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7. Abstract

A criticality safety analysis was performed to address the effect of the "hot cell rot" phenomenon on the long term storage of irradiated FFTF fuel in core component containers. The results show that seven FFTF fuel assemblies or six Ident-69 pin containers stored in core component containers within interim storage casks will remain safely subcritical.

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CRITICALITY SAFETY EVALUATION FOR LONG TERM STORAGE
OF FFTF FUEL IN INTERIM STORAGE CONTAINERS

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CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	3
2.0 SUMMARY	3
3.0 FUEL AND CONTAINER DESCRIPTIONS	4
4.0 ANALYSIS	5
4.1 Previous Analyses	5
4.2 Seven Fuel Assemblies in a CCC	9
4.3 Multiple ISC Storage	11
5.0 RESULTS	11
5.1 Hot Cell Rot	11
5.2 Seven Ident-69s in an CCC	16
5.3 Multiple ISC Storage	17
5.4 Critical Number	18
6.0 CONCLUSIONS	21
7.0 VALIDATION	22
8.0 REFERENCES	25
APPENDIX A	27
APPENDIX B	34

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CRITICALITY SAFETY EVALUATION FOR LONG TERM
STORAGE OF FFTF FUEL IN INTERIM
STORAGE CASKS

1.0 INTRODUCTION

In the current plan for long term, interim, storage of irradiated FFTF fuel, the fuel assemblies will be washed, and placed in Core Component Container (CCC) assemblies which, in turn, will be placed in Interim Storage Casks (ISC). The ISCs will be placed on a concrete pad at the Interim Storage Area (ISA) that is located at the northeast corner of the 400 property protection area. Each CCC can accommodate up to seven FFTF fuel assemblies or six pin containers. Previous analyses (Richard 1994, Erickson 1993, Wilcox 1991, Wilcox 1989) have shown that storage of six FFTF fuel assemblies or six pin containers in CCCs is acceptable from a nuclear criticality safety perspective. This document does not address Type B assemblies; they will be addressed in a separate document. Experimental assemblies will be evaluated on a case by case basis.

2.0 SUMMARY

It has been postulated (Waltar, 1993) that a degradation phenomenon, referred to as "hot cell rot", may affect irradiated FFTF mixed plutonium-uranium oxide (MOX) fuel during dry interim storage. "Hot cell rot" refers to a variety of phenomena that degrade fuel pin cladding during exposure to air and inert gas environments. It is thought to be a form of caustic stress corrosion cracking or environmentally assisted cracking. Steps will be taken to prevent the occurrence of this phenomenon; however, for conservatism, extreme cases of complete assembly disintegration were analyzed to ensure a criticality safe configuration. The geometries analyzed bound any reasonable configuration that may occur.

The k_{eff} of the most reactive configuration analyzed (without allowing for the intrusion of a moderating material such as water) was less than 0.95. Flooding of the interim storage area is considered to not be a credible event.

However, water was included in some of the criticality calculations to determine what effect it would have on k_{eff} if present. The most reactive hypothetical case analyzed assumed complete disintegration of fuel pins and duct, flooding of the CCC and suspension of the fuel pellets in water over a 36 inch height. This case led to a k_{eff} greater than 1.00. However, in order for this to occur the following independent and highly unlikely events must happen.

- flooding of the storage area
- failure of the ISC outer seal
- failure of the ISC inner seal
- failure of the CCC seal
- failure of the fuel pin cladding
- failure of the fuel assembly ducts
- optimization of the water/fuel geometry.

This combination of events far exceeds the double contingency principle generally used to assure criticality safety. The loss of any single one of these barriers would not result in loss of double contingency protection. If any one of these events does not transpire the k_{eff} of the ISC and its contents will remain below 0.95 at the two sigma confidence level. The requirements of DOE Order 5480.24 Section 7.a and 7.a.(2)(a), the double contingency principle, are met.

It can be concluded from this evaluation that unirradiated and irradiated FFTF fuel (29.32 wt% plutonium), stored in CCCs and ISCs, will remain safely subcritical during long term, interim storage.

3.0 FUEL AND CONTAINER DESCRIPTIONS

Figure 1 illustrates the construction of the Driver Fuel Assemblies (DFAs) for the FFTF. The fuel pin specifications are listed in Table 1. Figure 2 illustrates the radial geometry of the CCC with Ident-69 pin containers in the six tubes surrounding the center tube. The grapple is located on the CCC cover which allows insertion of a DFA into the center tube. The figure shows the CCC inside the small diameter cleaning vessel (SDCV). On the ISA, the CCC will reside in the Interim Storage Container (ISC). The ISC has an inner cavity, 150 inches long with a 21 inch diameter, to hold the CCC. The ISC itself consists of an inner stainless steel liner within a carbon steel shield

of 32 inch diameter. A 0.75 inch gap exists between the liner and shield. The shield is enclosed by a concrete annulus with an outside diameter of 83 3/4 inches. Total ISC height is 180 inches.

There are three high integrity mechanical seals blocking access of water from the outside into the CCC. The CCC lid contains one mechanical seal which functions once the lid is bolted on. After the CCC has been transferred into the ISC, the shielded closure is installed. The ISC closure contains redundant mechanical seals which function once its closure is bolted on.

4.0 ANALYSIS

4.1 Previous Analyses

Previous analyses have addressed the storage of six fuel assemblies and Ident-69 fuel pin containers in CCCs. This current report supplements the previous reports. All previous analyses assumed the center tube to be water filled. CCC dimensions for the previous reports (Wilcox 1991, Erickson 1993) were from drawing H-4-66696.

The Ident-69 analysis (Wilcox 1991) determined the multiplication factor for the most reactive Ident-69 fuel pin loading in a CCC. The most reactive arrangement of pins in an Ident-69 pin container is a fully flooded square array of 97 pins with a 0.4875 inch pitch. The multiplication factor for a CCC containing six such Ident-69s is 0.8484 ± 0.0055 (1 sigma).

The Wilcox analysis also addressed the reactivity effect of Ident-69 fuel pin breakage. This simulates the "hot cell rot" phenomenon. The results show that initially, as the fuel breaks up and mixes with the water, there is a small increase in reactivity. As more fuel pins break, the reactivity decreases. Wilcox concluded that the system will remain safely subcritical. Likewise, if the fuel pin breakage, within an Ident-69 pin container, is due to "hot cell rot," the pin container would be expected to retain its integrity and the system would remain safely subcritical.

The fuel assembly analysis (Erickson 1993) for six intact assemblies, concluded that 'the criticality criterion will not be exceeded and a criticality event is not credible during the normal fuel handling operations, nor during the accident conditions considered in this document.'

a) Cross-section Through Fueled Region

a) Axial Configuration

Figure 1:
BASIC DESIGN FEATURES OF FFTF DRIVER FUEL ASSEMBLY

Table 1:

FTR DRIVER FUEL ASSEMBLY NOMINAL DIMENSIONS AT 30°C

Number of pins per assembly	217
Fuel pellet end geometry	dished
Fuel pellet OD	0.494 cm (0.1945 in.)
Planar smeared density	0.855 g/cm ³
Fuel composition	(U,Pu)O _{1.96}
Cladding and duct material	316 SS
Cladding tube ID	0.508 cm (0.200 in.)
Cladding tube OD	0.584 cm (0.230 in.)
Spacer system	spiral wire wrap
Spacer wire diameter	0.142 cm (0.056 in.)
Spacer wire pitch	30.48 cm (12. in.)
Duct tube inner dimension	11.011 cm (4.335 in.)
Duct wall thickness	0.3048 cm (0.120 in.)
Fuel pellet stack length	91.44 ± 0.3175 cm (36 ± 0.125 in.)
Insulator pellet stack length	2.032 cm (0.8 in.) each end
Axial reflector length	14.478 cm (5.7 in.) each end
Axial reflector material	Inconel-600
Axial reflector geometry	cylindrical rod, 0.4813 cm (0.1895 in.) OD

(data from Erickson, 1993)

Figure 2: TOP VIEW OF CORE COMPONENT CONTAINER INSIDE OF SMALL DIAMETER CLEANING VESSEL
(CALCULATIONS MODELLED CCC IN 53 CM DIA. CAVITY OF 2.1 M DIA. INTERIM STORAGE CASK)

CCC's containing six FFTF fuel assemblies or six Ident-69 pin containers affected by "hot cell rot" were analyzed and found to be acceptable from a nuclear criticality perspective (Richard 1994). For any credible configuration k_{eff} will remain far below 0.95.

