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CASKS IN CONCRETE VAULT ON PFP GROUNDS

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7. Abstract A criticality safety evaluation is presented to permit EBR-II spent fuel casks loaded with metallic fuel rods to be stored in an 8-ft diameter, cylindrical concrete vault inside the PFP security perimeter. The specific transfer of three casks with Pu alloy fuel from the LAMPRE reactor from the burial grounds to the vault is thus covered. Up to seven casks may be emplaced in the casings with 30 inches center to center spacing. Criticality safety is assured by definitive packaging rules which keep the fissile medium dry and at a low effective volumetric density. APPROVED FOR PUBLIC RELEASE 12/2/94 D. Solis		
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CSER 94-011

Title: STORAGE OF METAL-FUEL LOADED EBR-II CASKS IN CONCRETE VAULT
ON PFP GROUNDS

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1. INTRODUCTION AND SUMMARY

This evaluation answers a request to permit transfer of a specific set of three irradiated fuel containers from retrievable storage at the Solid Waste Burial Grounds to inside an 2.44 m (8-ft) diameter concrete manhole casing to be set above ground within the security perimeter of the Plutonium Finishing Plant (PFP). The containers are EBR-II shielded casks with payloads of metallic fuel rods from the Los Alamos Molten Plutonium Reactor Experiment (LAMPRE). Trench storage of the LAMPRE fuel casks was allowed under limits (in Criticality Preventions Specifications SW-149-00051) generic for metallic fuel of all varieties. By using the same basis, this evaluation and the specifications for the vault storage will also apply generically for metal payloads. Details presented herein on the LAMPRE payloads then show conformance to the form, mixture, mass, and packaging specifications adopted for metal loaded casks.

The CPS for the burial grounds requires 1.52 m (5 ft.) spacing (center-to-center) for metal-loaded EBR-II casks arrayed with casks bearing spent oxide carbide and nitride fuel materials. In the circular vault, however, it is found that 0.76 m (2.5 ft) center-to center spacing of EBR-II casks with metallic payloads is sufficient (which would be with their spacer rings touching). With its casing inner diameter at 2.44 m (8 ft), the vault then can accommodate up to seven EBR-II casks, if the extra storage space is ever needed.

Payloads of irradiated metal in EBR-II casks must be as fuel rods within guide tubes which are doubly encapsulated in 10.2 cm (4 in.) and 12.7 cm (5 in.) diameter, weld-sealed inner cans, which then are placed in the 6-inch diameter central cavity of the cask. The fissile load is limited to 4000 grams total of Pu, ²³³U and ²³⁵U (in enriched-U) per cask. Fuel mixtures are not restricted, allowing metallic plutonium and/or uranium alloyed with lighter metal elements. Also, no restrictions are set on either the fraction of Pu in total Pu plus U or the enrichment of uranium. The safety qualification for the permitted loadings is based primarily on the evaluation in CSER 92-007 [REFERENCE 1] supporting their storage in the burial grounds. Some additional calculations are reported for the specific geometry and conditions of the concrete vault emplacement.

Figure 1 illustrates the features of the EBR-II casks, and Table 1 summarizes the restrictions on metal fuel payload in these casks.

MASTER

DRAWINGS
FROM
WHC-SD-WM-T1-395

FIGURE 1 DETAILS OF EBR-II STORAGE/TRANSPORT CASKS

Table I:

CRITICALITY SAFETY LIMITS FOR METALLIC FUEL PAYLOAD IN EBR-II CASKS

ALLOWED FISSILE MATERIALS:	PU-X, PU-U-X, OR ENRICHED U-X ALLOYS, WITH X AS ANY COMPATIBLE LIGHTER METAL ELEMENT (EXCEPT BE)
MAXIMUM FRACTION OF PU IN PU + U	NO LIMIT
²³⁵ U-ENRICHMENT IN ALLOY U:	NO LIMIT
MINIMUM ²⁴⁰ PU FRACTION IN PU:	NO LIMIT
TOTAL FISSILE: PU + ²³³ U + ²³⁵ U (IF U IS ENRICHED)	4000 G, MAXIMUM
REQUIRED FUEL FORM:	CLAD FUEL RODS, OR ROD SECTIONS (WITH OR W/O CLAD) STACKED WITHIN STEEL TUBES
REQUIRED CONTAINMENT	FUEL-BEARING TUBES WITHIN 4-IN. DIA. INNER STEEL CYLINDER WITHIN 5-IN DIA. 2ND STEEL CYLINDER, BOTH WELD SEALED
FUEL DIAMETER RESTRICTION:	DIAMETER OF METAL RODS (W/O CLAD) NOT TO EXCEED 60% OF DIAMETER OF LOADING TUBES. MAXIMUM METAL ROD DIAMETER 0.45 INCHES
ALLOWED TUBE DIAMETERS:	ODs OF 0.750, 0.625, 0.500 OR 0.437 IN.

2. VAULT, CASK AND PAYLOAD DESCRIPTIONS

2.1 Concrete Vault Specifications

The cylindrical concrete vault, sometimes dubbed a "manhole" because of its procurement source, is illustrated in Figure 2. The structure is a three-piece concrete assemblage (base-slab, cylindrical casing and topslab) commonly employed for street access to underground utilities, like stormdrains, sewer-pipe, etc.. Only in this usage there are no side penetrations or actual man-hole access port plus cover on the top. Also, the structure will be set above ground, and routine man access will not be permitted. The figure is a copy of the generic diagram from the unit fabricator, Western Concrete Products, Inc.

The inside dimensions of the vault casing are a diameter of 2.44 m (8 ft) and height of 1.82 m (6 ft). The cylindrical casing walls are 20.3 cm (8 in.) thick, and both the top and bottom round slabs are 30.5 cm (1 ft) thick. These data give an exterior diameter and height of 2.84 m (112 in.) and 2.44 m (96 in.), respectively. There are steel insets with threaded penetrations for lifting bolts emplaced around the casings and in the topslab. As shown in Fig. 2, the topslab rim extends below the top of the casing, where the wall thickness is reduced 10.2 cm (4 in.) and an O-ring groove is provided. Thus, sealing of the interior from outside weather is assured.

FIGURE 2: CONCRETE STORAGE VAULT CONSTRUCTION DETAILS

Western Concrete Products, Inc.

2651 N. DAKOTA ST. • SPOKANE, WASHINGTON 99207 • PHONE (509) 487-2726 • FAX (509) 487-0741

2.2 EBR-II Cask Features

The basic design of the EBR-II cask is shown in Figure 1, which was derived from the Hazard Class determination report [REFERENCE 2] for cask storage in the 200 - West area. Further details on the cask are found in this reference, including precise dimensions and material specifications for the containment vessels.

