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Informal Report

SAFETY ANALYSIS REPORT ON PACKAGING

EVALUATION OF THE HFBR FUEL SHIPPING
CASK VERSUS REQUIREMENTS OF ERDAM 0529

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PACKAGE DESCRIPTION

(a) Cask Description

The HFBR Spent Fuel Shipping cask, Model No. BR 63-0101, DOT No. 5608, is a lead filled 304 stainless steel weldment, 49-3/4 in. long by 30-1/8 in. wide and 49-1/4 in. high. The original cask had a 1/2" thick wall, 5/8" thick bottom plate and a 1" thick top plate. The cavity is formed by 3/8" thick plate. See Fig. 1(a). The first modification to the cask was the addition of a collar 2-1/2" high by 3-1/2" wide framing the opening of the cavity in the cask top. This collar is welded and bolted to the cask top. The cover is now bolted to this collar rather than the cask top itself. An additional spool piece 2" x 2-9/16" is laid on the step in the cavity to occupy the void that would have resulted from raising the cover to accommodate the longer fuel elements. The cover is fabricated from 1" thick plate to which the 3/8" thick bottom and sides are welded. This welded assembly encases the lead. See Fig. 1(b).

The present modification is aimed at the removal of the fillet weld joining the shell sides to the top plate and replacing it with a full penetration weld following the recommendations of the Cask Designer's Guide ORNL-NSIC-68.

A structural member with an "L" shaped cross-section will be added to the upper portion of the cask. This member will be joined by means of full penetration welds to the 1/2" thick side walls and collar. The space between this member and the original top surface will be filled with lead and steel. See Fig. 1(c). In order to obtain a high strength weld between the structural member to be added and the sides of the cask, the original closure fillet weld must have complete heel fusion since it will be used as a base for the new weld.

This entire fillet weld will be examined ultrasonically to determine the extent of heel fusion. A sample of the welded joint was duplicated and a section of the weld was machined away exposing the corner of the two pieces. This unwelded corner was then used as a defect for calibrating the ultrasonic equipment. The "V" shaped sample had end plates welded to it to form a trough and this assembly was then heated and filled with molten lead. The section of weld that was removed was rewelded with the lead backing to show that this method of weld repair is practical. The sample was then reinspected ultrasonically. No indication of heel non-fusion was detectable showing that this method of providing a full penetration weld between the added structural member and the sides of the cask is feasible.

The HFBR cask is a type B package, Fissile Class III, shipped by exclusive use of vehicle and having a Transport Index of 3.5. It is a stainless weldment, lead filled with internal fins for heat transfer and gusseting for strength. Externally, a skirt is supplied for positioning and ears for crane lifting with a custom lifting yoke. The cover is equipped with a lifting eye which will be secured when the cask is offered for transport. The cask cavity contains one step, upon which a 2" thick stainless steel collar rests. The cover bottoms on the collar. The cavity has a syphon line from its bottom to the cask tap, pipe-plugged when shipped, for pumping out. The cover has a vent line running through it. The cavity contains the fuel loaded in three boron-stainless steel baskets. The cover vent line is fitted with a T with a 10 psi relief valve on one arm of the T with a 1/4" needle valve on the other.

Heat is dissipated by conduction and convection, air being the only coolant required.

Sampling ports per se are not supplied but samples conceivably could be taken through the vent or syphon line.

The cask ears (see above and page 12) may be used as holding points for tie down bridles as well as lifting devices.

The cask contains fuel and fission products in solid form of Transport Group III. The cask may be used for the shipment of any special form material for which the cask shielding and thermal characteristics are safe.

The cask after modifications will weigh 25,734 lbs. unloaded, and 25,981 lbs. with fuel and baskets loaded. The number used in the calculations for the weight is 26,000 lbs. Total lead weight in the cask and cover is 22,489 lbs.

Drawings for the cask and modifications are appended. These include BR 63-0101-1-5B, BR 63-0101-2-4A, BR 63-0101-7-5A, and ME 12.2-1-5.

The cut fuel units are carried in 1.3% boron alloyed stainless steel compartmental baskets. Two four-element baskets and one six-element basket along with 14 elements comprise one cask load. The baskets weigh 30 and 45 pounds respectively. The drawings for the Baskets, BR 62-0102-0-4B and BR 62-0103-0-4A are appended.

(b) Description of Contents

The radioactive constituents are fission products produced by the fission of U^{235} . The radioactivity is about 4.5×10^5 curies at 270 days cooling, after operation at 60 Mw.

The fissile constituent is U^{235} . The usual quantity will be in the order of 2700-2900 grams for an average shipment. It may be as high as 4025-4150 grams for a shipment of fuel that has only been in the reactor for a short time, with about 5% burn-up. This would not be normal, but might be necessitated by some malfunction of reactor equipment.

The fuel plate and element assembly are completely described in an Appendix A which has been filed with Savannah River Operations Office. A copy of this is appended, along with a supplement issued December 15, 1970.

The cask is shipped dry; reflection is non-existent. The baskets in which the cut elements are stored contain boron.

The maximum weight of 14 cut fuel sections is 64,500 grams, of which 4,410 grams is U^{235} . This would be for a shipment with no burn-up. The above mentioned Appendix A may be consulted for amount and identity of non-fissile absorbers.

The maximum decay heat is in the range of 900-1000 watts. The fuel is cooled for approximately 270 days after discharge from the reactor, before shipping, under a normal routine.

Drawings for the Fuel Element Plates and Fuel Element Assembly, BR 51-0400-1-4A and BR 51-0400-0-5B respectively are appended.

AEC 0529 PART II PACKAGE STANDARDS

II A General Standards For All Packaging

IIA1 The HFBR cask is a 304 stainless steel weldment filled with lead. The fuel baskets are constructed of 1.3% boron-stainless steel alloy. The fuel elements are clad with 6061 aluminum alloy. In over 10 years of experience in shipping these casks in some 80 shipments no significant reaction, chemical or galvanic, has been noted.

IIA2 The cover is secured by 12 bolts 3/4 - 10 by 1" tapped length and weigh 2,072 pounds so that inadvertent opening is extremely unlikely. The cask is shipped by truck trailer with exclusive use of the vehicle. Seals are used to detect tampering.

IIA3A The lifting devices on the package are capable of supporting three times the weight of the cask without generating stress in excess of the yield strength of the material providing a lifting yoke with 4" width at ear is employed. The cask is provided with two lifting ears. Cask weight with cover is 25,734 lb., contents weight is 247 lb. for a total weight of ≈ 26000 lbs. As required by this section, each lifting ear must support $\frac{(26,000)(3)}{2} = 39,000$ lb.

A sketch of the lifting ear detail with calculations is shown in Fig. 2. The calculation is for a lifting device with a width of 4" at the ear.

Section at Pad-Ear

Taking the conservative assumption that the 3/8 in" strap carries no load and therefore the ear acts as a cantilever beam.

(a) Shear Stress

$$\tau = \frac{P}{A} = \frac{39,000}{6} = 6500 \text{ psi}$$

(b) Bending Stress

$$S = \frac{MC}{I}$$

$$M = 2 P = 78,000 \text{ in lb.}$$

$$S = \frac{78,000 (2)}{8} = 19,500 \text{ psi}$$

(c) Maximum Principal Stress

$$S_{\max} = \frac{S}{2} + \left[\left(\frac{S}{2} \right)^2 + \tau^2 \right]^{1/2}$$

$$S_{\max} = 9,750 + [(9750)^2 + (6500)^2]^{1/2}$$

$$S_{\max} = 21,470 \text{ psi}$$

$$S_{\max} < 30,000 \text{ psi yield stress } \therefore \text{ No damage}$$

Section at Pad-Shell

This pad is attached to the shell by a 3/8 in. fillet weld.

$$\text{Area weld} = 2(\pi)(6.5)(0.375)(0.707) = 10.83 \text{ in.}^2$$

$$I \approx \frac{\pi[(6.5) + (0.375)(0.707)]^4 - (6.5)^4}{64} = 15.2 \text{ in.}^4$$

(a) Shear Stress

$$\tau = \frac{P}{A} = \frac{39,000}{10.83} = 3600 \text{ psi}$$

(b) Bending Stress

$$M = 2.875(P) = 112,125 \text{ in.-lb.}$$

$$S = \frac{MC}{I} = \frac{112,125(3.52)}{15.2} = 25,966 \text{ psi}$$

(c) Maximum Principal Stress

$$S_{\max} = \frac{S}{2} + \left[\left(\frac{S}{2} \right)^2 + \tau^2 \right]^{1/2}$$

$$S_{\max} = 12,983 + \left[(12,983)^2 + (3600)^2 \right]^{1/2}$$

$$S_{\max} = 26,456 \text{ psi} < 30,000 \text{ psi yield stress}$$

(d) Maximum Shear Stress

$$\tau_{\max} = \left[\left(\frac{S}{2} \right)^2 + \tau^2 \right]^{1/2}$$

$$\tau_{\max} = 13,473 \text{ psi} < 20,000 \text{ psi shear yield stress}$$

Shell Stresses

The shell stresses will be below those calculated for the pad since the full 1/2 in. shell thickness will function.

IIA3b The lifting devices on the cover are capable of supporting three times the weight of the cover without generating stress in excess of the yield strength of the material. Cover Weight is 2,155 lbs. Dimensions of lift are shown in Fig. 3.

Tearing of Strap at Top

$$A = 3/4 \times 1.5 = 1.125 \text{ in}^2$$

$$S = \frac{2155 \times 3}{1.125} = 5,750 \text{ psi}$$

NOTE: Design load taken as 3x the weight of the lid.

Weld Area at Base - Neglecting side reinforcing plates

$$10 - 3 - 2(3/4) = 5-1/2 \text{ in. length}$$

$$\text{Area} = (5-1/2)(3/8)(2)(.707) = 2.92 \text{ in}^2$$

$$S = \frac{3P}{A} = \frac{3(2155)}{2.92} = 2,210 \text{ psi} < 30,000 \text{ psi YIELD}$$

IIA3c The cover lifting device will be covered during shipment to preclude its use for lifting the cask.

Although the cask cover bolts will withstand the three times cask weight loading the cover strap will not. An aluminum cover device will be installed over the cask cover yoke prior to transportation.

IIA3d Failure of the lifting devices will not impair the containment or shielding properties of the package because yield will occur in the lifting device at a lower load than that required to fail the junction with the shell. See calculation IIA3b.

IIA4a No tie-down devices integral or permanently fixed to the cask are supplied. Tie down is made with two 3/4 inch and two 5/8 inch wire ropes basket hitched around the cask and fixed to the truck bed as shown in Figure 4.

Since the tie-down system is not an integral part of the cask, it need not comply with the 10W-5W-2W criteria. The calculation below is supplied to show that no cask damage will result if the tie down cables are loaded to their maximum.

The cask lifting ears act as a pivot for the cables. The maximum possible ear loading occurs when each cable reaches its breaking strength. The breaking strength of high strength haulage cable of 3/4 in. dia. is 44,000 lbs. and of 5/8 in. dia. is 32,000 lbs.

The lifting ear loading is shown in Figure 5.

$$R = 2 \left[\frac{40}{108} (44,000) + \frac{40}{55} (32,000) \right] = 79,000 \text{ lb}$$

and the generated shear stress is

$$\tau = \frac{R}{A} \quad A = 6 \text{ in}^2$$

$$\tau = \frac{79,000}{6} = 13,167 \text{ psi}$$

The bending stress

$$S = \frac{MC}{I} \quad M = 3/8 (79,000) = 29,600 \text{ in. lb.}$$

$$I = 8 \text{ in}^4$$

$$S = \frac{(29,600)(2)}{8} \quad S = 7,400 \text{ psi}$$

The maximum principal stress

$$S_{\max} = \frac{S}{2} + \left[\left(\frac{S}{2} \right)^2 + \tau^2 \right]^{1/2}$$

$$S_{\max} = 17,377 \text{ psi (allowable} = 30,000)$$

IIA4b The cover lift is covered when the package is offered for shipment.

IIA4c Not applicable. There is no tie down device which is a structural part of the cask.

IIA5 A maximum transport index of 3.5 is permissible with this cask. Dose rates at three feet from an accessible surface have been on the order of 2 to 3 millirem/hour.

IIB Structural Standards for Type B and Large Quantity Packaging.

IIB1 Regarded as a simple beam supported at its end the package is capable of withstanding a static load, normal to and uniformly distributed along its length equal to 5 times its loaded weight without generating any stress in excess of the material's yield strength.

The thickness of the outer shell of the cask varies from 1/2 to 1 inch. In evaluating the structural resistance to uniform load the cask shell thickness will be conservatively taken as 1/2 inch. The uniform load will be assumed to act against the cask side; against the weakest cask section. Considering only the outer shell steel to resist the load, the section is shown in a of Figure 6. Ignoring the angled sections the strength calculation will be based on the section shown in b of Figure 6. The moment of inertia about x-x is then

$$I_{x-x} = 2 \left[\frac{36 (1/2)^3}{12} + 36 (1/2) (15)^2 + \frac{1/2 (18 \cdot 1/2)^3}{12} \right]$$

$$I_{x-x} \approx 8,628 \text{ in.}^4$$

The required uniform loading is $5W$ with the cask treated as a simply supported beam. The cask height is approximately 48 inches therefore the maximum stress is:

$$W \approx 26,000 \text{ lb (cask + contents)}$$

$$M = \frac{5Wl}{8} = \frac{5(26,000)48}{8} = 780,000 \text{ in. lb.}$$

$$S = \frac{MC}{I}$$

$$S = \frac{780,000 (15.5)}{8,628}$$

$$S = 1,400 \text{ psi} < 30,000 \text{ psi yield}$$

IIB2 Packaging is adequate to assure that there will be no loss of containment if subjected to an external pressure of 25 psig.