4.2 Seven Fuel Assemblies in a CCC

An evaluation (Bunch, 1992) of the maximum allowable k_{eff} for FFTF facilities concluded that a k_{eff} of 0.95 provides an adequate safety margin in the design or modification of facilities for cleaning, handling and storing fissile material at FFTF. The Monte Carlo criticality computer code, MONK6B (Smith, 1989), was used for the calculations in this present study. The validation documents (Macklin 1991, Miller 1994) for MONK6B specify that a calculated value of 0.935 or less is required to assure a k_{eff} of 0.95 or less, allowing for biases and a 2σ uncertainty.

The CCC consists of a ring of six radial storage tubes around a center storage tube Figure 2. Dimensions are from drawing number H-4-72005. There are no significant differences between the dimensions of drawing number H-4-72005, used for this study, and drawing number H-4-66696, used for previous studies. The central tube has the same diameter and a slightly greater wall thickness than the six radial tubes. For conservatism and simpler modeling, the central tube is assumed to have the same dimensions as the storage tubes. This assumption results in reduced steel mass for the center tube and has a negligible effect on the results. The CCC is designed to maintain its physical integrity and will not be adversely affected by 'hot cell rot'. For all seven tubes of the CCC the inner diameter used is 6.41 inches and the outer diameter is 6.65 inches. The total length of the CCC is 145 inches. The 0.12 inch tube wall thickness assumed is slightly greater than the actual wall thickness of 0.109 inch. However, the effect on the results of this analysis due to the difference in wall thickness is insignificant. Two previous analyses (Wilcox 1991, Erickson 1993) addressed the reactivity effect due to a change in wall thickness. Both concluded that the effect is within the statistical uncertainty of the calculations. From Wilcox, the k_{eff} change was +0.0014 for a wall thickness change from 0.134 inch to 0.109 inch.

For some cases, the fuel assemblies were assumed to be completely disintegrated within the storage tubes; in other cases the duct was assumed to remain intact. The isotopic composition of the fueled region of a fresh 4.1 Driver Fuel Assembly (DFA) was used. No burnup credit was taken. Table 2 presents the masses used for the fuel containing region of a fuel assembly. The fuel is 29.32 wt% plutonium containing 11.88 wt% ^{240}Pu . A ^{240}Pu content of ≥ 10.00 wt% rather than 11.88 wt% has only a minor affect on reactivity, and doesn't change conclusions of this report.

Table 2. Mass of MOX Fuel in a Fresh Type 4.1 DFA	
ISOTOPE	MASS (g)
Pu-239	8421.38
Pu-240	1151.97
Pu-241	100.49
Pu-242	18.97
U-235	46.64
U-238	23274.00
Am-241	41.86
0	4438.05

The fuel region length of an intact DFA is 36 inches. Each CCC will be stored within an ISC. Design specifications for the ISC require that it remain upright even in a design basis earthquake. If the DFA falls apart, the fuel region will collapse due to gravity to some shorter height. The minimum height that the fuel and stainless steel from cladding and the duct in the fuel region of a DFA could collapse to within a CCC storage tube, without compression, is about 12.3 inches. For this analysis the fuel region height of the collapsed DFAs within the seven storage tubes was varied from 12.3 inches to 36 inches under dry conditions and fully water flooded conditions. Additional calculations were performed for two fuel column heights under dry conditions with the fuel and stainless steel separated. If the stainless steel of the cladding and duct is separated from the fuel, the minimum fuel height is 7.2 inches.

Calculations show that a CCC containing seven moderated Ident-69 pin containers without "hot cell rot" would exceed the 0.95 k_{eff} limit (section 5.2). A previous analysis (Richard 1994), shows that six Ident-69 pin containers can be safely stored in a CCC. Design of the solid waste cask and ISC precludes having a pin container in the center tube at the ISA.

4.3 Multiple ISC Storage

After the filled CCCs are placed into ISCs, the ISCs will be stored on a concrete pad in the 400 Area. Up to 60 ISCs will be stored. The ISCs will contain fuel assemblies or Ident-69 pin containers. The neutronic interaction between ISCs has been analyzed. Each 20 inch diameter CCC resides in the 21 inch diameter hole in the center of an ISC. An ISC has a nominal outer diameter of 83 3/4 inches, including an 8 inch thick inner carbon steel liner surrounded by ordinary concrete. Most calculations assumed the inner steel liner to be 5.4 inches thick and the ISC outer diameter to be 85 inches. Calculations done with 8 inch thick carbon steel and an ISC outer diameter as small as 80 inches gave the same results. Substitution of carbon steel with stainless steel has no effect on k_{eff} .

5.0 RESULTS

5.1 Hot Cell Rot

Table 3 shows the k_{eff} of seven DFAs stored in a CCC within an ISC for the dry condition. The k_{eff} is smallest at 36 inches when the DFAs are intact. It increases to a maximum as the DFAs disintegrate and the fuel region collapses to the minimum 12.3 inch height. However, even at the minimum height the calculated k_{eff} of about 0.79 is far below the acceptable limit of 0.935. The results for all cases in this table assume that the disintegrated stainless steel cladding in the fuel region is homogeneously mixed with the fuel. The duct is intact for the 36.0 and 21.1 inch cases and disintegrated for the 12.3 inch case. When the duct is disintegrated, the resulting material mix assumes the inner diameter of the CCC storage tube. The 21.1 inch height is the minimum fuel height with the duct intact, and 12.3 inches is the minimum fuel height with the duct disintegrated.

Table 3. Seven Assemblies with Dry Rotted Fuel Pins in a Dry ISC			
Fuel Region Height (inches)	k_{eff}	Statistical Uncertainty ($\pm 1\sigma$)	Case Name
36.0	0.4352	0.0015	cc7df36d
21.1	0.5950	0.0019	cc7df21d
12.3	0.7862	0.0024	cc7df12d

Table 4 shows dry results with the less likely assumption that the stainless steel does not mix with the fuel. The entire assembly including the duct is assumed to have disintegrated. Comparison of the 12.3 inch height cases from Tables 3 and 4 shows the effect of separating out the stainless steel. At the minimum height of 7.2 inches the calculated k_{eff} of the CCC is a maximum of 0.9294. This is still below the 0.935 limit.

For tables 3 and 4, reflection is provided by the concrete and steel of the ISC, and the fuel is in powder form. For these dry cases, whether fuel is modeled as powder or pellets has an insignificant affect on reactivity.