In essence, the EBR-II cask is a 152 cm (5-ft) tall, 44.4 cm (17.5 in.) diameter steel casing with a 96.5 cm (38 in.) high, 15.24 cm (6 in.) diameter central payload cavity. Between the steel cavity pipe and the casing wall, top and bottom is 12.7 cm (5-in.) of shielding lead. The casing has 76.2 cm (30 in.) diameter steel rings around the top and bottom, primarily for the purpose of centering the casks within the cylindrical compartments of transport overpacks.

The loading of the payload cavity depends on the form of the spent fuel. For loadings of irradiated metallic fuel the required primary containment is a cylinder made from 10.2 cm diameter (nominal 4-in., schedule 40) stainless steel pipe. This 4-inch vessel is enclosed inside another stainless container of 5 inches diameter. Weld seals are required for both of these stainless vessels. Then, the double-encapsulated package is set within the cavity of the cask. After installing the upper shield plug, the cask is closed and sealed using a gasketed cover plate.

2.3 LAMPRE Fuel Specifications

The LAMPRE-fuel payload packages, double encapsulation within a 12.7 cm (5 in.) diameter steel canister, were shipped to Hanford in T-3 casks in early 1991. The revisions to the T-3 SARP [REFERENCE 3] in advance of the shipment included the following loading specifications, which were provided in a subsection 6.2.5 of the qualifying criticality safety evaluation CSER 91-005 [REFERENCE 4];

6.2..5 "LAMPRE Pu Metal Alloy Fuel in Spent Fuel Container

Spent fuel container payloads of Pu-Fe, or Pu-Co metallic alloy fuels or their mixtures may contain 97.5% maximum plutonium, with at least 6% ²⁴⁰Pu. The alloys of cesium and cobalt have a plutonium content greater than 38% of the alloy weight. The array is restricted to a 4-in diameter by 38-in. long cylindrical pipe inside the 5-in diameter pipe container. The fuel loading is limited to 0.375-in. OD fuel rod sections, with 0.425-in. OD (0.025-in.-thick tantalum) cladding, of arbitrary length, placed end-to-end in 0.625-in. or 0.750-in. OD steel tubing inside the 4-in. OD pipe.

Fissile loading (plutonium plus ²³⁵U) is 4 kg maximum for a one-container spent fuel container payload and 8 kg for a two-container payload. The atmosphere in 4-in. and 5-in. containers, with carbide, nitride or plutonium alloy reactor fuel, consists of nitrogen, argon, helium, or a mixture of these gases.

The Certificate of Compliance for the T-3 shipping casks included the following:

SPECIFICATIONS FOR LAMPRE FUEL IN NRC CERTIFICATE NO. 9312, Rev. 11 -Docket No. 71-9132

<u>Type</u>	<u>Fuel Description</u>	<u>Array Description</u>	<u>Maximum Fissile Package Loading</u>	<u>Pin Dimensions</u>
(10) LAMPRE Fuel Pins (spent fuel container)	97.5% Pu max-X alloy X=Fe, Co or Cs	Circular Array Individual Pins contained in 0.625" or 0.75" Dia. steel tubes.	8.0 kg*	0.425" Dia. 38" Active Fuel length

* Two payload canisters are allowed, with a 2 ft spacer between, in the 12 ft long loading cavity of the T-3 cask.

These payload specifications are readily seen to conform with the requirements in Table 1. Copies of burial ground receiving records for the three LAMPRE-fuel casks are attached as Appendix A.

3. CONTINGENCY ANALYSES

Error conditions, as examined in the evaluation for trench storage of metal loaded casks, can be divided into three categories:

- a) Payload errors; Mass overbatching, rod form/diameter, placement in steel tubes, double encapsulation, weld sealing, etc.
- b) Cask construction and spacing errors
- c) Water flooding events; array interstitial and ingress to payload

Payload errors were well covered by the numerous calculations reported in CSER 92-007, which are summarized in Section 5 below. For such errors, the fault would be with the organization which provided the original packaging of the inner canisters. Before cask storage is allowed, reviews of the shipping documentation must show there is sufficient evidence of proper packaging and loading controls.

Cask spacing errors also were studied in CSER 92-007 relative to the minimum 1.52 m (5 ft) center-to-center separations required for trench storage. In these studies, casks were arrayed 0.6m (24 in.) apart in a square grid (representing casks clustered with rings overlapping). Results of some additional cluster calculations are reported in Section 5 and 6, below; these were done to aid revisions of the SARP [REFERENCE 5] (for transfer of the casks in 21PF overpacks), and also for the manhole storage arrangement. Regarding possible cask construction errors, the absence of the lead shielding could be important for the reactivity of closely spaced casks: a case was run for such a scenario.

The condition of cask array flooding, not unexpected in the trench placements, becomes highly unlikely for the manhole storage. Payload water ingress was considered in the previous evaluations for EBR-II casks. However, because of the double encapsulation for metallic fuel, the sealing of the casks, and the above-ground protected storage, water entry inside of the 4-in primary container is deemed here to be not credible.

4. REVIEW OF EVALUATIONS FOR MIXED COMPOUND FUEL PAYLOADS

CSAR 79-035 and addenda [REFERENCES 6, 7 AND 8] are earlier evaluations for EBR-II style casks with mixed plutonium/uranium payloads as oxide, carbide and nitride compounds. The first two of these reports [REFERENCES 6 AND 7] concerned storage of PuO_2/UO_2 fuel rods actually irradiated in the EBR-II reactor. The packaging of the EBR-II fuel included insertion into 1.27 cm (0.5 in.) diameter tubes and the double encapsulation specified in Table 1. The casings were 54 cm (21.3 in.) in diameter without rings, and spacing between casks was not required.

The second addendum [REFERENCES 8] of CSAR 79-035 concerned casks loaded with mixed Pu-U compound fuel (allowing also carbide and nitride types) of unspecified form encapsulated in 12.7 cm (5 in.) diameter inner cans. With no double canning, payload flooding was considered plausible, and it was determined that the fuel should be no more than 50% Pu and casks should be spaced 1.52 m (5 ft) apart.

5. SUMMARY OF CSER 92-007 RESULTS

CSER 92-007 extended the studies to include cask payloads of metal fuel rods, under the restrictions given in Table 1. The safety qualification for the limits was provided by MONK6A Monte Carlo calculations modelling EBR-II casks with a variety of loadings and reflection conditions. With allowed loadings of 4 kg of plutonium (with 5% ^{240}Pu) as rods properly tubed and contained, the calculated k_{eff} values ranged up to 0.53, for a single cask buried in wet sand. The buried scenario is a potential condition in trench placement, and not counted as an error. The results for various error conditions are summarized as a contingency matrix in Table 2 (from CSER 92-007).