The bottom of the cask is probably the more critical since this plate is welded to the side plates with fillet welds. Its area is 1422 sq. in. for a load of 35,800 lbs. Assuming only the outer $3/8$ in. fillet weld to support this load we have for 143 in. weld length

$$S = \frac{35,800}{.375(.707)(143)} = 944 \text{ psi} < 30,000 \text{ psi yield}$$

IIC CRITICALITY STANDARDS FOR FISSILE MATERIAL PACKAGES

IIC1a,b Normal Conditions

The original criticality evaluation of the HFBR Spent Fuel Shipping Cask was done for type KD fuel elements containing 274 grams U-235. This

evaluation was substantiated by a critical experiment which mocked up two shipping casks, side by side, each with 14 unirradiated fuel elements in boron-stainless steel baskets and immersed in water. (See memorandum from K. Downes to R. W. Powell, dated 6/4/64, Criticality Test of HFBR Shipping Casks; Appendix B.) The results of these tests showed the k_{eff} to be less than 0.9, and probably between 0.5 and 0.75.

Criticality calculations were done for the HFBR Spent Fuel Shipping Cask with type KL fuel elements containing 315 grams U-235. (See memorandum from Hans Ludewig to Files, dated 11/16/70, Criticality Calculations Relative to Storage of the New HFBR Fuel Elements, Type KL -315 grams U-235, Appendix B.) In this case, the computed value of k_{eff} was 0.43. This result is considered to be in good agreement with the earlier critical experiments since values of k_{eff} in such low ranges are subject to considerable interpretation.

Current modifications to the HFBR Spent Fuel Shipping Cask will have no effect on criticality consideration since there are no changes to the inner structure, and only minor changes to the outer structure. Therefore, the criticality evaluations of 6/4/64 and 11/16/70 are still valid, and assure that the shipping cask is substantially subcritical with either KD or KL fuel elements, and in either dry or flooded situations.

IIC2 Not applicable as the cask contains no liquid contents.

IID Prior shipments of this cask show that it conforms to this section. See Sections E and F and calculations in Annexes 1 and 2.

IIE Standards for normal conditions of Transport for a Single Package.

IIE1a The cask is gasketed and sealed. Additionally the fuel is clad in aluminum and therefore release of radioactive material is highly unlikely.

IIE1b These casks have been used to make approximately 80 successful shipments to date and no decrease in shielding or evidence of deterioration or cracks has been experienced.

IIE1c The only gas in the casks is air, which precludes an explosion.

IIE1d The activity of the air in the cask has been monitored several times and averages 3×10^{-10} curies per cm^3 .

IIE1e Air is the only coolant for these casks.

IIE2a The package is sub-critical. (See Part II C)

IIE2b The geometric form of the package contents is maintained by the compartmented fuel baskets in normal conditions of transport.

IIE2c In leakage of water will not change criticality evaluations since maximum reactivity has been assumed.

IIE2d1 The effective volume of the system is not considered in evaluating nuclear safety. Therefore this section is not applicable.

IIE2d2 Nuclear safety evaluations for this cask are based on retention of boron-stainless steel basket integrity. Under Hypothetical Accident Conditions the basket retains its integrity. Therefore no change in nuclear safety will occur under normal conditions. (See Annex II, 1 Free Drop)

IIE2d3 Under Hypothetical Accident Conditions no aperture capable of passing a 4 inch cube is possible. Therefore under these less stringent conditions it is also not possible. (See Annex II, 2 Puncture)

IIE3 The aluminum cladding of the fuel is the containment vessel. Rupture of this would vent into the cask cavity, not into the atmosphere. Compliance with this section precludes the shipment of a leaking element. Leakers must be encapsulated with a containment shown to comply with 0529.

IIF Standards for Hypothetical Accident Conditions for A Single Package.

IIF1a The cask will meet the limit of 1000 mr/hr at three feet after the sequence of hypothetical accident conditions. Calculations indicate that after the 30 foot drop on a corner a dose of 970.6 mr/hr will prevail. (See Hypothetical Accident Conditions, Annex II)

IIF1b Total activity of the cask load is 4.5×10^5 curies of mixed fission products. .1% of this is 450 curies. The air in the casks contains about 25 micro curies, as measured, which is much less than the 450 curies criteria.

IIF2 Accident Conditions

The package as designed and modified, after the hypothetical accident will be subcritical. Tests conducted by K. Downes and calculations by Hans Ludewig (see IIC Criticality, Appendix B) indicate that as long as the initial geometry of sources and basket is maintained the package will remain subcritical. We have shown through calculations (1.C.3 Drop Effects on Cask Internals) that no gross deformation to sources or basket will occur during the hypothetical accident therefore the cask will remain subcritical even if the cask is flooded and subjected to close reflection by water.

IIF2a As shown in 1.C.3 (page 35) Drop Effect on Cask Internals, the fuel elements and the boron-stainless steel baskets will incur localized damage but no gross deformation of the elements nor collapse of the baskets is expected. Therefore the package will maintain its subcriticality after the hypothetical accident. (See Section IIC Criticality.)

IIF2b,c Water moderation and close reflection by water do not significantly change the subcriticality of the package after the hypothetical accident since the cask internals have suffered only localized damage and the experimental results (Downes memo) are still valid which indicate that criticality will not be reached.

IIG Not Applicable. Exclusive use of vehicle is used for shipment of each cask.

IIH Not Applicable.

III Not Applicable.

IIJ Specific Standards for a Fissile Class III Shipment

IIJ1,2 As long as the boron-stainless basket retains its integrity criticality cannot be reached regardless of flooding. A mock-up of two loaded baskets under water was made to ensure the sub-criticality of this configuration. (See Appendix B, K. Downes memo.)

PART III QUALITY ASSURANCE

The fabrication of the two spent fuel shipping casks was completed before the present requirements for quality assurance were added to the regulations. The casks were built to the standards prescribed by the ASME Boiler and Pressure Vessel Code, and the procedures followed were the accepted engineering practices of the day. Approximately 80 shipments have been made successfully with these casks so they have withstood the evidence of satisfactory service.

The original cask welding was performed at P. F. Avery Co. by two certified welders. Prior to construction, the two welders each prepared a double welded T section of half inch plate. These were radiographed and found acceptable using the ASME code as the acceptance standard. A one inch coupon cut from the middle of each test piece was polished and etched and upon metallographic examination the welds showed good uniformity and penetration. Welding procedures for the cask called for shielded metal arc passes with the final pass being tungsten gas shielded arc (Heliarc). All welds were checked by the dye penetrant method, pressure tested at 10 psig and checked for leaks.

The available original cask documentation and subsequent pertinent operating information has been assembled and is maintained in an auditable file by the BNL Isotope and Special Materials Group. Cask modification records are maintained by the BNL Reactor Division Special Projects Coordinator. The following documentation of original cask fabrication is presented in Appendix C:

- a. Manufacturing Procedure & Quality Control Check-off List
- b. Welding Record
- c. Radiograph Examination Record

The BNL Reactor Division has a program of routine maintenance inspection and retesting of casks to assure that the containers do not deteriorate with use.

The casks are inspected prior to each fuel loading utilizing the "Reuse Inspection of HFBR Fuel Cask" check off sheet. Also, on a regular basis as prescribed by an HFBR Tickler Card, the casks are given a thorough overall inspection which includes liquid dye penetrant tests and a check of the pressure relief valve setting. Typical copies of these forms are included in Appendix C.

The latest modification and any future modifications to the HFBR fuel cask will be executed in accordance with guidelines for quality level II components, as detailed in the BNL Reactor Division's Quality Assurance Manual. A copy of this manual is on file with the ERDA Brookhaven Area Office.

Fabrication details and documentation for the latest modification can be found in the BNL Reactor Division Reactor Modification Approval Form folder No. 75-6. The Quality Assurance Procedures section of that form is included in Appendix C.

PART IV OPERATING PROCEDURES

IVA Establishment and Maintenance of Procedures

IVAla The shipper has established and maintained operating procedures to assure that the determinations and controls required by this appendix are accomplished. (See Appendix D.)

IVAlb Regular and periodic inspection procedures are adequate to assure that the shipper follows the procedures required by these regulations.

IVB Not applicable.

IVC Not applicable.

IVD Routine Determinations

A check-off list titled "Spent Fuel Shipment Data Sheet" and a "Fuel Shipment Survey" covering all pertinent points of this section are executed for each shipment. Blank and executed reports typical of one shipment are appended (Appendix D).

IVE Records

The shipper maintains records to comply with this section.

IVF Documentation

It is not expected that these casks will be used except by the originator. Therefore documentation required by this section will not be prepared.

ANNEX I NORMAL CONDITIONS OF TRANSPORT

(EVALUATION OF THE CASK UNDER THE CONDITIONS OF AECM-0529 ANNEX I)

1. Heat - Direct sunlight at an ambient temperature of 130°F. This calculation will be made in accordance with the data and techniques presented in the "Cask Designer's Guide." For the purpose of estimating the solar heat input, the cask will be considered a rectangular solid with dimensions 50" long x 30" wide x 51" high, with a surface emissivity of 0.8, located with its long axis east-west. The data for incident solar heat flux at noon (BTU/HR-FT²) at 42°N latitude are: 310 at top, 125 at south side, 40 at east and west side and 25 at north side. The solar heat input is then:

$$\frac{1}{144} [310(50)(30) + 125(50)(51) + 25(50)(51) + 2(40)(30)(51)] = 6735 \frac{\text{BTU}}{\text{HR}}$$

To this must be added the decay heat load of 1200 watts or 4096 BTU/HR. Dividing by the cask outer surface area, the heat flux from the cask surface to ambient is,

$$\phi = (6735 + 4096) \frac{1}{59.5} = 182 \frac{\text{BTU}}{\text{HR-FT}^2}$$

This heat is transferred by a combination of radiant and convective heat transfer. That is:

$$\phi = (h_r + h_c) (t_s - t_a)$$

Values for the radiant and convective heat transfer coefficients, h_r and h_c , as a function of temperature are provided in Figure 5.5 of the Cask Designers Guide. As the cask surface temperature is in fact the unknown, the problem is solved by trial and error. A surface temperature is assumed, corresponding h_r and h_c values taken from the figure, and the surface temperature solved for. By this process the cask surface temperature was found to be 209°F for the 130°F ambient. The corresponding values of h_r and h_c were 1.39 and .82 respectively.

A conservative estimate of the corresponding cask interior temperatures may now be obtained if it is assumed that the temperature differences that exist at normal ambient conditions persist at these conditions. The normal temperature profiles are presented in the thermal section of Annex II. They are: surface temperature of 108°F, inner surface temperature of 125°F, average element temperature of 240°F and a peak element temperature of 271°F. Increasing all of these by the difference (209-108) = 101, the cask temperatures at 130°F ambient plus polar are:

Cask surface	= 209°F
Cask inner surface	= 226°F
Average element	= 341°F
Peak Element	= 372°F

These temperatures pose no difficulties.

2. Cold.

The cask temperature profile corresponding to an ambient temperature of -40°F can be obtained by using the normal condition temperature differences,

that is reducing all normal condition temperatures by $(80 - (-40)) = 120^{\circ}\text{F}$. The temperatures are:

Cask surface	= -12°F
Cask inner surface	= 5°F
Average element	= 120°F
Peak element	= 151°F

These temperatures pose no difficulties.

3. Pressure

The cask weldment, the cavity weldment, and the completed cask structure were routinely pressurized to 10 psig during construction to check for porosity in the welds. The cask has met this requirement.

4. Vibration

The casks have been used for fuel shipments with the present 22-1/2" cut fuel assemblies. As of May, 1974, about 40 shipments of each cask have been made. Inspection has revealed no detectable damage.

5. Water Spray

No damage would occur to the cask. It is sealed and gasketed so no water would leak into the cavity. Before shipment the cask is routinely scrubbed externally with water and a soap detergent and hosed down. This procedure is usually repeated twice before release of the cask for shipment.

6. Free Drop - Dropping on the bottom corner:

Dropping from a height of two feet:

$$\text{Kinetic Energy} = 26,000 \text{ lbs.} \times 24 \text{ ins.} = 624,000 \text{ in. lbs.}$$

Figure 7 shows drop energy vs. corner lead deformation for a flow pressure of lead = 6000 psi. From the figure for KE = 624,000 we read a deflection or crush of 3.6 in. With this deformation the remaining through corner lead thickness exceeds 10", the side wall thickness. No loss of shielding effectiveness will occur.

7. Corner Drop

Not applicable to this cask since its weight is over 10,000 lbs.

8. Penetration

Evaluation for this requirement was made by an actual drop test. No significant damage was sustained by the 1/2 inch plate.

9. Compression

Not applicable since the cask weighs more than 10,000 lbs.

ANNEX 2 HYPOTHETICAL ACCIDENT

1. Free Drop

1.a It is expected that maximum deformation would occur in a bottom corner impact with the cask striking at a 45° orientation to the unyielding surface. In this orientation the line through the corner to the center of gravity is approximately normal to the impact plane so maximum deflection of the corner should result.

A graphical layout was made to determine the volumes of lead displaced as the impact plane moved towards the C. G. and plotted (see Figure 7). Using a gross cask weight of 26,000# the kinetic energy to be absorbed is

$$KE = 26,000\# (30 \text{ ft.}) (12 \frac{\text{in.}}{\text{ft.}}) = 9.36 \times 10^6 \text{ in.}\#$$

Therefore the deformation would equal 9.85 inches. The distance from the corner of the cask to the corner of the cavity is 16.7 inches, of which 15.7 inches are lead and the remainder stainless steel. Subtracting the loss due to deformation from the original distance we have 6.85 inches remaining. This will suffice to meet the post accident shielding requirements of 1000 mr/hr at 3 feet. (See shielding section.)

Top corner drop results in a deformation of 2.58 in. It is different from the bottom corner drop in that the cask top surface is very rigid. The calculation for top corner drop follows (1.b).

Deformation for other drops were calculated and results are as follows:

Bottom Drop deformation is	1.15 inches
Side Drop deformation is	.87 inches
Short Side Drop deformation is	1.87 inches
Top Drop Deformation is	1.72 inches

In all of the previous calculations the value of 6000 psi for the flow pressure of lead was used, and no credit was taken for the energy absorbed in deforming the stainless steel shell. Therefore all of the previous deformations were calculated conservatively.