Table 4. Seven Dry Assemblies with Fuel and Stainless Steel Separated			
Fuel Region Height (inches)	k_{eff}	Statistical Uncertainty ($\pm 1\sigma$)	Case Name
12.3	0.7536	0.0023	ccc7dfns12
7.2	0.9294	0.0025	ccc7dfns7

Since stainless steel is a neutron absorber it might be expected that k_{eff} would increase when it is removed from the fuel. However, comparison of results for the 12.3 inch height from Tables 3 and 4, shows that removal of the stainless steel results in a reduction in k_{eff} for the dry condition. This can be explained as follows. The fissions in the MOX fuel occur primarily in the fast neutron energy region ($E_n > 100$ keV). However, a significant fraction (~30%) of the fissions in Pu-239 occur in the 0.4 eV to 100 keV neutron energy range. For the 12.3 inch case reported in Table 3, 42% of the volume is occupied by the stainless steel of the duct and cladding. When the stainless steel is removed, fewer neutron scattering interactions occur resulting in fewer neutrons in the 0.4 eV to 100 keV energy range. The result is a 24%

reduction in the number of fissions occurring in Pu-239 in the 0.4 eV to 100 keV energy range. This, along with a 2% decrease in the number of fast fissions results in a net reduction in total fissions by about 5.0%. Therefore, k_{eff} goes down. The reduced scattering also yields a higher neutron leakage fraction for the fissile medium.

Under fully flooded CCC conditions, as all the fuel pins collapse and disintegrate into a homogeneous mixture of fuel, clad, and water within the intact duct the highest value of k_{eff} occurs for the 36 inch fuel height, giving the 0.8201 value shown in Table 5. As the fuel pins disintegrate and collapse within the duct, k_{eff} decreases. The stainless steel of the cladding is homogeneously mixed with the fuel and water. Table 5 bounds the case of water inside the ISC with the CCC dry and the duct intact. No appreciable amount of fuel would be expected to come out of the duct with the duct intact. For intact pins (36 inch fuel length), k_{eff} is 0.7836.

The fully flooded condition assumes complete flooding inside the ISC, including inside and outside the CCC. Full flooding is a highly undermoderated condition. Any decrease in water density or volume would reduce k_{eff} .

Table 5. Disintegrated Fuel Pins Within Intact Ducts, Fully Flooded ISC			
Homogenized Fuel Region Height (inches)	k_{eff}	Statistical Uncertainty ($\pm 1\sigma$)	Case Name
36.0	0.8201	0.0028	ccc7dfas
31.5	0.8194	0.0029	cc7df31f
26.0	0.8144	0.0030	cc7df26f
21.1	0.7994	0.0028	cc7df21f

Since the fuel pin cladding (0.015 inch) is much thinner than the duct (0.12 inch), it will disintegrate long before the duct is affected. Before, if ever, the duct falls apart, the fuel pin debris would have settled so that the fuel region height would be much less than the original 36 inches.

The next set of calculations assumed a heterogeneous mix of fuel and water. The stainless steel of the cladding and duct was assumed to be homogeneously mixed with the water. The fuel pellets were modeled as though they were suspended and evenly distributed in the steel-water mix within each of the CCC tubes. This configuration is not considered credible, but the calculations were done to provide a better understanding of the dependency of k_{eff} on geometry. The results are tabulated in Table 6 for seven assembly loaded tubes in a CCC. At 36.0 inches k_{eff} is greater than 1.00 and decreases to 0.9695 at 13.0 inches. As with previous calculations, the CCC is contained within an ISC.

Table 6. Fuel Pellets Modeled as Dispersed Spheres, Fully Flooded ISC			
Fuel Region Height (inches)	k_{eff}	Statistical Uncertainty ($\pm 1\sigma$)	Case Name
36.0	1.1347	0.0028	spf7df36
27.0	1.0876	0.0030	spf7df27
18.9	1.0354	0.0030	spf7df19
13.0	0.9695	0.0030	spf7df13

To extend the fuel region beyond 36 inches would require the ISC containing a CCC to somehow tip over. Since the ISC is designed to remain upright in a design basis earthquake, it is not a credible event. However, during ISC movement in the 400 Area the potential exists for tipping. After a CCC is inserted into an ISC, the ISC will be sealed and loaded onto a flatbed truck for movement to the 400 Area storage pad. During this movement the ISC could conceivably fall off the truck. However, transportation to the 400 Area storage pad will happen long before "hot cell rot" can occur. So if it is assumed that the CCC and ISC are flooded, the assemblies will still be intact, and reactivity will be bounded by the results shown previously in Table 5 for 7 fuel assemblies and previous analyses for 6 pin containers (Wilcox 1991, Richard 1994). If the assumption is made that "hot cell rot" has occurred at the ISA, then a criticality would require the occurrence of other contingencies. Flooding must occur. The ISC seals must fail. The CCC seal

must fail. And finally, the ISC must tip over. These are all independent and unlikely events. More than two contingencies must occur to achieve criticality. In addition, the ISC seals will be tested prior to any movement to insure seal integrity. Consequently, criticality as a result of an ISC tipping over at the ISA is not credible. There would be no criticality safety consequence of dry ISCs tipping over at the ISA due to an industrial accident involving the mobile crane.

The possibility exists for some fuel pins within the intact DFA duct to disintegrate while the remainder remain intact. Because the duct is so much thicker than the cladding it would be reasonable to expect a mixture of intact pins and disintegrated pins only while the duct is still intact. With the duct still intact reactivity increases as the pins disintegrate for the fully flooded condition. As the undermoderated intact pins fall apart and the pieces mix homogeneously in the water, the moderation improves and therefore reactivity continues to go up until all of the pins disintegrate. Since the duct is much thicker than the pin cladding, the pins will be completely disintegrated before the duct fails. As duct failure occurs and assuming homogenous mixture of debris and water within the CCC storage tubes, the reactivity continues to increase. The homogeneous mix of disintegrated fuel in powder or pellet form (Table 5 and Table 6, respectively) and water is more conservative than the inclusion of some intact pins.

Figure 3 shows plots of results for CCCs with fuel assemblies for the various geometric configurations analyzed. The only cases where k_{eff} exceeds 0.935 are those in which the CCC is flooded, 'hot cell rot' and complete duct failure has occurred.

If the fuel form is assumed to be powder rather than pellets, the resulting k_{eff} is less for any given height. For example, for the duct disintegrated case with a fuel region height of 36" and full water moderation k_{eff} is 1.0595 when the fuel is in powder form and 1.1347 when the fuel is in pellet form.

Therefore, for conservatism, the disintegrated fuel is assumed to be in the pellet form when the DFAs are completely disintegrated.

Eventually the ISCs will be transported away from the 400 Area. "Hot cell rot" may have affected some fuel pins by that time. The assembly ducts will remain intact. If the ISC were to somehow fall over onto its side during transportation, the fuel region of the "hot cell rot" affected pins may extend beyond the normal 36 inch length. Since the 36 inch fuel region length is an undermoderated condition, any increase will result in improved moderation and higher k_{eff} 's. Table 7 shows the affect of increasing the fuel region from 36 inches to 140 inches. The fuel is modeled as fuel pellet size spheres, the duct is intact and flooding is assumed.

Table 7. k_{eff} for Horizontal ISC (Intact Duct)			
Fuel Region Length (inches)	k_{eff}	Statistical Uncertainty ($\pm 1\sigma$)	Case Name
36	0.8418	0.0028	ccc7hexsp
50	0.8521	0.0028	ccc7hexsp05
70	0.8714	0.0028	ccc7hexsp07
120	0.8758	0.0029	ccc7hexsp12
140	0.8576	0.0027	ccc7hexsp14

As the fuel region is extended k_{eff} rises to a maximum of 0.8758 at 120 inches and then drops off. The results clearly show that with ducts intact, "hot cell rot" affected fuel pins, flooding and tipping over the ISC remains subcritical.