Unless otherwise cited for the Table 2 cases, the total cask loading is 4 kg of Pu, with a 5% ^{240}Pu fraction. The cases on the diagonal of the table matrix are single error situations, and the off-diagonal cells are double-faulted scenarios combining the column header and row header error stipulations. The top line is each of the matrix cells is the MONK6A case number, and the bottom line is the calculated k_{eff} .

The standard deviations on the k_{eff} values were ± 0.004 or less for the calculations using the MONK6A code on the CRAY computer. Section 8, "VALIDATION OF ANALYTICAL METHODS", in CSER 92-007 documents the derivation of the bias and statistical uncertainties for the code. For assurance of subcriticality, including a 5% Δk margin, a maximum allowed calculated k_{eff} of 0.935 was derived. Further discussions about the statistics and uncertainties are presented in the MONK6 validation reports [REFERENCES 9 AND 10].

Table 2: CONTINGENCY MATRIX FOR METAL PAYLOADS IN EBR-II SPENT FUEL CASKS

SINGLE ERROR	OVER BATCH (M x 2)	OMIT 4" INNER CAN (V)	OMIT LOADING TUBES (T)	WRONG FORM, OVERSIZE (F, D)	INTERIOR OF CASK FLOODED (W)	CASKS CLOSER THAN 60" C-TO-C
OVER BATCH (M x 2 or 3)	EBRMT09 8 kg Pu 73 rods .26"x6.2" 0.634	EBRMT12 12 kg Pu 55 rods .38"x6.2" 0.750	EBRMT19 8 kg Pu 61 rods .4"x 3.7" 0.946	EBRMT16 8 kg Pu, 31 rods .5"x 3.7" 0.857	EBRMT15 8 kg Pu 73 rods .26"x 6.2" 0.827	EBRMT33 ∞ Array 24" c/c 8kg Pu ea 0.683
OMIT 4 IN DIAM. INNER CAN (V)	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	EBRMT13 61 rods, .26" x 4" + A1 fill 0.525	EBRMT20 43 rods, .38" x 3" + A1 fill 0.761	EBRMT21 19 rods, .53 x 3", + A1 fill 0.703	EBRMT23 61 rods, .26" x 4" + A1 fill 0.663	EBRMT35 ∞ Array 24" c/c spread 5" 0.453
OMIT STEEL LOADING TUBES (T)	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	EBRMT27 43 rods, .38" x 3" 42 Nat.U 0.794	ECASK13 L/D=1.0 button in sand 0.870	EBRMT24 43 rods, .38" x 3" + A1 fill 0.812	EBRMT36 ∞ Array 24" c/c U filler 0.821
FUEL DIA OVER 60% OF TUBE DIAM (D)	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	EBRMT17 19 rods, .53" x 3" + A1 fill 0.688	EBRMT25 19 rods, .53" x 3" + A1 fill 0.759	EBRMT37 ∞ Array 24" c/c U filler 0.745
INTERIOR OF CASK WATER FLOODED (W)	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	EBRMT10 61 rods, .26" x 4" A1 ends 0.672	EBRMT32 ∞ Array 24" c/c w H2O mix 0.684
CASKS SPACED CLOSER THAN 60" C-TO-C	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX XXXXXXXXXX	EBRMT31 ∞ Array 24" c/c A1 filler 0.508

SYMBOL

ERROR CONDITION

- D Diameter of fuel (w/o clad) exceeds 60% of loading tube diameter
F Metal payload not as fuel rods, or diameter (w/o clad) > 0.45"
M Fissile mass overbatch: x-factor gives load as multiple of 4 kg limit
T Rods not contained inside of steel tubes of four specific sizes
V Payload not contained within 4-inch inner stainless steel vessel
W Water entry into interior of cask, inside of 4" inner can, payload
S Casks spaced less than 5 feet center to center (for storage array)

The most reactive situations result from the error of not placing the metal fuel rods into steel loading tubes. As a second contingency, before criticality is possible, the payload would have to be about double the 4.0 kg limit placed on the content of Pu plus ^{235}U . Such error conditions are failures of administrative controls during payload packaging, which should have been precluded by adherence to loading procedures and requirements for supervisor checkoffs.

Water ingress into the primary container of these metallic payloads would not have as great an impact as for special-form payloads of Pu-oxide, nitride and carbide fuels. This is because the pin form maintains a degree of heterogeneity, so the Pu cannot be as effectively moderated. Furthermore, for the reasons cited earlier, such payload flooding is not credible.

Also, as a result of the heterogeneity and dry conditions, the most reactive fuel configurations with metal rods are those most compact axially in the 4-inch diameter inner containment, obtained using short rods without stacking in the tubes. Payloads of fewer, longer metal rods (or stacking in the tubes) with the same cask total fissile content will always render lower k_{eff} values because of the increased neutron leakage per unit mass.

The metal specifications allow constituents of uranium; enriched, natural and/or depleted. Separate MONK6A problems were run for enriched-U metal payloads (w/o Pu), with the ^{235}U content up to the 4 kg limit. In all cases the substitution of ^{235}U for plutonium in the allowed fissile content produced lower k_{eff} values. For example, replacing the Pu(5% ^{240}Pu) payload in Case EBRMT24 of Table 2 with ^{235}U rods of the same size and number reduced k_{eff} from 0.812 to 0.627. Any ^{238}U component, as part of enriched U or in mixed U plus Pu alloys, also serves to reduce k_{eff} for a given total fissile content.

6. ARRAY AND CLUSTER CALCULATIONS FOR SARP

Of more relevance to the safety qualification of shipping packages are the calculations modelling arrays of casks. Table 3 is a compilation of some of the array data in CSER 92-007 with results from some new calculations done in support of Packaging Safety Engineering revisions to the SARP [REFERENCE 5] for transporting EBR-II casks in 21PF overpacks; the SARP needed changes to allow transfer of the LAMPRE fuel casks. The table first lists results of several MONK6 cases modelling infinite 1-tier arrays of the EBR-II casks with plutonium metal loadings. Latter cases in the table involve 3-cask clusters in a cuboidal cell with close-in concrete walls. Cases with numbers up through EBRMT49 were derived from the cask storage evaluation (CSER 92-007, using MONK6A), whereas the higher number cases were done with MONK6B on behalf of the SARP revision.