The dynamic flow pressure of lead was taken as 6000 psi, a value 20% greater than the Cask Designers Guide recommendation of 5000 psi. The rationale for adopting the higher value is as follows:

In all drop calculations no specific accounting was taken for the energy absorbed in deforming the outer stainless steel cask shell. The Designers Guide sample calculation of a cylindrical cask side impact indicates that 76% of the drop energy is absorbed by the lead, 13% by the steel shell, and 11% by the cask ends. That is, almost 25% of the drop energy is absorbed in deforming steel, a quantity not to be neglected when combined with the conservative value of lead flow pressure recommended. The procedure adopted to account for steel deformations was simply to increase the flow pressure of lead 20% over the recommended value, from 5000 psi to 6000 psi. In the bottom corner impact orientation, the only impact orientation where lead deformation is critical, this procedure is considered conservative. For that orientation, the ratio of steel to lead volume deformed is greatest simply because of geometry. For other impact orientations, the use of a higher lead flow pressure results in higher g loadings and is again conservative.

1.b Cask Top Corner Impact

Reference to the included drawings will indicate that the cask upper surface is an extremely rigid structure made up of approximately 2 to 3 inches of steel with some lead filled voids. Consequently the deformations

incurred during impact on a top corner will be different from those predicted for bottom corner impact. In top corner impact, the rigid top structure will act as a load spreading member distributing the corner loading to the entire top surface lead. This action will reduce local lead deformations but result in higher "G" loadings. In the following calculation it will be assumed that in fact the top is perfectly rigid and therefore capable only of undergoing rigid body translations and rotations with the substructure lead then absorbing the impact energy. In reality the top steel will undergo some local deformations absorbing a fraction of the impact energy and lessening the gross lead deformations.

As indicated in Figure 8, the impact force can be resolved into x and y components. In fact transferring forces to the cask centerline we have $M = F_y \frac{L}{2}$ as shown in Figure 9. The force component F_y pushes the rigid top structure directly back crushing the lead behind it. Therefore

$$F_y = pA ,$$

where $A = 906 \text{ in}^2$, the net cross sectional area of top lead, $p = 6000 \text{ psi}$, lead flow pressure.

The moment then is given by

$$M = pA \frac{L}{2} ,$$

and from the geometry

$$F_x = F_y ,$$

The absorbed kinetic energy is then given by

$$E_{in} = F_y \delta_y + F_x \delta_x + M \theta ,$$

where θ is the rotation about point A.

The work component $F_x \delta_x$ represents a shear deformation of the top lead and cask side wall steel. As such it is difficult to estimate its magnitude and therefore it will be neglected. This assumption will lead to conservatively large estimates for the lead deformations caused by F_y & M (the deformations which result in maximum shielding loss).

Then

$$E_{in} = F_y \delta_y + M \theta$$

$$E_{in} = pA \delta_y + p A \frac{L}{2} \theta . \quad (1)$$

Again there seems to be no apparent way to assess the relative magnitudes of δ_y and θ . In this calculation it will be assumed that equal fractions of energy are absorbed by each force or

$$pA \delta_y = pA \frac{L}{2} \theta$$

$$\delta_y = \theta \frac{L}{2} , \quad \theta = \frac{2\delta_y}{L} ,$$

and therefore

$$E_{in} = 2 pA \delta_y , \quad \delta_y = \frac{E_{in}}{2pA} ,$$

and

$$\delta_{\max} = \delta_y + L\theta \quad (2)$$

$$\delta_{\max}^* = \delta_y + L \frac{2\delta_y}{L} = 3\delta_y$$

$$\delta_{\max} = \frac{3E}{2pA} = \frac{3(9.36 \times 10^6)}{2(6000)(906)} = 2.50 \text{ in.}$$

As indicated in Figure 10 the deformation in the direction of travel corresponding to $\delta_{\max}$ is $.707 \delta_{\max}$ or $\delta_g = 1.82 \text{ in.}$ With that deformation the remaining through corner lead thickness is still greater than 10", the side wall thickness. Therefore no loss of shielding effectiveness will result.

The forces F_x and F_y are

$$F_x = F_y = pA = 6000(906) = 5.45 \times 10^6 \text{ lb.}$$

Although the work done by F_x was neglected its effect on the cask shell will be evaluated. The force is resisted by the entire perimeter of outer shell steel ($134 \text{ in} \times 1/2 \text{ in} = 67 \text{ in}^2$), the perimeter of the cavity steel ($90 \text{ in} \times$

*If in Equation 1 δ_y is set to zero, and using (2) $\delta_{\max} = \frac{2E_{in}}{pA}$ if θ is

taken as zero, $\delta_{\max} = \frac{E_{in}}{pA}$.

$3/8 \text{ in} = 33.8 \text{ in}^2$), and the shear resistance of the cask top surface lead.

Calculating the maximum shear load this composite system will resist, we have

$$F_{\max} = \tau_S A_S + \tau_L A_L,$$

where

$$\tau_S = \text{shear strength steel} = 2/3 (80,000) = 53,400 \text{ psi},$$

$$\tau_L = \text{shear strength lead} = 2/3 (2400) \approx 1600 \text{ psi},$$

$$A_S = 67 + 33.8 = 100.8 \text{ in.}^2 \text{ area of steel},$$

$$A_L \approx 906 \text{ in.}^2 \text{ area lead},$$

$$F_{\max} = 53,400 (100.8) + 1600 (906) = 6.83 \times 10^6 \text{ lb.},$$

since $F_{\max} > F_x$, the cask should remain intact.

1.c Free Drop Supplementary Calculations

1.c.1 Top Drop

During top drop the cask lifting yoke is damaged beyond reuse but in its destruction no puncture into the cover lead may be permitted.

The yoke structure consists of 30 linear inches of $3/4 \text{ in.}$ thick plate welded to the 1 in. thick cover plate. Taking the crush strength of steel as $80,000 \text{ psi}$, and assuming no buckling occurs, the puncture load is

$$F = 30 (.75) (80,000) = 1.8 \times 10^6 \text{ lb.}$$

Resisting this load is the 1 in. thick cover plate. Assuming a shear mode of failure on the rectangle formed by the outer perimeter of the yoke

structure the shear stress developed in the plate is

$$\tau = \frac{F}{A}$$

$$A \approx 2(11 + 12.5) = 47,$$

$$\tau = \frac{1.8 \times 10^6}{47} = 38,300 \text{ psi}$$

which is below the max. shear strength of 53,400 psi and no puncture should occur.

Another possible action during top drop is the crushing of the cover bolt heads and consequent loss of closure. To prevent this a 1/2 in. thick. S.S. plate has been welded to the cover. The combined cross sectional area of the added plate (128 in²), the bolt heads (12 x 1.04 = 12.48 in²) and the lifting yoke (30 x 3/4 = 22.5 in²) provides sufficient crush strength to resist the loads applied during to drop as the following calculation shows:

The force acting on the cover during top drop is given by

$$F = p A_1$$

$$A_1 = 906 \text{ in}^2 = \text{area of top lead,}$$

$$p = 6000 \text{ psi,}$$

$$F = 6000 (906) = 5.436 \times 10^6 \text{ lb.}$$

The compressive stress generated in the top steel structure is

$$S = \frac{F}{A_{\text{Bolts}} + A_{\text{Yoke}} + A_{\text{Plate}}}$$

$$S = \frac{5.436 \times 10^6}{12.48 + 22.5 + 128} \approx 33,354 \text{ psi,}$$

Since the compressive strength of stainless steel is 80,000 psi bolt head crush will not occur. As is evident from the drawings, partial bolt head crush will occur before the other structure absorbs the load.

1.c.2 Side Impact

The possibility of shell puncture by the lifting ear during side impact will be evaluated.

The lifting ear is a 1 1/2 in x 4 in S.S. plate with a compressive strength of

$$F = S_u A$$

$$F = 80,000(6) = 480,000 \text{ lb}$$

This load is resisted by the 1/2 in. thick shell and by the 1 in. thick existing pad. The maximum shear strength of this composite, using $2/3(80,000) = 53,400$ psi as the maximum shear stress is then:

$$\begin{aligned} F_{\max} &= 53,400 (A_s + A_p) \\ A_s &= 1/2(2) (1.5 + 4) = 5.5 \text{ in}^2 \\ A_p &= 1(2) (1.5 + 4) = 11.0 \text{ in}^2 \\ F_{\max} &= 53,400 (5.5 + 11) = 881,100 \end{aligned}$$

Since $F_{\max} > F$ the lifting ear will not puncture the shell.

1.c.3 Drop Effect on Cask Internals

As shown, the cask proper will withstand the free drop accident condition. In the following calculations the impact effects on the individual fuel element assemblies and on the boron steel element basket assemblies are evaluated.

Summarizing the results, no gross damage to the fuel element assemblies nor gross collapse of the boron steel baskets is expected. Localized deformation or damage will occur but the specific magnitude of this is impossible to estimate. However, since the fuel is metallic no contamination hazard should result and only minimal effects on criticality are expected.

In the preceeding calculations the deformation for various impact orientations was determined. During these events the loading on the cask internals may be estimated by evaluating the average deceleration or "g" loading for each event. The "g" loading is given by

$$g(a)\delta = a (360)$$

a = acceleration due to gravity

$$g = \frac{360}{\delta}$$

360 = drop height

δ = deformation (in)

then

	δ	g
Bottom corner	9.85	37
Top corner	2.58	140
Short side	1.87	194
Long side	0.87	414
Top	1.72	209
Bottom	1.15	313

and the structure loading is wg.

1.c.3a Element Integrity (Drawing No. BR51-0400-1-4A and BR51-0400-0-5A)

1. Using $g = g_{\max} = 414$. Impact element axis parallel to surface. See Figure 11.

a) Fuel Plate (shown in Figure 12)

$$P = Wg = .050 \times .11 \text{ g} = .0055 \text{ g}$$

Shear Stress

$$\tau = \frac{PL}{A} = \frac{0.0055 \text{ g} (2.445)}{2(.05)} = .135 \text{ g}$$

and for $g_{\max} = 414$ $\tau \approx 56 \text{ psi neg.}$

Bending Stress

$$\sigma = \frac{MC}{I} = \frac{PL^2}{12} \times \frac{6}{t^2} = \frac{0.0055 \text{ g} (2.445)^2 (6)}{12 (.05)^2}$$

$$\sigma \approx 6.6 \text{ g}$$

$$\sigma = 6.6 (414) = 2732 \text{ psi neg.}$$

b) End Plate (shown in Figure 13)

$$P = .14 (.11) \text{ g} = .0154 \text{ g}$$

Shear

$$\tau = \frac{PL}{A} = \frac{0.0154 (2.445) \text{ g}}{2 (.06)}$$

$$\tau = 0.314 \text{ g}$$

$$\tau_{\max} = 130 \text{ psi neg.}$$

Bending

$$\sigma = \frac{PL^2}{12} \frac{6}{t^2} = \frac{0.0154(2.445)^2(6)g}{12(.06)^2}$$

$$\sigma = 12.79 \text{ g}$$

$$\sigma_{\max} = 5300 \text{ psi} \ll 30,000 \text{ psi allowed}$$

c) Buckling

(1) Fuel plates parallel to surface (see Figure 14).

Assume each side plate to support 1/2 wt. at its center

$$W'_{\text{tot}} \approx \frac{10 \text{ lb}}{\text{elem}} \frac{1}{24 \text{ in.}} = 0.416 \text{ lb/in.}$$

then

$$P = \frac{W' t g}{2} = 0.208 \text{ g}$$

Critical Load

P_{CR} for pinned ends

$$P_{\text{CR}} = \frac{EI\pi^2}{L^2} \quad I = \frac{bh^3}{12} = \frac{1(.187)^3}{12} = 5.4 \times 10^{-4}$$

$$P_{\text{CR}} = \frac{(10 \times 10^6) (5.4 \times 10^{-4}) (3.14)^2}{(3.194)^2} = 5240 \text{ lb}$$

$$@ 414 = g \quad P = 0.208(414) = 86 \ll 5240.$$

(2) Condition one rotated 90° (shown in Figure 15)

In this case assume each fuel plate supports its share where $P = W_{\text{tot}} g$.

Plates having curvature have bending stresses developed. I.E.: (shown in Figure 16)

$$P = W_t g \frac{1}{N} = \frac{.416g}{17} = .0244g$$

$$\sigma = \frac{MC}{I} = \frac{6M}{t^2} = \frac{6(.0244)(.166)g}{(.04)^2}$$

$$\sigma = 15.14 g$$

$$\sigma_{\text{max}} = 6268 \text{ psi} \ll 30,000 \text{ psi allowed}$$

(3) Element normal to surface (shown in Figure 17)

Taking $P = W_t g$, supported only by box section formed by outer plates

$$P_{\text{CR}} = \frac{1}{4} \frac{EI \pi^2}{L^2}$$

$$I = \frac{(3.194)(2.82)^3 - (2.914)(2.445)^3}{12}$$

$$I = 2.44 \text{ in.}^4$$

$$P_{\text{CR}} = \frac{1}{4} \frac{(10 \times 10^6)(2.44)(3.14)^2}{(12)^2} \approx 4.18 \times 10^5 \text{ lb.}$$

and for

$$g = 414$$

$$P = 10(414) = 4140 \ll P_{\text{CR}}$$

1.3.3.b Basket Integrity (Drawing No. BR62-0102-0-4B and BR62-0103-0-4A)

Fuel element consolidation will occur if basket welds fail or if basket structure buckles. Checking weld strength as shown in Figure 18.

$$P = W_e g$$

$$W_e = 10 \text{ lb, element wt.}$$

and assuming the egg crate connection to have the same strength as the weld, the weld shear force is

$$P_w = \frac{P}{2} = 5 g .$$

The weld shear stress is

$$\tau = \frac{P_w}{a}$$

$$A = 2(1 \frac{1}{2})(3/32)(.707) = .199 \text{ in.}^2$$

and using maximum $g = 414$

$$\tau = \frac{5(414)}{.199} = 10,400 \text{ psi} < 20,000 \text{ psi allowed}$$

and welds should resist loading.

