being investigated. The presence of the salt mixture mandates that special attention be focused on the removal and storage of this fuel.

Homogeneous Reactor Experiment (HRE) fuel. This SNF consists of 135 gal of sulfuric acid solutions containing 4 kg of uranium. In 1964, the spent solutions were disposed of in seven unlined auger holes. Preliminary indications from newly installed monitoring wells are that little or no migration of the active components of this mixture have taken place.

Miscellaneous SNF stored in Oak Ridge National Laboratory's (ORNL's) Solid Waste Storage Areas (SWSAs). This SNF includes a wide variety of plutonium oxide/uranium oxide/thorium oxide fuels in the form of intact, cut-up fuel elements and microspheres. Most of these fuels were placed in below-grade storage positions during the 1970s, and little is known about their current condition.

SNF stored in the Y-12 Plant 9720-5 Warehouse including Health Physics Reactor (HPRR), Space Nuclear Auxiliary Power- (SNAP-) 10A, and DOE Demonstration Reactor fuels. This material is stored at Y-12 because it contains highly enriched uranium with very low burnups. This material can be defined as contact-handled SNF. Therefore, this material is not self-protecting and requires more safeguards protection than is readily available at the ORNL site.

I. INTRODUCTION

The most recent inventory of the amount of spent nuclear fuel (SNF) stored in the United States indicates that approximately 2700 metric tons heavy metal (MTHM) exist. This SNF consists primarily as stored material at the U.S. Department of Energy (DOE) Hanford, Idaho, and Savannah River sites. About 1 MTHM (or about 0.03% of the nation's total) is stored at the DOE complex in Oak Ridge, Tennessee. The Oak Ridge SNF, which is presented in Table 1, is currently divided into 16 different listings; two of these categories contain less than 1 kg of heavy metal (HM). However small the quantity of material stored at Oak Ridge, some of the material is quite singular in character and, thus, may pose unique management concerns. Currently, indications are that it may be very expensive to qualify a single SNF type for disposal in the proposed national high-level waste (HLW) geologic repository. A clear understanding of the various SNF types stored at Oak Ridge is vital to the development of a national program plan for the management of SNF.

A discussion of the various types of SNF stored at Oak Ridge follows. Included are various issues that pertain to each fuel type. It is intended that the presented list be as complete as possible. However, given the uncertainties in the current definition of what is included in the national SNF program, there may very well be some future deletions or additions in the list of the Oak Ridge material.

The following information has been extracted from a variety of sources, including the Oak Ridge SNF data base, internal and external Oak Ridge National Laboratory (ORNL) reports, formal and informal presentations, and personal communications of the authors. One of the most complete sources for information on SNF at all of the DOE facilities is *DOE Programmatic Spent Nuclear Fuel Management and Idaho National Engineering Laboratory Environmental Restoration and Waste Management Program's Draft Environmental Impact Statement*, DOE/EIS-0203-D, June 1994.

II. OAK RIDGE SNF INVENTORY

A. High-Flux Isotope Reactor (HFIR) fuel. The HFIR is an operational beryllium-reflected, light-water-cooled and -moderated, flux-trap-type reactor. The reactor uses 540 aluminum-clad involute fuel plates containing 93% enriched ^{235}U fuel (Fig. 1). The reactor became operational in 1965 and is normally operated at a level of 85 MW. Current missions for the HFIR include the production of isotopes for medical and industrial applications, neutron-scattering experiments, and various material-irradiation experiments. HFIR is the only source of transuranic isotopes, especially ^{252}Cf, in the western world.

The HFIR averages ten fuel cycles per year. Currently, there are 57 HFIR cores (576 kg of HM) in on-site pool storage with a total capacity of 60 cores. Reracking the existing storage facility and installing modular dry-storage units are being considered in order to expand the limited storage capacity.

In the past, HFIR SNF was shipped to the Savannah River Site (SRS). If shipment of SNF to another DOE site is precluded or if the reracking at the HFIR is not approved, the reactor will be required to shut down because the pool storage racks will run out of room in early 1995.