The geometry prescriptions for the Table 3 infinite-array cases set the casks with their spacer rings overlapping, giving center-to-center spacings of 60.3 cm (23.75 in.), which is the sum of the casing and ring radii. Such spacing was adopted as an error condition for trench storage, from a hypothesized compaction of the array after impacts by an uncontrolled vehicle. As a shipping mode error, in the absence of supervision and disregarding regulations, cask handlers might be tempted to set numerous upright casks so spaced in a transport van (using a forklift).

Table 3: MONK6 CALCULATIONS FOR ARRAYS OF METAL LOADED EBR-II CASKS

CASE ID Fissile Makeup per Cask	PAYLOAD FORM	CASK INTERIOR CONDITION (Dry in all cases)	ARRAY TYPE*, MEDIUM BETWEEN CASKS	k _{eff.} (Std. Dev.) **	ERRORS (per Table 2 foot notes)
<u>EBRMT31</u> 4 kg Pu, 5% ²⁴⁰ Pu	.26"d x 3.94" rods in 61 of 73 .44" tubes. Al ends	6-row hex less 3/ corner. 12 inter- mixed Al rods	∞ XY, Air	0.5081 (0.0027)	S for all
<u>EBRMT51</u> as above	As above	As above	∞ XY, Water	0.4715 (0.0030)	as above
<u>EBRMT55</u> 8 kg Pu, 5% ²⁴⁰ Pu	.26"d x 7.87" rods in 61 of 73 .44" tubes. Al ends	6-row hex less 3/ corner. 12 inter- mixed Al rods	∞ XY, Air	0.6395 (0.0032)	M x 2, S in all
<u>EBRMT37</u> 4 kg Pu, 5% ²⁴⁰ Pu	19 .53"d x 3.1" rods in 31 .63" tubes. Nat.U ends	OVERSIZE RODS: 4- row hex -6 corners, 12 Nat.U outer rods	∞ XY, Air	0.7447 (0.0035)	D, S for all
<u>EBRMT36</u> 4 kg Pu, 5% ²⁴⁰ Pu	43 .38"d x 2.6" rods in 85-rod hex array. Nat.U ends	NO TUBES: 6-row hex less corners, 42 Nat.U outer rods	∞ XY, Air	0.8210 (0.0034)	T, S for all
<u>EBRMT56</u> As above	As above	As above	∞ XY, Water	0.7923 (0.0058)	As above
<u>EBRMT42</u> 4 kg Pu 5% ²⁴⁰ Pu	.26"d x 3.94" rods in 61 of 73 0.44" tubes. Al ends	6-row hex less 3/ corner, Al in 12 outer tubes: Dry	3 Cross stacked in Air	0.5102 (0.0028)	S x 2
<u>EBRMT52</u> As above	As above	As above	As Above, Water	0.5136 (0.0047)	As above
<u>EBRMT57</u> 4 kg Pu 5% ²⁴⁰ Pu	.26"d x 3.94" rods in 61 of 73 0.44" tubes. Al ends	6-row hex less 3/ corner, Al in 12 outer tubes	3 Cord- stacked + water	0.5212 (0.0030)	S x 2
<u>EBRMT58</u> 8 kg Pu 5% ²⁴⁰ Pu	.26"d x 7.87" rods in 61 of 73 .44" tubes. Al ends	6-row hex less 3/ corner, Al in 12 outer tubes	3 Cord- stacked + water	0.6823 (0.0032)	M x 2, S x 2

NOTE: Loading error or upset condition indicated by bold type.

* For ∞ XY, upright casks are spaced 23.75 inches center-to-center in infinite, 1-tier, square-grid array. Cross-stacked cluster has one horizontal cask between two upright casks, with casings touching, within cuboidal concrete-wall cell. Cord stacking has ring-less cask casings piled horizontally in triangular cross-section stack on concrete floor of cuboidal cell.

** Case series EBRMT01 --- 49 calculated with MONK6A on CRAY. Series EBRMT51 --- and up done with MONK6B on SUN workstation. Bias and validations same for both.

The shipping safety evaluation requires accounting for potential array flooding due to transport mishaps (overturn of cargo into body of water, etc). The first two cases in Table 3, for spaced arrays of properly loaded casks, show that water between casks serves to isolate the fissile media in the different casks and thus reduce reactivity. A similar reduction in k_{eff} (Δk of about -0.03) due to array flooding is obtained when, as an internal error condition, the 4 kg payloads of plutonium rods are not contained inside of steel tubes as required; this is shown by comparing results for case EBRMT56 against case EBRMT36.

The last four cases in Table 3 modelled three casks only, in upset configurations with their 0.445 m (17.5-in.) diameter casings in contact. A cluster consisting of a fallen cask set between two vertical casks was modelled in cases EBRMT42 and EBRMT52, without and with water flooding around the units, respectively; here the water only slightly increases reactivity, probably because the lead shielding within the casks already supplies an effective isolating medium. The flooded-cell k_{eff} with 4 kg payloads is about the same as for an isolated cask with the same payload buried in wet sand.

The last two cases in Table 3 model a potential accident scenario where damage has effectively eliminates the casks' 0.76 m (30-in.) diameter spacer rings. Then, the three units are stacked horizontally like cordwood, with casings in contact along their length, on a concrete pad with close-in concrete walls. Cell water flooding is again assumed (but not inside casks). The k_{eff} with 4 kg payloads (Case EBRMT57) is seen to be not much more than for the cross-stacked 3-cask case (Case EBRMT52), due mostly to the limited length of the fueled regions. Thus, for properly loaded and shielded metal payloads, even stacking of casks without spacer rings will retain a condition of reactivity far below the criticality safety limit.

Cases EBRMT55 and EBRMT58 show the effect of casks overloaded by a factor of 2, achieved by doubling the length of the metal rods. In the infinite array of spaced casks, the overbatch effect is a Δk of $+0.131 \pm 0.004$ (EBRMT55 versus EBRMT31). For cask casings in contact along their lengths the effect increases to a Δk of $+0.161 \pm 0.004$ (EBRMT58 versus EBRMT57) because of the greater solid angles of interactions.

7. CALCULATIONS FOR VAULT CONFIGURATIONS

Additional calculations were done with MONK6B modelling seven EBR-II casks within a 2.44 m (8-ft) diameter concrete vault. The geometric input specifications for the vault conformed with the Section 2.1 description, except for modelling a 2.0 m (6.5 ft) inside height and making the cylindrical casing wall 30 cm (1 ft) thick. Seven casks with their 0.76 m (2.5 ft) rings touching fit well inside the casing diameter in a hexagonal pattern. Sample inputs for the vault calculations are attached as Appendix B, which includes also a SCAN-code picture showing the modelling.