The two impact orientations that could lead to basket buckling are short side and long side impact. Consider short side impact (shown in Figure 19) where

$$P = (W_{\text{mid}} + W_{\text{upper}})g = 177 g ,$$

then the buckling load on center web is

$$F = \frac{1}{2} W_{low} g + \frac{5P}{8} = \frac{70}{2} g + \frac{5}{8} (177) g = 146 g$$

or

$$F = 146 (194) = 28,324 \text{ lb} .$$

The critical load for the center web is

$$P_{CR} = \frac{2\pi^2 EI}{L^2}$$

The coefficient 2, taken to indicate end fixity is between fixed and pinned,

$$I = \frac{22(.125)^3}{12} = 3.584 \times 10^{-3}$$

$$P_{CR} = \frac{2(\pi)^2 (29 \times 10^6) (3.584 \times 10^{-3})}{(6.875)^2}$$

$$P_{CR} = 43,400 \text{ lb}$$

Since $F < P_{CR}$, buckling should not occur.

Corner Weld Shear

$$\tau = \frac{3P}{16 A} = \frac{33.188(194)}{.707(3/32)(7)} = 13,877 \text{ psi} < 20,000 \text{ psi allowed.}$$

Short side impact should not lead to collapse.

Long Side Impact (shown in Figure 20)

where

$$P = \frac{1}{2} \frac{W_{\text{total}}}{3} g$$

$$W_{\text{tot}} = 247 \text{ lb} = \text{total wt. cask internals}$$

$$P = \frac{1}{2} \frac{(247)(414)}{3}$$

$$g = 414 \text{ long side impact}$$

$$P = 17,000 \text{ lb.}$$

The critical load is

$$P_{\text{CR}} = \frac{2 EI \pi^2}{L^2}$$

$$I = 3.58 \times 10^{-3}$$

$$P_{\text{CR}} = \frac{2 (29 \times 10^6) (3.58 \times 10^{-3}) (\pi)^2}{(3.75)^2}$$

$$P_{\text{CR}} = 145,700 \text{ lb.}$$

since $P \ll P_{\text{CR}}$, no buckling.

2. Puncture

Using 80,000 psi as the ultimate tensile strength and 26,000 pounds as the total cask weight the minimum shell thickness required according to Figure 2.2 page 18 of the Cask Designer's Manual is less than .5 inches. Using the formula

$$t = \left(\frac{W}{S} \right)^{.71}$$

where W = total weight

S = ultimate tensile strength

t = thickness

$$t = \left(\frac{26000}{80000} \right) .71 = .45 \text{ inches is required. The minimum thickness}$$

of the outer shell is .5 inches. Therefore the outer shell will not puncture.

3. Thermal

As of May 1974, a total of 80 fuel shipments have been made with these casks. For these shipments the fuel burnup-cooling times varied such that the decay heat of the as shipped contents varied from 560 to 1736 watts. Prior to shipment, external and internal cask temperatures were monitored providing a record of cask thermal characteristics. The measurements were made in ambient, still air at an ambient temperature of approximately 78°-80°F. Figure 21 shows a plot of the most recent data.

The decay heat vs. cooling time characteristics for the proposed fuel, 14 elements, were estimated on the basis of 2 twenty day cycles of 60 mw full power operation and 2 days shut down between cycles (reference: K. Shure, WAPD-BT-24). The calculated data are shown graphically in Figure 22.

The actual basis for all the thermal calculations is a decay heat of 1200 watts per 14 elements or 86 watts per element. From Figure 22, this corresponds to shipment after 270 days cooling. The temperatures to be expected for a normal shipment at an ambient temperature of 80°F can be obtained from Figure 21, a cask surface temperature of 108°F and an average element temperature of 240°F. From an extrapolation from earlier measurements the corresponding inner cask surface temperature is 125°F. Assuming a peak to average element power level ratio of 1.27, the expected element peak temperature is 271°F.

From the fire test calculation which follows an average element temperature of 703.2°F can be expected with a maximum of 734.2°F for a peak element.

The normal temperature profile may be used to estimate the temperature profile that will exist at elevated temperatures. Conservatively, we may assume the normal temperature differences persist at elevated temperatures. If in addition, we take a 3°F reduction in cask surface temperature to account for increased radiant heat transfer at elevated temperatures, the temperature distribution at 130°F ambient is:

Outer Shell	$= 130 + (108-83) = 155^{\circ}\text{F}$
Inner Shell	$= 130 + (125-83) = 172^{\circ}\text{F}$
Element Average	$= 130 + (240-83) = 287^{\circ}\text{F}$

The fire test calculation, which follows, indicates that the cask after the modifications will meet the requirements of the accident conditions. The cask will contain 7,082# of molten lead at the conclusion of the fire and the inner wall temperature will reach 588.2°F. Calculations indicate that the change in volume due to molten lead can be accommodated easily by expansion of the outer shell. Fuel element temperatures and cask temperatures obtained after the fire do not exceed those allowable for the materials used.

For a description of the "Energy Balance Method" see Irradiated Fuel Shipping Cask Designer's Guide and Fire Test and Thermal Behavior of a 15 ton Lead-Shielded Cask, DP 1070, by G. P. Wachtell and J. W. Langhaar. The method, shown by comparison to test data to provide conservative results, is used extensively.

In the procedure one determines two pertinent time parameters, the time to initiate melting at a location not subject to end effects (t_1) and the time to go completely molten (t_2). The calculation of t_1 is based on a per unit external surface area model of the cask which typifies the straight length cask geometry. For a rectangular cask, it would be a linear segment taken at the cask mid-plane, the actual steel and lead thicknesses being used. For a cylindrical cask it would be a cylindrical segment taken at the cask mid-plane.

W_{OS}	2464#
W'_{OS}	20.2#/ft ²
W_{is}	429.6#
W'_{is}	15.5#/ft ²
W_L	22490#
W'_L	583#/ft ²

Effective area of cask is 59.5 ft², lead thickness, D = 10 inches, and the shell thickness is 0.5 inches.

Assuming $T_o = 155^\circ\text{F}$ then $T_{s-1} = 418^\circ\text{F}$ and $\bar{Q}_1 = 16,600 \text{ BTU/HR FT}^2$ (see Figures 5.21 and 5.22 CDG).

4. Average T solid lead at t_1

$$T_{L-1} = 621 - \frac{\bar{Q}_1 D}{36K} = 621 - \frac{16,600 (10)}{36 (18.6)}$$

$$= 373^\circ\text{F} \text{ (see Figure 5.23 CDG)}$$

5. Average T inner shell at t_1

$$T_{is-1} = 621 - \frac{\bar{Q}_1 D}{24K} = 621 - \frac{16,600 (10)}{24 (18.6)}$$

$$= 249^\circ\text{F} \text{ (see Figure 5.24 CDG)}$$

6. Determination of t_1

$$T_{os-1} = 621 + \frac{\bar{Q}_1 x}{24K} = 621 + \frac{16,600(.5)}{24(18.6)} \quad x = \text{shell thickness}$$

$$= 639.6^\circ\text{F} \quad (\text{see Figure 5.25 CDG})$$

$$H'_{os-1} = W'_{os}(T_{os-1} - T_o).125 = 20.2(639.6 - 155).125 = 1224$$

$$H'_{is-1} = W'_{is}(T_{is-1} - T_o).125 = 15.5(249 - 155).125 = 182$$

$$H'_{L-1} = W'_L(T_{L-1} - T_o).0325 = 583(373 - 155).0325 = 4130$$

$$H'_{T-1} = 5536 \text{ BTU/FT}^2$$

$$t_1 = \frac{H'_{T-1}}{\bar{Q}_1} = \frac{5536}{16,600} = .3335 \text{ hrs or } 20.0 \text{ minutes}$$

7. Total Heat Absorbed at t_1

$$H^*_{T-1} = H'_{T-1} A = 5536(59.5) = 329,392 \text{ BTU}$$

8. Molten Lead at t_1

$$H_{os-1} = W_{os}(T_{os-1} - T_o).125 = 2464(639.6 - 155).125 = 149,257$$

$$H_{is-1} = W_{is}(T_{is-1} - T_o).125 = 429.6(249 - 155).125 = 5,048$$

$$H_{L-1} = W_L (T_{L-1} - T_O) .0325 = 22490 (373 - 155) .0325 = 159,342$$

$$H_{T-1} = 313,647 \text{ BTU}$$

$$\Delta H_{T-1} = H_{T-1}^* - H_{T-1} = 329,392 - 313,647 = 15,745$$

$$W_{ML-1} = \frac{\Delta H_{T-1}}{(621 - T_{L-1}) (.0325) + 10.55} = \frac{15,745}{(621 - 373) (.0325) + 10.55}$$

$$W_{ML-1} = 846\#$$

9. Superheat

$$T_{SUP} = 4.3(h/2) = 4.3 (49.25/2) \quad h = \text{cask height}$$

$$T_{SUP} = 105.9^\circ\text{F}$$

10. Surface Temperature of Cask at t_2

$$T_{OS-2} = T_{OS-1} + T_{SUP} = 639.6 + 105.9 = 745.5^\circ\text{F}$$

11. Heat Flux Absorbed t_1 to t_2 or $\bar{Q}_2$

$$\bar{Q}_2 = [(1935)^4 .9 - (T_{OS-2})^4] (.173 \times 10^{-8}) .8$$

$$= [(1935)^4 .9 - (1205.5)^4] (.173 \times 10^{-8}) .8$$

$$= 14,532 \text{ BTU/HR FT}^2 \quad (\text{see Figure 5.29 CDG})$$

12. Total Heat Absorbed by Cask at t_2

$$H_{OS-2} = W_{OS} (T_{S-2} - T_O) .125 = 2464 (745.5 - 155) .125 = 181,874$$

$$H_{LS-2} = W_{LS} (621 + T_{SUP} - T_O) .125 = 429.6 (621 + 105.9 - 155) .125 = 30,711$$

$$H_{LM} = W_L (621 - T_O) .0325 = 22490 (621 - 155) .0325 = 340,611$$

$$H_{LS} = W_L (T_{SUP}) .038 = 22490 (105.9) .038 = 90,504$$

$$H^*_{T-2} = 643,700$$

13. Determination of t_2

$$t_2 - t_1 = \frac{H^*_{T-2} - H_{T-1}}{\bar{Q}_2 A} = \frac{643,700 - 313,647}{14,532 (59.5)} = .3817 \text{ hrs}$$

$$t_2 = t_1 + (t_2 - t_1) = .3335 + .3817 = .715 \text{ hrs or 43 minutes}$$

14. Molten Lead at .5 hrs

$$W_{ML-2} = W_{ML-1} + (W_L - W_{ML-1}) \frac{(.5 - t_1)^{1.5}}{(t_2 - t_1)^{1.5}}$$

$$= 846 + (22490 - 846) \frac{(.5 - .3335)^{1.5}}{.3817^{1.5}}$$

$$W_{ML-2} = 7082\# \text{ at } t = .5 \text{ hrs or } 10.8 \text{ ft}^3$$

15. Inner Wall Temperature

$$H^*_S = .125 (W_{OS} + W_{LS}) = .125 (2464 + 429.6) = 361.7$$

$$H^*_L = .0325 (W_L) = .0325 (22,490) = 730.9$$

$$H^*_T = H^*_S + H^*_L = 1092.6 \text{ BTU/}^\circ\text{F}$$

$$\text{Heat absorbed at } .5 \text{ hrs} = H^*_{T-1} + (.5 - t_1) \bar{Q}_2 A$$

$$H^*_{.5} = 329,392 + (.5 - .3335) 14,532 (59.5)$$

$$H^*_{.5} = 473,270$$

$$T_{LS} = T_O + \frac{H^*_{.5}}{H^*_T} = 155 + \frac{473,270}{1092.6} = 588.2^\circ\text{F}$$

Average element temperature = $588.2 + 115^\circ = 703.2^\circ\text{F}$, peak element temperature = average element temperature + $31^\circ = 703.2^\circ\text{F} + 31^\circ\text{F} = 734.2^\circ\text{F}$ where 115° is the Δt between cavity wall and fuel plate and 31° is the temperature difference between a peak and average element.

Change in volume due to lead melting

$$V_{SLRT} = \text{Vol solid lead @ xm temperature} = \frac{22,490\#}{700\#/\text{ft}^3} = 32.2 \text{ ft}^3$$

$$V_{SL} = \text{Vol solid lead @ } 621^{\circ}\text{F} = \frac{22,490\# - 7082\#}{687\#/\text{ft}^3} = 22.4 \text{ ft}^3$$

$$V_{ML} = \text{Vol molten lead @ } 621^{\circ}\text{F} = \frac{7082\#}{657\#/\text{ft}^3} = 10.8 \text{ ft}^3$$

$$\Delta V_L = V_{SL} + V_{ML} - V_{SLRT} = 22.4 + 10.8 - 32.2 = 1 \text{ ft}^3$$

or 1728 in^3 must be accommodated by the thermal expansion of the cask shell and elongation of the shell.

$$\begin{aligned}\Delta V_{OS} &= V_{SLRT} [1 + \alpha(T_{OS-2} - T_0)]^3 - V_{SLRT} \\ &= 32.2(1 + 1 \times 10^{-5}(745.5 - 155))^3 - 32.2\end{aligned}$$

$\Delta V_{OS} = .574 \text{ ft}^3$ accommodated by thermal expansion of shell, remainder to elongation.

$$\Delta V_L - \Delta V_{OS} = (V_{SLRT} + \Delta V_{OS})[(1 + \epsilon)^3 - 1]$$

$$\epsilon = \left[\frac{\Delta V_L + V_{SLRT}}{V_{SLRT} + \Delta V_{OS}} \right]^{1/3} - 1$$

$$\epsilon = \left[\frac{1 + 32.2}{32.2 + .574} \right]^{1/3} - 1 = .0043 \text{ in/in}$$

Allowable elongation for stainless steel is .5 in/in, therefore the shell will not rupture.

After the fire test, the volume of the cask has increased by $1 - .574 = .426 \text{ ft}^3$ due to permanent elongation of the outer shell. On cooling down, this results in a void of $.426 \text{ ft}^3$. Assuming the worst orientation, with a corner up, this (see Figure 7) would result in a 7.2-inch loss in lead for shielding. Subtracting the 7.2 inches from the 15.7 inches of lead yields 8.5 inches of lead remaining which more than meets the minimum noted in the shielding section.

