ATTACHMENT (1)

BACKGROUND AND ANALYSIS

Calvert Cliffs Nuclear Power Plant, Inc.
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BACKGROUND

The primary purpose of the spent fuel pool (SFP) is to maintain the spent fuel assemblies in a safe storage condition. Per 10 CFR 50.68, if no credit for soluble boron is taken, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with unborated water. If credit is taken for soluble boron, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with borated water, and the k-effective must remain below 1.0 (subcritical) at a 95% probability, 95% confidence level, if flooded with unborated water. In addition, the maximum nominal U-235 enrichment of the fresh fuel assemblies is limited to five weight percent.

The current Technical Specification limits the maximum enrichment for standard fuel assemblies to 4.52 weight percent. Currently, the Calvert Cliffs analysis shows that all requirements are met using the maximum fresh fuel enrichment with the Value Added Pellet (VAP) fuel design with the present storage configuration, assuming no soluble boron credit. The current Calvert Cliffs Technical Specifications limit VAP fuel with enrichments less than or equal to 4.30 (4.52 Standard) weight percent U-235 to be stored in the Calvert Cliffs Nuclear Power Plant (CCNPP) SFPs.

The proposed change would allow the maximum fresh fuel enrichment with the VAP fuel design to be increased to five weight percent, assuming credit for soluble boron in the SFP. Two analyses were completed to determine the necessary boron concentrations for both the proposed Technical Specification boron concentrations (Technical Specification 4.3.1 and 3.7.16). One analysis determined the minimum boron concentration due to criticality considerations. The second analysis determined the minimum boron concentration to ensure that acceptable levels of subcriticality are maintained assuming credible boron dilution events.

Calculations have been completed to document the Calvert Cliffs SFP Rack Criticality Methodology that ensures that the spent fuel rack multiplication factor, k-effective, is less than the 10 CFR 50.68 regulatory limit with 5.0 weight percent VAP fuel and with partial credit for soluble boron in the SFP (Attachment 4). For an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 weight percent VAP fuel at the worst case temperature, a maximum unborated k-effective value of 0.986 is calculated (including all biases and uncertainties), which is less than the 10 CFR 50.68 value of 1.0. The maximum k-effective value of 0.947 at a moderator boron concentration of 300 parts per million (ppm) (including all biases and uncertainties) is less than the 10 CFR 50.68 value of 0.95. Note that 300 ppm is a minimum boron concentration requirement. The proposed change to the Technical Specification 4.3.1 adds 15 percent to this value to account for any unknown uncertainties, which increases the boron level to 350 ppm required to safely store 5 weight percent VAP fuel in the SFP.

An additional consideration, needed to allow the credit of the soluble boron, is the negative reactivity required, to ensure that acceptable levels of subcriticality are maintained, assuming a design basis event occurs. For spent fuel storage, we must consider credible boron dilution events. The analysis for the boron dilution events determined what the minimum SFP boron concentration needs to be at the start of a credible event in order to ensure the boron concentration does not go below 350 ppm. The proposed changes will add Technical Specification 3.7.16, "Spent Fuel Pool Boron Concentration," to provide sufficient negative reactivity to ensure acceptable levels of subcriticality for spent fuel storage assuming a dilution event. The minimum SFP boron concentration of 2000 ppm supports the normal and accident boron assumptions in the required calculations (see Attachment 5). With credit being taken for soluble boron in the SFP, a Surveillance Requirement will be included in Technical Specification 3.7.16 to ensure

the appropriate minimum concentration of soluble boron is maintained in the SFP for both normal and accident conditions. The proposed Surveillance Requirement to verify the SFP boron concentration is appropriate because no major replacement of pool water is expected to take place over a short period of time. This proposed Surveillance Requirement Frequency conforms to the Improved Standard Technical Specification Frequency.

SYSTEM DESIGN

The SFP is a large rectangular structure that holds the spent fuel assemblies from the reactors in both units. Each half of the pool is 54 feet long, 25 feet wide, and approximately 39 feet deep (the floor elevation varies). Borated water fills the SFP and completely covers the spent fuel assemblies. The SFP is constructed of reinforced concrete 5 1/2 to 6 feet in thickness and is lined with a 3/16-inch stainless steel liner that serves as a leakage barrier. A 3 1/2-foot dividing wall separates the SFP, with the north half being associated with Unit 1 and the south half associated with Unit 2. A slot in the dividing wall has a removable gate that allows movement of fuel assemblies between the two halves of the pool. The SFP is located in the Auxiliary Building between the two containment structures. Each half of the SFP is equipped with vertical spent fuel racks installed on the pool bottom. The fuel rack cells are individual double-walled containers approximately 14 feet high. The inner wall of each cell is made from a 0.06-inch thick sheet of stainless steel formed into a square cross-section container, indented on the corners, with an inside dimension of 8.56 inches. The outer, or external, wall is also formed from a stainless steel sheet 0.06 inches thick.

Plates of borated, neutron absorbing material are inserted between the two walls, in each of the four spaces formed by the indentations in the inner wall. The plates used in the Unit 1 SFP are made of a composite material (carborundum) consisting of a boron carbide (B_4C) powder in a fiberglass matrix and are 6.5 inches wide by 0.09 inches thick. Each plate originally contained at least 0.024 grams of boron-10 per square centimeter of plate (only 0.020 g/cm^2 was assumed in the original analysis to account for loss over 40 years). Calvert Cliffs has a coupon surveillance program to test the condition of the carborundum material. As a result of our License Renewal, it was necessary to account for the additional boron that could be lost between 40 and 70 years. In addition, previous criticality calculations also considered a 10% uncertainty in addition to using the worst-case boron-10 loading. This uncertainty is to account for the experimental variation in the boron loss rate measurement. The spacing between the cells is maintained at 10 3/32 inches, center to center, by external sheets and welded spacers. The boron plate inserts and assembly spacing help maintain the SFP assemblies in a subcritical condition.

The racks are designed to withstand all anticipated loadings. Structural deformations are limited to preclude any possibility of criticality. The Seismic Category 1 racks are supported in such a manner as to preclude a reduction in separation under either the Operating Basis or Safe Shutdown Earthquake. The racks are designed not to collapse or bow under the force of a fuel assembly dropped into an empty cavity or dropped horizontally across the top of the racks assuming no drag resistance from the water. Heavy loads in excess of 1600 lbs are prohibited from travel over spent fuel assemblies in the SFP unless such loads are handled by a single-failure proof device. The Spent Fuel Cask Handling Crane, which is designed in accordance with the single-failure proof criteria of NUREG-0554 and NUREG-0612, is used to handle heavy loads in the SFP area. Thus, the cask or heavy object drop accident is not a credible event.

The VAP fuel is contained in a 14x14 assembly array. The VAP fuel rods were modeled with three different clad materials (Zirlo, Optin, and Zirc-4) to maximize assembly reactivity. No shims were modeled in the fuel assemblies. Analyses have shown that, with the exception of Westinghouse Integral Fuel Burnable Absorber rods, the neutron multiplication factor for an assembly without Integral Burnable

Absorbers (IBAs) is always greater (throughout burnup) than the k-effective for an assembly with IBAs, including UO_2-Gd_2O_3, UO_2-Er_2O_3, and Al_2O_3-B_4C rods. This was verified for the current CCNPP fuel design with UO_2-Er_2O_3.

CRITICALITY ANALYSIS

Most of the criticality calculations in Attachment (4) model a single assembly in a storage cell, with mirror boundary conditions on all surfaces, to simulate an array of infinite axial and radial extent. Eccentric positioning uncertainties were modeled with a ten-by-ten array of storage cells, with mirror boundary conditions on all surfaces, to simulate a ten-by-ten array of infinite axial and radial extent. The assembly drop accident was simulated with a model of the entire Unit 1 SFP.

Regulatory guidance dictates that the analysis methods and neutron cross-section data shall be benchmarked by comparison with critical experiment data for similar configurations. The benchmarking process should establish a calculational bias and uncertainty of the mean with a one-sided tolerance factor of 95% probability at a 95% confidence level. NUREG/CR-6361, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages" provides documentation for 180 criticality experiments with geometries, materials, and neutron interaction characteristics representative of LWR fuel in core, storage, and cask arrangements. NUREG/CR-6361 was used as design input and as the primary reference for the validation calculation package. The objective of the validation package was to satisfy the intent of ANSI/ANS-8.1 with respect to LWR fuel criticality evaluations in reactor core, spent fuel rack, and cask environments and to satisfy the intent of ANSI/ANS-8.17 with respect to a determination of the bias and uncertainty in the bias. The validation package validates the SCALE 4.4 code package with the 44 neutron energy group ENDF/B-V based cross-section library for use in LWR type fuel criticality evaluations. The SCALE 4.4 nuclear analysis software package was verified on a dedicated CCNPP computer and validated for Light-Water Reactor (LWR) fuel criticality analysis. Estimates are made for the bias, uncertainty in the bias and trending with important physical parameters. The storage rack type category exhibits a bias of -0.0008 and a 95/95 one sided uncertainty of 0.0076.

The SCALE 4.4 CSAS25 code module with the 44 group ENDF/B-V cross section library was utilized in Attachment (4) to perform the KENO criticality calculations. CSAS25 uses the SCALE Material Information Processor (MIP) and the associated material composition library to calculate material number densities, to prepare geometry data for resonance self-shielding, and to create data input files for the cross-section processing codes, BONAMI and NITAWL-II. The CSAS25 sequence then invokes the KENO-Va Monte Carlo criticality code.

The maximum k-effective value for the SFP was obtained by summing the calculated value, the calculational bias, and the total uncertainty defined as a statistical combination of the calculational and mechanical uncertainties. Any bias that reduces the calculated value of k-effective was not applied. Mechanical and material uncertainties may be treated by assuming worst case conditions or by performing sensitivity studies and obtaining worst case uncertainties. Uncertainties may be combined statistically provided that they are independent variations. Sensitivity analyses determined the worst-case reactivity for moderator temperature (4°C), fuel cladding composition (Optin), enrichment (5.0 weight percent), soluble boron concentration (0 and 300 ppm), and carborundum poison loading (0.0177 gm B_{10}/cm^2 corresponding to a 70 year service life). Reactivity uncertainties were determined for stack height density, storage cell pitch, storage cell rack steel thickness, carborundum poison loading, and eccentric loading within a storage cell for 0 and 300 ppm soluble boron concentration. Note that burnup was not credited in the Unit 1 SFP criticality calculations, thus no uncertainties relating to burnup credit were necessary. The worst-case uncertainty of 0.01901 Δk at 0 ppm was utilized for all cases.

During inspection/reconstitution activities in the SFP, assemblies are put on 20.5" vertical spacers. This process lifts the active fuel region of the affected assembly above the carborundum poison plates and thus could affect reactivity. A finite radial and axial model of the Unit 1 SFP of nominal dimensions, containing the maximum enrichment of 5.0 weight percent VAP fuel at the worst case temperature of 4°C at a soluble boron density of 0 and 300 ppm, was modeled with alternate and sequential assemblies in a row on spacers to simulate the reconstitution/inspection process. Sufficient margin exists in going from a two-to-three dimensional model to counteract any increase in reactivity from raising a row of assemblies on spacers. In addition, there is no significant reactivity penalty between reconstituting an entire row of assemblies or alternate assemblies in a row. Current CCNPP procedures require alternate assemblies in a row to be on spacers, which completely decouples the assemblies in reactivity analysis. This will conservatively remain unchanged.

Dropping an assembly horizontally on top of the SFP racks is not possible at Calvert Cliffs due to the design of the spent fuel handling machine and due to the height of the SFP racks. The bottom of the outer mast assembly is at elevation 49'6", while the top of the SFP racks is at elevation 45'0". Therefore, since the fuel assemblies used at Calvert Cliffs are over 13' in length, an assembly can not be dropped from the spent fuel handling machine and fall horizontally onto the racks. Dropping an assembly of 5.0 weight percent VAP fuel onto the SFP racks was analyzed, even though it is not a credible accident. Per regulatory guidance and ANSI-N 16.1-1975, the double contingency principle was applied. It required two unlikely, independent, concurrent events to produce a criticality accident. The double contingency principle means that realistic conditions may be assumed. For example, if soluble boron is normally present in the SFP water, the loss of soluble boron is considered as one event and a second concurrent event need not be assumed. Therefore, total credit for the presence of soluble boron may be assumed in evaluating this accident condition. The normal SFP boron concentration is conservatively assumed to be 2000 ppm, which will be supported by proposed Technical Specification 3.7.16. A finite radial and axial configuration of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 weight percent fuel at the worst case temperature of 4°C was modeled with a soluble boron density of 2000 ppm for the dropped assembly accident with and without reconstitution. The dropped assembly is effectively decoupled from the assemblies stored in the SFP storage racks as was noted in previous Combustion Engineering/Westinghouse computations. Taking credit for 2000 ppm soluble boron, per the double contingency principle, drops the k-effective value to well below the regulatory requirement for all cases.

Dropping an assembly and having it stand upright atop another assembly in the SFP racks is less limiting than the current analysis, which assumes infinite axial extent. Thus, there are no adverse consequences for a vertical assembly drop accident in this analysis.

For an infinite array of maximum enrichment fresh fuel, there is no fuel misloading incident and therefore, the required soluble boron to maintain k-effective below 0.95 remains unchanged. Thus there are no adverse consequences for a fuel misloading accident in the Unit 1 criticality analysis.