5.2 Seven Ident-69s

A set of calculations were done to determine the maximum number of Ident-69s that a CCC inside an ISC can contain. The calculated k_{eff} 's for six or seven Ident 69s are shown in table 8.

Table 8. CCC Containing Ident-69s Fully Water Moderated			
Number of Ident-69s (97 Intact Pins Each)	k_{eff}	Statistical Uncertainty ($\pm 1 \sigma$)	Case Name
6	0.8651	0.0029	ccc6id69wa
7	0.9927	0.0031	ccc7id69wa

Six Ident-69s contained in a CCC have been shown to be acceptable from a nuclear criticality perspective (Richard 1994). Examination of Table 8 shows that a CCC containing seven DFAs has a k_{eff} of 0.9927. Therefore, a CCC is restricted to contain no more than 6 Ident-69s. Additionally, an Ident-69 is not allowed in the center tube of a CCC.

The seven assembly (dry, section 5.1) case bounds the error of a fuel assembly or pin container in the center tube of a CCC containing six Ident-69s, for the dry condition.

5.3 Multiple ISC Storage

Seven fuel assemblies or six Ident-69 pin containers will be placed into a CCC which, in turn, will be stored inside an ISC. Up to 60 ISCs will be stored on a concrete pad at the Interim Storage Area (ISA) of the 400 Area. The MONK6 Monte Carlo code was used to determine the neutronic interaction between the stored ISCs. For all cases, each CCC was assumed to contain seven intact and fully flooded 4.1 DFAs with the full 36 inch fuel region height. The ISC cavity containing the CCC is also fully flooded and the ISCs are adjacent. Results are shown in Table 9. The first case is for a single ISC surrounded by 6 inches of water reflection. The next two cases are infinite arrays of ISCs. For the first infinite array case, the space between the ISCs is empty, for the second case the space between ISCs is water filled. There is a small increase in k_{eff} (less than 1 sigma) when the number of ISCs increase from

one to infinity with or without moderation outside the ISC. Full moderation outside the ISCs requires the storage pad to be completely flooded. This is considered to not be a credible event. Without flooding k_{eff} is slightly less for the infinite array. Even with flooding, k_{eff} is far less than 0.95 for assemblies or pin containers. Since the cases shown include flooding inside the CCC and ISC, the k_{eff} for the more realistic completely internally dry case will be far less. The occurrence of "hot cell rot" will have no affect on ISC interaction. It is clear that any number of ISCs can be safely stored on the 400 Area storage pad without any spacing restriction.

Table 9. Multiplication Factors for Multiple ISCs				
Number of ISCs	Moderation Outside ISC	k_{eff}	Statistical Uncertainty ($\pm 1\sigma$)	Case Names
1	Water	0.8201	0.0028	ccc7dfas
Infinite Array	None	0.8208	0.0029	infiscd
Infinite Array	Water	0.8219	0.0028	infiscw

There are no fire fighting restrictions for ISA, and the fire fighting category should be A.

5.4 Multiple CCCs

Table 10 lists the k_{eff} for up to 64 dry adjacent CCCs. Each CCC contains 7 intact Type A assemblies. These results also bound dry pin containers with up to 217 Type A pins per pin container. Nuclear Safety Limit 20.3.2 states that when fissionable material is securely packaged within a container of high integrity, the geometry restrictions imposed by the container may be taken into account. Both the CCC and ISC are containers of high integrity, therefore moderator exclusion can be assumed to determine the critical number. For a single dry unreflected CCC, k_{eff} is 0.3096. For an 8 x 8 array of

unreflected dry CCCs k_{eff} is 0.9672. A critical number is the number of CCCs necessary to achieve criticality. Nuclear Safety Limit 20.3.2 requires that a batch shall not exceed 0.45 of a critical quantity. It is clear that a single dry CCC containing seven fuel assemblies or six pin containers is far less than 0.45 of a critical quantity. In addition, a single dry CCC is less than 0.33 of a critical quantity, which justifies not having a Criticality Alarm System for the ISA. 'Hot cell rot' will not occur in CCCs prior to insertion into the ISC and storage on the storage pad. The occurrence of 'hot cell rot' in ISCs was addressed in Section 5.3.

Table 10. K_{eff} of Adjacent, Dry CCCs Loaded with DFAs			
Number of CCCs	k_{eff}	Statistical Uncertainty ($\pm 1\sigma$)	Case Name
1	0.3096	0.0013	1cccw7dfad
2	0.3491	0.0013	2cccw7dfad
64	0.9672	0.0030	64cccw7dfad

As shown in Section 5.3, an infinite array of ISCs is far below critical. Therefore, it is not credible to have a critical number of ISCs as shown in Table 9.

6.0 CONCLUSIONS

The results of this study show that the plan for storage of seven irradiated FFTF driver fuel assemblies and six pin containers in ISCs is acceptable from a criticality safety perspective. A criticality alarm system is not required at the ISA.

The k_{eff} of the most reactive credible configuration of a single CCC or ISC analyzed (without allowing for flooding) is less than 0.8. For intact fuel assemblies k_{eff} is 0.4352 for the dry case and 0.8201 for the flooded case.

The flooded six pin container case with intact pins has a k_{eff} of 0.865. The dry pin container case (intact pins) is bounded by the dry fuel assembly (intact pins) case.

Complete disintegration of the fuel pins, within the duct, and flooding of the CCC are both considered not credible. However, even if the pins disintegrated and the system is flooded, k_{eff} would not exceed 0.8418. The flooded six pin container case with disintegrated pins would remain safely subcritical.

There is negligible neutronic interaction between ISCs containing CCCs. Therefore, storage of any number of ISCs on the 400 Area storage pad without spacing is acceptable from a criticality safety perspective.

If an ISC is tipped onto its side during transportation and "hot cell rot" and flooding occurs, k_{eff} will not exceed 0.8758.

The only situations in which k_{eff} was found to exceed 0.935 required the following independent and highly unlikely conditions:

- Flooding of the storage area - The ISCs will be stored on a concrete pad above the flood plain and will have environmental covers for protection from rain and snow.
- Failure of the ISC outer seal - The ISC outer seal would prevent water from reaching the ISC inner seal.

- Failure of the ISC inner seal - the ISC inner seal would prevent water from reaching the CCC.
- Failure of the CCC seal - The CCC seal would keep water out of the storage tubes.
- Failure of the fuel pin cladding - requires the occurrence of 'hot cell rot.'
- Failure of the fuel assembly ducts - The fuel assembly ducts are almost an order of magnitude thicker than the fuel pin cladding. There has been no observed case of duct failure or degradation due to "hot cell rot" and is not expected to occur.
- Optimization of the water/fuel geometry - A critical configuration the fuel material would have to remain optimized in water without duct integrity.

This combination of events far exceeds the double-contingency principle generally used to assure nuclear criticality safety. If any one of these seven conditions is not satisfied, the k_{eff} of the ISC and its contents and an array of ISCs will remain below 0.95 allowing for biases and a two sigma confidence level. Finally, the concurrent occurrence of all these events is not credible. The fire fighting category is A for the ISA.

7.0 VALIDATION

In order to verify the accuracy of the methods used in this analysis, comparison calculations were made with previous criticality analyses done for the CCC, i.e. the original Wilcox (1989) analysis and an updated Erickson (1993) analysis. Both of these earlier analyses used the MCNP computer code and assumed intact DFAs in the CCC (drawing H-4-66696); i.e., no occurrence of 'hot cell rot' of the fuel assemblies was considered.