Table 4 presents the details and results of the 7-cask vault array calculations. The first case (EBRMT61) is a configuration of properly loaded and spaced casks, with 4 kg of plutonium each. The k_{eff} here of 0.515 is near the same as for an isolated cask with the same payload buried in wet sand.

Table 4: MONK6B CALCULATIONS FOR METAL LOADED EBR-II CASKS IN 8-FT DIA. VAULT

CASE ID (No of Casks)	NO. OF CASKS PITCH	CENTRAL CASK SPECIFICATIONS		OUTER ROW CASK SPECIFICATIONS		MEDIUM BETWEEN CASKS	MONK6B RESULTS k_{eff} (Std. Dev.)
		PAYLOAD FORM	FISSILE MAKEUP	PAYLOAD FORM	FISSILE MAKEUP		
EBRMT61	$\frac{7}{30.0''}$	.26"d x 3.9" rods in 61 of 73 .44" tubes. Al ends	4 kg Pu, 5% ^{240}Pu Dry	.26"d x 3.9" rods in 61 of 73 .44" tubes. Al ends	4 kg Pu, 5% ^{240}Pu	Air	0.5151 (0.0030)
EBRMT64	$\frac{7}{30.0''}$	.26"d x 3.9" rods in 61 of 73 .44" tubes. Al ends	4 kg Pu, 5% ^{240}Pu Dry	.26"d x 3.9" rods in 61 of 73 .44" tubes. Al ends	4 kg Pu, 5% ^{240}Pu Dry	Water: Water also in 6" ID cask cavity	0.5378 (0.0029)
EBRMT62	$\frac{7}{30.0''}$	.26"d x 7.9" rods in 61 of 73 .44" tubes. NO LEAD SHIELDING IN CASK	8 kg Pu, 5% ^{240}Pu	.26"d x 3.9" rods in 61 of 73 .44" tubes. Al ends	4 kg Pu, 5% ^{240}Pu	Air	0.5414 (0.0030)
EBRMT65	$\frac{7}{23.75''}$	.26"d x 7.9" rods in 61 of 73 .44" tubes. Al ends	8 kg Pu, 5% ^{240}Pu	.26"d x 7.9" rods in 61 of 73 .44" tubes. Al ends	8 kg Pu, 5% ^{240}Pu	Air	0.6304 (0.0030)

Note error conditions indicated in bold type

Case EBRMT64 in Table 4 has the same fuel and cask array as in the first case, except the vault is flooded. In addition, it is assumed for this situation that all of the cask outer seals have failed so that water fills the 15.8 cm (6.2 in.) outer diameter gap annulus between the payload can and the inner wall of the cask cavity pipe. The Δk effect of $+0.023 \pm 0.004$ from the normal conditions comes predominately from the water inside the cask, acting as a moderator and closer reflector.

For the third Table 4 case two errors are modelled for the central cask; a), the payload is double-batched using fuel rods twice as long, and b), the lead shielding annulus is not present. On balance, the ~3% higher k_{eff} for Case EBRMT62 (versus the normal first case) is a positive effect of higher fissile content offset somewhat by the extra neutron leakage from the center cask. At the cask spacings involved, the lack of lead does not appear to be of consequence to neutron interactions between cask payloads.

The last case in Table 4 has all seven cask payloads double-batched and the casks have been clustered closer, with their spacer rings overlapping (as done for the infinite-array cases in Table 3). The Δk_{eff} of $+0.115 \pm 0.004$ (Case EBRMT65 versus Case EBRMT61) for fuel doubling with hex-grid clustering of seven casks agrees qualitatively with the $+0.0131 \Delta k_{eff}$ found in Table 3 for infinite square-grid arrays (EBRMT55 voice EBRMT31).

None of the plausible error scenarios studied, thus, have given k_{eff} values close to the 0.935 value for assured subcriticality.

8. CONCLUSIONS

As for certified shipping containers in general, the assurance of subcriticality for the EBR-II casks with metal payloads relies predominately on the interior design of the container and payload confinement, and on the precautions observed during the payload preparation to conform with mass and form restrictions. The dimensions and integrity of the outer container walls then provide adequate isolation between separate fissile accumulations.

The analyses reported above readily demonstrate that the loading of EBR-II casks according to the Table 4 restrictions provides assurance of subcriticality satisfying the Double Contingency criteria set forth in the Hanford site Nuclear Criticality Safety Manual, WHC-CM-4-29. Spacing of more than that provided with the rings touching (0.76 m diameter) is not necessary, so that up to seven cask may safely be stored in a 2.28 m (8 ft) diameter concrete vault.

The data included and appended for the loadings of the LAMPRE fuel casks show their loadings are within the envelope of the specifications for allowed metal fuel in the adopted CPS limits.

These studies can also be considered adequate justification for storage of metal-loaded EBR-II casks in small arrays (3 x 3) inside vaults of the PFP or in buildings of the Central Waste Complex, if ALARA concerns are satisfied. Also, it should be intuitively obvious that ceramic fuel rods (mixed oxide, carbide or nitride) packaged under the Table 1 payload restraints would be just as safe as the metal payloads, and could be stored with rings in contact. An addendum to

this report with results of calculations modelling specific ceramic fuels should be prepared for confirmation of the reactivity differences if such storage is contemplated.

9. REVIEWER'S COMMENTS

S.J. Altschuler of Criticality Radiological Analyses carried out the independent, technical reviews of the evaluation, for which the following comments were provided. Editorial comments have been incorporated into the body of the report.

The number densities input to the MONK runs have been checked and are correct. The other MONK input appears adequate.

As an alternate method of analysis, assume the casks, shielding, liners, tubes, etc., do not exist. Using the Surface Density vs. Shape Factor (Unit Surface-to-Volume Ratio) Method:

$$\begin{aligned} 4\text{kg Pu metal} &= 203\text{cm}^3 = 3.646\text{cm radius sphere}; & s/v &= 3/R = 0.823/\text{cm} \\ 8\text{kg Pu metal} &= 406\text{cm}^3 = 4.594\text{cm radius sphere}; & s/v &= 3/R = 0.653/\text{cm} \end{aligned}$$

According to Table V of RFP-1585 [REFERENCE 11], the safe surface density for the 4kg Pu metal spheres is 1.0kg/ft. The floor area of the circular vault is 50.3 ft² which would allow 12 casks each with 4kg of Pu metal.

In the reference [11], a 8kg metal unit would not be allowed because it would not be safe if flooded. Flooding is not regarded as a credible contingency in our case. In another study [REFERENCE 12, TABLE II], a 32 by 32 1 array of 4.4kg Pu metal units has a k-effective of 0.901 ± 0.008 when one unit is double batched. The unit in this example is a cylinder 7.05cm D and 5.72cm H.