The top opening of the SFP racks has angled lead-in guides, which effectively block the spaces between the cavities, as well as guide the fuel assembly into the open tube. Also to avoid the possibility of inadvertently placing a fuel assembly between the outermost storage cell and the pool wall, the top rack surface is extended to cover this space. Thus the abnormal placement of a fuel assembly in the SFP racks is not a credible event.

DILUTION ANALYSIS

The objective of the evaluation in Attachment (5) was to confirm that design features, instrumentation, administrative procedures, and sufficient time are available to detect and mitigate boron dilution in the SFP before the boron concentration is reduced below the value assumed in the SFP criticality analyses that credit boron to remain below the design basis criticality limit of 0.95 k-effective. Attachment (5) identifies the potential boron dilution sources and dilution events, the instrumentation available for detection of dilution, and the operating and administrative procedures available for the detection and mitigation of dilution. The report also identifies the potential events which could dilute the soluble boron contained in the Unit 1 SFP and quantifies the dilution rates and response times of each event.

Flooding

Spent fuel pool flooding by tsunami, hurricane, and storms are not credible events at Calvert Cliffs. Since there has been no record of tsunamis on the northeastern United States coast, it is not believed that the site will be subjected to a significant tsunami effect. The relative frequency of hurricane occurrence for the Calvert Cliffs site is slightly more than one hurricane per year. For the Probable Maximum Hurricane it is assumed that the peak hurricane surge is coincident with normal high tide and with a 99th percentile wave height. The total predicted wave run-up is to Elevation 27.1', which is considerably less than the 69' elevation of the top of the SFP. Thus the maximum hypothetical flood level is below the top of the SFP elevation. The Auxiliary Building is a concrete structure and qualified for high winds. Therefore, severe storms with high winds are not expected to cause sufficient damage to the roof to allow a large volume of rain to enter the building and become an unborated source of water to the pool. The 6" lip around the SFP should cause the bulk of any entering rain water to flow out of the SFP area via the 13 floor drains, 13 doors, and 2 tendon end cap shafts.

The onsite water sources that can flood the SFP and possibly cause dilution below the minimum boron concentration are the two pretreated water storage tanks of 500,000 gallons each, the two condensate storage tanks of 315,000 gallons each, the demineralized water storage tank of 350,000 gallons, and the two refueling water tanks of 420,000 gallons each. The large volume of water necessary to dilute the pool to the boron endpoint precludes many small tanks as potential dilution sources. No tanks containing any significant amount of water are stored in the vicinity of the SFPs. The large unborated water sources, such as reactor makeup water and demineralized water, are in tanks at elevations below the spent fuel pool, so that gravity feed from these tanks to the SFP is not possible. It is very unlikely that the large volumes of water necessary to substantially dilute the spent fuel pool (i.e., to the boron endpoint) could be transferred from these tanks to the SFP without being detected by plant personnel.

The possibility of a fire in the SFP area leading to a boron dilution event is not a credible event. Typically, combustible loadings around the pool area are minor. If the fire hose stations were used to extinguish a fire, the volume of water required to extinguish a local fire is not expected to be of sufficient magnitude to dilute the pool such that a several hundred ppm reduction in the pool boron concentration would occur. Water for the fire protection system is supplied by two 2,500 gallons per minute (gpm) full-capacity fire pumps. The fire pumps take suction from the two 500,000 gallon capacity pretreated water storage tanks. Fire in the fuel handling building could result in unborated water entering the SFP while attempting to extinguish the fire. However, the rate of addition of unborated water from a fire would be insufficient to exceed the minimum boron level of 350 ppm, since sufficient time would exist to take compensatory measures (i.e., add additional boron to the SFP).

In addition, the discussion that follows on incomplete boron mixing indicates that the unborated water would tend to float on the surface of the pool and overflow the SFP as water continues to flow into the SFP. Thus the fuel assemblies should remain surrounded by borated water. Finally, assuming that the

fire is not directly over the SFP, the 6" lip around the SFP should cause the bulk of the water used to extinguish the fire to flow out of the SFP area via the 13 floor drains, 13 doors, and 2 tendon end cap shafts. At a dilution rate of 2,500 gpm directly into the SFP, it will take 6.95 hours to dilute the SFP from 2000 to 350 ppm. It is not credible that dilution could occur for this length of time without operator notice, since this event would activate the SFP high level alarm and initiate Auxiliary Building flooding. In addition, in excess of 1,043,000 gallons of pretreated water must be added to the SFP to reach 350 ppm soluble boron concentration. Assuming that a fire hose was inserted into the SFP and discharged at the maximum rate of 2500 gpm, it would exhaust the pretreated water storage tank that it was aligned to in approximately 3.45 hours. Two well water pumps would automatically actuate and pump 600 gpm into the pretreated water storage tank. An additional 13 hours would be required for the SFP to be diluted to 350 ppm boron at this rate. Note that this dilution by flooding scenario bounds all others. Even in the unlikely event that the SFP is completely diluted of boron, the SFP will remain subcritical by a design margin of k-effective not to exceed 0.986.

The unlikely probability of an inadvertent boron dilution event reducing the SFP boron concentration to less than 350 ppm is based on the assumption of complete mixing of the boron in the SFP. The complete mixing assumption may not always be valid, if the circulation flow in the SFP is insufficient to prevent stratification. Where stratification has occurred (Robinson 2 December 20, 1988 and San Onofre 1 January 23, 1989), it was observed that the diluted water floated on the higher borated water. This suggests that if stratification does occur, the water with the higher boron concentration will tend to be in the lower level of the SFP where the fuel assemblies are located. Circulating the SFP water via the SFP cooling or purification systems can eliminate the possibility of boron stratification in the SFP.

Another type of incomplete boron mixing is a ribbon effect, where a channel of unborated water bores its way to a SFP assembly location. If the SFP cooling or purification systems are in operation, mixing will occur in the piping systems eliminating any ribbon effects. Assuming that the SFP cooling and purification systems are not in operation, an analysis using turbulent jet and diffusion theory was performed to determine the extent of any ribbon effect. For an initial SFP concentration of 2000 ppm and an unborated discharge from a 10" diameter pipe (the largest discharge pipe in the SFP is from an 8" diameter pipe, use of a 10" is conservative), the boron concentration will reach 350 ppm within 29" of the nozzle discharge. The active fuel region of the fuel assembly is more than 29" from the nozzle discharge. Thus, it is unlikely that a diluted ribbon flow of less than 350 ppm could reach the fuel.

The SFP instrumentation is not powered from the emergency diesel generators, thus, a loss-of-offsite power would affect the plant's ability to respond to a dilution event. However, the loss-of-offsite power would also affect electric pumps involved in the dilution event. The large unborated water sources such as reactor makeup water and demineralized water are in tanks at the tank farm at elevations below the SFP, so that gravity feed from these tanks to the SFP is not possible.

Loss of SFP Inventory

Structural failures, where makeup can compensate for the loss-of-coolant, can also initiate a dilution event.

The SFP is designed to preclude the loss of structural integrity. A 3/16" solid stainless steel liner plate was used on the inside face of both pools for leak tightness, and all of the field welds have leak-test channels welded to the outer side of the liner plates. The channels are grouped into ten zones, each with its own detector pipe to localize leaks in the liner seams. Even with the precautions described, small leaks may still occur in the SFP. Early leakage detection is assured by a Surveillance Requirement (SR 3.7.13.1), which requires that the minimum pool level be verified at least once every

seven days. In practice, the level is checked once every 12 hours as required by the Auxiliary Building log sheets. In addition, a level alarm keeps the Control Room Operator aware of level changes.

The likelihood of a fuel handling incident is minimized by administrative controls and physical limitations imposed on fuel handling operations. All refueling operations are conducted in accordance with prescribed procedures under direct surveillance of a qualified supervisor. Mechanical interlocks prevent inadvertent disengagement of a fuel assembly from the fuel handling machine; consequently, the possibility of dropping and damaging of a fuel assembly is remote. Even though the assembly drop is an unlikely event, the SFP concrete plus liner plate are stronger than the assembly bottom casting and fuel and guide tubes for impact of a fresh or irradiated VAP fuel assembly with an inserted control element assembly (1350-1360 lbm). The bottom casting is, in turn, stronger than the fuel and guide tubes. Essentially all impact kinetic energy absorption will take place in the fuel and guide tubes. Interface forces between the bottom assembly and the liner plate would be limited by the buckling of the fuel and guide tubes. The interface forces, therefore, will be of insufficient magnitude to cause perforation of the liner plate. In addition, for impact over the collection trenches in the SFP, the interface forces between the bottom assembly and the liner plate would be limited by the buckling of the fuel and guide tubes. The interface forces, therefore, will be of insufficient magnitude to cause perforation of the liner plate. Therefore, for both full contact impact and impact over the collection trenches of a fresh or irradiated VAP fuel assembly with an inserted control element assembly (1350-1360 lbm), the liner plate would not be perforated.

The most serious failure to the system is the loss of SFP water. This is avoided by routing all SFP piping connections and penetrations above the water level and providing them with siphon breakers to prevent gravity drainage. The SFP inlets to the SFP cooling and purification systems are above the spent fuel racks but penetrate the SFP liner at 65' 11" elevation, while the SFP discharge pipes from the shutdown cooling system, purification system, refueling water tank, and demineralized water tank are above the spent fuel racks but also penetrate the SFP liner at 65' 11" elevation. The SFP does not contain any permanent drains, thereby, preventing accidental drain down.

Loss of Spent Fuel Pool Cooling

The Spent Fuel Pool Cooling (SFPC) system is common to both units. The SFPC system is a closed-loop system consisting of two half-capacity 1,390 gpm pumps and two half-capacity heat exchangers in parallel, a bypass 128 gpm cartridge-type filter which removes insoluble particulates, and a bypass 128 gpm mixed bed resin demineralizer which removes soluble ions. The SFPC heat exchangers are cooled by service water. The normal configuration for the cooling system is one pump/one cooler loop in operation on each half of the SFP to cool the water. However, the purity and clarity of the water is maintained by passing a portion of the flow through the purification system. The purification system consists of a filter to remove insoluble particulates and a demineralizer (ion exchanger) which removes soluble ions. Ten skimmers are provided in the spent fuel pools to remove accumulated dust and debris from the surface of the water. Connections are provided for tie-in to the shutdown cooling system to provide for 2,000 gpm of additional heat removal in the event that the reactor cores are off-loaded resulting in 1,830 fuel assemblies contained in the pool. A total loss-of-cooling is not part of the system's design basis for the SFPC system and pool structural components (e.g., pool liner plate, SFPC piping and pumps). The entire SFPC system is tornado-protected and is located in a Seismic Category I structure.

Even though loss of SFP cooling is not part of the system's design basis, because the SFPC system is a Class III system, the effect of that event was analyzed. Assuming that the Units' 1 and 2 SFPs contain 1,830 assemblies generating the maximum possible heat load, and assuming the worst case initial SFP

temperature of 155°F, then the time to boil can be calculated as 7.34 hours. Time to uncover the fuel assemblies is 79.0 hours. However, loss of the pool water via boiling will not result in a loss of soluble boron, since the soluble boron is not volatile. Thus loss of SFPC system without makeup flow is not a mechanism for boron dilution. A worst-case scenario involves adding sufficient unborated water to the SFP to just keep the water from boiling and letting the excess fluid flow down the Auxiliary Building gravity drains associated with the SFP overflow level. It would take 24.88 hours to dilute the SFP to 350 ppm under this scenario. It is not credible that dilution could occur for this length of time without operator notice, since this event would activate the high level alarm and initiate Auxiliary Building flooding. In addition, in excess of 1,043,000 gallons of demineralized water must be added to the SFP to reach 350 ppm soluble boron concentration. This is three times more water volume than is contained in the demineralized water tank.

CONCLUSION

The proposed change would allow the maximum fresh fuel enrichment with the VAP fuel design to be increased to five weight percent, assuming credit for soluble boron in the SFP. The analyses contained in Attachments (4) and (5) demonstrate that the requirements of 10 CFR 50.68 are met.

Allowing the maximum enrichment for fresh fuel to be increased to five weight percent, assuming partial credit for soluble boron will allow the number of fresh fuel assemblies per cycle to be decreased. This will decrease Independent Spent Fuel Storage Installation storage requirements, decrease permanent Department of Energy storage requirements and decrease fuel cycle costs.

ATTACHMENT (2)

DETERMINATION OF SIGNIFICANT HAZARDS

The proposed change has been evaluated against the standards in 10 CFR 50.92 and has been determined to not involve a significant hazards consideration in operation of the facility in accordance with the proposed amendment:

1. *Would not involve a significant increase in the probability or consequences of an accident previously evaluated.*

   The proposed change will increase the maximum enrichment limit of the fuel assemblies that can be stored in the Unit 1 spent fuel pool (SFP) by taking credit for soluble boron in maintaining acceptable margins of subcriticality. The proposed change will modify Technical Specification 4.3.1 "Criticality" and add Technical Specification 3.7.16 "Spent Fuel Pool Boron Concentration." The postulated accidents for the SFP are basically four types; 1) dropped fuel assembly on top of the storage rack, 2) a misloading accident, 3) an abnormal location of a fuel assembly, and 4) loss-of-normal cooling to the SFP.