The fuel rods in the DFAs for the original Wilcox analysis were modeled as a homogenized cylinder preserving the fuel element volumes within the six storage tubes of the CCC. A variety of calculations was done for various situations. A comparison calculation was made for a fully water flooded case. The CCC was fully flooded with 100% water density in the voids and steam around the fuel pins inside the DFA. Atom densities for the mixture of fuel and water were taken from the original analysis and inserted into the MONK6 model of the CCC used for the current analysis. The results are shown in Table 11.

Table 11. Comparison of Original MCNP and MONK6		
Computer Code	k_{eff}	Statistical Uncertainty ($\pm 1\sigma$)
MCNP (original analysis)	0.652	not given
MONK6	0.6451	0.0027

The updated Erickson (1993) analysis explicitly modeled the fuel pins within the hexagonal DFA duct. The fuel enrichment used was equivalent to a 4.1 DFA. For comparison to the MONK6 calculations a fully flooded case was used. All voided regions had full water density including the voids between the fuel pins within the duct. The only difference between the calculations is that the Erickson MCNP calculation used explicitly modeled fuel pins while the MONK6 calculation used homogenized atom densities for the fuel pins and water within the duct. Table 12 presents the results.

Table 12. Comparison of MCNP and MONK6			
Computer Code	k_{eff}	Statistical Uncertainty ($\pm 1\sigma$)	Case Name
MCNP	0.7034	0.0040	-
MONK6	0.7084	0.0026	hotrot50h2

The results of these comparisons demonstrate the consistency between the three independent analyses.

Direct comparisons of MONK6A calculations against critical experiments involving mixed oxide fuel pins akin to the FFTF fuel have been reported by Rogers (1991) in a Safety Analysis for Packaging (SARP) for the T-3 cask (which will accomodate an Ident-69 container). Evaluations of the calculated/experimental bias and combined uncertainties indicate that system calculation k-effective values limited to 0.932 or less are acceptable, that the true values will not exceed 0.95 with 95% confidence. Miller (1994) demonstrated the equivalence of MONK6B to MONK6A by virtue of the cross-section library of the two versions being identical.

8.0 REFERENCES

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APPENDIX A
Sample MONK6B Input File

* A MONK6A model of a Core Component Cask (CCC) within an Interim
* Storage Container (ISC). The ISC is a cylindrical concrete
* container with an annulus for the CCC; the diameter is 85 inches
* and the length is 180 inches. The annulus has a carbon steel
* liner and carbon steel end pieces. Dimensions of the annulus
* are 21 inches in diameter and 150 inches in length. This CCC
* contains 7 DFAs.

* Fully flooded 7 radial tubes. Fuel region height 91.44 cm. 43.60 percent water density

* in fuel region, 100% in voids. Duct intact

FISSION

* Number of Material	Number of Nuclides
5	21

NUCNAME S

* Keyword	Nuclide	Concentration(number density)
-----------	---------	-------------------------------

* Fuel and stainless steel homogeneous mix

CONC	PU239	0.002210
	PU240	0.0003011
	PU241	0.00002615
	PU242	0.000004915
	U235	0.00001245
	U238	0.006134
	AM241	0.00001089
	O	0.03198
	MN	0.0002603
	MO	0.0002117
	FE	0.009296
	CR	0.002756
	NI	0.001884
	C	0.00003362
	HINH2O	0.02916

* Stainless steel

CONC	MN	0.00155
	MO	0.00126
	FE	0.05536
	CR	0.01641
	NI	0.01122
	C	0.0002003

* Carbon steel

CONC	FE	0.083491
	C	0.003921

* Concrete

CONC	H	0.014868
	O	0.041519
	SI	0.006037
	FE	0.0001968
	NA23	0.000304
	C	0.003814
	CA	0.011588
	MG	0.000587
	AL27	0.000735

* Water

CONC	HINH2O	0.06689
	O	0.03344

*

*

CM

*

* The following input describes the geometry

NEST 4

* This nest describes the Interim Storage Cask (ISC).

* This is the inner region that holds the Core Component Container (CCC).

1 ZROD ORIGIN 0 0 38.10 P2 27.00 381.00

* This is the carbon steel liner

2 ZROD 3 40.64 457.20

* This is the concrete

3 ZROD 4 107.95 457.20

* This is outside the ISC

4 ZROD 5 123.20 472.45

* the following cluster describe the CCC within the ISC

CLUSTER 30

* stainless steel in tubes below fuel region

1 ZROD ORIGIN	0	0	38.10	P3	8.45	60.174
2 ZROD ORIGIN	0	16.94	38.10	P4	8.45	60.174
3 ZROD ORIGIN	14.6705	8.47	38.10	P5	8.45	60.174
4 ZROD ORIGIN	14.6705	-8.47	38.10	P6	8.45	60.174
5 ZROD ORIGIN	0	-16.94	38.10	P7	8.45	60.174
6 ZROD ORIGIN	-14.6705	-8.47	38.10	P8	8.45	60.174
7 ZROD ORIGIN	-14.6705	8.47	38.10	P9	8.45	60.174

*

*fuel region in the 7 tubes

8 ZROD ORIGIN	0	0	98.274	P10	8.45	91.44
9 ZROD ORIGIN	0	16.94	98.274	P11	8.45	91.44
10 ZROD ORIGIN	14.6705	8.47	98.274	P12	8.45	91.44
11 ZROD ORIGIN	14.6705	-8.47	98.274	P13	8.45	91.44
12 ZROD ORIGIN	0	-16.94	98.274	P14	8.45	91.44
13 ZROD ORIGIN	-14.6705	-8.47	98.274	P15	8.45	91.44
14 ZROD ORIGIN	-14.6705	8.47	98.274	P16	8.45	91.44

*

* stainless steel in the tubes above fuel region

15 ZROD ORIGIN	0	0	189.714	P17	8.45	74.07
16 ZROD ORIGIN	0	16.94	189.714	P18	8.45	74.07
17 ZROD ORIGIN	14.6705	8.47	189.714	P19	8.45	74.07
18 ZROD ORIGIN	14.6705	-8.47	189.714	P20	8.45	74.07
19 ZROD ORIGIN	0	-16.94	189.714	P21	8.45	74.07
20 ZROD ORIGIN	-14.6705	-8.47	189.714	P22	8.45	74.07
21 ZROD ORIGIN	-14.6705	8.47	189.714	P23	8.45	74.07

*

* water in the 7 tubes above the stainless steel

22 ZROD ORIGIN	0	0	263.784	P24	8.45	129.916
23 ZROD ORIGIN	0	16.94	263.784	P25	8.45	129.916
24 ZROD ORIGIN	14.6705	8.47	263.784	P26	8.45	129.916
25 ZROD ORIGIN	14.6705	-8.47	263.784	P27	8.45	129.916
26 ZROD ORIGIN	0	-16.94	263.784	P28	8.45	129.916
27 ZROD ORIGIN	-14.6705	-8.47	263.784	P29	8.45	129.916
28 ZROD ORIGIN	-14.6705	8.47	263.784	P30	8.45	129.916