4. Water Immersion

Due to the strength of the top surface of the cask with the collar and cover it is thought that failure of the 5/8" x 5/8" Fiberfrax gasket is unlikely. This material is an alumina-silica fibre for use to 2300°F. On the assumption that inleakage would occur however, criticality would not be affected since the flooded condition is also safe (see Criticality Section).

Shielding

Using the nomograph Figure 7.1, page 219 and reproduced as Figure 23, and Figure 7.6, page 225 of the Cask Designer's Manual, the 40 day irradiation time, 270 day decay period, 247.32 pounds of fuel,** cladding, coolant and basket and 30 megawatts of power* with 10 inches of lead shielding gives,

$$72 = \frac{WI}{Q} \text{ and } I = \frac{72(30)}{247.32}$$

$$I = 8.73 \text{ mr/hr}$$

The rate at three feet, $W/H = 49.75/49.25 = 1.01$

$$r/H = 36/49.25 = .731$$

* 30 Mw corresponds to 14 fuel elements when full reactor power is 60 Mw.

**See page 2.

Therefore, ratio of rate at three feet to surface rate is .5 or 4.37 mr/hr, assuming cosine² distribution.

With the same assumptions used above, 6.0 inches of lead would give a surface rate of 1,941 mr/hr and a rate of 970.6 mr/hr at the three feet mark required by the regulations after the accident.

Due to the conservatism of the nomograph and actual experience with measuring radiation levels of these casks when loaded it is probable that 6 inches of lead would suffice to meet the post accident requirement of 1000 mr/hr at three feet.

Average dose rates measured on the two casks range from 2.5 to 2 mr/hr at the side, 2 to 1.7 mr/hr at the ends, and .5 to 1.5 mr/hr at the bottom. Both casks have exhibited a "hot spot" on the cover giving spot values of 35 mr/hr and 12 mr/hr when fully loaded. The above values are contact readings recorded as part of the usual shipping procedures by the health physics personnel using a CS-40 meter in shipments involving about 260,000 curies of fission product activity.

ORIGINAL CONSTRUCTION

(a)

AS MODIFIED FOR LONGER FUEL ELEMENT

(b)

FINAL CONSTRUCTION

(c)

FIG. 1'

FIG. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

FIG. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Fig. 18

Fig. 19

Fig. 20

FIG. 21

TOTAL DECAY HEAT FOR ONE-HALF
CORE (14 ELEMENTS)

FIG 22

ORNL DWG 69-3495R2

W= TOTAL WT. IN CAVITY: POUNDS OF FUEL, CLADDING, COOLANT
AND HARDWARE.

I= RADIATION LEVEL AT CASK, mr/hr.

Q= REACTOR MEGAWATTS FOR TOTAL FUEL IN CASK.

Fig. 2.3. Shielding for Casks and Vessels.

APPENDIX A

FORM OF APPENDIX A AGREEMENT

DESCRIPTION OF HIGH FLUX BEAM
REACTOR FUEL ELEMENT ASSEMBLY

Revision Dated March 23, 1967

APPENDIX A AGREEMENT

NO. _____ UNDER

CONTRACT NO. AT(38-1)-_____ WITH

THIS AGREEMENT entered into this _____ day of _____, 19____, constitutes an agreement by the Commission to receive under the terms and conditions of Contract AT(38-1)-_____ the specification material described herein. This Agreement provides a detailed description of the material to be delivered to the Commission in accordance with Contract No. _____ and also enumerates the specifications and requirements which the Company must meet. Failure of the material delivered hereunder to comply with the specifications and requirements given in this Agreement will result in the material being non-specification material.

The following definitions are applied to the Specification Material described in this Agreement:

The Fuel Element: The smallest integral unit of clad fuel (or blanket) containing Source or Special Nuclear Material (SSNM), i.e., a plate, tube, rod, disc, etc.

Subassembly: If used, is a group of elements, combined in a structural unit, which is grouped with other subassemblies to form the larger unit called the assembly.

Assembly: A group of elements or subassemblies combined in a structural unit. The assembly is usually that fuel structure which is removed from the reactor as an individual unit.

A separate Appendix A Agreement will be required for each element, subassembly, or assembly which is different in description.

All dimensions must be given in feet and inches and all weights in grams or kilograms.

A. Form and Composition of Specification Material

1. Drawings. The following drawings(s), six (6) copies of which are on file at the Commission's Savannah River Operations Office and which are incorporated herein by reference thereto, constitute(s) a comprehensive illustration of the fuel elements, subassemblies, and assemblies to be delivered under this Contract as charged to the reactor, in sufficient detail and accuracy to permit chemical processing under this Contract:

ME-107-352-4B

ME-107-353-5B

2. Material Description. The following summarizes the description of fuel elements, subassemblies, assemblies and assemblies modified after discharge. Where dimensions are required, the nominal dimensions, as charged to the reactor, must be used and the best estimates of the maximum change in these dimensions because of irradiation must be given. Weights must be dry, unirradiated weights with the expected range of weights also to be included.

A. Element Description

- a) Type (plate, disc, rod, tube, etc.) Curved Plate
- b) Nominal Dimension (including clad and bond) _____
17 at 2-5/8x21-3/4x.050 2 at 2-5/8x23x.140
- c) Nominal Weight 17 at 143.396 gms. 1 at 356.65 gms. (Upper)
1 at 346.546 gms (Lower)
- d) Weight of SSNM Before Irradiation
AEC Prime Contractor
(1) ~~XXXXXXXXXXXXXXXXXXXX~~ special nuclear material

Total U 297.756 gms. in Assembly - 2 Outer Plates at
8.373 gms. U; 17 Inner Plates at
U-232 16.53 gms. U

U-233 7.80 gms. and 15.5 gms. U²³⁵ respectively

U-235 278.0 $\frac{\text{WT U-235}}{\text{WT Total U}} = \frac{278.00}{297.756} = 93.15\%$

93.15%
(enrichment)

Total Pu _____
Pu-239 _____
Pu-241 _____

- (2) Company-owned special nuclear material and source material.

Total U _____
U-232 _____
U-233 _____
U-235 _____

$\frac{\text{WT U-235}}{\text{WT Total U}} =$

(enrichment)

Total Pu _____

Pu-239 _____

Pu-241 _____

Total TR _____

U - 30 wt % Al - 67 wt %
Si - 3 wt %

a) Chemical form of SSNX (UO_2 , UC, etc.) 93.15% U²³⁵ 6.85% U²³⁸

Weight 297.75 gms. U per
Element Assembly

f) Fabricated form of SSNX (pellets, slugs, ribbons)

and loading pattern in element Plate (NTR) Type

g) Alloy or dispersing material (Al, SS, etc.) 3% wt % Silicon
67% wt % Al-1100

Weight 638.95 gms. (Al + Si)

h) Cladding Material (Al, SS, etc.) Aluminum 6061 (ASTM-B-209-38T
Alloy G5)

and method of sealing Hot Rolled

0.15 Min.

Thickness 0.141 Max. Weight 2149.434 gms. per Assy

i) Bonding Material, if any (Na, Al-Si, etc.) _____

Thickness _____ Weight _____

j) Spacers, inactive end material (MgO , SS, etc.) _____

Dimensions _____ Weight _____

k) Other materials contained in fuel element:

1.653 gms. Silicon in each of 17 Inner Fuel Plates

0.8373 gms. Silicon in each of 2 Outer Plates

Total = 29.7756 gms. Silicon per Cut Assembly

Any material not covered by the above shall be added to describe the element completely.

b. Subassembly

- a) Number of elements _____
- b) Over-all dimensions _____
- c) Total weight _____
- d) Casing Material (Zr, Al, etc.) _____ Dimensions _____
Weight _____
- Sideplate Material _____ Dimensions _____
Weight _____
- Spacer Material _____ Dimensions _____
Weight _____
- End Box Material _____ Dimensions _____
Weight _____
- Braze or Weld Material _____ Weight _____
- Other Structural Material _____ Dimensions _____
Weight _____

e. Assembly

elements

- a) Number of ~~XXXXXXXXXX~~ 17 Inner Plates + 2 Outer Plates
- b) Over-all dimensions 2.880"x3.220"x22-1/2" - Cut Section as Shipped
- c) Over-all weight Cut Section as Shipped = 4156.3557 gms.
- d) Construction material in addition to that under A.2.b.d)):
Casing Material	_____	Dimensions	_____	Wt	_____
		Comb.	1/4x5/8x		
Spacer Material	6061	Dimensions	2-3/4	Wt	15.1937 gms.
	Not				
End Box Material	Shipped	Dimensions	-	Wt	-
Braze or Weld Material	_____			Wt	_____
			2 at .187x.307x		
Sideplate Material	6061	Dimensions	22-1/4	Wt	1,000.228 gms
Other Structural Material	_____	Dimensions	_____	Wt	_____

3. Identification. Each separately removable unit in a processing batch must be identified by a durable metal tag or label, or by embossing. Identification of the units to be delivered under this Appendix A Agreement are as follows:

The cut fuel assembly section is engraved with an identification letter "K" plus serial numbers: 2" high by .005" to .010" deep on each side plate. Cut length is 22-1/2". Each fuel element (plate) has a stamped serial designation 1/8" high by .005" deep.

B. Post-Irradiation Specifications

1. SSNM Content After Irradiation. The average and maximum SSNM content and ownership thereof (i.e. ~~Ownership of the material~~) is to be specified in grams per element. The best available value should be given and the uncertainty stated.

AEC Prime Contractor

~~Special Nuclear Material~~ Special Nuclear Material

and Source Material Resulting From Irradiation.

	<u>Average</u>	<u>Maximum</u>	<u>Uncertainty</u>
Total U	<u>224 gms.</u>	<u>235 gms.</u>	<u>± 5%</u>
Total Pu	<u> </u>	<u> </u>	<u> </u>
U-232	<u> </u>	<u> </u>	<u> </u>
U-233	<u> </u>	<u> </u>	<u> </u>
U-235	<u>193 gms.</u>	<u>203 gms.</u>	<u>± 5%</u>
Pu-239	<u> </u>	<u> </u>	<u> </u>
Pu-241	<u> </u>	<u> </u>	<u> </u>

Note: For any specific shipment the amount of U²³⁵ and total U remaining can be taken from the HIGH FLUX BEAM REACTOR FUEL BURN-UP RECORD, a copy of which is attached. These sheets will be sent with each shipment.

Company-owned Special Nuclear Material and Source Material

	<u>Average</u>	<u>Maximum</u>	<u>Uncertainty</u>
Total U	_____	_____	_____
Total Pu	_____	_____	_____
Total Th	_____	_____	_____
U-232	_____	_____	_____
U-233	_____	_____	_____
U-235	_____	_____	_____
Pu-239	_____	_____	_____
Pu-241	_____	_____	_____

2. Delivery of Thorium Fuels

For thorium fuels only, a processing batch may not be delivered to the Commission until such time as the composition is such that

99.9% of the U-233 would have been formed (expressed as $\frac{\text{U-233}}{\text{Pa-233} + \text{U-233}}$ = 0.999 minimum).

C. Specifications for Fuel Units which contain exposed SSNM or which have warped.

1. A fuel element with exposed SSNM shall be canned in a container whose material and design shall be approved by the Commission unless the Commission determines that such canning is unnecessary.
2. Units distorted beyond specified dimensional limits must be considered on an individual basis. The Company should provide the Commission with complete dimensional information for each warped unit at least 60 days before delivery.

3. If material normally removed from the element or subassembly by the Company cannot be removed due to warpage or other reasons, the Company must notify the Commission at least 60 days before delivery giving complete dimensional, material and weight information. Detailed structural drawings are also required by the Commission.
- D. The value of R for specification material as described in this Appendix A Agreement or for non-specification material which the Commission determines could be chemically processed in the AEC reference fuel processing plant, referred to in Article IX of this Contract, at the same daily rate as specification material, shall be _____.
- E. The assumed basic processing services for material described in this Appendix A (MS) (do not) include the recovery of plutonium contained in such material.

UNITED STATES OF AMERICA

BY: UNITED STATES ATOMIC ENERGY COMMISSION COMPANY

BY: _____

BY: _____

TITLE: _____

TITLE: _____

DATE: _____

DATE: _____

Appendix A

SUPPLEMENT TO APPENDIX "A" - REVISION DATED MARCH 23, 1967

The following drawings describe the proposed new fuel element.

BR 51-0400-0-5A HFBR Fuel Element, Type KL, Assembly

BR 51-0400-1-4A HFBR Fuel Element, Type KL, Details

The element assembly is identified by 2 inch high engraved letters KL, on each side plate. Engraving depth is .005 to .010 inches. Cut length is 24-1/2". Each fuel element (plate) has a stamped core and melt designation 1/8" high by .005" deep.

The nominal U^{235} content is 315 grams. It is anticipated that shipment will be made after 270 days cooling time, with fission burnup at 28.6% U^{235} for the average half core. Fission plus capture will average 33.6% U^{235} .

The core length has been lengthened 2" over the type K element.

Revisions of supplement to Savannah River according to the manufacturer's drawings.

There are 17 inside curved plates, with a chordal width of 2.615", and a width of 2.627" before forming.

It is therefore of interest to determine the amount of additional material in the additional 2" length.

The additional materials in this section are given in the following calculations.

INSIDE FUEL PLATES #2 to #18 - CLADDING WEIGHTS

For Solid Al. $0.050" \times 2.622" = 0.1310$ sq. in.

Fuel Alloy Space $2.241" \times 0.022" = 0.0493$ sq. in.

.0817 sq. in. Net Aluminum

$.0817 \times 2" = .1634$ cu. in. at $.0910^*$ lbs./cu. in. = 0.01485 lbs.

.01485 lbs = 6.75 gms/plate; at 17 plates = 115.0 gms.

UPPER FUEL PLATE #1

For Solid Al. $0.140" \times 2.620" = 0.3670$ sq. in.

Less edge cuts $0.178 \times .0365 = 0.0065$ sq. in.

0.3605 sq. in. net

Fuel Alloy Space $.0095 \times 2.241 = 0.0213$ sq. in.