Each HFIR fuel assembly contains approximately 9.4 kg of ^{235}U (no burnup credit) in a matrix that is not suitable for disassembly. Current estimates are that the criticality limit for the geologic repository waste package may be 700 g of fissile mass. Although several methods for the conversion of SNF to HLW have been proposed, none have been successfully demonstrated.

The Advanced Neutron Source (ANS) reactor is currently in the conceptual design stage as a replacement for the HFIR and may be operational as early as the year 2002 or 2003. Current estimates are that up to 18 cores will be discharged per year. The configuration of the fuel elements is expected to be similar to the present HFIR fuel design.

B. Bulk Shielding Reactor (BSR) and Oak Ridge Research Reactor (ORR). These two reactors were shut down in 1987 (ORR) and in 1991 (BSR). Most of this fuel was transported to the SRS, but 41 elements for the BSR and 32 elements for the ORR remain in on-site wet storage in the BSR pool. The total amount of these 73 elements is about 59 kg HM. Both the BSR and ORR used material test reactor-type (MTR-type) assemblies of an aluminum-clad plate-type design (Fig. 2). The fuel-containing matrix is a uranium-oxide (in the BSR) or uranium-silicide (in the ORR) and aluminum mixture. The BSR fuel is 93% enriched in ^{235}U, whereas the ORR fuel is 20% enriched.

C. Molten Salt Reactor Experiment (MSRE) fuel. The MSRE operated from June 1965 to December 1969 at a normal power level of 8 MW. The purpose of the reactor was to test the practicality of a molten-salt-reactor concept. The circulating fuel solution was a mixture of fluoride salts containing uranium fluoride as the fuel. The initial charge was ^{235}U, but this was later replaced with a charge of ^{233}U. Processing capabilities were included as part of the facility for on-line fuel additions, removal of impurities, and

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uranium recovery. Following reactor shutdown, the fuel and flush salts were drained to three critically safe storage tanks.

Currently, the inventory at the MSRE consists of about 11,550 kg of the fluoride salt mixture (4,650 kg fuel salt, 4,290 kg flush salt, and 2,610 kg coolant salt). The uranium salt is contained mainly in the fuel salt and is predominately ^{233}U (31 kg) with lesser amounts of ^{234}U, ^{235}U, and ^{238}U. The remainder of the salt mixture is composed of lithium fluoride, beryllium fluoride, and zirconium fluoride. A total mass of 38 kg HM is present in the three Hastelloy N™ storage tanks (Fig. 3).

Some migration of fissile material has been detected from the storage tanks and is currently being investigated. If left uncorrected, access to the hot-cell area, where the tanks are contained, may become difficult. The presence of the fluoride salt mixture will mandate that special care be taken in the removal and storage of this fuel. The approach that will be used has yet to be decided upon.

D. Homogenous Reactor Experiment (HRE) fuel. The HRE (Fig. 4) was operated from 1957 through 1961 to evaluate the potential application of aqueous fueled homogenous reactors to power plant applications and in 1959 operated for 105 d (a record, at the time, for continuous reactor operation). The fuel for the HRE consisted of 145 gal of 4*M* sulfuric acid solution containing 4.5 kg of 85% ^{235}U enriched uranium. In 1964, the residual fuel solution and fission products were disposed of in seven unlined auger holes in the Melton Valley region at ORNL. The auger holes are 1 ft in diameter, 17 ft deep, and 10 ft apart. After disposal, the wells were backfilled with soil, and concrete caps and brass plaques were installed to mark the well locations. Preliminary indications from recently installed monitoring wells have not indicated any migration of the material.