*

* stainless steel cap on top

29 ZROD ORIGIN	0	0	393.70	2	25.50	12.70
----------------	---	---	--------	---	-------	-------

*

* water surrounding the CCC

30 ZROD ORIGIN	0	0	38.10	5	27.00	381.00
----------------	---	---	-------	---	-------	--------

*

*

* parts 3 through 9: stainless steel below fuel

NEST 2

1 ZROD ORIGIN	0	0	38.10	BH2	8.14	60.174
2 ZROD ORIGIN	0	0	38.10	2	8.45	60.174

NEST 2

1 ZROD ORIGIN	0	16.94	38.10	BH2	8.14	60.174
2 ZROD ORIGIN	0	16.94	38.10	2	8.45	60.174

NEST 2

1 ZROD ORIGIN	14.6705	8.47	38.10	BH2	8.14	60.174
2 ZROD ORIGIN	14.6705	8.47	38.10	2	8.45	60.174

NEST 2

1 ZROD ORIGIN	14.6705	-8.47	38.10	BH2	8.14	60.174
2 ZROD ORIGIN	14.6705	-8.47	38.10	2	8.45	60.174

NEST 2

1 ZROD ORIGIN	0	-16.94	38.10	BH2	8.14	60.174
2 ZROD ORIGIN	0	-16.94	38.10	2	8.45	60.174

NEST 2

1 ZROD ORIGIN	-14.6705	-8.47	38.10	BH2	8.14	60.174
2 ZROD ORIGIN	-14.6705	-8.47	38.10	2	8.45	60.174

NEST 2

1 ZROD ORIGIN	-14.6705	8.47	38.10	BH2	8.14	60.174
2 ZROD ORIGIN	-14.6705	8.47	38.10	2	8.45	60.174

*

* parts 10 through 16: fuel region

NEST 2						
1 ZROD ORIGIN	0	0	98.274	BH1	8.14	91.44
2 ZROD ORIGIN	0	0	98.274	2	8.45	91.44
NEST 2						
1 ZROD ORIGIN	0	16.94	98.274	BH1	8.14	91.44
2 ZROD ORIGIN	0	16.94	98.274	2	8.45	91.44
NEST 2						
1 ZROD ORIGIN	14.6705	8.47	98.274	BH1	8.14	91.44
2 ZROD ORIGIN	14.6705	8.47	98.274	2	8.45	91.44
NEST 2						
1 ZROD ORIGIN	14.6705	-8.47	98.274	BH1	8.14	91.44
2 ZROD ORIGIN	14.6705	-8.47	98.274	2	8.45	91.44
NEST 2						
1 ZROD ORIGIN	0	-16.94	98.274	BH1	8.14	91.44
2 ZROD ORIGIN	0	-16.94	98.274	2	8.45	91.44
NEST 2						
1 ZROD ORIGIN	-14.6705	-8.47	98.274	BH1	8.14	91.44
2 ZROD ORIGIN	-14.6705	-8.47	98.274	2	8.45	91.44
NEST 2						
1 ZROD ORIGIN	-14.6705	8.47	98.274	BH1	8.14	91.44
2 ZROD ORIGIN	-14.6705	8.47	98.274	2	8.45	91.44

*

* parts 17 through 23: stainless steel above fuel

NEST 2						
1 ZROD ORIGIN	0	0	189.714	BH2	8.14	74.07
2 ZROD ORIGIN	0	0	189.714	2	8.45	74.07
NEST 2						
1 ZROD ORIGIN	0	16.94	189.714	BH2	8.14	74.07
2 ZROD ORIGIN	0	16.94	189.714	2	8.45	74.07
NEST 2						
1 ZROD ORIGIN	14.6705	8.47	189.714	BH2	8.14	74.07
2 ZROD ORIGIN	14.6705	8.47	189.714	2	8.45	74.07
NEST 2						
1 ZROD ORIGIN	14.6705	-8.47	189.714	BH2	8.14	74.07
2 ZROD ORIGIN	14.6705	-8.47	189.714	2	8.45	74.07
NEST 2						
1 ZROD ORIGIN	0	-16.94	189.714	BH2	8.14	74.07
2 ZROD ORIGIN	0	-16.94	189.714	2	8.45	74.07
NEST 2						
1 ZROD ORIGIN	-14.6705	-8.47	189.714	BH2	8.14	74.07
2 ZROD ORIGIN	-14.6705	-8.47	189.714	2	8.45	74.07
NEST 2						
1 ZROD ORIGIN	-14.6705	8.47	189.714	BH2	8.14	74.07
2 ZROD ORIGIN	-14.6705	8.47	189.714	2	8.45	74.07

*

* parts 24 through 30: water above DFAs in tubes

NEST 2						
1 ZROD ORIGIN	0	0	263.784	5	8.14	129.916
2 ZROD ORIGIN	0	0	263.784	2	8.45	129.916
NEST 2						
1 ZROD ORIGIN	0	16.94	263.784	5	8.14	129.916
2 ZROD ORIGIN	0	16.94	263.784	2	8.45	129.916
NEST 2						
1 ZROD ORIGIN	14.6705	8.47	263.784	5	8.14	129.916
2 ZROD ORIGIN	14.6705	8.47	263.784	2	8.45	129.916
NEST 2						
1 ZROD ORIGIN	14.6705	-8.47	263.784	5	8.14	129.916
2 ZROD ORIGIN	14.6705	-8.47	263.784	2	8.45	129.916
NEST 2						
1 ZROD ORIGIN	0	-16.94	263.784	5	8.14	129.916
2 ZROD ORIGIN	0	-16.94	263.784	2	8.45	129.916
NEST 2						
1 ZROD ORIGIN	-14.6705	-8.47	263.784	5	8.14	129.916
2 ZROD ORIGIN	-14.6705	-8.47	263.784	2	8.45	129.916
NEST 2						
1 ZROD ORIGIN	-14.6705	8.47	263.784	5	8.14	129.916
2 ZROD ORIGIN	-14.6705	8.47	263.784	2	8.45	129.916

*

* fuel region hole input

* hole type	number of materials	material numbers
TRIANGLE	3	1 2 5
* lattice pitch	inner radius	outer radius
4.0	1.8	1.9

* duct dimensions

WRAP		
* number of tubes	center to	center to
* on side	inner duct	outer duct
2	5.50545	5.81025
* material inside	tube	interstitial
* tube	material	material
1	1	1
* duct material	rest of space	
2	5	

* end of fuel region input

*

*

* stainless steel hole input

* hole type	number of materials	material numbers
TRIANGLE	2	2 5
* lattice pitch	inner radius	outer radius
4.0	1.8	1.9

* duct dimensions

```

WRAP
* number of tubes      center to      center to
*   on side            inner duct      outer duct
*       2              5.50545         5.81025
* materials inside     tube            interstitial
*   tube              material         material
*       2              2               2
* duct material        rest of space
*       2              5
* end of stainless steel region
*
* End of geometry input
*
* Superhistory option using 10 generation per superhistory
* and nu multiplication factor = 1.0
SUPERHIST 10 1.0
* First stage Last stage Neutrons per stage time limit Source
*   -3         10         1000         160         -1
*
* Starting source
MULTIFISS
STD
REGION 1 IN PART 1 /
END
CODE 5
FSCN*
-50.00 50.00 440.0 50.00 50.00 440.0 -50.00 -50.00 440.0
-50.00 50.00 300.0 50.00 50.00 300.0 -50.00 -50.00 300.0
-50.00 50.00 200.0 50.00 50.00 200.0 -50.00 -50.00 200.0
-50.00 50.00 110.0 50.00 50.00 110.0 -50.00 -50.00 110.0
-30.00 30.00 110.0 30.00 30.00 110.0 -30.00 -30.00 110.0
-50.00 50.00 50.00 50.00 50.00 50.0 -50.00 -50.00 50.0
-50.00 1.00 440.0 50.00 1.00 440.0 -50.00 1.00 30.0
-50.00 8.00 440.0 50.00 8.00 440.0 -50.00 8.00 30.0
END