If we assume the rods are smeared out over the inner container as a right circular cylinder with height equal to its diameter, 4.0 inches, actually 5.263cm radius from the computer printouts, we get

$$\begin{aligned} 4\text{kg Pu} &= 916\text{cm}^3 = 4.37\text{g/cm}^3 = 0.22 \text{ of alpha Pu metal density}; & s/v &= 0.57 \\ 8\text{kg Pu} &= 916\text{cm}^3 = 8.73\text{g/cm}^3 = 0.44 \text{ of alpha Pu metal density} \end{aligned}$$

According to Figure II of RFP-1585 [REFERENCE 11] both units are subcritical, the 4kg ones very much so.

If we assume that these smeared units are flooded so that their interstices are filled with the interspersed water, they could be regarded as equivalent to wet oxide. Figure 4 of [Reference 13] shows that these units are safe.

These mathematical models were developed for a large room (67ft by 67ft by 10ft), since the manhole is smaller, then according to Reference 14 the safe surface densities could be increased by a factor of 2.9.

The code used for these models was KENO or KENO II with the Hansen-Reach B cross-section set. The limits for a "safe" array were $(k + 4\sigma) < 0.90$ for metal and $(k + 4\sigma) < 0.94$ for wet and dry oxide.

10 REFERENCES

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2. WH-SD-WM-TI-395: "Hazard Class and Facility-Use Determination for Irradiated Fuel Storage in EBR-II Casks in the 200 West Area", R.J. Van Fleet, September 5, 1989.
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7. SD-SQA-CSA-20115, Rev. 0: "CSAR 79-035, Addendum 1; Storage of EBR-II Spent Fuel", R.D. Carter. Report approved 3/4/80. SD issue date March 3, 1989
8. SD-SQA-CSA-20116, Rev. 0: "CSAR 79-035, Addendum 2; Storage in EBR-II Spent Fuel Storage Casks", W.A. Blyckert. Report approved 7/11/84. SD issue date March 3, 1989
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11. S.J. Altschuler and C. L. Schuske, "Models for the Safe Storage of Fissile Metal", Nuclear Technology, 13, 131-147 (February 1972). Also published as Rocky Flats Report, RFP-1585, and as "Surface Density as a Useful Parameter in the Storage and Handling of Fissile Metal", Trans. Am. Nuc. Soc., 13, 2, 667 (1970).
12. S.J. Altschuler and C. L. Schuske, "A Study of Criticality Parameters Affecting the Handling and Storage of Fissile Metal", Nuclear Technology, 18, 55-62 (April 1973).
13. C. L. Schuske and S.J. Altschuler, "Models for the Safe Storage of Wet and Dry Fissile Oxides", Nuclear Technology, 19, 84-95 (August 1973)
14. C. L. Schuske and S.J. Altschuler, "Storage Capacity for Fissile Material as a Function of Facility Size", Nuclear Technology, 20, 179-189 (December 1973)

APPENDIX A:

PAYLOAD DATA FOR THREE EBR-II CASKS WITH LAMPRE FUEL

<u>ITEM</u>	<u>DESCRIPTION</u>	<u>PAGE</u>
A.1	SOLID WASTE STORAGE/DISPOSAL RECORD - - EBR-II CASK LANL-S/N-060	17
A.2	SOLID WASTE STORAGE/DISPOSAL RECORD - - EBR-II CASK LANL-S/N-062	18
A.3	SOLID WASTE STORAGE/DISPOSAL RECORD - - EBR-II CASK LANL-S/N-063	19

[illegible]54-6000-226 (07,82)

APPENDIX A, ITEM A.2

01431

SOLID WASTE STORAGE/DISPOSAL RECORD 07431				Page 1 of 1	
Storage/Disposal Site			Waste Designation ☐ TRU ☐ LLW ☐ MW ☐ C+ ☐ Classified		
I certify that a physical inspection of the waste packages to the extent possible and a cross check of the applicable documentation have been performed in accordance with TO-100-050 or TO-100-110.			SWSDR No. (DO NOT WRITE IN THIS SPACE)		
Signature - Acceptance <i>Shirley Cornwell</i>			Waste Generator Battelle/Pacific Northwest Lab		
Date 4-12-90			Charge Code, SO No., or MPO No D7R30		
Area 200 W			WRM No. N/A		
Facility 218-W4C		Unit TR 1	Name of Contact (Type or Print Clearly) R.L. Spinks		
Storage Location (S01)			Address/Phone 327/8/300 (PB-24) 376-5431		
Module NA	Tier NA	Position NA	I certify that: (1) No capital property is included in this waste unless documented by a Property Disposal Request and described below. (2) To the best of my knowledge, the information entered below is complete and accurate, and the waste package is in compliance with WHC-EP-0063 and the Storage/Disposal Approval Record (SDAR). (3) Unless designated as Mixed Waste (MW), this waste is not a dangerous waste as defined by Chapter 173-303 WAC or other applicable state or federal regulation governing the management of hazardous waste. (4) The charge code is correct.		
Disposal Location (D81)					
Beginning Coordinates N W					
Ending Coordinates N W					
Signature <i>R. Spinks</i>			Date 4/10/90		
WASTE PACKAGE INFORMATION					
PIN LANL S/N-062		POINT OF ORIGIN 324 Bldg - 300 Area		Physical Description of Waste and Comments Waste Designation: LAMPRE Spent nuclear fuel and cladding. Lead shielding in cask: 2000 Kg PNL/PITL Record No. SS2400 EBR-II SFSC Inner Container #300-14 in EBR-II Cask S/N-062	
CONTAINER TYPE EBR-II Spent Fuel Cask		K x W x H or D x L 59.5" long x 30" dia			
CONTAINER VOLUME (m ³) 24.5		EMPTY TARE WEIGHT OF CONTAINER (kg) 2,267.95			
DATE PACKAGED 05/08/89		GROSS WEIGHT (kg) 2,365.47			
THERMAL POWER 10.8 ☐ <0.1 W ft ³		ORGANIC MATL VOL % N/A			
DOSE RATE (mrem/hr) 1.0 0.3 at 1 m		NEUTRON (>20 mrem/hr) N/A			
REFERENCES					
DOE/NRC TAG NO. HYA-VUC-49		RSR NO. Onsite No. 00017		FISSION/ACTIVATION RADIONUCLIDES (Do not include Uranium, Thorium, or TRU elements)	
PROPERTY DISPOSAL REQUEST NO. N/A		SDAR NO. 2-9G-2R-2 3/28/90			
WASTE CATEGORY (CHECK ONE) ☐ BW ☐ CE ☐ DD ☐ DS ☐ SS ☒ NC	WASTE CONTENTS DESCRIPTION				
	WASTE DESCRIPTION		VOLUME %	WEIGHT (kg)	
	Spent fuel and cladding.		100	2.6	
TOTALS		100	2.6	total 2.13.2	
TRU/FISSILE/SOURCE MATERIAL (Uranium, Thorium, and TRU elements)					
ELEMENT	ISOTOPIIC DISTRIBUTION (Weight %)		WEIGHT (g)	TRU WASTE ONLY	
Pu	Pu-239 (94.00) Pu-240 (6.00)		2228 g	Pu-239 (g)	Pu-240 (g)
TOTALS			2228 g	2228 g	269.6