E. Miscellaneous SNF stored in ORNL's Solid Waste Storage Area (SWSA). A variety of SNF and other materials were placed in shielded, retrievable stainless-steel dry storage positions during the 1970s and 1980s. These facilities are now closed to further storage, and the existing material is expected to be removed once new storage is completed in the late 1990s. The storage cylinders vary from 20 to 76 cm in diameter and from 3 to 4.6 m in depth. Each storage cylinder is fabricated from stainless steel, placed on a concrete pad, held in place by concrete collars or slabs, and backfilled with dirt or concrete. Facility 7823A has 8 storage positions containing less than 1 kg of HM, the 7827 facility consists of 54 storage positions with 85 kg HM, and the 7829 facility has 10 storage positions with about 10 kg HM. The SNF stored in the SWSA wells varies in the degree to which it is characterized. Some of this SNF is well defined; however, some of it is assumed to be fuel based only on the listed isotopes. Very little is known about the fuel form or condition. In addition, a separate 13- by 100-cm pipe, containing 23 kg HM of grouted uranium-thorium fuel microspheres [irradiated in the Keuring van Electrotechnische Materialen Suspension Test Reactor (KSTR), Netherlands] was disposed of in 1988.

F. SNF stored in the Y-12 Plant 9720-5 Warehouse. The 9720-5 building at the Y-12 Plant is a large warehouse containing vaults for the storing and safeguarding of highly enriched uranium. The SNF material at 9720-5 is in dry storage and is either very low burnup or unirradiated material. Currently, irradiated SNF located at 9720-5 includes about 5 kg HM of Space Nuclear Auxiliary Power- (SNAP-) 10A fuel, 184 kg HM from the Health Physics Research Reactor (HPRR), and 2 kg HM from the DOE Demonstration Reactor.

The stored SNAP-10A material includes the entire reactor and 36 fuel rods of 93% enriched uranium zirconium hydride in a liquid sodium-potassium (NaK) alloy (Fig. 5). The reactor is secured vertically in a double 55-gal stainless steel drum, which in turn is placed in a standard uranium hexafluoride (UF_6) shipping container. The burnup of this fuel was very low, with the inner drum and outer shipping container providing the only shielding present.

The HPRR material is composed of a uranium-molybdenum alloy that can be stacked into a right circular cylinder to construct a small unmoderated and unshielded reactor (Fig. 6). Two cores and a variety of test specimens are currently stored at the 9720-5 Warehouse in a disassembled condition in 14 individual "bird cages." This material has very little "burnup" and is contact-handled.

The DOE Demonstration Reactor material is anticipated to contain about 2 kg of highly enriched uranium from a Lockheed 10-kW pool-type light-water-moderated and -cooled reactor that was operated briefly in Brazil in 1969. The SNF and various other unknown components are currently stored in eight 3- by 5-ft packages. It is unknown which, or how many, of the packages contain the SNF.

III. CONCLUSIONS

As is readily apparent, the Oak Ridge SNF spans the spectrum in terms of properties and compositions. The initial fissile isotopes for these fuels include ^{233}U, ^{235}U, ^{232}Th, and possibly some plutonium isotopes. Enrichments range from 1.3 to over 93%. Fuel alloys include oxides, alloyed metals, fluoride salts, silicides, dissolved uranium, and zirconium hydrides. The physical forms show as much variation—from dissolved salts, frozen salts, powders, grouted microspheres, bare components, intact assemblies, to various unknown materials. Claddings include aluminum, Zircaloy™, stainless steel, graphite, Hastelloy™, and none. The Oak Ridge SNF is located in a variety of places—from well-characterized pools, to burial in soil, to shipping containers that have not been opened. Issues relating to potential corrosion, migration of fissile material in soils, and inadequate characterization of some SNF all point out that Oak Ridge is a microcosm of the DOE SNF universe. The result is that, while the Oak Ridge SNF is a relatively small quantity compared to the rest of DOE's SNF inventory, the range of its characteristics dictate that it must to be addressed fully in the development of a national SNF management plan.