   There is no increase in the probability of a fuel assembly drop accident in the SFP when considering the higher enriched fuel or the presence of soluble boron in the SFP water. Dropping a fuel assembly on top of the SFP storage racks is not credible at Calvert Cliffs due to the design of the spent fuel handling machine and due to the height of the SFP storage racks. The handling of the fuel assemblies has always been performed in borated water and will not change as a result of crediting soluble boron in the SFP criticality analysis. The proposed change does not change the general design and characteristics of the fuel assemblies. Therefore, the proposed change does not increase the probability of a fuel assembly drop accident.

   There is no increase in the probability of the accidental misloading of irradiated fuel assemblies into the SFP storage racks when considering the higher enriched fuel or the presence of soluble boron in the SFP water for criticality control. Fuel assembly placement will continue to be controlled pursuant to approved fuel handling procedures.

   Due to the design of the SFP storage racks, an abnormal placement of a fuel assembly into the SFP storage racks is not possible. Also, the design of the SFP prevents an inadvertent placement of a fuel assembly between the outer most storage cell and the pool wall. The proposed change does not make any change to the design of SFP. Therefore, there is no increase in the probability of abnormal placement of a fuel assembly into the SFP storage racks.

   The proposed change will not result in any changes to the SFP cooling system, and the fuel assembly design and characteristics are not changed by an increase in fuel enrichment. Therefore, there is no increase in the probability of a loss of SFP cooling. Also, since a high concentration of soluble boron has always been maintained in the SFP water, there is no increase in the probability of the loss of normal cooling to the SFP water considering the presence of soluble boron in the pool water for criticality control.

   There is no increase in the consequences of an accidental drop or accidental misloading of a maximum enriched fuel assembly into the SFP storage racks, because the criticality analysis demonstrates that the pool will remain subcritical following either event, even if the pool contains a boron concentration less than the proposed Technical Specification limit. The proposed Technical Specification limit will ensure that an adequate SFP boron concentration will be maintained.

   There is no increase in the consequences of a loss-of-normal SFP cooling because the Technical Specification boron concentration provides significant negative reactivity. Loss of the SFP water via boiling will not result in a loss of soluble boron, since the soluble boron is not volatile. Therefore,

loss of spent fuel pool cooling system without makeup flow is not a mechanism for boron dilution. Even in the unlikely event that soluble boron in the SFP is completely diluted via unborated makeup flow, a pool completely filled with maximum enriched unburned assemblies will remain subcritical by a design margin of k-effective not to exceed 0.986.

Therefore, the proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. *The proposed change does not create the possibility of a new or different kind of accident from any accident previously evaluated.*

The proposed change will increase the maximum enrichment limit of the fuel assemblies that can be stored in the Unit 1 SFP by taking credit for soluble boron in maintaining acceptable margins of subcriticality. Increasing the maximum enrichment limit does not create a new type of criticality accident.

Soluble boron has been maintained in the SFP water and is currently required by procedures. Therefore, crediting soluble boron in the SFP criticality analysis will have no effect on normal pool operation and maintenance. Crediting soluble boron will only result in increased sampling to verify the boron concentration. This increased sampling will not create the possibility of a new or different kind of accident.

A dilution of the SFP soluble boron has always been a possibility. However, the boron dilution event previously had no consequences, since boron was not previously credited in the accident analysis. The initiating events that were considered for having the potential to cause dilution of the boron in the SFP to a level below that credited in the criticality analyses fall into three categories: dilution by flooding, dilution by loss-of-coolant induced makeup, and dilution by loss-of-cooling system induced makeup. The spent fuel pool dilution analysis demonstrates that a dilution that could increase the rack k-effective greater than 0.95 is not a credible event. It is not credible that dilution could occur for the required length of time without operator notice, since this event would activate the high level alarm and initiate Auxiliary Building flooding. In addition, in excess of 1,043,000 gallons of unborated water must be added to the SFP to reach the minimum soluble boron concentration. This is more water volume than is contained in both pretreated water storage tanks and also more water volume than is contained in the demineralized water storage tank and both condensate storage tanks combined. Even in the unlikely event that soluble boron in the SFP is completely diluted, the SFP will remain subcritical by a design margin of k-effective will not exceed 0.986.

The proposed change will not result in any other change in the plant configuration or equipment design. Therefore, the proposed change does not create the possibility of a new or different kind of accident from any previously evaluated.

3. *The proposed change does not involve a significant reduction in a margin of safety.*

The Technical Specification changes proposed by this license amendment request will provide an adequate safety margin to ensure that the stored fuel assembly array of maximum enriched fuel will always remain subcritical. Those limits are based on a plant specific criticality analysis performed for the Calvert Cliffs Unit 1 SFP, that include technically supported margins.

While the criticality analysis utilized credit for soluble boron, the SFP rack k-effective will remain less than 0.986 with no soluble boron with a 95 percent probability at a 95 percent confidence level.

This substantial reduction in the SFP soluble boron concentration was evaluated and shown not to be credible. Soluble boron is used to provide subcritical margin such that the spent fuel pool k-effective is maintained less than or equal to 0.95. Since k-effective is less than or equal to 0.95, the current margin of safety is maintained.

Therefore, the proposed change does not involve a significant reduction in a margin of safety.

ATTACHMENT (3)

TECHNICAL SPECIFICATIONS

MARKED-UP PAGES

iii

3.7.16-1

4.0-2

NEW

3.7 PLANT SYSTEMS

3.7.16 Spent Fuel Pool (SFP) Boron Concentration

LCO 3.7.16 Boron concentration of the SFPs shall be ≥ 2000 ppm.

APPLICABILITY: When fuel assemblies are stored in the SFPs.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
	--------NOTE------- LCO 3.0.3 is not applicable. --------------------	
A. Spent Fuel Pool boron concentration not within limit.	A.1 Suspend movement of fuel assemblies in the SFPs.	Immediately
	AND	
	A.2 Initiate action to restore boron concentration to within limit.	Immediately

SURVEILLANCE REQUIREMENTS

SURVEILLANCE		FREQUENCY
SR 3.7.16.1	Verify boron concentration is greater than 2000 ppm.	7 days

4.0 DESIGN FEATURES

4.3 Fuel Storage

4.3.1 Criticality

4.3.1.1 The spent fuel storage racks are designed and shall be maintained with:

INSERT A

a. Fuel assemblies having a maximum U-235 enrichment of 4.52 weight percent;

b. $k_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 9.7.2 of the Updated Final Safety Analysis Report (UFSAR);

c. d. A nominal 10-3/32-inch center-to-center distance between fuel assemblies placed in the high density fuel storage racks;

4.3.1.2 The new fuel storage racks are designed and shall be maintained with:

a. Fuel assemblies having a maximum U-235 enrichment of 5.0 weight percent;

b. $k_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 9.7.1 of the UFSAR;

c. $k_{eff} \leq 0.95$ if moderated by aqueous foam, which includes an allowance for uncertainties as described in Section 9.7.1. of the UFSAR; and

d. A nominal 18-inch center-to-center distance between fuel assemblies placed in the storage racks.

Insert A

a. Fuel assemblies having a maximum U-235 enrichment of 5.00 weight percent for the Unit 1 pool and 4.52 weight percent for the Unit 2 pool;

b. For Unit 1, $k_{eff} < 1.00$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 9.7.2 of the Updated Final Safety Analysis Report (UFSAR) and $k_{eff} \leq 0.95$ if fully flooded with water borated to 350 ppm, which includes an allowance for uncertainties as described in Section 9.7.2 of the UFSAR;

c. For Unit 2, $k_{eff} \leq 0.95$ if fully flooded with unborated water, which includes an allowance for uncertainties as described in Section 9.7.2 of the UFSAR;

ATTACHMENT (4)

CALVERT CLIFFS UNIT 1

SFP CRITICALITY ANALYSIS

Calvert Cliffs Nuclear Power Plant, Inc.
May 1, 2003

ESP No.:	ES200100780	Supp No.	0	Rev. No.	0	Page 1 of 1

FORM 19, CALCULATION COVER SHEET

INITIATION (Control Doc Type - DCALC) Page 1 of 109

DCALC No.: CA06011 Revision No.: 0

Vendor Calculation (Check one): ☐ Yes ☒ No

Responsible Group: NEU

Responsible Engineer: Gerard E. Gryczkowski

CALCULATION

ENGINEERING DISCIPLINE:

☐ Civil ☐ Instr & Controls ☒ Nuc Engrg
☐ Electrical ☐ Mechanical ☐ Diesel Gen Project
☐ Life Cycle Mngmt ☐ Reliability Engrg ☐ Nuc Fuel Mngmt
☐ Other:

Title: UNIT 1 SPENT FUEL POOL ENRICHMENT LIMIT WITH SOLUBLE BORON CREDIT

Unit ☒ UNIT 1 ☐ UNIT 2 ☐ COMMON

Proprietary or Safeguards Calculation ☐ YES ☒ NO

Comments:

Vendor Calc No.: REVISION NO.:

Vendor Name:

Safety Class (Check one): ☒ SR ☐ AQ ☐ NSR

There are assumptions that require Verification during walkdown: AIT #:

This calculation **SUPERSEDES**:

REVIEW AND APPROVAL:

Role	Name	Date
Responsible Engineer:	Gerard E. Gryczkowski	12/4/2002
Independent Reviewer:	J.B. Couch / J.R.Massari	12/10/02 12/11/2002
Approval:	M.T.Finley	12/11/02

2. LIST OF EFFECTIVE PAGES

Page	Latest Rev	Page	Latest Rev	Page	Latest Rev	Page	Latest Rev	Page	Latest Rev
001	0	002	0	003	0	004	0	005	0
006	0	007	0	008	0	009	0	010	0
011	0	012	0	013	0	014	0	015	0
016	0	017	0	018	0	019	0	020	0
021	0	022	0	023	0	024	0	025	0
026	0	027	0	028	0	029	0	030	0
031	0	032	0	033	0	034	0	035	0
036	0	037	0	038	0	039	0	040	0
041	0	042	0	043	0	044	0	045	0
046	0	047	0	048	0	049	0	050	0
051	0	052	0	053	0	054	0	055	0
056	0	057	0	058	0	059	0	060	0
061	0	062	0	063	0	064	0	065	0
066	0	067	0	068	0	069	0	070	0
071	0	072	0	073	0	074	0	075	0
076	0	077	0	078	0	079	0	080	0
081	0	078	0	083	0	084	0	085	0
086	0	087	0	088	0	089	0	090	0
091	0	092	0	093	0	094	0	095	0
096	0	097	0	098	0	099	0	100	0
101	0	102	0	103	0	104	0	105	0
106	0	107	0	108	0	109	0		

3. REVIEWER COMMENTS

CA06011 REVIEW COMMENTS from J.R. Massari

Section 6A References to Attachment 3 should be changed to Attachment C. There is no Attachment 3.
Response Done

Section 6B Reference to the Data xls(Fuel) spreadsheet should be changed to Z1INP.XLS(Fuel) There is no Data xls spreadsheet on the attached CD-ROM
Response: Done

Section 6C.
(a) All reference to the Data.xls(Fuel) spreadsheet should be changed to Z1INP XLS(Fuel) There is no Data xls spreadsheet on the attached CD-ROM.
Response Done

(b) For consistency with the hand drawn figures in the back of the calc and the values in the KENO models, the storage rack wall section dimension 1.15" should be 1 15125" and 1.03" should be 1 03125".
Response: Done

(c) Detail D of Reference 22 appears to indicate that the N-S spacing (dimension "N") between the 10x10, 8x10, and 7x10 modules is a minimum of 2 5" rather than the 2.25" used in the model Section B of Reference 22 appears to indicate that the E-W spacing (dimension "C") is 2 75" ± 0 25" (e g , min = 2 5") and 2.75" was used in the model
Response: Nominal dimensions were utilized in all accident analyses Per Ref 23 Section A-A, N is 2 25" nominal Per Ref.23 Section B-B, C is 2 75" nominal Sufficient margin exists on all accident calculations to compensate for any discrepancy in asbuilt conditions

(d)Reference 23 indicates that dimension "D" is 96" rather than the 83-3/8" used in the hand-drawn figure in back The 83-3/8" appears to be the distance to the elevation change, but not the side of the pool Thus, the section represented by dimensions "F"x"L" should be water rather than concrete However, this hand-drawn figure is not entirely representative of the model since that region and the region represented by "D"x"L" is assumed to be concrete in the model.
Response: The above simplification should have no effect on the reactivity results.