0.3392 sq. in. Net Aluminum

$0.3392 \text{ sq. in.} \times 2 = 0.6784 \text{ cu. in. at } .0910 \text{ lbs/cu. in.} = .0616 \text{ lbs.}$
 $.0616 \text{ lbs} = 28.0 \text{ gms for plate \#1}$

LOWER FUEL PLATE #19

For All Al. $0.140 \times 2.609 = 0.36600 \text{ sq. in.}$

Less edge cuts $0.075" \times 0.187 = \underline{0.01405}$

0.35195 sq. in.

Fuel Alloy Space $.0095 \times 2.241 = \underline{0.0213}$

$0.33065 \text{ sq. in. Net Aluminum}$

$0.3306 \text{ sq. in.} \times 2" = 0.6612 \text{ cu. in @ } .091 \text{ lbs/cu. in.} = .0602 \text{ lbs.}$

$.0602 \text{ lbs.} = 27.35 \text{ gms. for plate \#19.}$

SIDE PLATES

For solid Aluminum $0.187" \times 3.079" = 0.576 \text{ sq. in.}$

Less $1/32"$ chamfers $.032" \times .032" = \underline{.001025}$

0.575 sq. in.

Less 17 plate cutouts

$\frac{0.069" + 0.050"}{2} \times .087 = .00517 \text{ sq. in. each} \times 17 = 0.085 \text{ sq. in.}$

Less #1 cutout $.087 \times .109 = .00948$ $= 0.00948$

Less #19 cutout 0.00690

$\frac{.089 + .070}{2} \times .087 = .0069$ 0.10138 sq. in.

Then Net Aluminum in Side Plates

0.57500

$- \underline{0.10138}$

0.47362 sq. in.

$.047362 \times 2" = 0.94724 \text{ cu. in. at } .091 \text{ lbs./cu. in.} = .0860 \text{ lbs.}$

$.0860 \text{ lbs} = 39.0 \text{ gms/plate} = 78 \text{ gms. Total.}$

TOTAL STRUCTURAL ALUMINUM

Plates 2 to 18	115.0 gms.
Upper Plate	28.0
Lower Plate	27.35
Side Plates	<u>78.0</u>
	248.35 gms.

MATERIALS IN THE FUEL ALLOY

U ²³⁵	315 gms. - 93.15% Enrichment 30 wt. %
U ²³⁸	24
Al.	765 68 wt. %
Si	<u>22.5</u> 2 wt. %
	1,126.5 gms.

Fuel alloy volumes

Plate #1	.0213 sq. in. x 22.75 = 0.485 cu. in.
Plate #19	.0213 sq. in. x 22.75 = 0.485 cu. in.
Plates #2 to 18	.0493 sq.in.x22.75x17 = <u>19.05</u> cu. in.
	20.02 cu. in.

The fuel alloy volume in the 2" added length is

Plate #1	.0213 sq. in. x 2" = .0426 cu. in.
Plates #2 to 18	.0493 x 2" x 17 = 1.672
Plate #19	.0213 sq. in. x 2" = <u>0.0426</u>
	1.7552 cu. in.

Then $\frac{315}{20.02} = 16.58$ gms. U²³⁵ per cu. in.

$16.58 \times 1.755 = 27.4$ grams U²³⁵ added.

Then $\frac{27.4}{315} = .0870$ = Ratio for other materials

U ²³⁸	= 24 x .0870 = 2.18 gms. added
Al	= 765 x .0870 = 66.50 " "
Si	= 22.5 x .0870 = 1.95 " "

Combining the structural aluminum with the above materials gives the following for a 2" section.

Total structural aluminum	246.3 grams
Fuel alloy aluminum	66.5
U ²³⁵ Fuel alloy	27.4
U ²³⁸ Fuel alloy	2.18
Silicon in Alloy	<u>1.95</u>
Total weights	346.33 grams

Figure HFBR Type KL Fuel Element,

APPENDIX B

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: 6/4/64

TO: R. W. Powell
FROM: K. Downes *KD*
SUBJECT: Criticality Test of
HFBR Shipping Casks:

The requirement that two adjacent shipping casks full of HFBR fuel have a k_{eff} of less than 0.9 was tested at the BNL Critical Facility.

An assembly was built and run under the Limits, Rules, and Procedures of the BNL Experimental Physics Group. This assembly (shown in Fig. 1) consisted of a 25" x 36" x 25" tank surrounded on the bottom and four sides by 10" of lead. A central island of 20" x 24" x 25" of lead was put in the tank with holes for a neutron source and water level probe. A control rod of 0.030" x 7" x 25" of Cd was sheathed by Plexiglass and attached to an existing control rod drive. The source (1 gm RaBe) was surrounded by 1" of paraffin and inserted in the central hole. Three pairs of boron-lined ion chambers were connected to the existing micro-micro-ammeters. The fourth pair of ion chambers was connected to the log N circuit. The HFBR Console was modified for the rod and water control.

The fuel elements used were the ones constructed for the HFBR critical experiment. The boron-steel liners were supplied by the Operations Division.

The k_{eff} of three different assemblies was checked. The first experimental loading was 14 elements on one side of the assembly in the boron-stainless steel liners; the second loading was 28 elements in the boron-stainless steel liners. The third loading consisted of 14 elements without the liners.

Results: The criticality characteristics of the first two assemblies were essentially the same. The ratios of ion chamber current, I with fuel/I without fuel, ranged from 2 to 4 depending on instrument scale, source position, and chamber position. The 28 element assembly was only slightly more reactive than the 14

element loading. These two assemblies certainly show a k_{eff} of less than 0.9. A best estimate would be $0.5 < k_{eff} < 0.75$.

The third assembly was not completely filled with water because extrapolation of the approach curves indicated that criticality would have been achieved at a water height of between 15" and 20".

KD:ed

BROOKHAVEN NATIONAL LABORATORY

MEMORANDUM

DATE: November 16, 1970

TO: Files

FROM: Hans Ludewig *HL*

SUBJECT: Criticality Calculations Relative to
Storage of the New HFBR Fuel Elements
(Type KL - 315 grams ^{235}U)

The storage and handling of fresh and spent fuel elements is investigated in this memorandum for the new fuel elements. Storage in the HFBR vault, the storage canal and the shipping cask are investigated. In addition, the emergency shutdown of the HFBR by a cadmium nitrate solution is also checked. A total of four different situations are considered which will be treated under different headings. The results are summarized on the Table.

I. HFBR Vault

Two different storage geometries are used in the vault. Firstly, fuel elements are hung on the wall with 3-3/4" separation between the centers. Secondly, a two tiered storage rack is used, with individual bins for each fuel element. The details of this facility are described in reference 1. Not included in the description of the storage facility is the presence of a cadmium sheet separating the two rows of fuel elements; this was a subsequent addition.

- (a) In carrying out the analysis of the wall storage area, an infinite plane slab of flooded homogenized fuel element material was considered to be reflected by an "infinite" water reflector (15 cm). It is felt that this representation is conservative since no account was taken of the neutron leakage out of the ends of the fuel elements and the space separating the fuel elements was neglected. The calculation was carried out using 1-DX², a one dimensional diffusion theory code and the cross section library was based on the 26 group Russian³ cross section set. The value of k_{eff} determined from this model was .91.
- (b) The two tiered storage facility was again treated in infinite slab geometry. In this case the geometrical model used was made up of two rows of flooded fuel elements separated by a steel plate and a cadmium sheet and reflected by a steel plate and an infinite thickness of water. This geometrical model is considered conservative because the steel plates separating the fuel element within each row were not accounted for. In this case the calculation was carried out with the DSN code ANISN⁴ using four angular quadratures and 26 groups³. The value of k_{eff} determined by this method was .92.

II. Storage Canal

Three different safety situations are met in the spent fuel storage canal. Firstly, the temporary storage rack¹ in which the spent fuel elements are inserted as they come out of the reactor. Secondly, the long term storage racks¹ in which the fuel is stored and finally a requirement that five fuel elements in their most reactive configuration should be sub-critical.

- (a) A single cell was considered in the representation of the temporary storage rack. The rectangular cross section of the cell was transformed to a circular one, by conserving the area, and the height of the cell was considered exactly. The finite size of the rack in the other two directions was simulated by a buckling. The buckling was determined assuming a reflector savings of 8 cm and was found to be $.00267 \text{ cm}^{-2}$. This calculation was carried out using the (R-Z) option of 2-DB⁵, a two-dimensional diffusion theory code, and 26 groups.³ The value of k_{eff} was computed to be .76 for this model.
- (b) The long term storage rack was considered using two different models. Firstly, a model based on one used in a previous analysis⁶ was considered. In this case few group cross sections for the fuel region, boron steel + water region and water region were generated using HAMMER⁷. The cross section at right angles to the length of the fuel elements was represented exactly in (X-Y) geometry and the element length was considered to be infinite. For this model the value of k_{eff} was computed to be .67 using 2-DB. A second model based on 1-DX and the 26 group library was also considered. In this case it was assumed that the fuel elements were of finite height simulated by a transverse buckling, which was based on a reflector savings of 8 cm, i.e., $B_2^2 = .001823 \text{ cm}^{-2}$. The boron steel, water and fuel region were considered to have the correct thickness and reflected by an infinite water reflector. The corresponding value of k_{eff} was computed to be .72. Both models are considered to over estimate the true value of k_{eff} , since in the first case no axial leakage was considered and in the second case the boron steel plates separating the fuel elements were neglected.
- (c) The most reactive configuration for five fuel elements in light water would occur when they are most closely packed. This calculation was carried out using a cylinder of equal cross sectional area to five elements and the height was simulated by a buckling, i.e., $B_2^2 = .001813 \text{ cm}^{-2}$. The calculation was carried out using 1-DX and the 26 group library resulting in a k_{eff} of .80.

III. Shipping Cask

The criticality aspects of the present shipping casks have been investigated by Downes⁸ in an experimental mock-up, simulating two adjacent

casks. The criticality aspects of the revised shipping cask with new elements are investigated by calculation. The casks are made of lead 11" thick with an internal cavity 23-3/4" x 22-3/4" x 8". It was decided to simulate the casks in (R-2) geometry using 2DB, i.e., making a circle of the 23-3/4" x 22-3/4" area. Furthermore, it was felt that the most reactive situation would occur if two casks were placed side by side with their largest areas adjacent to each other. Because of the large number of mesh points to be used in this calculation, it is necessary to reduce the number of groups. The 26 groups were collapsed to 4, using 1-DX. The geometrical model consisted of a homogenized fuel and boron steel + water region, surrounded by 11" of lead and reflected by an infinite water reflector on all sides except one which was adjacent to the second cask. The value of k_{eff} computed for this model was .43.

The results of these calculations show that the estimated value of k_{eff} for these systems with the boron steel liners in place, does not change significantly.

IV. Poison Solution

The final situation to be considered was the emergency shutdown of the HFBR using cadmium nitrate solution. In this case the reactor was considered as a three region sphere with a thimble region, a fresh fuel region and a reflector. The cadmium content of each region was proportional to the homogenized quantity of light water in the respective region. Using the 26 group library and ANISN with four angular quadratures, a determination of k_{eff} was carried out. This value was found to be .44.

SUMMARY

In conclusion it should be stated that no account was taken of the fact that the fuel elements in the canal were partially depleted of U^{235} . This adds a further margin of safety to these situations.

Thus, it is felt that based on these calculations, all situations considered are safe. The summary of the k_{eff} values are given in the table.

TABLE 1

	Situation	k_{eff}	Remarks
CANAL	Long Term Storage	.72	1-DX, $B_z^2 = .001813 \text{ cm}^{-2}$ 26 groups
	Long Term Storage	.67	2-DB, $B_z^2 = 0.0$, HAMMER 4 groups
	Temporary Storage	.76	2-DB, $(B_x^2 + B_y^2) = .00267 \text{ cm}^{-2}$, 26 groups
	Five Fuel Elements	.80	1-DX, $B_z^2 = .001813 \text{ cm}^{-2}$, 26 groups
VAULT	Two-Tiered Storage	.92	ANISN $B_z^2 = 0.0$, DS4, 26 groups
	Wall Storage	.91	1-DX, $B_z^2 = 0.0$, 26 groups
	Shipping Cask	.43	2-DB, 4 groups from 1-DX 26 groups
	Poison Solution	.44	ANISN (Sphere) DS4, 26 groups

Reference

1. J. M. Hendrie, "Final Safety Analysis Report on the Brookhaven High Flux Beam Reactor", BNL-7661, (1964).
2. R. W. Hardie, et al., "1-DX, A One-dimensional Diffusion Code for Generating Effective Nuclear Cross Sections", BNWL-954 PNL (1969).
3. L.P. Abagyan, et al., "Group Constants for Nuclear Reactor Calculations", Consultants Bureau, N. Y. (1964).
4. W. W. Engle, "A Users Manual for ANISN, A One-dimensional Discrete Ordinates Transport Code, with Anisotropic Scattering", Union Carbide Corp., K-1693 (1967).
5. W. W. Little et al., "2-DB User's Manual", BNWL-831 P.N.L. (1968).
6. B. R. Sehgal, "Reactivity of HFBR Spent Fuel Storage Facility", BNL memorandum R.P.-389R. (1966).
7. J. E. Suich et al., "The HAMMER System", DP-1064, SRL (1967).
8. K. Downes, "Criticality Test of HFBR Shipping Casks". Memorandum to R. W. Powell, R.P. 515 (1964)

APPENDIX C

GENERAL WELDING NOTES AND SPECIFICATIONS

Materials

Walls and bottom of cask body to be fabricated from 347 stainless steel plate, one side No. 4 finish (standard polish). Polished sides to be the outside surfaces.

Cavity insert to be as above. Polished sides to be on the inside of the cavity, and the top of the cover plate.

All other materials to be of 304 stainless steel as noted on drawings BR63-0101-1-5A and BR63-0101-2-4A.

All welding electrodes or rod used in construction to be of stainless steel. Use E-347-15 or 16 with 347 and E-308-15 or 16 with 304.