Table 1. SNF—Oak Ridge

SNF category	Total mass (kg)	Heavy metal mass (kg)	Enrichment
High Flux Isotope Reactor (HFIR) fuel (as of December 1994)	7,974	576	93.15% ^{235}U
Bulk Shielding Reactor (BSR) fuel	184	6.9	93.15% ^{235}U
Oak Ridge Research Reactor (ORR) fuel	143	52	19.8% ^{235}U
Molten Salt Reactor Experiment (MSRE) fuel	11,500	38	2.33–18.37% ^{235}U 38.78–84.53% ^{233}U
Homogeneous Reactor fuel	500	4.5	86% ^{235}U
Dry storage–Building 7823A	175	0.8	Varies
Dry storage–Building 7827	~1,400	84.9	Varies
Dry storage–Building 7829	552	10.2	Varies
Keuring van Electrotechnische Materialen Suspension Test Reactor (KSTR) fuel	132	23	89.9% ^{235}U
Material–Building 3525	1	0.1	LEU to HEU
Storage carousels–Building 4501			
Depleted U fuel	6.4	5.6	1.33–2.87% ^{235}U
Enriched U fuel	1.4	1.3	5.76–7.6% ^{235}U
Storage areas – Building 7920	Unknown	5	0.48% ^{235}U
Tower Shielding Reactor (TSR) fuel	182	9.2	93.15% ^{235}U
Health Physics Research Reactor (HPRR) fuel	204	184	93.14% ^{235}U
Space Nuclear Auxiliary Power-(SNAP-)10A Reactor	Unknown	5	93.29% ^{235}U
DOE Demonstration Reactor fuel	Unknown	2	90–93% ^{235}U

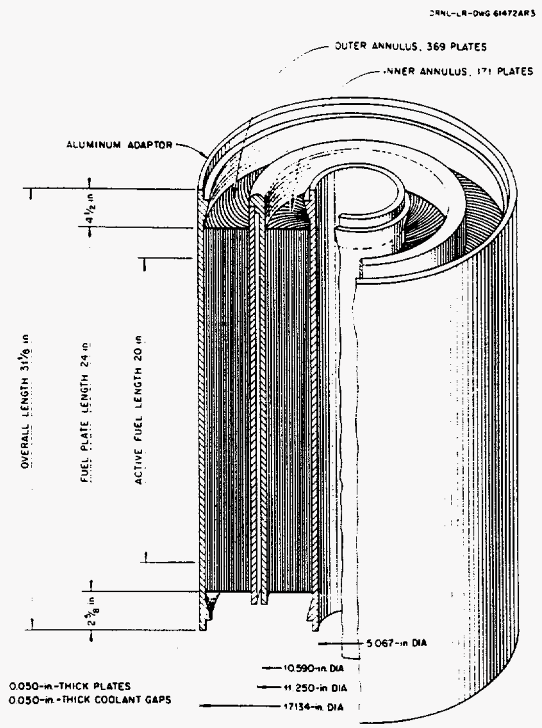


Fig. 1. HFIR fuel element.

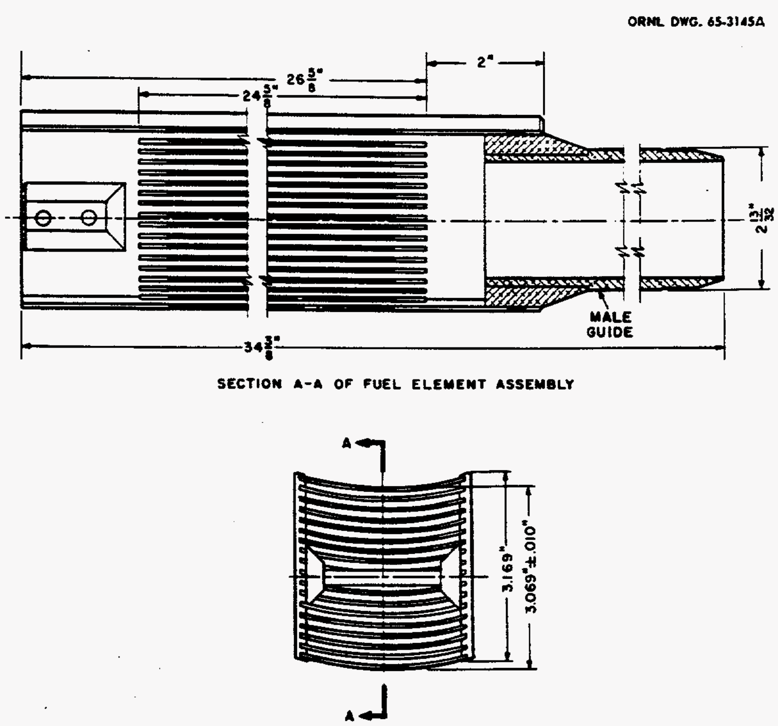


Fig. 2. BSR/ORR fuel element.