Section 7.A The statement that no degradation of the carborundum sheets is assumed is not true Reference 15 indicates that the 0 020 g/cm^2 boron loading value used in this calculation is based on a 40-year degraded value of the original loading of 0 024 g/cm^2 (see Section 9 B 7 comments below)
Response: Done

Section 8 In Reference 11, the word "Outsided" should be changed to "Outside".
Response: Done

Section 9. While checking the KENO geometry, it was noted that all of the cases assume that the pellet-to-clad gap contains void (which it normally does) However, in cask related criticality safety work that I have been involved in previously, it was standard practice to assume a "worst case" condition that the gap was filled with water of the same composition as that exterior to the fuel rod This is an NRC requirement for cask criticality safety analysis (NUREG-1536, p 6-3). Unless it's been considered in the previous analyses (which I haven't found it so far) it seems that this represents an unanalyzed condition given that we have assemblies with failed rods stored in the racks To examine the impact, water was placed in the gap region of the 0 and 300 ppm cases with the highest k_{eff} (KU1A02 and KU1D03) The cases were rerun on the safety related machine PC0398, and the results are presented below A Δk of 0 00792 is indicated for the 0 ppm case, and 0 00718 is indicated for the 300 ppm case. If treated as an uncertainty (which is questionable since it is a one-sided effect), and combined with the other uncertainties discussed below and in the calc, the resulting k_{eff} values are still less than the limit of 1 0 for the 0 ppm case and less than the limit of 0 95 for the 300 ppm case

Case	Enr(w/o)	T(K)	SHD(%)	Pitch(in)	Steel(cm)	Clad	PPM	B4C g/cm2	Water in Gap	k-calc	sigma	k_{eff}
KU1A02	5 0	277.15	0 945	10 09375	0 1524	optin	0	0 02	no	0.96623	0.00113	**0.98691**
KU1D03	5 0	277.15	0 945	10 09375	0 1524	zirc4	300	0 02	no	0 92737	0 00105	**0.94805**
KU1A02gap	5 0	277.15	0.945	10 09375	0 1524	optin	0	0 02	yes	0 97199	0 00103	n/a
KU1D03gap	5.0	277 15	0 945	10 09375	0.1524	zirc4	300	0 02	yes	0 93238	0 00112	n/a

Response: The Unit 1 model assumes all unburned fuel, which should have no defects and no water in the gaps Fuel with defects and with water in the gaps would have sufficient negative reactivity due to burnup to compensate for any positive reactivity due to water in the gaps

Section 9.B.4. There seems to be some confusion in this section between stack height density and pellet density. Stack height density considers the void created by dishing and chamfering the pellets, and thus, will always be lower than the pellet density The ranges quoted from References 5 and 6 are for pellet density, not stack height density as indicated in this section Also, the lower limit of the range for VAP pellet density should be 94 5%, not 94 0%, as indicated by Addendum SPI 13-12 to 00000-PD-110 (Ref 6) Drawing 12131-0430 indicates the dishing and chamfering account for 0 0123 cc/pellet. Therefore, the stack height density ranges from 92-95% of theoretical
Response: Current analyses are conservative.

Section 9.B.7. This section maintained the assumption that 0 020 g/cm^2 was a worst case assumption for B-10 loading in the Carborundum poison material, and considered no uncertainty for this value. However, Reference 15 indicates that 0 020 g/cm^2 represents the amount of the original boron remaining after 40 years (original minimum loading was 0 024 g/cm^2) Section 2.1.3.7 of the CCNPP License Renewal Application indicates that CCNPP will perform an analysis to demonstrate that the Carborundum can perform its criticality control function for a 70-year service life The NRC acknowledged this commitment in NUREG-1705, Section 3.10 2.4 Therefore, at a minimum, it seems that a bias should be considered which accounts for the additional boron that could be lost between 40 and 70 years. In addition, previous criticality calculations (e.g , Ref. 15 p 29, CA04166 p 29) have also considered a 10% uncertainty in addition to using the worst-case B-10 loading Reference 15 indicates that this uncertainty is to account for the experimental variation in boron loss rate measurement.

Reference 15 indicates that a B-10 loading of 0.02 g/cm^2 represents a 15% loss over 40 years Extrapolating this loss rate to 70 years yields (with the implicit assumption that the rate remains constant) a B-10 loading of 0.0177 g/cm^2 (0 024 – 70/40*0 15*0 024) and 0 01593 g/cm^2 for the 10% uncertainty case Substituting this loading on the Densities sheet of the z1inp.xls spreadsheet yields a B_4C Density Fraction of 0.213007 for the nominal 40-70 yr case, and 0 19706 for the 10% uncertainty case This value was substituted as the volume fraction for material 5 (B4C) in the 0 and 300 ppm cases with the highest k_{eff} (KU1A02 and KU1D03) The cases were rerun on the safety related machine PC0398, and the results are presented below A 40-70 yr bias (LX cases) of 0 00466 is indicated for the 0 ppm case, and 0 00504 is indicated for the 300 ppm case An uncertainty (LXu cases) of 0.00607 is indicated for the 0 ppm case, and 0 00466 is indicated for the 300 ppm case. This results in a maximum total bias and uncertainty of 0 01846 (occurs for 0 ppm) Adding the bias and uncertainty to the original results yields k_{eff} values that are less than the limit of 1.0 for the 0 ppm case and less than the limit of 0.95 for the 300 ppm case.

Case	Enr(w/o)	T(K)	SHD(%)	Pitch(in)	Steel(cm)	Clad	PPM	B_4C g/cm^2	H_2O in Gap	k-calc	Sigma	k_{eff}
KU1A02	5.0	277.15	0 945	10 09375	0 1524	optin	0	0 02	No	0.96623	0.00113	**0.98469**
KU1D03	5.0	277.15	0 945	10 09375	0 1524	zirc4	300	0 02	No	0 92737	0 00105	**0.94583**
KU1A02LX	5.0	277.15	0.945	10 09375	0 1524	optin	0	0 0177	No	0 96875	0 00101	n/a
KU1D03LX	5 0	277.15	0.945	10.09375	0.1524	zirc4	300	0 0177	No	0 93031	0 00105	n/a
KU1A02LXu	5 0	277.15	0.945	10 09375	0.1524	optin	0	0 01593	No	0 97279	0 00102	n/a
KU1D03LXu	5 0	277.15	0.945	10 09375	0 1524	zirc4	300	0.01593	No	0 93281	0 00111	n/a

Response Done

Note that CCNPP surveillance procedure ETP 86-03R currently tracks degradation of carborundum samples in high dose locations, and is credited as an aging management program in UFSAR Chapter 16. Revisions to this calculation will impact the limits used in this procedure for predicting rack life Question 1 should definitely be answered in the affirmative on the 54 37 scoping screen

Section 9.D.3. The statement is made that a fuel assembly drop is not credible because of the design of the fuel handling machine and the racks. For completeness of this argument, the credibility of a drop of a fresh fuel assembly from the Aux Building Hoist and the New Fuel Elevator should also be addressed since these are (either normally or during certain operations) very close to the racks in the U1 pool
Response: Done

Section 12.D.2. These cases appear to show a slight (non-statistically significant) trend that is opposite from that shown for stack height density with 0 ppm B The calculated SHD uncertainty is also more that a factor of 2 lower than that estimated for the 0 ppm case. Additional cases were run to verify the trend of increasing k_{eff} with increasing SHD, thus verifying that the higher SHD range used in the calc is still conservative (see Section 9 B 4 comment) The results are provided in the graph below. The results suggest that the SHD uncertainty should be 0 00469 ($k_{c955} + \sigma_{955} - k_{c945} + \sigma_{945}$), which is very close to that for the 0 ppm range However, this will have no impact on the results of the calculation since the total bias and uncertainty for the 300 ppm case is still less that that for the 0 ppm case, the latter of which was used as the bias and uncertainty for all cases.
Response Done

CA06011 Reviewer Comments from J. B. Couch

Pellet Density vs. Stack Density: Section 9 B.4 The current uranium dioxide pellet specification (reference 6) requires the pellet density to "be between 94.5% and 96 5% of theoretical density on a geometric basis " The manufacturing target value is 95 5%. KENO input requires stack density not pellet density Because of the pellet dishes and chamfers constitute about 1.5% of the volume of the pellet stack; the stack density is always less than the pellet density.

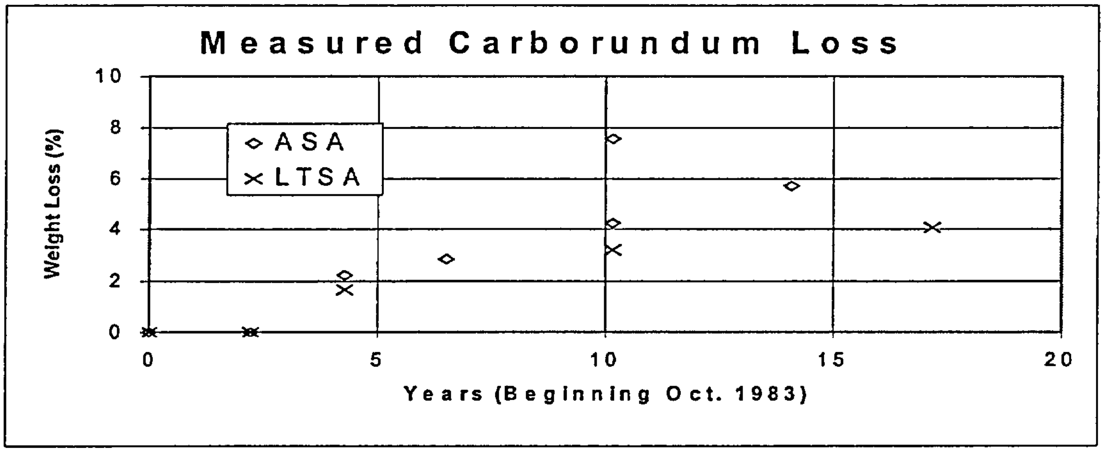
	Pellet Density (% Theoretical)	Stack Density (% Theoretical)
Minimum	94 5	93 08
Nominal	95.5	94.07
Maximum	96.5	95 05

The above values assume nominal pellet dimensions. The VAP pellet diameter (0 381 inch) has a ±0 0005 inch manufacturing tolerance Using the maximum density and maximum pellet diameter is equivalent to an effective maximum stack density of 95.30% The KENO calculations conservatively use 96 5% for the maximum stack density
Response: OK

SFP Rack Service Life
Section 9 B.7. The calculation uses a 26 2% boron loss (0.024 to 0 0177 g/cm^2) over the life of the spent fuel pool racks This is a conservative assumption based on the measured data

ETP 86-03, "Analysis of Neutron Absorbing Material in the Spent Fuel Storage Racks," provides direction for long term surveillance of the neutron absorption material samples in both spent fuel pools' racks The samples are in two different sample assemblies an Accelerated Surveillance Assembly (ASA) and a Long Term Surveillance Assembly (LTSA) After each refueling, freshly discharged fuel assemblies surround the ASA samples ETP 86-03, revision 3 contains the following measured data of carborundum loss:

	Service Year	ASA (% loss)	LTSA (% loss)
Oct-83	0 00	0	0
Apr-86	2 20	0	0
Feb-88	4 30	2 25	1.67
Apr-90	6 50	2.87	na
Dec-93	10.17	7.52	3.19
Dec-93	10.17	4 28	na
Nov-95	12 08	na	na
Nov-97	14 08	5 70	na
Dec-00	17.17	na	4 10



Except for the obvious anonymous data, the ASA shows a very linear trend of 0 414% loss per year. Using this ASA data, this results in a conservative service life of 63 years (26 2% allowable loss ÷ 0 414% loss per year) for the carborundum The Unit 1 spent fuel pool racks were installed in 1983. Based on the carborundum loss, the service life of 63 years ends in 2046 This exceeds the requirement for a service until 2044. (Unit 1 license expires in 2034 plus 10 years of decommissioning).

Response OK

Combination of Uncertainties

Sections 12.A 7 and 12 D 7. The total bias and uncertainty is calculated base on the following method

$$\text{Total bias and uncertainty} = \text{Bias} + \sqrt{\sigma_B^2 + \sigma_{MC}^2 + \sum \sigma_i^2} \qquad \text{(Equation 1)}$$

Where: σ_B is the bias uncertainty

σ_{MC} is the Monte Carlo uncertainty

σ_i are the uncertainties of the off-nominal cases

The off-nominal cases account for pellet density, storage cell pitch, steel thickness, and eccentric position Each off-nominal uncertainty is calculated by

$$\sigma_i = k_i - k_B + \sigma_{MC\text{-}i} + \sigma_{MC\text{-}B} \qquad \text{(Equation 2)}$$

Where. k_i is the neutron multiplication factor for the off nominal case

k_B is the neutron multiplication factor for the base case

$\sigma_{MC\text{-}i}$ is Monte Carlo uncertainty for the off nominal case

$\sigma_{MC\text{-}B}$ is Monte Carlo uncertainty for the base case

Since the Monte Carlo uncertainty (σ_{MC}) is included in each of the off nominal uncertainty calculations (Equation 2), it does not need to be included again in the calculation of the total uncertainty (Equation 1)

Response Done

Stainless Steel Thickness Tolerance

Paragraph 9.B.6 uses a stainless steel thickness of 0 060 ±0 005 inches and infers the value is from reference 15. However, page 15 of reference 15 uses 0 060 ±0 010 inches

Response Done

4. TABLE OF CONTENTS

5. PURPOSE

The primary purpose of the spent fuel pool (SFP) is to maintain the spent fuel assemblies in a safe storage condition. Per 10 CFR 50 App.A GDC 62 (Ref.1), criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations. Per 10 CFR 50.68 (Ref.2), if no credit for soluble boron is taken, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with unborated water. If credit is taken for soluble boron, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with borated water, and the k-effective must remain below 1.0 (subcritical) at a 95% probability, 95% confidence level, if flooded with unborated water. In addition, the maximum nominal U-235 enrichment of the fresh fuel assemblies is limited to five percent by weight.

One of the existing analyses of record (Ref.28) allows the storage of standard fresh fuel assemblies with a maximum fresh fuel enrichment of 4.52 w/o U-235, based on the older pellet design utilizing smaller pellet diameters and stack densities; a k-effective less than 0.95 including uncertainties and biases, and no soluble boron credit. Ref.29 determined the maximum fresh fuel enrichment with VAP fuel with the present storage configuration, such that, K-effective is less than 0.95 with uncertainties and biases and assuming no soluble boron credit. VAP fuel with enrichments less than or equal to 4.30 w/o U-235 can now be safely stored in the CCNPP Spent Fuel Pools. Note that VAP fuel is more reactive than similarly enriched standard fuel, thus any analysis performed for VAP fuel conservatively bounds that for standard fuel.