Pressure Tests

Completed cask to be pressure-tested for leaks at 10 psig air. The 3" holes in top plate to be suitably blanked and gasketed for this test. Every weld to be checked with "LEAK-TEC" (American Gas and Chemicals, Inc. - Formula #277-C).

Cask shell to be pressure-tested at 10 psig air prior to insertion and welding of the cavity insert. Suitable cover plate, gasket and retaining bolts to be provided for this test. Every weld to be checked with "LEAK-TEC".

Cavity insert to be pressure-tested at 10 psig air prior to its insertion and welding to the cask body. Suitable cover plate and gasket to be provided for this test. Such cover plate to be arranged to allow visual inspection of, and access to, the 12 bolting bosses and the two dowels. Every weld to be checked with "LEAK-TEC".

All welds are to be air-tight at the pressures stated. If leaks are discovered, the weld in that area is to be suitably ground and rewelded. When testing the cask body and the cavity insert individually and a leak is discovered, the weld on the opposite side shall be checked for cracks by suitable dye penetration methods. Repairs to be made to both sides before final assembly of the two units.

All tests to be performed in presence of Brookhaven National Laboratory Inspector.

General Welding Notes

All main welds on inside of cask body to be shielded-metal arc and continuous. Final weld leg to be 1/2". Bonding fin welds to be as noted.

Interior cask trunnion and gusset welds to be shielded-metal arc and continuous. Exterior welds on trunnions to have final pass gas-tungsten arc. Weld leg to be 3/8", or as noted.

All main welds on exterior of cavity insert to be shielded-metal arc and continuous. Weld leg to be 3/8" at bolting bosses, syphon drain line to be welded as noted on drawing.

All welds on the inside of the cavity insert are to be electric arc. Weld leg to be at least 1/4" in the 8 1/8" x 25" section and 3/8" at top of 13 5/8" x 30 1/2" section. Final pass on this section to be gas-tungsten arc.

All welds on the outside of the cask body are to be shielded-metal arc, final pass to be gas-tungsten arc. Final weld leg to be 3/8".

Drawing Legend

SMAW - Shielded-Metal Arc Weld

GTAW - Gas-Tungsten Arc Weld

SMAW-GTAW - Shielded Metal Arc Weld with final pass Gas-Tungsten Arc Weld. The amount of metal deposited on this last pass need only be enough to produce a smooth finish.

Issued **1/20/65**

Rev.
Rev.

Page **1** of **4** Pages

MANUFACTURING PROCEDURE AND QUALITY CONTROL CHECK OFF LIST

CUSTOMER: **BROOKHAVEN** CUST. ORDER NO.: **031167**

PFAC JOB NO.: **J-434** DELIVERY REQUIRED MARCH 15, 1965

OPER.		PFAC Q.C.	CUST. Q.C.	GOVT. INSP.
10	Fabricate and weld cask less cavity insert per customer drawings.	<i>[Signature]</i>		
15	Pressure containing welds in place of radiography must be dye penetrant inspected, or magnaflux checked prior to welding insert to cask.			
	Customer must witness work in progress. Q.C. see purchase order for details. <i>with Refer to letter</i>	<i>[Signature]</i>	<i>[Signature]</i>	<i>[Signature]</i>
15A	<i>1 Cask & 2 Box of Covers w/ Brookhaven Rep. 3/23/65</i>			
20	Sample double fillet weld made by the welders who would be doing the work, be submitted to a radiographic check, and the sample sectioned and micro-etched. One sample for each welder must be submitted.	<i>3/23/65</i> <i>[Signature]</i>	<i>[Signature]</i>	
	Quality Control - see letter dated 7/28/64 to G. Domangue on contractual clarifications of x-ray requirements.	<i>[Signature]</i>		

P. F. AVERY CORP. WELDING RECORD

OP. # MOCK-UP

JOB # 434 CUSTOMER BROOKHAVEN DATE 1/29/65

GENERAL ORDER BNL Letter dated 7/28/64

GOV'T. CONTRACT # _____ DWG. # _____

JOINT

[illegible]

P.F.A.C. INSP.

REMARKS:

Reuse Inspection of HFBR Fuel Cask

Cask Serial # _____ Date _____

Returned on _____ By (Carrier) _____

Initial/Date

1. Exterior radiation check _____
2. Radiation check as cover opened _____
3. Interior radiation check _____
4. Remove shipping tags & labels _____
5. Visual Inspection

Acceptable

- a. Identification plates _____
- b. Signs of corrosion _____
- c. Physical damage* _____
- d. Cover gasket _____
- e. Gasket surfaces _____
- f. Hold down bolts _____
- g. Vent & drain clear of obstructions _____
- h. Other _____

6. Cask ready for fuel loading _____
Supervisor _____ Date _____

7. This form along with the "Spent Fuel Shipment Data Sheet" and the H.P. attachment goes to the Isotope and Special Materials Group at time of shipment.

*Note: Use reverse side to document any damage and subsequent repairs.

TICKLER FILE CARD

FILE HFBR FUEL SHIPPING CASK NO. 1 & NO. 2 CARD NO. 1

LOCATION HFBR Equipment Level COMPLETE IN one week

TIME SCHEDULE Annually - April 1st ROUTE TO Day Supervisor

NOTE: TICKLER CARDS TO BE CHECKED BY Assistant Operations AFTER THEY ARE SIGNED BY PERSON ASSIGNED TO COMPLETE TASK.
Group Leader

[illegible]

OUT	RETURNED	COMMENTS	SIGNATURE	CHECKED BY

DESCRIPTION OF TASK

Complete "Reuse Inspection of HFBR Fuel Cask" record sheet.

Inventory cover bolts. Should have 12 with each cask plus 12 spares in canal area storage cabinet.

Remove pressure relief valve and bench check for proper setting. (5 psi $\pm$ $\frac{1}{2}$ psi)
Replace on cask.

Every 3 years have exterior containment and lifting fixture welds dye-penetrant tested by Central Shops Quality Control Group.

a. Give Central Shops advance notification

b. Obtain test results documentation from Quality Control Group and forward to Isotope and Special Materials Group for recordkeeping.

SAFETY PRECAUTIONS Have H.P. check cask before commencing work.

IV. QUALITY ASSURANCE PROCEDURE
(Items underlined are required QA Documentation)

- A. Clean Casks and have H.P. Check Radiation Levels.
- B. Provide detailed drawings of Modification.
- C. Ultrasonic test of top fillet weld where the shell sides join the top, for full penetration weld.
 - 1. Calibrate instrument using sample model of joint.
 - 2. The test is to be performed by a qualified inspector.
 - 3. An inspection report is required.
- D. Grind out areas in top fillet weld where inspection indicated weld was not full penetration. Also, grind and cut away lifting trunnions (investigate possibility of burning away lifting trunnions).
 - 1. Review grinding operation with H.P. and Safety with regard to Radiation and OSHA aspects.
 - 2. Provide enclosure, vents, hoods, respirators, etc., as required by safety review.
 - 3. Grinding will be done in accordance with IV, F-2, below.
- E. Write Purchase Order for material needed for modification. 304L Stainless Steel is preferred but type 304 or 347 is also acceptable. A certified mill test report is required, and material shall be marked on arrival in such a manner that it is identifiable throughout the fabrication procedure.
- F. Fabrication details will appear on the detailed drawings and job sketches. During fabrication the following general quality assurance items shall be observed.
 - 1. Stainless steel is to be cut only by machining, abrasive cutting, or arc cutting with inert-gas-shielding tungsten-arc, plasma arc, or flux injection methods.
 - 2. Grinding or machining of stainless steel shall not be done with tools that have been used on carbon steel. Tools and grinding wheels shall be freshly sharpened and dressed. Wire brushing shall be done only with stainless steel brushes that have not previously been used on materials other than stainless steel.

3. The marking on each piece of material shall be retained until fabrication is complete. If the material is cut into two or more parts, or if the marked surface is to be removed, the marks shall be carefully transferred prior to cutting.
4. Productions welding shall not be undertaken until both the welding procedure and the welders have been qualified. Each welding procedure to be used in construction shall be in accordance with Section IX of the ASME Boiler and Pressure Vessel Code. Two welders shall be certified using the certified procedures with the same nondestructive testing as required for the production welds, in accordance with Section IX of the ASME Boiler and Pressure Vessel Code. All such qualifications must be approved by a BNL Central Shops Quality Control Inspector.
5. The welding procedure shall include control of the width of any bead of welding. String beading is preferred. Weave beading with covered electrodes shall not result in a weld bead with a width greater than three times the diameter of the electrode core wire. Wash passes or remelting to improve the surface appearance is not permitted.
6. Surfaces to be welded shall be clean and free of foreign material such as grease, oil, lubricants, and marking paints for a distance of at least 3 inches from the welding edge. When weld metal is to be deposited over a previously welded surface, any slag shall be removed.
7. Welding electrodes shall be type 308L. They shall be dry when used. They shall be used within 9 hours after their removal from a sealed receiving container or a vented electric oven maintained at 150° to 350°F.
8. Outside cask surfaces shall be kept as smooth as possible to facilitate cask decontamination when in use.
- G. Lead in the form of sheet and brick shall be packed into the upper structural member as tight as practical without melting, before the last closure member is put in place.
- H. The structural welds required for the addition of the "L" shaped cross sectional member to the top of each fuel cask shall be inspected for full penetration in the following manner.
 1. After the root pass -
 - a. Inspect visually for defects such as cracks, pinholes, and incomplete fusion.
 - b. A liquid penetrant test of the joint shall be made by a qualified inspector using approved procedures.

2. After the weld is completed the joint shall be ultrasonically nondestructive tested by a qualified inspector using an approved test sample of the joint to calibrate the instrument.
3. Defects shall be ground down to sound metal, repaired, and retested until approved.

APPENDIX D

APPENDIX D Operating Procedures

IV-A Establishment and Maintenance of Procedures

Written procedures have been established to assure that necessary determinations and controls are accomplished. The review of completed check lists prior to each shipment assures that the procedures are followed. All records are maintained on file for periodic inspection by internal inspection teams and appropriate third party review. The following procedures are now in effect:

Procedure for Handling Shipping Casks

The procedure below includes the operations which are performed for each shipment to meet the requirements of AEC Appendix 0529.

1. Prior to loading a cask, it is visually inspected to determine that it has not been damaged, that the cover and sealing gaskets are free from defects, and the relief and vent valves are intact.
2. After loading with fuel and upon withdrawal from the canal, the cover bolts are tightened.
3. The external surfaces are washed and decontaminated.
4. The cask is flushed internally with clean water and allowed to remain full of water.
5. After fifteen minutes, an initial water sample is drawn from the cask cavity and four hours later a final sample is drawn.
6. The samples are counted for gross beta, gamma activity. They are considered acceptable if either condition below is met:
 - a. The final sample is not greater than a factor of ten above the initial sample and the final sample is below 10^{-4} $\mu\text{c/cc}$.

b. The final sample is not greater than 10^{-2} $\mu\text{cc/cc}$ and no mixed fission products are seen on a gamma scan.

7. When the water samples meet acceptable guidelines, the cask is drained and blown with compressed air to remove any excess moisture.

8. The cask is allowed to stabilize in temperature for a period of 24 hours.

9. Temperature readings are taken of the air at the top of the cask cavity and the top of a fuel element using a thermocouple probe.

10. The cask cover is sealed using the relief and vent valve assembly. The drain connection is plugged.

The above operations are carried out by Reactor Operations Personnel under the supervision of a Shift Supervisor.

11. Temperature and water sample results are phoned direct to DuPont personnel at SRP, so they may plan their unloading and handling procedures.

12. Prior to and after loading the cask on the shipping vehicle, smears are taken on the outer surface of the cask to ensure that the surface contamination is within the allowable D.O.T. levels.

13. Radiation levels of the cask are taken at contact and at 3 feet.

14. Prior to each fuel shipment, the Shift Supervisor inspects the shipping vehicle for foreign devices.

Inspection Procedure

Data sheets are completed by Reactor Operations and Health Physics personnel as each required task is completed to indicate and record that the necessary operations have been satisfactorily performed. Prior to each shipment, these data sheets are reviewed by supervisory personnel of the Special Materials Handling Group.

Procedure for Loading HFBR Fuel Shipping Cask

The following steps must be conducted for each loading of an HFBR Fuel Shipping Cask.

1. Remove cask cover and take out boron baskets. Flush off boron baskets and replace them in their proper cut rack positions in the canal.
2. Clean cask cavity thoroughly prior to placing cask in canal.
3. Jet the area of the canal where the cask is to be set down.
4. With cask full of water, position in canal for loading.
5. Jet baskets of fuel to be shipped prior to loading in cask.
6. Remove cask from canal, bolt top down, flush cask cavity for about 20 minutes (in the 1/2" vent on cask top, out 3/8" drain) and leave full of water.
7. Wait 15 minutes after flushing and take initial water sample from cask.
8. Four (4) hours after initial sampling take a second water sample from cask.
9. Blow water out of cask (compressed air via regulator into 1/2" vent on cask top, out 3/8" drain). Plug drain connection

and install nipple with attached relief valve and needle valve into 1/2" vent connection on cask top.

10. Twenty-four (24) hours or more after blowing out cask measure cask and fuel temperatures.

- a. Top of cut fuel element - Insert T.C. through 1/2" vent connection in cask top. When end of T.C. stops against fuel, note temperature indication on potentiometer.
- b. Air at top of cask cavity - After measuring fuel temperature, withdraw T.C. slightly, (1/2"). Temperature indication should drop sharply. At this point note air temperature on potentiometer.
- c. Exterior surface of cask - Attach alcohol thermometer to top and sides of cask with apiezon. Take reading after thermometer stabilizes - ~ 30 minutes.

Water Sample Activity Guidelines

The increase of gross β , γ activity from initial to 4 hr. sample should be less than a factor of 10.

Reading in the 10^{-4} to 10^{-2} $\mu\text{c/cc}$ range are acceptable if no MFP are seen on a gamma scan,

Cask and Fuel Element Temperature Guidelines

The following are maximum temperature guidelines:

Exterior Surface of Cask:

Top 116°F

Side 116°F

Interior of Cask:

Air at top of cask cavity 273°F

Top of cut fuel element 370°F

Additional Transportation Arrangements and Controls

1. Shipment from Upton, New York to Dunbarton, South Carolina is under contract with Tri-State Motor Freight, Inc., of Joplin, Missouri, using a specially adapted truck-trailer, handling one cask per trip.