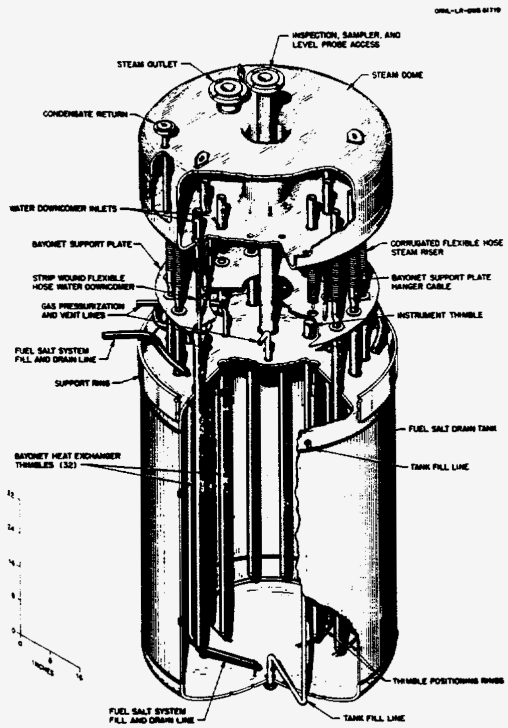


Fig. 3. MSR fuel-salt storage tank.

Fig. 4. HRE reactor vessel.

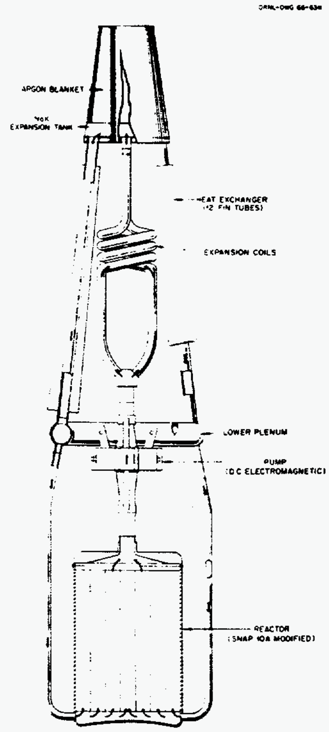


Fig. 5. SNAP-10A reactor.