The purpose of this report is to document the Calvert Cliffs Nuclear Power Plant (CCNPP) Spent Fuel Pool (SFP) Rack Criticality Methodology that ensures that the spent fuel rack multiplication factor, k-eff, is less than the 10 CFR 50.68 (Ref.2) regulatory limit with 5.0 wt% Value Added Pellet (VAP) fuel and with partial credit for soluble boron in the SFP. The current analysis is performed in accordance with methodology similar to that of Ref.31.

For an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o VAP fuel at the worst case temperature of 40°F, the maximum unborated k-effective value of 0.986 is calculated with all biases and uncertainties, which is less than the 10 CFR 50.68 regulatory value of 1.0. The maximum k-effective value of 0.947 at a moderator boron concentration of 300 ppm with all biases and uncertainties is less than the 10 CFR 50.68 regulatory value of 0.95. (If credit is taken for soluble boron, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with borated water, and the k-effective must remain below 1.0 (subcritical) at a 95% probability, 95% confidence level, if flooded with unborated water.). Note that 300 ppm is a minimum boron concentration requirement. Per Technical Assumption 7J, 15% should be added to this value to account for all uncertainties. Thus a boron level of 350 ppm with uncertainties is required to credit soluble boron in the SFP and to safely store 5 w/o VAP fuel in the SFP.

A finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o VAP fuel at the worst case temperature of 40°F at a soluble boron concentration of 0 and 300 ppm was modeled with alternate and sequential assemblies in the row closest to the SFP wall on spacers to simulate the reconstitution/inspection process. Sufficient margin exists in going from a two to three dimensional model to counteract any increase in reactivity from raising a row of assemblies on spacers. In addition, there is no

reactivity penalty between reconstituting an entire row of assemblies or alternate assemblies in a row.

Dropping an assembly of 5.0 w/o VAP fuel onto the SFP racks was analyzed, even though it is not a credible accident. Per Ref.4, the double contingency principle was applied. It required two unlikely, independent, concurrent events to produce a criticality accident. The double contingency principle means that realistic conditions may be assumed. For example, if soluble boron is normally present in the SFP water, the loss of soluble boron is considered as one accident condition and a second concurrent accident need not be assumed. Therefore, total credit for the presence of soluble boron may be assumed in evaluating this accident condition. Per Technical Assumption 7.I, the normal SFP boron concentration is conservatively assumed to be 2000 ppm. A finite radial and axial configuration of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F was modeled as a function of soluble boron concentration (300, 0, 2000 ppm) for the dropped assembly accident with and without reconstitution. The dropped assembly is effectively decoupled from the assemblies stored in the SFP storage racks as was previously noted in Ref.32. Taking credit for 2000 ppm per the double contingency principle drops the k-effective value to well below the regulatory requirement for all cases.

6. INPUT DATA

Inputs and assumptions have been developed conservatively consistent with applicable safety analysis guidance. Selected KENO input decks are listed in Attachment I. The basic structure of these decks are similar and are as follows:

(6.A) Materials
The following material designations are used in the KENO input decks. The A, B, C, and D series calculations use material types 1-6 as described below. The E, F, G, H, and I series calculations use material types 1-10 as described below, except for cases KU1E01 and KU1E02, which use material types 1-6 as described below and which define material types 7, 8, and 9 as unborated water, SS304, and concrete, respectively.

(6.A.1) Material 1 is UO_2 at the indicated enrichment, stack height density, and temperature per Z1INP.XLS(CALCLIST) (Attachment A).
(6.A.2) Material 2 is fuel clad. Three materials are modeled:
(a) Zirlo fuel clad is detailed in Z1INP.XLS(DENSITIES) (Attachment C).
(b) Optin fuel clad is detailed in Z1INP.XLS(DENSITIES) (Attachment C).
(c) Zirc4 fuel clad is a standard composition of Ref.21.
(6.A.3) Material 3 is borated moderator as detailed in Z1INP.XLS(DENSITIES) (Attachment C).
(6.A.4) Material 4 is SS304. a standard composition of Ref.21.
(6.A.5) Material 5 is carborundum as detailed in Z1INP.XLS(DENSITIES) (Attachment C).
(6.A.6) Material 6 is guide tube clad and is composed of ZIRC4, a standard composition of Ref.21.
(6.A.7) Material 7 comprises the upper end fitting as detailed in Z1INP.XLS(DENSITIES) (Attachment C).
(6.A.8) Material 8 comprises the lower end fitting as detailed in Z1INP.XLS(DENSITIES) (Attachment C).
(6.A.9) Material 9 is the SS304 SFP liner, a standard composition of Ref.21.
(6.A.10) Material 10 is the SFP concrete structure, a standard composition of Ref.21.

(6.B) Fuel and Assembly Parameters
The fuel and 14x14 assembly parameters for standard and VAP fuel designs are detailed in Z1INP.XLS(Fuel) (Attachment D). Note that per Ref.28 the Unit 1 SFP enrichment limit is 4.56 w/o for the standard fuel design, while per Ref.29 the Unit 1 SFP enrichment limit is 4.30 w/o for the VAP fuel design. Thus since theVAP fuel design is more limiting, all calculations performed in this work will model VAP assemblies.

(6.C) KENO Geometry:
The SFP is a large rectangular structure which holds the spent fuel assemblies from the reactors in both units. Borated water fills the SFP and completely covers the spent fuel assemblies. The SFP is constructed of reinforced concrete and is lined with a stainless steel plate which serves as a leakage barrier. A dividing wall separates the SFP, with the north half being associated with Unit-1 and the south half associated with Unit-2. A slot in the dividing wall has removable gates which allow movement of fuel assemblies between the two halves of the pool. The SFP is located in the Auxiliary Building between the two containment structures.

Each half of the SFP is equipped with vertical spent fuel racks installed on the pool bottom. The fuel rack cells are individual double-walled containers approximately 14 feet long. The inner wall of each cell is made from a 0.06 inch thick sheet of stainless steel formed into a square

cross-section container, indented on the corners, with an inside dimension of 8.56 inches. The outer, or external, wall is also formed from a stainless steel sheet 0.06 inches thick. Plates of borated, neutron absorbing material are inserted between the two walls, in each of the four spaces formed by the indentations in the inner wall. The plates are made of a boron carbide (B_4C) composite material (carborundum) and are 6.5 inches wide by 0.09 inches thick. Each plate contains at least 0.024 grams of boron-10 per square centimeter of plate. Attachments E and G display a single SFP planar and axial storage cell geometry. The spacing between the cells is maintained at 10 3/32 inches, center to center, by external sheets and welded spacers. The boron plate inserts and assembly spacing help maintain the SFP assemblies in a subcritical condition. Units 1-8 in each of the KENO input decks define an assembly seated in a fuel rack cell.

Storage Cell Pitch = 10.09375" (Ref.15)
Storage Cell Inner Dimension = 8.5625" (Ref.15)
Poison Sheet = 6.5" * 0.09" (Ref.15)
Inner Steel Wall = 0.06" (Ref.15)
Outer Steel Wall = 0.06" (Ref.15)

Unit 1: Fuel pin cell (Z1INP.XLS(FUEL))
Unit 2: Guide tube cell (Z1INP.XLS(FUEL))
Unit 3: Storage rack wall section 6.5" * (0.06" SS + 0.09" B_4C + 0.06" SS)
Unit 4: Storage rack wall section (0.06" SS + 0.09" B_4C + 0.06" SS) * 6.5"
Unit 5: Storage rack wall section 1.15125" * 0.12" SS
Unit 6: Storage rack wall section 0.12" * 1.03125" SS
Unit 7: 2 * 2 fuel cell
Unit 8: 14 * 14 assembly in fuel rack cell

During inspection/reconstitution activities in the SFP, assemblies are put on 20.5" spacers (Ref. 25) adjacent to the SFP wall. This process lifts the active fuel region of the affected assembly above the carborundum poison plates (Attachment G) and thus could affect reactivity. Units 11-18 in the KENO input decks define an assembly seated on a rack spacer in a fuel rack cell.

Unit 11: Fuel pin cell on spacer (Z1INP.XLS(FUEL))
Unit 12: Guide tube cell on spacer (Z1INP.XLS(FUEL))
Unit 13: Storage rack wall section 6.5" * (0.06" SS + 0.09" B_4C + 0.06" SS)
Unit 14: Storage rack wall section (0.06" SS + 0.09" B_4C + 0.06" SS) * 6.5"
Unit 15: Storage rack wall section 1.15125" * 0.12" SS
Unit 16: Storage rack wall section 0.12" * 1.03125" SS
Unit 17: 2 * 2 fuel cell on spacer
Unit 18: 14 * 14 assembly on spacer in fuel rack cell

For accident analysis, an assembly dropped across the top of the SFP racks must be modeled. Units 21-24 in the KENO input decks define an assembly in the horizontal position.

Unit 21: Horizontal fuel pin cell (Z1INP.XLS(FUEL))
Unit 22: Horizontal guide tube cell (Z1INP.XLS(FUEL))
Unit 23: Horizontal 2 * 2 fuel cell
Unit 24: Horizontal 14 * 14 assembly

The Unit 1 SFP racks are vertical cells grouped in 6 10x10, 2 8x10, and one 7x10 modules. Units 30-37 in the KENO decks define these arrays. Unit 40 is the entire Unit 1 SFP structure to the outside concrete boundary (Attachment F).

Unit 30:	10x10 array
Unit 31:	8x10 array
Unit 32:	10x8 array
Unit 33:	7x10 array
Unit 34:	10x9 array
Unit 35:	10x1 array on spacers
Unit 36:	7x9 array
Unit 37:	7x1 array on spacers

The SFP is located in the Auxiliary Building between the two containment structures. Designed in two identical sections separated by a 3 1/2 foot thick dividing wall, the pool is constructed of reinforced concrete and lined with 3/16 inch stainless steel. Each half of the pool is 54 feet long, 25 feet wide and approximately 39 feet deep (the floor elevation varies). The SFP walls and floor are 5 1/2 or 6 feet thick, depending on the location.
Unit 40: Unit 1 SFP

A specific listing of the KENO deck structure by case is as follows with units deviating from the above description in parentheses:

KU1A01-KU1A11	Units 1-8
KU1A12	Units 1-8, Unit 9 (10x10 array)
KU1A13-KU1A14	Units 1-7, Units 8-11 (assemblies eccentrically positioned in storage cells), Unit 12 (10x10 array)
KU1B01-KU1B09	Units 1-8
KU1C01-KU1C05	Units 1-8
KU1D01-KU1D11	Units 1-8
KU1D12	Units 1-8, Unit 9 (10x10 array)
KU1D13-KU1D14	Units 1-7, Units 8-11 (assemblies eccentrically positioned in storage cells), Unit 12 (10x10 array)
KU1E01-KU1E04,	Units 1-8, Unit 9 (10x10 array)
KU1F01-KU1F02	Units 1-40
KU1F01-KU1F02	Units 1-18, Unit 20 (10x10 array), Unit 21 (8x10 array), Unit 22(10x8 array), Unit 23 (7x10 array on spacers), Unit 24 (10x10 array on spacers), Unit 30 (Unit 1 SFP)
KU1G03-KU1G04	Units 1-40
KU1H01-KU1H03	Units 1-40
KU1I01-KU1I03	Units 1-40

Verification that the input geometries are constructed correctly can be seen by an inspection of the KENO generated plots in Attachment H.

(6.D) KENO Parameters
(6.D.1) Maximum runtime is 500 minutes.
(6.D.2) Number of generations is 1010
(6.D.3) Number of particles per generation is 600
(6.D.4) Number of skipped generations is 10
(6.D.5) Per Ref.4, the SFP storage racks should be assumed to be infinite in the lateral dimension or to be surrounded by a water reflector and concrete or structural material as appropriate to the design. The fuel may be assumed to be infinite in the axial dimension, or the effect of a reflector on the top and bottom of the fuel may be evaluated. Thus reflective boundary conditions are modeled on all sides and on top and bottom.

7. TECHNICAL ASSUMPTIONS

The following technical assumptions were utilized in this work:

(7.A) Reference 15 indicates that 0.020 g/cm^2 represents the amount of the original boron remaining after 40 years (original minimum loading was 0.024 g/cm^2). Section 2.1.3.7 of the CCNPP License Renewal Application indicates that CCNPP will perform an analysis to demonstrate that the Carborundum can perform its criticality control function for a 70-year service life. The NRC acknowledged this commitment in NUREG-1705, Section 3.10.2.4. Therefore, a bias is included which accounts for the additional boron that could be lost between 40 and 70 years. In addition, previous criticality calculations (e.g., Ref. 15 p. 29, CA04166 p. 29) have also considered a 10% uncertainty in addition to using the worst-case B-10 loading. Reference 15 indicates that this uncertainty is to account for the experimental variation in boron loss rate measurement.

(7.B) No burnup was credited in these evaluations.

(7.C) No CEA insertion was credited in these evaluations.