```

APPENDIX B

INDEPENDENT REVIEW CHECKSHEET

AND

REVIEWER'S COMMENTS

CHECKLIST FOR INDEPENDENT REVIEW

WHC-SD-FF-CSER-004

0

Document Checked - Number: _____ Revision: _____
Title : CRITICALITY SAFETY EVALUATION FOR LONG TERM STORAGE OF FFTF FUEL IN INTERIM STORAGE CASKS

Yes	No	N/A	
☒	☐	☐	Problem Completely defined.
☒	☐	☐	Appropriate analytical method used.
☒	☐	☐	Necessary assumptions are appropriate, explicitly stated, and supported.
☒	☐	☐	Computer codes and data files documented.
☒	☐	☐	Data used in calculations explicitly stated in document.
☐	☐	☒	Sources of non-standard formulas/data are referenced and the correctness of the reference verified.
☒	☐	☐	Data checked for consistency with original source information is applicable.
☐	☐	☒	Mathematical derivations checked including dimensional consistency of results.
☒	☐	☐	Models appropriate and used within range of validity or use outside range of established validity justified.
☐	☐	☒	Hand calculations checked for error.
☒	☐	☐	Code run streams correct and consistent with analysis documentation.
☒	☐	☐	Code output consistent with input and with results reported in analysis documentation.
☒	☐	☐	Acceptability limits on analytical results applicable and supported. . . . Limits checked against sources.
☒	☐	☐	Safety margins consistent with good engineering practices.
☒	☐	☐	Conclusions consistent with analytical results and applicable limits.
☒	☐	☐	Results and conclusions address all points required in the problem statement.

I have checked the analysis/calculations and it is complete and accurate to the best of my knowledge.

Allen Z. Herz 4/12/95
Engineer/Checker Date

Note: Any hand calculations, notes, or summaries generated as part of this check should be signed, dated, and attached to this checklist. Material should be labeled and recorded so that it is intelligible to a technically qualified third party.

REVIEWER'S COMMENTS

The technical content of this evaluation was reviewed by A. L. Hess of the Consequence Analyses group, who provides the following comments.

This evaluation for the criticality potential for ISC storage of irradiated FFTF fuel suffering the effects of postulated "Dry Rot" is comprehensive, and the various scenarios studied cover the range of plausible fuel redistributions should the clad and fuel disintegrate. Examination of the MONK6B problem modelling shows the represented geometries and compositions to be conservative. This reviewer concurs that such dry rot effects do not increase the reactivity conditions to a level where the required subcritical margins are exceeded, within the double-contingency criterion. For dry conditions, a criticality hazard could only be approached if the fuel was effectively separated from all clad and be compacted at the bottom of the assembly ducts in all seven of the DFAs in a Core Component Container; these stipulations are beyond plausibility.

For pin-loaded Ident-69 containers, at most six CCC tubes could be loaded, each carrying not more than 217 pins (as in a DFA, per loading rules). Considering also that the Ident-69 components would not suffer Dry Rot, the unflooded loadings of pins in the compartmented Ident-69 containers would be less reactive than dry-rotted DFAs in the CCC tubes.

It has been long recognized that full water flooding conditions might create a criticality hazard with Ident-69s loaded into CCC tubes, especially with a pin count and lattice spacing combination which optimizes moderation. The dry rot effects in such conditions would not necessarily increase the hazard. However, the multiplicity of the tube, container and casks seals, which would have to be breached to admit water into all fuel regions, renders the flooding criticality not credible.

In the course of this review for dry-rotted DFAs in seven CCC tubes, the reviewer studied all of the predecessor CSERs covering the loadings of Core Component Containers in various casks and pits, to become familiar with the full range of loading/contingency scenarios. To aid in this task, by a reviewer relatively new to the FFTF fuel storage criticality aspects, three tables were prepared to summarize past calculations. Table B.1 concerns calculations for DFA-loaded CCCs, dry and with water ingress. Tables B.2 and B.3 address Ident-69 loadings. The Monte-carlo cases in these tables are only those where the 36-inch full height of fuel is retained.

In Table B.1, the most reactive case for dry DFAs with normal height fuel is the basic configuration of DFAs with intact fuel pins in seven CCC tubes ($k = 0.466$). The situation where the fuel clad and MOX pins have disintegrated and are effectively homogenized (but still 36" high) reduces k a few percent due to the loss of in-pin multiplication effects. For the flooded cask with seven DFAs, the blending of fuel, clad and water for pins suffering dryrot provides the highest k (0.82), because of the enhanced effective moderation.

At the request of this reviewer, the author submitted some additional calculations modelling Ident-69 loadings in tubes of CCCs in the storage casks. These added cases, concerned with loadings of more than 97 pins per Ident-69 container, are identified in Tables B.2 and B.3 as "extra1 - through extra7".

Table B.2 summarizes results from various CSERs for pin-loaded Ident-69s under unflooded situations. By operational rules, each Ident-69 may not be loaded with more than 217 fuel pins, the same as for a driver fuel assembly in a CCC tube. More than likely, for irradiated fuel, 217 pins could not be emplaced because of bowing, but it is likely that there would be more than the 97 pin count giving optimum moderator/fuel ratios in flooded conditions. The "extra" cases in Table B.2 show what the effects are of stuffing more than the allowed numbers of pins in an Ident-69 as an error contingency. For case "extra1", 321 pins are packed in each Ident 69 casing at the same pitch as in a DFA, and for case "extra3" there are 490 pins packed in without any wire wrappers. The cases "extra2" and "extra4", with 462 and 704 pins respectively, modelled wire-wrapped and unwrapped pin packings directly inside the CCC tubes without containment in Ident-69 casings; this error condition might be plausible for a few CCC tubes assuming a complete disregard of procedures under loss of proper supervision.

For the dry stipulation on the Table 2 cases, it is seen as expected that the reactivity increases as number of pins within the Ident-69/CCC tubes. The latter three cases, with pin counts over 321 per tube and k_{eff} values over 0.80, represent concurrent combinations of pin conditions, operator errors and oversight faults (including a loaded central CCC tube) that go beyond credibility.

Flooded CCCs bearing pin-loaded Ident-69s are represented in the various Monte-carlo calculations cited in Table B.3. For most of these cases, lighter loadings of pins are used because when flooded the fuller packings would be undermoderated. The "extra7" case near the bottom in Table B.3 has the allowed 217 pins spaced evenly to fill the Ident-69 casings in seven CCC tubes. In the last case, the pins are packed in Ident-69s with wirewraps intact (the pitch being the same as in a DFA duct), again in seven CCC tubes. The last three case scenarios would not be possible without a deliberate cutoff of a Ident-69 container end to make it fit in the central CCC tube. The differential on k_{eff} for the center tube being loaded is about +15% $\Delta k/k$. Thus, the worst plausible configuration of six, pin-loaded Ident-69s in an ISC cask would not give a k-effective exceeding 0.93 under flooding conditions.

Reviewer's recommendations for text clarifications and/or further explanations and descriptions have been incorporated into the report. MONK6B input listings for some of the more crucial calculations were checked and found to accurately portray the case descriptions (see attached checksheet).