Page 19

^0^4^3^2

Page 1 of 1

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APPENDIX B:

SAMPLE MONK6 PROBLEM INPUT LIST AND SCAN OUTPUT

<u>ITEM</u>	<u>DESCRIPTION</u>	<u>PAGES</u>
B.1	MONK6B INPUT FOR CLUSTER OF 7 EBR-II CASKS IN CIRCULAR VAULT	21, 22
B.2	SCAN HORIZONTAL SECTION FOR CLUSTER OF 7 EBR-II CASKS IN VAULT	23

Item B.1: MONK6B INPUT DATA

* Case EBRMT62: 7 CASKS -8FT CAISSON, 30"SPACNG, 8KG CNTR W/O LEAD
FISSION
* * * * * E B R M T 6 2 * * * * *
* 61 LOADED TUBES, .437 IN DIAM., 6-ROW HEX ARRAY W 3 / CORNER OMITTED
* 6-ROW HEX ARRAY OF .437IN DIA TUBES, 61 W PU, OUTER 12 ALUMINUM
* PITCH = 1.1100 CM, FUEL MATERIAL DIA. = .262IN, MAX ALLOWED
* FUEL MATERIAL = 19.6 G/CC PU WITH 5% PU-240
* 6 CASKS WITH FUEL HEIGHT = 10 CM FOR TOTAL CASK LOAD OF 4 KG PU
* CENTER CASK WITH FUEL HEIGHT = 20 CM FOR TOTAL CASK LOAD OF 8 KG PU
* SHIELDING LEAD ANNULUS IN CENTER CASK MISSING.
* CLADDING AND TUBE STEEL MODELLED, FUELPINS AT TUBE CENTERS
* HALF THICKNESS USED FOR CLAD - -0.0125 INCHES
* VOID = .01 VOL% WATER USED TO REPRESENT AIR FOR SCAN VISUALIZATION
* Reference : WHC-SD-WM-TI-395 "Hazard Class and Facility Use
* determination for Irradiated Fuel Storage in EBR-II
* Casks in the 200 West Area"

* Date : October 21, 1994

* * * * * MATERIAL DATA * * * * *

Material #	Material Name	Symbol
1	Water	"
2	Carbon Steel	I
3	304 Stainless Steel	3
4	Lead	B
5	Concrete	C
6	Dry Sand 80% TD SiO2	S
7	Wet Sand, w 20 v/o H2O	W
8	19.6 g/cc Pu-239 metal, 5% Pu240	X
9	Aluminum for fuel rod cladding	A
10	0.01 vol% water for air	.

* No of Materials No. of Elements

	10	17			
H	C	N	O	Na	
Al	Si	Ca	Cr	Fe	
Ni	Pb	U235	U238	Pu239	
Pu240	Pu241				
Nuclide Tape Reference Numbers					
923A	902B	259A	933C	182E	
935A	25E	138E	446C	908A	
907A	26C	9159	9160A	9161	
402C	60A				

*** ##### COMPOSITION MATRIX #####

CONC	0.06688	0.0	0.0	0.03344	0.00
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
CONC	0.0	0.003921	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.084391
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
CONC	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.01654	0.06331
	0.00651	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0

CONC	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
	0.0	0.03298	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
CONC	0.007023	0.0	0.0	0.045396	0.0
	0.003358	0.012905	0.0026147	0.0	0.0013437
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
CONC	0.0	0.0	0.0	0.04855	0.0
	0.0	0.01214	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
CONC	0.01338	0.0	0.0	0.05524	0.0
	0.0	0.01214	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
CONC	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
	0.002469	0.0	0.000000	0.0	0.046906
CONC	0.0	0.0	0.0	0.0	0.0
	0.06027	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
CONC	0.0000067	0.0	0.0	0.0000033	0.00
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0
	0.0	0.0	0.0	0.0	0.0

CM

* GEOMETRY DATA *

* P1 VERTICAL CASK WITH FUEL CENTERED 15 IN OFF GROUND

NEST	10				
1	ZCYL	H1	5.263	20.000	-48.000
2	ZCYL	9	5.263	48.260	-48.260
3	ZCYL	3	5.723	49.210	-49.210
4	ZCYL	10	6.575	49.530	-49.530
5	ZCYL	3	7.179	50.670	-50.670
6	ZCYL	10	7.880	52.970	-54.230
7	ZCYL	2	8.414	53.500	-54.760
8	ZCYL	4	21.272	66.200	-67.460
9	ZCYL	2	22.225	67.153	-68.412
10	ZCYL	2	22.225	74.935	-76.195