(7.D) No shims were modeled in the fuel assemblies. The analyses in Refs.35-37 demonstrate that, with the exception of Westinghouse IFBA rods, the neutron multiplication factor for an assembly without Integral Burnable Absorbers (IBAs) is always greater (throughout burnup) than the k-eff for an assembly with IBAs, including UO_2-Gd_2O_3, UO_2-Er_2O_3, and Al_2O_3-B_4C rods.

(7.E) It is assumed that the modeling methodology to be used at CCNPP will be similar to that employed in Ref.8.
(7.E.1) All criticality calculations were run with 1010 generations and 600 neutrons per generation to improve statistics.
(7.E.2) The first ten generations are omitted when calculating the average eigenvalue of the system.
(7.E.3) The default value was used for the start option of flat neutron distribution.
(7.E.4) No albedo boundary conditions were applied.
(7.E.5) No neutron biasing in the water reflection region was used.
(7.E.6) Structural components such as control and safety rod guides, support angles and channels, and tanks were neglected. This is conservative, since they are parasitic neutron absorbers.
(7,E.7) Trace chemical elements were neglected.
(7.E.8) The 44 group ENDF-B/V cross section library is utilized.

(7.F) This work does not address encapsulated fuel stored in assembly guide tubes, which would increase total reactivity. Thus encapsulated fuel can not be stored in the guide tubes of fuel assemblies stored in the Unit 1 Spent Fuel Pool. Encapsulated fuel can be stored in empty grid cages in the Unit 1 Spent Fuel Pool, since that would constitute a decrease in reactivity.

(7.G) The most reactive fuel type, 5.0 w/o VAP fuel, is modeled.

(7.H) U234 and U236 are conservatively not modeled in the fuel pellet.

(7.I) Per Refs.33 and 34, the Technical Specification Refueling Boron Concentration is greater than 2150 ppm. 2000 ppm will be conservatively used in this work.

(7.J) Per Refs.33 and 34, the Refueling Boron Concentration uncertainty is 7.5%. 15% will conservatively assumed in this work.

8. REFERENCES

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(3) "Review and Acceptance of Spent Fuel Storage and Handling Applications", B.K.Grimes (NRC) to All Power Reactor Licensees, 4/14/78

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(21) "Standard Composition Library", NUREG/CR-0200 Rev.6 Volume 3 Section M8

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(23) "Auxiliary Building SFP Liner Plan and Sections Sheet 1", BGE Drawing 61-706-E Rev.18.

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(27) "Guide Tube Assembly Details", BGE Drawing E-STD-701-303 Rev.5.

(28) "Reanalysis of Calvert Cliffs Unit 1 Spent Fuel Pool Criticality Calculations", ABB/CE Calculation A-CC1-FE-0005 Rev.0, 4/14/92.

(29) "Spent Fuel Pool Enrichment Limit with Value Added Pellets", CA04662.

(30) "Criticality Analysis for Units 1 and 2 Spent Fuel Pools", CA04166.

(31) "Westinghouse Spent Fuel Rack Criticality Analysis Methodology", WCAP-14416-NP-A. Rev.1

(32) "Separation Distance to Neutronically Decouple Fresh Fuel Assemblies in the Spent Fuel Pool", P.F.O'Donnell to P.H.Gavin, CC-FE-0130 Rev.0, 3/5/98.

(33) "Unit 1 Cycle 15 Technical Data Book", NEOP-13 Rev.14.

(34) "Unit 2 Cycle 14 Technical Data Book", NEOP-23 Rev.14.

(35) "Study of the Effect of Integral Burnable Absorbers for PWR Burnup Credit", NUREG/CR-6760, ORNL/TM-2000-321, March 200.

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(37) "Cross Section Generation for 2.00 w/o Erbia Pins for VAP Using ENDF/B-VI Library", CA04732.

9. METHOD OF ANALYSIS

(9.A) Calculational Methodology
The SCALE 4.4 CSAS25 code module (Ref.9) with the 44 group ENDF/B-V cross section library was utilized in this work to perform the KENO criticality calculations. CSAS25 uses the SCALE Material Information Process (MIP) and the associated material composition library to calculate material number densities, to prepare geometry data for resonance self-shielding, and to create data input files for the cross section processing codes, BONAMI and NITAWL-II. The CSAS25 sequence then invokes the KENO-Va Monte Carlo criticality code.

(9.B) Calculation of Biases and Uncertainties:
Per Ref.3, the analysis methods and neutron cross-section data shall be benchmarked by comparison with critical experiment data for similar configurations. The benchmarking process should establish a calculational bias and uncertainty of the mean with a one-sided tolerance factor of 95% probability at a 95% confidence level. The maximum k-eff value for the SFP shall be obtained by summing the calculated value, the calculational bias, the total uncertainty defined as a statistical combination of the calculational and mechanical uncertainties, and the burnup axial distribution bias. A bias that reduces the calculated value of k-eff should not be applied. Mechanical and material uncertainties may be treated by assuming worst case conditions or by performing sensitivity studies and obtaining worst case uncertainties. Uncertainties may be combined statistically provided that they are independent variations.

(9.B.1) Methodology Bias and Uncertainty
The SCALE 4.4 nuclear analysis software package (Ref.9) was verified on a dedicated CCNPP computer (Ref.7). The Ref.8 calculation package documented the validation of SCALE 4.4 for Light-Water Reactor (LWR) fuel criticality analysis.

Criticality safety standards ANSI/ANS-8.1 (Ref.10) and ANSI/ANS-8.17 (Ref.11) apply to criticality methods validation and to criticality evaluations, respectively. ANSI/ANS-8.1 requires that a validation be performed on the method used to calculate criticality safety margins. The validation shall be documented in a written report describing the method, computer program and cross section libraries used, the experimental data, the areas of applicability and the bias and margins of safety. ANSI/ANS-8.17 prescribes the criteria to establish sub-criticality safety margins.

The USNRC has issued NUREG/CR-6361, "Criticality Benchmark Guide for Light-Water-Reactor Fuel in Transportation and Storage Packages" (Ref.12). This guide provides documentation for 180 criticality experiments with geometries, materials, and neutron interaction characteristics representative of LWR fuel in core, storage and cask arrangements. NUREG/CR-6361 was used as design input and as the primary reference for the validation calculation package.

The objective of the Ref.8 calculation package was to satisfy the intent of ANSI/ANS-8.1 (Ref.10) with respect to LWR fuel criticality evaluations in reactor core, spent fuel rack, and cask environments and to satisfy the intent of ANSI/ANS-8.17 (Ref.11) with respect to a determination of the bias and uncertainty in the bias. The Ref.8 calculation package validates the SCALE 4.4 code package (Ref.9) with the 44 neutron energy group ENDF/B-V based cross section library for use in light-water-reactor (LWR) type fuel criticality evaluations. Estimates are made for the bias, uncertainty in the bias and trending with important physical parameters.

Criticality evaluations were performed with the CSAS25 sequence of the SCALE 4.4 code package and with the 44 neutron energy group ENDF/B-V based cross section library. CSAS25 uses the SCALE Material Information Process (MIP) and the associated material composition library to calculate material number densities, to prepare geometry data for resonance self-shielding and to create data input files for the cross section processing codes. The BONAMI and NITAWL-II codes are then used to perform problem dependent cross section processing and resonance correction. The CSAS25 sequence then invokes the KENO-V.a Monte Carlo criticality code. KENO-Va is capable of modeling each critical experiment in three dimensions including explicit representation of the fuel rod array and any associated water or metal reflector regions.

Statistical evaluations included calculating the range of calculated k-eff, the mean k-eff, standard deviation of the mean, bias, 95/95 uncertainty in the bias, and the average Monte Carlo error for the whole group of experiments as well as categories within a data base. Trending of k-eff with physical parameters, i.e. fuel rod pitch, fuel enrichment, moderator to fuel ratio, soluble boron concentration, assembly separation, and average energy group causing fission, was evaluated by creating scatter plots k-eff versus each physical parameter and then performing linear regression on the data. The strength of a trend was evaluated by the magnitude of the correlation coefficient from the linear regression.

In addition, the validation results were organized into three groupings: reactor core type experiments, storage rack type experiments and cask type experiments. For each of these groupings, a bias and 95/95 uncertainty is also specified for use in criticality safety evaluations. The bias and 95/95 uncertainty statistics are determined as follows. For any group or category of k-eff results, the bias is defined as $\beta = \langle k\text{-eff}\rangle - 1$ where <k-eff> is the average for the category or group of critical experiments. According to this definition of bias, the bias is negative if $k < 1$ and positive if $k > 1$. ANSI/ANS-8.17 (Ref.11) requires that the total uncertainty in the mean k-eff or equivalently the bias should include uncertainties for the computation of <k-eff>, the statistical convergence (Monte Carlo error) in computed k-eff and experimental uncertainty. Thus, the total uncertainty in the bias is the square root of the pooled variance of the variance in <k-eff> (σ_{keff}^2) plus the average Monte Carlo variance of the category of critical experiments (σ_{mc}^2) plus the average variance of the experimental uncertainty (σ_{exp}^2), i.e.,

$$\sigma_\beta = \mathrm{sqrt}(\sigma_{keff}^2 + \sigma_{mc}^2 + \sigma_{exp}^2)$$

The average Monte Carlo variance is approximately $(0.0017)^2$ in these criticality evaluations. NUREG/CR-6361 (Ref.12) does not provide an estimate of experimental uncertainty, but the International Handbook of Evaluated Criticality Safety Benchmark Experiments, Volume IV, Ref.13 provides extensive analysis of the experimental uncertainty associated with the benchmark experiments referenced in NUREG/CR-6361 as well as others. Review of the experimental uncertainties associated with the LWR type critical experiments provides an average experimental uncertainty of ±0.0024. Per Ref.8, σ_{keff} is 0.0035 for the storage rack type experiments. Thus, the total uncertainty in the bias becomes:

$$\sigma_\beta = \mathrm{sqrt}(\ 0.0017^2 + 0.0024^2 + 0.0035^2)$$

The 95/95 uncertainty in the bias is the standard deviation, σ_β, times one-sided 95% confidence factor from a Student "t" distribution with n-2 degrees of freedom or:

$$\sigma_{95/95} = t_{05} * \sigma_\beta$$

where n is the number of k_{eff} results in the category or group of critical experiment. For large samples, t_{05} approaches 1.645 (Ref.14).

The storage rack type category combines the results for the 123 critical experiments including the results for the core-type, separator plate, separator plate-soluble boron, and flux trap-void experiments but excluding the reflector wall categories. The storage rack type category exhibits a bias of -0.0008 and a 95/95 one sided uncertainty of 0.0076.

A histogram for the frequency of k-eff values shows a tight clustering of k-eff values near k-eff = 1 and a near normal distribution. Scatter plots were constructed of k-eff versus fuel rod pitch, k-eff versus fuel enrichment, k-eff versus H_2O/fuel volume ratio, k-eff versus $H/^{235}U$ atom ratio, k-eff versus soluble boron concentration, k-eff versus assembly separation, and k-eff versus average group of fission, respectively. Also included in each plot is the associated regression line and equation with correlation coefficient. Review of these plots indicates all the trend lines are nearly horizontal with very small correlation coefficients. Thus, there are no significant trends indicated.

(9.B.2) Temperature Bias
Per Ref.4, the evaluation of normal storage should be done at the temperature (water density) corresponding to the highest reactivity. In poisoned racks, the highest reactivity will usually occur at a water density of 1.0000 (i.e., at 4°C or 40°F or 277.15°K). However, if the temperature coefficient of reactivity is positive, the evaluation should be done at the highest temperature expected during normal operation: i.e., equilibrium temperature under normal refueling conditions (including full-core offload), with one coolant train out of service and the pool filled with spent fuel from previous reloads. Per UFSAR 9.4.1, in the event that any one loop is lost, the remaining two loops (either two SFPC loops or one SFPC loop and one SDC loop) can continue to maintain the pool temperature at or below 155°F (68°C or 341.48°K @ 0.9785 gm/cc per Ref. 16) for 1830 fuel assemblies in the SFP including a full core offload.

(9.B.3) Storage Cell Pitch Uncertainty
Per Ref.4, mechanical and material uncertainties may be treated by assuming worst case conditions or by performing sensitivity studies and obtaining worst case uncertainties. Per Ref.15, the mechanical design of the fuel racks is such that the average pitch between boxes is maintained by structural members at 10.09375 ± 0.03125 inches. Thus a nominal pitch of 10.09375 inches will be assumed, and an uncertainty value to ± 0.03125 inches will be included in the mechanical and material uncertainty value. See Attachment E.

(9.B.4) Stack Height Density Uncertainty
Per Ref.4, mechanical and material uncertainties may be treated by assuming worst case conditions or by performing sensitivity studies and obtaining worst case uncertainties. Per UFSAR Tables 3.3-1 and 3.3-2, the maximum stack height density is 10.31 gm/cc (<94.5% theoretical density). Per Ref.5 for standard fuel pellets, the stack height density can range between 93.5% and 96.0% of theoretical density, while per Ref.6 for value added fuel pellets, the stack height density can range between 94.0% and 96.5% of theoretical density. Thus a nominal stack height density of 94.5% of theoretical density will be assumed, and an uncertainty value to 96.5% of theoretical density will be included in the mechanical and material uncertainty value.