Reviewer

Date

Table B.1: SUMMARY OF MONTE-CARLO CALCULATION RESULTS FOR FFTF FUEL ASSEMBLIES IN CORE COMPONENT CONTAINERS

CODE (Report Year)	CASE #	MODELLING OF TUBES		PIN LATTICE DETAILS (36 inch fuel height)				WATER FLOODING CONDITION	REFLECTOR AROUND CCC CASING	CALCULATION RESULTS	
		With Pins	Tubes Present	Array Type	Pitch (cm)	Outer Radius	Pins/ tube			k_{eff}	Std. Dev.
MONK6B (1994)	lccconttd	6	6 DFAs in 6 CCC	hexag.	.7214	DFA hexduct	217 29% Pu	All Dry	None	0.2611	0.0010
MCNP (1993)	SWTPAB	6	6 DFAs in 6 CCC	hexag.	.7214	DFA hexduct	217 29% Pu	All Dry in SDCV	water in SWT Pit	0.2878	0.0015
MONK6B (1994)	hotrot 53h2	6	6 DFAs in 6 CCC	Dryrot: Homog. Fuel, clad, and void		DFA hexduct	217 29% Pu	All Dry	ISC case + concrete	0.3825	0.0013
MONK6B (1995)	lcccw 7dfad	7	7 DFAs in 7 CCC	hexag.	.7214	DFA hexduct	217 29% Pu	All Dry	None	0.3096	0.0010
MONK6B (1995)	drydfas7	7	7 DFAs in 7 CCC	hexag.	.7214	DFA hexduct	217 29% Pu	All Dry	ISC case + concrete	0.4660	0.0017
MONK6B (1995)	cc7d f36d	7	7 DFAs in 7 CCC	Dryrot: Homog. Fuel, clad, and void		DFA hexduct	217 29% Pu	All Dry	ISC case + concrete	0.4352	0.0015
MCNP (1989)	Table-2 Item B.2	6	6 DFAs in 6 CCC	homogeneous Fuel, clad, duct, water		CCC tube ID	217 31% Pu all 239	Flooded	water in SWT Pit	0.670	0.01
MCNP (1993)	SWTPAC	6	6 DFAs in 6 CCC	hexag.	.7214	DFA hexduct	217 29% Pu	Water in All Voids	water in SWT Pit	0.7034	0.0040
MONK6B (1994)	hotrot 50h2	6	6 DFAs in 6 CCC	Dryrot: Fuel, clad and water homogenized		DFA hexduct	217 29% Pu	Water in All Voids	ISC case + concrete	0.7084	0.0026
MONK6B (1995)	ccc7dfas	7	7 DFAs in 7 CCC	Dryrot: As above		DFA hexduct	217 29% Pu	Water in All Voids	ISC case + concrete	0.8201	0.0028

Table B.2

SUMMARY OF MONTECARLO CALCULATION RESULTS FOR DRY FFTF FUEL-LOADED INDENT-69S IN CORE COMPONENT CONTAINERS

CODE (Report Year)	CASE #	MODELLING OF TUBES		PIN LATTICE DETAILS (36 inch fuel length)				WATER FLOODING CONDITION	REFLECTOR AROUND CCC CASING	CALCULATION RESULTS	
		With Pins	Tubes Present	Array Type	Pitch (cm) ^a	Outer Radius	Pins/ tube			k _{eff}	Std Dev
MCNP (1991)	ID69v15	6	6 ID69s in 6 CCC	Square	1.238	6.79 cm	97 29% Pu	All Dry	Dry ISC case + concrete	0.2009	0.0078
MCNP (1991)	ID69v16	6	6 ID69s in 6 CCC	Square	1.238	6.79cm	97 29% Pu	All dry	Solid Waste Cask, dry	0.2068	0.0049
MONK6B (1995)	dry dfas7	7	7 DFAs ^b in 7 CCC	hexag	.7214	hexduct 11.0 cm f-to-f	217 29%Pu	All Dry	ISC case + concrete	0.4660	0.0017
MONK6B extra1	pins inccr	7	7 ID69s no CCC	hexag	.7214	6.79cm	~321 29%Pu	All Dry	ISC case + concrete	0.6081	0.0020
MONK6B extra2	pins inccc	7	no ID69s 7 CCC ^c	hexag	.7214	8.14cm	~462 29% Pu	All Dry	ISC case + concrete	0.8070	0.0024
MONK6B extra3	pins inccr1	7	7 ID69s no CCC	hexag	.5842 (a)	6.79cm	~490 29% Pu	All Dry	ISC case + concrete	0.8427	0.0025
MONK6B extra4	pins inccc1	7	no ID69s 7 CCC ^c	hexag	.5842 (a)	8.14cm	~704 29% Pu	All Dry	ISC case + concrete	1.0862	0.0029

a) 0.7214 cm lattice pitch is pin spacing inside of DFA hexduct; for any lesser pitch, the fuel pin wire wrappers would have to be absent. Minimum pitch w/o wrap is .5842 cm pin diameter.

b) No Ident-69s: 7-DFA case listed here to show maximum k for 217 pins per CCC tube in dry conditions.

c) For these cases, fuel pins would have to be loaded directly into the tubes of the Core Component Container.

Table B.3: SUMMARY OF MONTECARLO RESULTS FOR FFTF FUEL-LOADED INDENT-69S IN FLOODED CORE COMPONENT CONTAINERS

CODE (Report Year)	CASE #	MODELLING OF TUBES		PIN LATTICE DETAILS (36 inch fuel height)				WATER FLOODING CONDITION	REFLECTOR AROUND CCC CASING	CALCULATION RESULTS	
		With Pins	Tubes Present	Array Type	Pitch (cm)	Outer Radius	Pins/ tube			k _{eff}	Std Dev
MCNP (1989)	Table 2 Case C.1	6	6 ID69s in 6 CCC	square	1.011	6.63 cm	137 31% Pu all 239	fully flooded	full water reflection	0.970	0.01 high since no ²⁴⁰ Pu was assumed
MCNP (1991)	ID69v14	6	6 ID69s in 6 CCC	Square	1.238	6.79 cm	97 29% Pu	fully flooded	Flooded ISC	0.8421	0.0067
MCNP (1991)	ID69V	6	6 ID69s in 6 CCC	Square	1.238	6.79cm	97 29% Pu	fully flooded	SDCV in flooded SWTP	0.8484	0.0055
MCNP (1991)	ID69v14	6	6 ID69s in 6 CCC	Square	1.238	6.79cm	97 29% Pu	fully flooded	Flooded SWC	0.8511	0.0058
MCNP (1991)	ID69vx	6	6 ID69s in 6 CCC	Square + ring of 68	.7214, .59 in ring*	6.79cm	97 29% Pu	fully flooded	SDCV in flooded SWTP	0.9127	0.0050
MONK6A (1991)	CCC03	6	6 hex- ducts in 6 CCC	hexag	1.270	13.6cm flat to flat	91 29% Pu	CCC tubes but not between	6" water around SDVC	0.9072	0.0030
MONK6B (1995)	ccc6 id69wa	6	6 ID69 in 6 CCC	square	1.238	6.79 cm	97 29% Pu	Water in All Voids	ISC case + concrete	0.8651	0.0029
MONK6B (1995)	ccc7 id69wa	7	7 ID69 in 7 CCC	square	1.238	6.79 cm	97 29% Pu	Water in All Voids	ISC case + concrete	0.9927	0.0031
MONK6B extra7	pins incccf	7	7 ID69 in 7 CCC	hexag	.8779	6.79 cm	217 29% Pu	Water in All Voids	ISC case + concrete	0.9916	0.0030
MONK6B extra6	pins inccrf	7	7 ID69s no CCC	hexag	.7214	6.79 cm	~321 29% Pu	Water in All Voids	ISC case + concrete	1.0762	0.0029

* For ring pins packed this close, their wire wrappers would have to be absent.