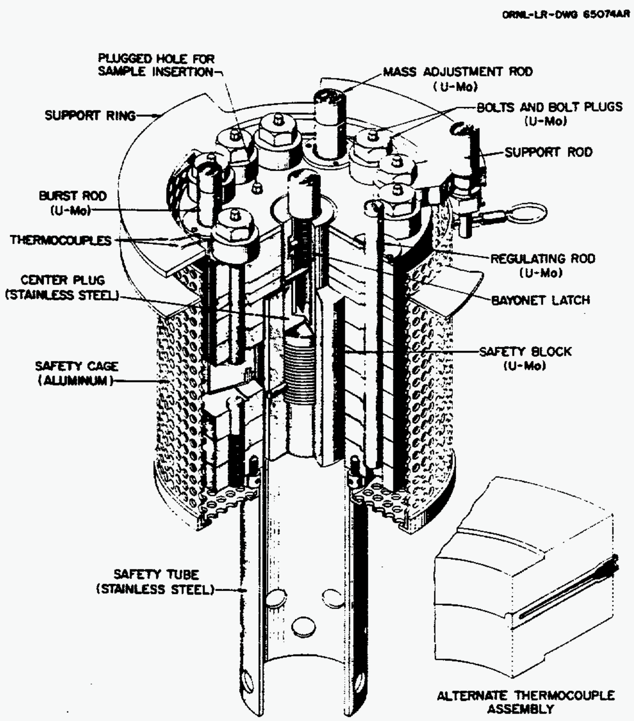
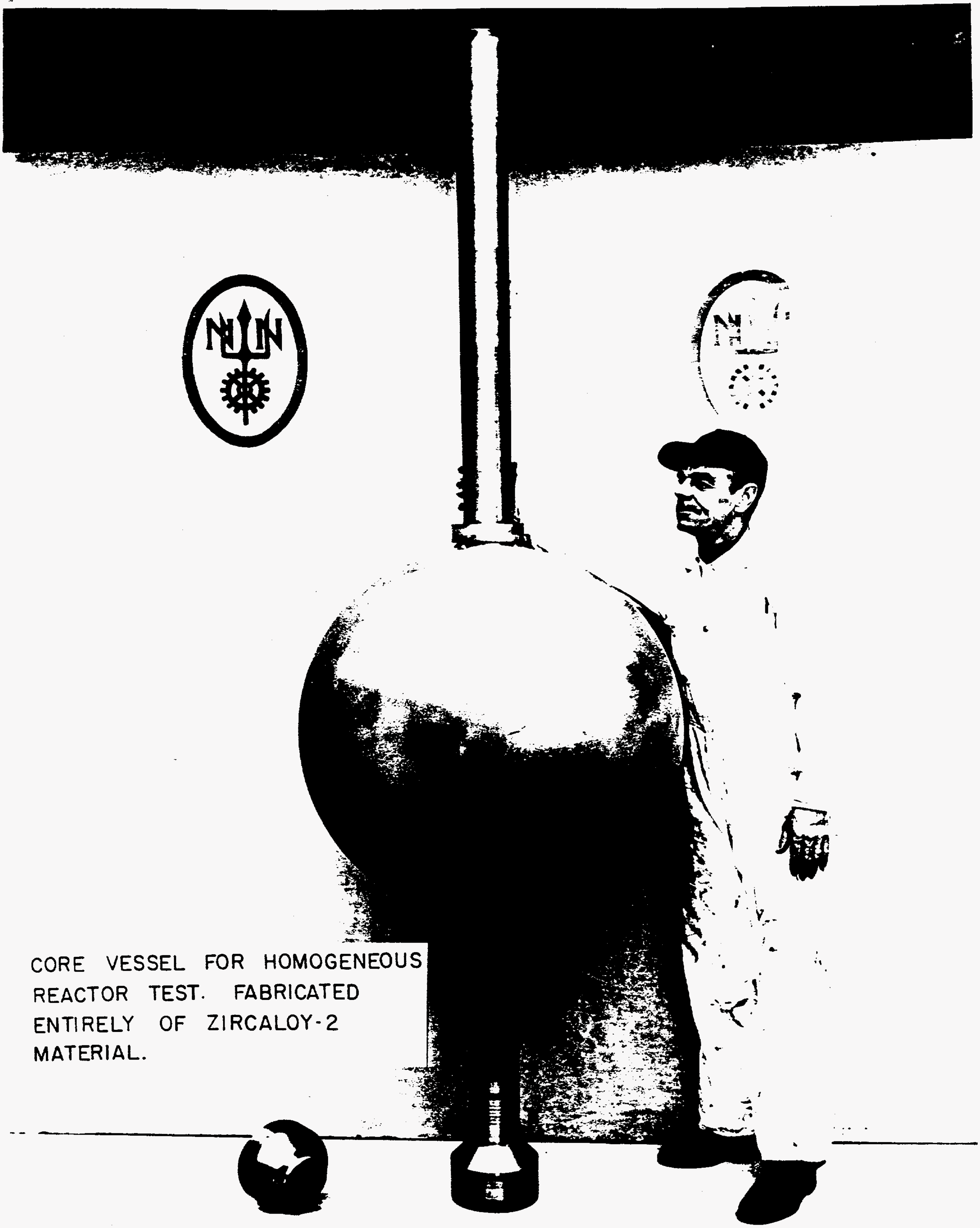


Fig. 6. HPRR.



CORE VESSEL FOR HOMOGENEOUS REACTOR TEST. FABRICATED ENTIRELY OF ZIRCALOY-2 MATERIAL.