* P2 CENTER VERTICAL CASK WITH FUEL CENTERED 15 IN OFF GROUND

* FOR CENTRAL CASK WITHOUT LEAD SHIELDING, 20 CM FUEL LENGTH

NEST	10				
1	ZCYL	H4	5.263	20.000	-48.000
2	ZCYL	9	5.263	48.260	-48.260
3	ZCYL	3	5.723	49.210	-49.210
4	ZCYL	10	6.575	49.530	-49.530
5	ZCYL	3	7.179	50.670	-50.670
6	ZCYL	10	7.880	52.970	-54.230
7	ZCYL	2	8.414	53.500	-54.760
8	ZCYL	10	21.272	66.200	-67.460

```

*****
  9 ZCYL  2  22.225  67.153  -68.412
 10 ZCYL  2  22.225  74.935  -76.195
* P3 CORNER VERTICAL CASK WITH FUEL CENTERED 15 IN OFF GROUND
  NEST 10
  1 ZCYL  H1  5.263  20.000  -48.000
  2 ZCYL  9  5.263  48.260  -48.260
  3 ZCYL  3  5.723  49.210  -49.210
  4 ZCYL 10  6.575  49.530  -49.530
  5 ZCYL  3  7.179  50.670  -50.670
  6 ZCYL 10  7.880  52.970  -54.230
  7 ZCYL  2  8.414  53.500  -54.760
  8 ZCYL  4 21.272  66.200  -67.460
  9 ZCYL  2 22.225  67.153  -68.412
 10 ZCYL  2 22.225  74.935  -76.195
* P4 4TH TYPE IS CLUSTER OF 7 CASKS TOUCHING AT RINGS
  CLUSTER 8
  1 ZROD ORIGIN -38.10  66.00  0.10  P1 22.225 151.130
  2 ZROD ORIGIN +38.10  66.00  0.10  P3 22.225 151.130
  3 ZROD ORIGIN -76.20  0.00  0.10  P3 22.225 151.130
  4 ZROD ORIGIN  0.00  0.00  0.10  P2 22.225 151.130
  5 ZROD ORIGIN +76.20  0.00  0.10  P1 22.225 151.130
  6 ZROD ORIGIN -38.10 -66.00  0.10  P1 22.225 151.130
  7 ZROD ORIGIN +38.10 -66.00  0.10  P3 22.225 151.130
  8 ZROD 10 121.92 200.0
* P5 NEST FOR CONCRETE CAISSON WALL AND OUTER CUBOID
  NEST 3
  1 ZROD ORIGIN 152.00 152.00 30.0  P4 121.92 200.0
  2 ZROD ORIGIN 152.00 152.00 0.0   5  151.92 260.0
  3 BOX 10 304.0 304.0 260.0
*****
  *
  * HOLE 1 FOR TRIANGULAR ARRAY OF 73 PINS
  * 6-ROW HEXAGON MINUS THREE AT EACH CORNER
  * No.Mats Matls Pitch R1 R2
  * TRIANGLE 4 3 8 9 10 1.110 0.4660 0.5549
  * No.Rows D1 D2 array pattern
  * WRAP 6 5.250 5.260 MATS 6
    0 0 9 9 0 0
    0 -2 -2 -2 -2 -2 -2 0
    9 -2 -2 -2 -2 -2 -2 9
    9 -2 -2 -2 -2 -2 -2 9
    0 -2 -2 -2 -2 -2 -2 0
    0 -2 -2 -2 -2 -2 -2 0
    9 -2 -2 -2 -2 -2 -2 9
    9 -2 -2 -2 -2 -2 -2 9
    0 -2 -2 -2 -2 -2 -2 0
    0 0 9 9 0 0
  *
  * MR MC MI MW1 MW2
  * -2 3 10 10 10
*****
  * * * * HOLE # 2 FOR FUEL PIN - FUEL, CLAD AND GAP
  * No.Matls Mat.Nos No.Cylndrs R1 M1 R2 M2 M3
  * GLOBE 3 8 9 10 2 0.3647 9 0.3330 -3 10
*****

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```

*****
* * * * HOLE #3 - FOR LAYERS OF FUEL OR AL FILLER IN PINS
* No.MtIs Mat.Nos. Shift origin to bottom Direction cosines
  PLATE 3 8 9 10 HTRANS 0.0 0.0 -48.00 0.0 0.0 1.0
* # Planes D1 M1 D2 M2 M3
  2 14.905 9 4.905 8 9
*****
* HOLE 4 FOR TRIANGULAR ARRAY OF 73 PINS
* 6-ROW HEXAGON MINUS THREE AT EACH CORNER
* No.Mats Matls Pitch R1 R2
* TRIANGLE 4 3 8 9 10 1.110 0.4660 0.5549
* No.Rows D1 D2 array pattern
  WRAP 6 5.250 5.260 MATS 6
    0 0 9 9 0 0
    0 -5 -5 -5 -5 -5 -5 0
    9 -5 -5 -5 -5 -5 -5 9
    9 -5 -5 -5 -5 -5 -5 9
    0 -5 -5 -5 -5 -5 -5 0
    0 -5 -5 -5 -5 -5 -5 0
    9 -5 -5 -5 -5 -5 -5 9
    9 -5 -5 -5 -5 -5 -5 9
    0 -5 -5 -5 -5 -5 -5 0
    0 0 9 9 0 0
  *
  * MR MC MI MW1 MW2
  * -5 3 10 10 10
*****
* * * * HOLE # 5 FOR FUEL PIN - FUEL, CLAD AND GAP
* No.Matls Mat.Nos No.Cylndrs R1 M1 R2 M2 M3
  GLOBE 3 8 9 10 2 0.3647 9 0.3330 -6 10
*****
* * * * HOLE #6 - FOR LAYERS OF FUEL OR AL FILLER IN PINS
* No.MtIs Mat.Nos. Shift origin to bottom Direction cosines
  PLATE 3 8 9 10 HTRANS 0.0 0.0 -48.00 0.0 0.0 1.0
* # Planes D1 M1 D2 M2 M3
  2 21.00 9 1.00 8 9
*****
  *
  * CONTROL DATA
  * SUPERHIST 5 1.0
  * First Stage Last Stage Number/Stage Time Source
  * -5 250 100 0 STDV 0.0030 -1
*****
  *
  * SOURCE
  * Line Source X1 Y1 Z1 X2 Y2 Z2
  * LINE 152.00 152.00 64.20 152.0 152.0 72.20
  * END
  *
  * SCAN PICTURE INPUT
  *
  * CODE 10
  * "I3BCSWXA"
  * Top Left Top Right Bottom Left
  * 0.00 304.0 68.10 304.0 304.0 68.10 0.00 0.00 68.10
  * 0.00 152.0 260.0 304.0 152.0 260.0 0.00 152.0 0.00
  * 127.0 177.0 68.10 177.0 177.0 68.10 127.0 127.0 68.10
  * 127.0 152.0 80.0 177.0 152.0 80.0 127.0 152.0 25.0
  * END

```

SYMBOL	Material Name	PICTURE FRAME IS	
I	Water	X= 0.00, Y= 304.00, Z= 68.10 (TOP LEFT)	FROM CASE EBRMT62
3	Carbon Steel	X= 304.00, Y= 304.00, Z= 68.10 (TOP RIGHT)	
B	304 Stainless Steel	X= 0.00, Y= 0.00, Z= 68.10 (BOTTOM LEFT)	
C	Lead		
X	Concrete		
A	19.6 g/cc Pu-239 metal, 5% Pu-240		
.	Aluminum for fuel rod cladding		
.	0.01 vol% water for air		
U	Natural Uranium		
		SCALE	
		HORIZONTAL: 1 CHARACTER = 2.338 CM	
		VERTICAL: 1 LINE = 3.897 CM	

ITEM B.2:
SCAN HORIZONTAL SECTION FOR CLUSTER OF 7 EBR-II CASKS IN MANHOLE