(9.B.5) Enrichment Uncertainty
Per Ref.4, mechanical uncertainties may be treated by assuming worst case conditions or by performing sensitivity studies and obtaining worst case uncertainties. Per 10 CFR 50.68 (Ref.2), the maximum nominal U-235 enrichment of the fresh fuel assemblies is limited to five percent by weight. Thus, the assumption of 5.0 w/o fresh fuel is a worst case condition.

(9.B.6) Steel Thickness Uncertainty
Per Ref.4, mechanical and material uncertainties may be treated by assuming worst case conditions or by performing sensitivity studies and obtaining worst case uncertainties. Per Ref.15, the mechanical design of the fuel racks is such that the average wall thickness is 0.060 ± 0.010 inches. Thus a nominal wall thickness of 0.060 inches will be assumed, and an uncertainty value to ± 0.010 inches will be included in the mechanical and material uncertainty value. See Attachment E.

(9.B.7) Poison Loading Uncertainty
Ref. 15 indicates that 0.020 g/cm^2 represents the amount of the original boron remaining after 40 years (original minimum loading was 0.024 g/cm^2). Section 2.1.3.7 of the CCNPP License Renewal Application indicates that CCNPP will perform an analysis to demonstrate that the Carborundum can perform its criticality control function for a 70-year service life. The NRC acknowledged this commitment in NUREG-1705, Section 3.10.2.4. Therefore, it was necessary to accounts for the additional boron that could be lost between 40 and 70 years. In addition, previous criticality calculations (Ref.15 p.29, CA04166 p.29) have also considered a 10% uncertainty in addition to using the worst-case B-10 loading. Ref.15 indicates that this uncertainty is to account for the experimental variation in boron loss rate measurement.

Ref. 15 indicates that a B-10 loading of 0.02 g/cm^2 represents a 15% loss over 40 years. Extrapolating this loss rate to 70 years yields (with the implicit assumption that the rate remains constant) a B-10 loading of 0.0177 g/cm^2 (0.024 – 70/40*0.15*0.024) and 0.01593 g/cm^2 for the 10% uncertainty case. Substituting this loading on the Densities sheet of the z1inp.xls spreadsheet yields a B_4C Density Fraction of 0.213007 for the nominal 40-70 yr case, and 0.191706 for the 10% uncertainty case. This value was substituted as the volume fraction for material 5 (B_4C) in the 0 and 300 ppm cases with the highest k_{eff} (KU1A02 and KU1D03). A 40-70 yr bias (LX cases) of 0.00466 is indicated for the 0 ppm case, and 0.00504 is indicated for the 300 ppm case. An uncertainty (LXu cases) of 0.00607 is indicated for the 0 ppm case, and 0.00466 is indicated for the 300 ppm case.

(9.B.8) Eccentric Positioning Uncertainty
Per Ref.4, mechanical uncertainties may be treated by assuming worst case conditions or by performing sensitivity studies and obtaining worst case uncertainties. It is possible for a fuel assembly not to be positioned centrally within a storage cell , because of clearance between the assembly and the cell wall. Calculations will be performed to determine the effects of eccentrically located fuel. It will be assumed that the fuel assemblies will be displaced diagonally within their storage cells as far as possible towards and away from each other. This will generate an uncertainty value, which will be included in the mechanical and material uncertainty value. See Attachment E.

(9.B.9) Clad Composition Uncertainty
Per Ref.4, mechanical uncertainties may be treated by assuming worst case conditions or by performing sensitivity studies and obtaining worst case uncertainties. Current fuel pin clad composition includes both zirlo and optin (Refs.17-18). The SFP reactivity with zirlo, optin, and zirc4 cladding will be determined, and the most reactive will be utilized in this work.

(9.B.10) Fuel Depletion Uncertainty
No burnup credit assumed for the Unit 1 SFP.

(9.B.11) Axial Distribution Burnup Bias
No burnup credit assumed for the Unit 1 SFP.

(9.C) Calculations

(9.C.1) The k-effective of an infinite radial and axial array of 5 w/o enriched fuel at 0 ppm soluble boron will be calculated to determine compliance with 10 CFR 50.68.

(9.C.2) The k-effective of an infinite radial and axial array of 5 w/o enriched fuel as a function of soluble boron will be calculated to determine the minimum required boron concentration to be in compliance with 10 CFR 50.68.

(9.C.3) The k-effective of an infinite radial and axial array of fuel at 0 ppm soluble boron will be calculated as a function of enrichment for comparison with previously determined enrichment limits as determined via Ref.29.

(9.C.4) Biases and uncertainties will be determined at the unborated and borated moderator conditions, and the most conservative value will be used.

(9.C.5) The k-effective values of an infinite array of 10x10 storage modules containing 5.0 w/o VAP fuel will be calculated for comparison with the infinite radial and axial array of single storage modules containing 5.0 w/o VAP fuel.

(9.C.6) The k-effective values for a finite radial and axial model of the Unit 1 SFP containing 5.0 w/o VAP fuel will be calculated for comparison with the infinite radial and axial array of single storage modules containing 5.0 w/o VAP fuel.

(9.C.7) The k-effective values for a finite radial and axial model of the Unit 1 SFP containing 5.0 w/o VAP fuel will be calculated for reconstitution conditions, where an entire row of assemblies or alternate assemblies in a row are placed on rack spacers.

(9.C.8) The k-effective values for a finite radial and axial model of the Unit 1 SFP containing 5.0 w/o VAP fuel will be calculated for a horizontally dropped assembly atop the fuel racks during normal and reconstitution conditions.

(9.D) Accident Conditions

Per Ref.3, for accident conditions, the following assumptions apply: (i) The double contingency principle of ANSI N 16.1-1975 shall be applied. It shall require two unlikely, independent, concurrent events to produce a criticality accident. (ii) Realistic initial conditions (e.g., the presence of soluble boron) may be assumed. (iii) Accidents shall include dropping of a fuel assembly on top of the racks, abnormal placement of a fuel assembly in the SFP, a cask or heavy object drop onto the SFP racks, effect of tornado or earthquake on the deformation and relative position of the fuel racks, and loss of cooling systems or flow unless single failure proof.

(9.D.1) Fuel Misloading Accident:

Because there is no fuel misloading incident for an infinite array of maximum enrichment fresh fuel, the required soluble boron to maintain K-effective below 0.95 remains unchanged. Thus there are no adverse consequences for a fuel misloading accident in this analysis.

(9.D.2) Abnormal Placement of a Fuel Assembly in the SFP Racks:

The top opening of the SFP racks has angled lead-in guides, which effectively block the spaces between the cavities, as well as guide the fuel assembly into the open tube. Also to avoid the possibility of inadvertently placing a fuel assembly between the outermost storage cell and the pool wall, the top rack surface is extended to cover this space. Thus the abnormal placement of a fuel assembly in the SFP racks is not a credible event.

(9.D.3) Horizontal Assembly Drop Accident:

Dropping an assembly on top of the SFP racks from the Spent Fuel Handling Machine (SFHM) is not possible at CCNPP due to the design of the SFHM and due to the height of the SFP racks. The bottom of the outer mast assembly is at elevation 49'5", while the top of the SFP racks is at elevation 45'0". While not a credible accident, this accident will be explicitly analyzed in Section 9.C.8 of this work.

Dropping an assembly on top of the SFP racks from the Cask Handling Crane (CHC) or the New Fuel Elevator (NFE) is also not a credible accident. The CHC is designed in accordance with the single-failure proof criteria of NUREG-0554 and NUREG-0612 and is used to move assemblies into the new fuel elevator. The NFE is utilized to lower new fuel from the operating floor to the bottom of the SFP, where it is then grappled by the Spent Fuel Handling Machine. The elevator is powered by a cable winch, and the assembly is contained in a simple support structure whose wheels are captured on two rails. Dropping an assembly from the NFE would require a catastrophic failure of the NFE, which is not a credible event and which has never occurred to date.

Per Ref.4, the double contingency principle shall be applied. It shall require two unlikely, independent, concurrent events to produce a criticality accident. The double-contingency principle means that realistic conditions may be assumed. For example, if soluble boron is normally present in the SFP water, the loss of soluble boron is considered as one accident condition and a second concurrent accident need not be assumed. Therefore, total credit for the presence of soluble boron may be assumed in evaluating this accident condition.

(9.D.4) Vertical Assembly Drop Accident:
Dropping an assembly vertically will not cause abnormal placement of a fuel assembly in the SFP racks since the top opening of the SFP racks has angled lead-in guides, which effectively block the spaces between the cavities, as well as guide the fuel assembly into the open tube. Also to avoid the possibility of inadvertently dropping a fuel assembly between the outermost storage cell and the pool wall, the top rack surface is extended to cover this space. Dropping an assembly and having it stand upright atop another assembly in the SFP racks is less limiting than the current analysis, which assumes infinite axial extent. Thus there are no adverse consequences for a vertical assembly drop accident in this analysis.

(9.D.5) Cask or Heavy Object Drop onto the SFP Racks:
The racks are designed to withstand all anticipated loadings. Structural deformations are limited to preclude any possibility of criticality. The Seismic Category 1 racks are supported in such a manner as to preclude a reduction in separation under either the Operating Basis or Safe Shutdown Earthquake. The racks are designed not to collapse or bow under the force of a fuel assembly dropped into an empty cavity or dropped horizontally across the top of the racks assuming no drag resistance from the water. Heavy loads in excess of 1600 lbs are prohibited from travel over spent fuel assemblies in the SFP unless such loads are handled by a single-failure proof device. The Spent Fuel Cask Handling Crane, which is designed in accordance with the single-failure proof criteria of NURE-0554 and NUREG-0612, is used to handle heavy loads in the SFP area. Thus the cask or heavy object drop accident is not a credible event.

(9.D.6) Boron Dilution Accident:
This proposed criticality design basis for the SFP racks assumes that the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity will not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with borated water, and the k-effective will remain below 0.986 (subcritical) at a 95% probability, 95% confidence level, if completely flooded with unborated water. Dilution events that have the potential to dilute the SFP boron concentration to a value less than the minimum required are not credible events based on existing level alarms and the stored inventory of demineralized water in the systems interfacing with the SFP. Even in the unlikely event that the SFP is completely diluted of boron, the SFP will remain subcritical by a design margin of k-eff not to exceed 0.986. Thus boron dilution to less than the required minimum is not a credible event; however, in the unlikely event of complete dilution, no adverse consequences would result.

(9.D.7) Loss of Coolant Accident:
The most serious failure to the system is the loss of SFP water. This is avoided by routing all SFP piping connections above the water level and providing them with siphon breakers to prevent gravity drainage (UFSAR 9.4.4).

The SFP is designed to preclude the loss of structural integrity. The SFP is designed in two identical sections separated by a 3 1/2 foot thick dividing wall, the pool is constructed of reinforced concrete and lined with 3/16 inch stainless steel. Each half of the pool is 54 feet long, 25 feet wide and approximately 39 feet deep (the floor elevation varies). The SFP walls and floor are 5 1/2 or 6 feet thick, depending on the location.

Even with the precautions described, small leaks may still occur in the SFP. Early detection of pool leakage and prompt replacement of water is essential. Early leakage detection is assured by a surveillance which requires that the minimum pool level be verified at least once every 7 days. In practice, level is checked one every 12 hours as required by the Auxiliary Building log sheets. In addition, a level alarm keeps the Control Room Operator aware of level changes. PEO 0-067-02-O-M (SFP Leakage Test) requires a regular check for leakage, as well.

(9.D.8) Loss of Cooling Accident:
The design of the SFP Cooling System and pool structural components (e.g., pool liner plate, SFPC piping and pumps) for total loss of cooling is not part of the system's design basis (UFSAR 9.4.4). The entire Spent Fuel Pool Cooling System is tornado-protected and is located in a Seismic Category I structure.

(9.D.9) Natural Phenomena Incident:
The racks are designed to withstand all anticipated loadings. Structural deformations are limited to preclude any possibility of criticality. The Seismic Category 1 racks are supported in such a manner as to preclude a reduction in separation under either the Operating Basis or Safe Shutdown Earthquake.

Since there has been no record of tsunamis on the northeastern United States coast, it is not believed that the site will be subjected to a significant tsunami effect (UFSAR 2.6.6).

The relative frequency of hurricane occurrence for the CCNPP site is slightly more than one hurricane per year. For the Probable Maximum Hurricane (PMH), it is assumed that the peak hurricane surge is coincident with normal high tide and with a 99th percentile wave height. The total predicted wave run-up is to Elevation 27.1', which is considerably less than the 69' elevation of the top of the SFP. Thus the maximum hypothetical flood level is below the top of the SFP elevation (UFSAR 2.8.3).

Missiles generated externally to the plant could be from high winds (tornadoes or hurricanes). Missiles generated internally to the plant could be from the malfunction or structural failure of plant equipment, such as the turbine generator. Internal and external missile protection is provided by the 6 foot thick SFP walls. In addition, a 2 foot thick concrete missile barrier positioned at the 118-foot elevation protects the SFP from a high trajectory missile generated by a turbine overspeed incident.

10. CALCULATIONS

A list of all of the KENO calculations is included in Attachment A.

(1) Cases KU1A01-KU1A06 model an unborated infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of temperature (40°F and 155°F) and as a function of fuel clad material (zirlo, optin, and zirc4).

(2) Cases KU1A02 and KU1A07 model an unborated infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of stack height density (0.945 and 0.965) at the worst case temperature of 40°F for a fuel clad material composed of optin.