2. The cask is loaded onto the truck by BNL personnel, and is tied down by Tri-State personnel, under BNL supervision. Unloading at the Savannah River Plant is done by DuPont personnel.

3. The driver carries radiation monitoring equipment and is instructed in its use.

4. The driver has a list of local AEC offices along the route. In the event of a minor accident, he would:

(a) Monitor the truck and cask.

(b) Notify local police and fire authorities if normal transport levels had changed.

(c) Call, or have police call, the nearest AEC office for assistance.

There are two 60 lb CO₂ fire extinguishers mounted on the rear of the cab of the truck.

5. In the event of a serious accident, in which the driver was incapacitated or killed, the vehicle bears the required placarding on all four sides. This would alert rescuers and the local police and fire authorities.

IV-B Not Applicable

IV-C Preliminary Determination

1. The modified casks will be checked for cracks, pinholes, and other defects using visual, ultrasonic, and dye penetrant inspection procedures. These tests will be performed by certified inspectors from the Quality Control section of BNL Central Shops Division.
2. Not Applicable
3. During fabrication and upon completion of the modifications, each cask will be checked by BNL Central Shops Division Quality Control Inspectors to insure that the modified casks have been fabricated in accordance with the approved design. Each cask is marked with its model number etched on a plate welded to the cask.

IV-D Routine Determinations

All items included under this heading are adequately covered in Part IV-A and Part III of this evaluation. A check-off list titled "Spent Fuel Shipment Data Sheet" and a "Fuel Shipment Survey" covering all pertinent points of this section are executed for each shipment. Blank and executed reports typical of one shipment are appended (Appendix D).

IV-E Records

The shipper maintains the following records on each shipment. Copies of these record forms are appended (Appendix D).

1. Spent Fuel Shipment Data Sheet - Includes the following information:

Shipment date

Shipment Cask D.O.T. SP# and serial number

Cask inspection

Temperature of fuel, internal air, and cask

Vehicle inspection

Supervisor in charge of shipment

2. Health Physics Fuel Shipment Survey Sheet - Includes the following information:

Smearable contamination of cask

Radiation levels at contact and at 3 feet

Cask water samples obtained prior to draining.

3. Fuel Burnup Record Sheet - Includes the following information:

Date that elements were charged

Date that elements were rotated

Date that elements were discharged

Accumulated MWD

For the individual element assemblies -

Element identification number

Initial uranium content in grams

Core position when charged

Core position when rotated

Total U-235 fissions in grams

Total U-235 consumed (includes conversion to U-236)

Uranium remaining

U-235 remaining

Percent burnup.

4. Nuclear Material Transaction Report - Includes the following information.

Name and address of shipper
Name and address of receiver
Material type and description
Transaction type
Transfer authority
Date shipped.

IV-F Documentation of Technical Backup Support for Specification, Certified, and special permit packagings.

The packaging in question was designed exclusively for the purpose of transporting spent HFBR Fuel Elements by Brookhaven Laboratory. As such, we consider it a highly specialized design for the sole use of the originator. If in the future these specialized casks are to be adopted for more general utilization, an appropriate technical document will be prepared prior to such use.

REACTOR DIVISION

SPENT FUEL SHIPMENT DATA SHEET

1. REACTOR: _____ SCHEDULED SHIPMENT DATE: _____

2. FUEL DESIGNATION: $\frac{1}{2}$ CORE # _____ HFBR SHIPMENT # _____

3. CASK CERTIFICATE # USA/ _____ SERIAL # _____

4. PRIOR TO FUEL LOADING INITIALS DATE

Reuse Inspection of HFBR Fuel Cask check
off sheet completed.

5. AT TIME OF FUEL LOADING

a. Date Loaded: _____, Using Boron

S.S. Baskets # _____ # _____ # _____

b. Cask Temp. measurements at equilibrium

External Surface _____ °F Measured at _____

Inside Air _____ °F Date _____

Fuel _____ °F Time _____

6. PRIOR TO TRUCK LOADING

a. Carrier _____

Tractor # _____ Trailer # _____

b. Vehicle Inspected

c. Protective Plates fastened over cover
lifting eye

7. WHEN LOADED ON TRUCK

a. Visual inspection of cask condition is
satisfactory - including vent and drain
connections

b. Tie-downs in place, as per attached sketch

8. ATTACHED COMPLETED COPY OF HEALTH PHYSICS SHEET ENTITLED "FUEL SHIPMENT
SURVEY # _____"

9. DATA SHEET COMPLETED

SUPERVISOR IN CHARGE OF SHIPMENT _____

Signature

Date

10. ORIGINAL OF THIS FORM WITH HP ATTACHMENT AND CASK CHECK SHEET GOES TO
ISOTOPES AND SPECIAL MATERIALS GROUP AT TIME OF SHIPMENT.

TOP VIEW

SIDE VIEW

HFBR SPENT FUEL CASK HAULAGE
CABLE TIE-DOWN ARRANGEMENT

SPENT FUEL SHIPMENT DATA SHEET

SCHEDULED SHIPMENT DATE: 6/25/73

AND/OR SHIPMENT # CZD-DZA-Z7

SERIAL # 2

DATE _____

RPA

6-18-73

S.S. Baskets # 126 # 104 # 5

RGH

6-18-73

RFA

6.18-23

External Surface 120 °F Measured at Side

Inside Air 159 °F Date 6/21/73

Pro

6/22/73

Fuel 254 °F Time 1630

~~Date Loaded:~~

~~_____~~ Liner # ~~_____~~ Pig # ~~_____~~

~~b. Closure Gasket & Bolts in Good Condition~~

RW

$$6 \overline{) 25} \overline{) 73}$$

rw

6/25/73

PM

6/25/73

SHEET ENTITLED "FUEL SHIPMENT SURVEY # 1615110/30"

10. DATA SHEET COMPLETED.

SUPERVISOR IN CHARGE OF SHIPMENT

R. E. Wayte
Signature

BROOKHAVEN NATIONAL LABORATORY

FUEL SHIPMENT SURVEY # 161 SAV130

REACTOR H.F.B.R.

DATE 6/25/73

SURVEYOR J. F. B. R.

MAX. SMEARABLE CONTAMINATION (d/m/100 sq. cm) 70 B. 1000 #3

MAX. RADIATION LEVEL (mrem/hr @ contact) TOP 35 SIDE 2.0 ENDS 1.5 BOTTOM 1.0

MAX. RADIATION LEVEL @ 3 FT FROM EXTERNAL SURFACE (mrem/hr) < 1.0

CASK WATER SAMPLES (uc/cc)

INITIAL

6/20

H³ 2.02 x 10⁻³

S 2.89 x 10⁻⁴

4- HOUR

H³ 3.17 x 10⁻³

S 4.38 x 10⁻⁴

HIGH FLUX BEAM REACTOR FUEL BURNUP RECORD

1/2 Core Designation # _____

	<u>Date</u>	<u>Day No.</u>	<u>Reactor MWD</u>	<u>Acc. MWD</u>
Charged Position A	_____	_____	_____	A _____
Shifted to Position B	_____	_____	_____	B _____
Discharged	_____	_____	_____	

Element No.	Initial Uranium	Pos. A	Pos. Fact.	U-235 Fissioned	Pos. B	Pos. Fact.	U-235 Fissioned	Total, U-235 Fissioned	Uranium Remaining	Final Enrich.
K-		C-15	.0320		C-1	.0451				
K-		16	.0329		2	.0365				
K-		17	.0320		3	.0451				
K-		18	.0305		5	.0442				
K-		19	.0305		6	.0442				
K-		20	.0320		8	.0451				
K-		21	.0329		9	.0365				
K-		22	.0320		10	.0451				
K-		23	.0305		12	.0442				
K-		24	.0305		13	.0442				
K-		25	.0335		14	.0430				
K-		26	.0335		4	.0430				
K-		27	.0335		7	.0430				
K-		28	.0335		11	.0430				
Total										

Element No.	Initial U-235	Pos. A	Pos. Fact.	U-235 Consumed	Pos. B	Pos. Fact.	U-235 Consumed	Total, U-235 Consumed	U-235 Remaining	% Burnup
K-		C-15	.0376		C-1	.0530				
K-		16	.0387		2	.0429				
K-		17	.0376		3	.0530				
K-		18	.0358		5	.0519				
K-		19	.0358		6	.0519				
K-		20	.0376		8	.0530				
K-		21	.0387		9	.0429				
K-		22	.0376		10	.0530				
K-		23	.0358		12	.0519				
K-		24	.0358		13	.0519				
K-		25	.0394		14	.0505				
K-		26	.0394		4	.0505				
K-		27	.0394		7	.0505				
K-		28	.0394		11	.0505				
Total										

Note: All weights in grams

POSITION FACTORS

Fuel Element Position

Fresh Fuel Core

Equilibrium Core

C-16, 21

0.0305 (0.0358)

0.0329 (0.0387)

C-2, 9

0.0386 (0.0454)

0.0365 (0.0429)

C-15, 17, 20, 22

0.0299 (0.0351)

0.0320 (0.0376)

C-1, 3, 8, 10

0.0475 (0.0558)

0.0451 (0.0530)

C-25, 26, 27, 28

0.0311 (0.0365)

0.0335 (0.0394)

C-4, 7, 11, 14

0.0454 (0.0533)

0.0430 (0.0505)

C-18, 19, 24, 23

0.0284 (0.0334)

0.0305 (0.0358)

C-5, 6, 12, 13

0.0463 (0.0544)

0.0442 (0.0519)

The first set of factors under each heading represents U-235 consumed in fission absorption only. The numbers in parenthesis represent the U-235 consumed in fission and non-fission absorptions.

DOCUMENTATION (Only if document is classified Secret)

Page of Pages Copy of Copies, Serials

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7. Name and Address of Shipper		Lic. No.		8. Name and Address of Receiver		Lic. No.		Transaction Type ☐		1	
								Transaction Type ☐		2	
								Transaction Type ☐		3	
										4	
										5	
										6	
										7	
9. Shipped for Account of		RIS		10. Shipped to Account of		RIS		11. Date of Transfer of Financial Responsibility		Mo. (29-30)	
										Day (31-32)	
										Yr. (33)	
										12. Transfer Authority—SNM Draft Number, Reference, or Order Number (34-50)	
										1	

[illegible][illegible]

DESIGNATION		DATE	BY	CHKD	APP'D
100-100-100-100	100-100-100-100	100-100-100-100	100-100-100-100	100-100-100-100	100-100-100-100
100-100-100-100	100-100-100-100	100-100-100-100	100-100-100-100	100-100-100-100	100-100-100-100
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100-100-100-100	100-100-100-100	100-100-100-100	100-100-100-100	100-100-100-100	100-100-100-100

REVISIONS

NO.	DESCRIPTION	DATE
1	AS ISSUED	100-100-100-100

GENERAL NOTE: ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED. ALL DIMENSIONS ARE TO BE FOLLOWED WITH THIS WARNING.

SECTION AA

SECTION BB

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Sheet No. 1

1-THIS DIMENSION DETERMINED BY FABRICATOR
2-THE FULL CORE THICKNESS OVER THE CORE LENGTH
SHALL BE NOT LESS THAN .020" NOR MORE
THAN .022" AT ANY POINT EXCEPT FOR THE
LAST 1/2 INCH AT EACH END WHERE THE
THICKNESS SHALL NOT EXCEED .025"

3-THE THICKNESS DIMENSION INDICATED APPLIES TO THE SPECIFIED LOADING AND THE USE OF 30W/O FUEL ALLOY. FABRICATOR CAN USE LOWER THAN 30W/O FUEL IF DESIRED, IN WHICH CASE THE THICKNESS WILL BE PROPORTIONATELY LARGER

4: THIS RELIEF IS ALLOWED FOR ROLL SWAGING IF REQUIRED.

5-SCRATCH DEPTH LIMIT ON FUEL BEARING PLATE SURFACES IS .003

FUEL ELEMENT		UNIT NO. 1	
DATE	TIME	OPERATOR	TESTER
10/10/68	14:00	J. H. H. H.	J. H. H. H.
FUEL ELEMENT TYPE		K. L.	
DETAILS			
BR 51-0400-1

1. The building is a single-story structure.
 2. The building is located at the intersection of Main Street and 1st Avenue.
 3. The building is owned by the City of New York.
 4. The building is used for the purpose of a public library.
 5. The building is situated on a lot measuring 100 feet by 100 feet.
 6. The building is situated on a lot measuring 100 feet by 100 feet.
 7. The building is situated on a lot measuring 100 feet by 100 feet.
 8. The building is situated on a lot measuring 100 feet by 100 feet.
 9. The building is situated on a lot measuring 100 feet by 100 feet.
 10. The building is situated on a lot measuring 100 feet by 100 feet.

GENERAL INFORMATION		STRUCTURAL INFORMATION		FINISH INFORMATION	
ITEM	DESCRIPTION	ITEM	DESCRIPTION	ITEM	DESCRIPTION
1	Foundation	1	Foundation	1	Foundation
2	Foundation	2	Foundation	2	Foundation
3	Foundation	3	Foundation	3	Foundation
4	Foundation	4	Foundation	4	Foundation
5	Foundation	5	Foundation	5	Foundation
6	Foundation	6	Foundation	6	Foundation
7	Foundation	7	Foundation	7	Foundation
8	Foundation	8	Foundation	8	Foundation
9	Foundation	9	Foundation	9	Foundation
10	Foundation	10	Foundation	10	Foundation

WELSH, FIDELITY
ALL 49.65 49.75 IN 49.85
49.85 49.95 50.05 50.15 50.25
50.35 50.45 50.55 50.65 50.75

				BROOKHAVEN NATIONAL LABORATORY UPTON, N Y
				NPGR SPENT PULP CHANGE
				STORAGE & SHIPPING BRACKET
				SIN ELEMENT EXTENDING GASKET
				BR-32093-0 A/A