(3) Cases KU1A02, KU1A08, and KU1A09 model an unborated infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell pitch (10.0625, 10.09375, and 10.125 in) at the worst case temperature of 40°F for a fuel clad material composed of optin.

(4) Cases KU1A02, KU1A10, and KU1A11 model an unborated infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell steel thickness (0.1270, 0.1524, and 0.1778 cm) at the worst case temperature of 40°F for a fuel clad material composed of optin.

(5) Case KU1A12 models an unborated infinite axial and radial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of optin. The purpose of this case is to verify that thc reactivity of the infinite axial and radial array of 10x10 storage cells in KU1A12 is equivalent to the infinite axial and radial array of single storage cells in KU1A02.

(6) Cases KU1A13 and KU1A14 model an unborated infinite axial and radial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of eccentric positioning within the storage cell at the worst case temperature of 40°F for a fuel clad material composed of optin.

(7) Cases KU1B01-KU1B09 model an unborated infinite axial and radial array of storage cells of nominal dimensions as a function of fuel enrichment (4.9 to 4.1 w/o) at the worst case temperature of 40°F for a fuel clad material composed of optin. The purpose of these calculations is to show consistency with the previous design basis calculations to determine maximum enrichment with VAP fuel.

(8) Cases KU1C01-KU1C05 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of soluble boron (100 to 500 ppm) at the worst case temperature of 40°F for a fuel clad material composed of optin. The purpose of these calculations is to determine the minimum boron concentration required to achieve 0.95 k-effective.

(9) Cases KU1D01-KU1D06 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of temperature (40°F and 155°F) and as a function of fuel clad material (zirlo, optin, and zirc4) at the worst case soluble boron concentration of 300 ppm.

(10) Cases KU1D03 and KU1D07 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of stack height density (0.945 and 0.965) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm.

(11) Cases KU1D03, KU1D08, and KU1D09 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell pitch (10.0625, 10.09375, and 10.125 in) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm.

(12) Cases KU1D03, KU1D10, and KU1D11 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell steel thickness (0.1270, 0.1524, and 0.1778 cm) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm.

(13) Case KU1D12 models an infinite axial and radial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. The purpose of this case is to verify that the reactivity of the infinite axial and radial array of 10x10 storage cells in KU1D12 is equivalent to the infinite axial and radial array of single storage cells in KU1D03.

(14) Cases KU1D13 and KU1D14 model an infinite axial and radial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of eccentric positioning within the storage cell at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm.

(15) Cases KU1E01 and KU1E03 model an infinite radial but finite axial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of upper and lower end fitting composition (unborated water, smeared composition) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm.

(16) Cases KU1E02 and KU1E04 model an unborated infinite radial but finite axial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of upper and lower end fitting composition (unborated water, smeared composition) at the worst case temperature of 40°F for a fuel clad material composed of optin.

(17) Case KU1F01 models a finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. The purpose of this calculation is to determine the amount of conservatism inherent in an infinite versus finite SFP model.

(18) Case KU1F02 models an unborated finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of optin. The purpose of this calculation is to determine the amount of conservatism inherent in an infinite versus finite SFP model.

(19) Cases KU1G01 and KU1G03 model a finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. KU1G01 models the reconstitution of alternate assemblies in the row closest to the SFP wall. KU1G03 models the reconstitution of all of the assemblies in the row closest to the SFP wall.

(20) Cases KU1G02 and KU1G04 model an unborated finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of optin. KU1G02 models the reconstitution of alternate assemblies in the row closest to the SFP wall. KU1G04 models the reconstitution of all of the assemblies in the row closest to the SFP wall.

(21) Cases KU1H01-KU1H03 model a finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F as a function of soluble boron concentration (300, 0, 2000 ppm) for the dropped assembly accident.

(22) Cases KU1I01-KU1I03 model a finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F as a function of soluble boron concentration (300, 0, 2000 ppm) for the dropped assembly accident and assuming reconstitution of all of the assemblies in the row closest to the SFP wall.

(23) Cases KU1A02LX and KU1A02LXu model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell B_{10} density (0.0177 gm/cm^2 B_{10} and 0.01593 gm/cm^2 B_{10}) at the worst case temperature of 40°F for a fuel clad material composed of optin at a soluble boron concentration of 0 ppm.

(24) Cases KU1D03LX and KU1D03LXu model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell B_{10} density (0.0177 gm/cm^2 B_{10} and 0.01593 gm/cm^2 B_{10}) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at a soluble boron concentration of 300 ppm.

Additional input calculations and result compilations were performed manually in the Excel spreadsheet X1inp.xls.

11. DOCUMENTATION OF COMPUTER CODES

Per Ref.4, acceptable computer codes for criticality applications include, but are not necessarily limited to the following: NITAWL-KENO5a.

This work employs KENO.Va, a functional module in the SCALE system, and the Criticality Safety Analysis Sequence Number 25 (CSAS25) to calculate the k-effective of a three-dimensional system (Ref.9). CSAS25 uses the SCALE Material Information Process (MIP) and the associated material composition library to calculate material number densities, to prepare geometry data for resonance self-shielding, and to create data input files for the cross section processing codes, BONAMI, NITAWL-II, and XSDRNPM. BONAMI performs resonance self-shielding calculations for nuclides that have Bondarenko data associated with their cross sections. NITAWL-II applies a Nordheim resonance self-shielding correction to nuclides having resonance parameters. XSDRNPM provides cell-weighted cross sections based on the specified unit cell and can calculate k-effective for a one-dimensional system. The CSAS25 sequence then invokes the KENO-Va Monte Carlo criticality code.

Ref. 7 constitutes a verification that the computer codes of SCALE 4.4 have been successfully installed on the NEU computer PCB386 with the Windows NT operating system and with a PENTIUM II XEON processor. SCALE 4.4 includes the codes CSAS, SAS1, SAS2H, SAS3, SAS4, QADS, HTAS1, ARP, and CSAS6, which codes calculate nuclear criticality, source term, radiation shielding, heat transfer, and cross section processing.

The SCALE 4.4 CSAS module with the 44 group ENDF/B-V cross section library for criticality safety evaluations of LWR fuel in spent fuel rack, in-core, and cask type environments is validated in Ref.8 via comparison of the computational CSAS outputs with the 180 criticality experiments documented in Ref.12. The validation is performed in compliance with the standards of ANSI/ANS-8.1 (Ref.10) and ANSI/ANS-8.17 (Ref.11). ANSI/ANS-8.1 requires that a validation be performed on the method used to calculate criticality safety margins. The validation shall be documented in a written report describing the method, computer program, and cross section libraries used, the experimental data, the areas of applicability, the uncertainties and biases, and the margins of safety. ANSI/ANS-8.17 prescribes the criteria to establish sub-criticality safety margins.

Additional input calculations and result compilations were performed manually in the Excel spreadsheet X1inp.xls.

12. RESULTS

The results of the reactivity calculations are documented in Attachment B.

(12.A.1) Cases KU1A01-KU1A06 model an unborated infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of temperature (40°F and 155°F) and as a function of fuel clad material (zirlo, optin, and zirc4). Case KU1A02 is the most reactive condition at 40°F and for optin fuel clad. This worst case condition will be assumed in all unborated calculations.

(12.A.2) Cases KU1A02 and KU1A07 model an unborated infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of stack height density (0.945 and 0.965) at the worst case temperature of 40°F for a fuel clad material composed of optin. The reactivity difference results in a 0.00417 Δk-effective uncertainty.

(12.A.3) Cases KU1A02, KU1A08, and KU1A09 model an unborated infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell pitch (10.0625, 10.09375, and 10.125 in) at the worst case temperature of 40°F for a fuel clad material composed of optin. A storage cell pitch (Case KU1A09) of 10.0625 in results in the highest reactivity value. The reactivity difference results in a 0.00575 Δk-effective uncertainty.

(12.A.4) Cases KU1A02, KU1A10, and KU1A11 model an unborated infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell steel thickness (0.1270, 0.1524, and 0.1778 cm) at the worst case temperature of 40°F for a fuel clad material composed of optin. A storage cell steel thickness (Case KU1A11) of 0.1778 cm results in the highest reactivity value. The reactivity difference results in a 0.00569 Δk-effective uncertainty.

(12.A.5) Case KU1A12 models an unborated infinite axial and radial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of optin. The purpose of this case is to verify that the reactivity of the infinite axial and radial array of 10x10 storage cells in KU1A12 is equivalent to the infinite axial and radial array of single storage cells in KU1A02. The resultant k-effective values are well within the error margins of the calculations: 0.96623±0.00113 for Case KU1A02 versus 0.96643±0.00109 for Case KU1A12.

(12.A.6) Cases KU1A13 and KU1A14 model an unborated infinite axial and radial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of eccentric positioning within the storage cell at the worst case temperature of 40°F for a fuel clad material composed of optin. An eccentric positioning which maximizes the distance between assemblies (Case KU1A14) results in the highest reactivity value. The reactivity difference results in a 0.00249 Δk-effective uncertainty.

(12.A.7) The above uncertainty values are combined with the Methodology Bias and Uncertainty of Section 9.B.1 and with the maximum calculated Δk-effective to yield a total bias and uncertainty value of 0.01229 for the unborated moderator condition at the worst case temperature of 40°F for a fuel clad material composed of optin. Note that the total uncertainty value is the square-root of the sum of the squares of the individual uncertainty values.

(12.A.8) The total bias and uncertainty is added to the k-effective value from Case KU1A02 to obtain the maximum unborated k-effective value of 0.97852, which is less than the 10 CFR 50.68 regulatory value of 1.0. (If credit is taken for soluble boron, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with borated water, and the k-effective must remain below 1.0 (subcritical) at a 95% probability, 95% confidence level, if flooded with unborated water.)

(12.B.1) Cases KU1B01-KU1B09 model an unborated infinite axial and radial array of storage cells of nominal dimensions as a function of fuel enrichment (4.9 to 4.1 w/o) at the worst case temperature of 40°F for a fuel clad material composed of optin. The purpose of these calculations is to show consistency with the previous design basis calculations to determine maximum enrichment with VAP fuel. Ref.29 determined the maximum fresh fuel enrichment with VAP fuel with the present storage configuration, such that, K-effective is less than 0.95 with uncertainties and biases and assuming no soluble boron credit. Per Ref.29, VAP fuel with enrichments less than or equal to 4.30 w/o U-235 can now be safely stored in the CCNPP Spent Fuel Pools. The corresponding value from this work is 4.26 w/o U-235 VAP fuel assuming a 40 year life carborundum value.

(12.C.1) Cases KU1C01-KU1C05 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of soluble boron (100 to 500 ppm) at the worst case temperature of 40°F for a fuel clad material composed of optin. The purpose of these calculations is to determine the minimum boron concentration required to achieve 0.95 k-effective with biases and uncertainties. The total bias and uncertainty is added to the k-effective value from Case KU1C03 to obtain the maximum k-effective value at 300 ppm soluble boron of 0.93943, which is less than the 10 CFR 50.68 regulatory value of 0.95. (If credit is taken for soluble boron, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with borated water, and the k-effective must remain below 1.0 (subcritical) at a 95% probability, 95% confidence level, if flooded with unborated water.)

(12.D.1) Cases KU1D01-KU1D06 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of temperature (40°F and 155°F) and as a function of fuel clad material (zirlo, optin, and zirc4) at the worst case soluble boron concentration of 300 ppm. Case KU1D03 is the most reactive condition at 40°F and for zirc4 fuel clad. This worst case condition will be assumed in all borated calculations.

(12.D.2) Cases KU1D03 and KU1D07 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of stack height density (0.945 and 0.965) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. The reactivity difference results in a 0.00173 Δk-effective uncertainty.

(12.D.3) Cases KU1D03, KU1D08, and KU1D09 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell pitch (10.0625, 10.09375, and 10.125 in) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. A storage cell pitch (Case KU1D09) of 10.0625 in results in the highest reactivity value. The reactivity difference results in a 0.00450 Δk-effective uncertainty.

(12.D.4) Cases KU1D03, KU1D10, and KU1D11 model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell steel thickness (0.1270, 0.1524, and 0.1778 cm) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. A storage cell steel thickness (Case KU1D11) of 0.1778 cm results in the highest reactivity value. The reactivity difference results in a 0.00291 Δk-effective uncertainty.

(12.D.5) Case KU1D12 models an infinite axial and radial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. The purpose of this case is to verify that the reactivity of the infinite axial and radial array of 10x10 storage cells in KU1D12 is equivalent to the infinite axial and radial array of single storage cells in KU1D03. The resultant k-effective values are well within the error margins of the calculations: 0.92737±0.00105 for Case KU1D03 versus 0.92726±0.00105 for Case KU1D12.

(12.D.6) Cases KU1D13 and KU1D14 model an infinite axial and radial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of eccentric positioning within the storage cell at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. Note that both cases are less reactive than the nominal case. Thus no uncertainty will be applied for eccentric positioning.

(12.D.7) The above uncertainty values are combined with the Methodology Bias and Uncertainty of Section 9.B.1 and with the maximum calculated Δk-effective to yield a total bias and uncertainty value of 0.01055 for the borated moderator condition at the worst case temperature of 40°F for a fuel clad material composed of zirc4. Note that the total uncertainty value is the square-root of the sum of the squares of the individual uncertainty values. Also note that since the uncertainties and biases for the unborated condition exceed those for the borated condition, the unborated biases and uncertainties will conservatively be applied in all calculations.

(12.D.8) The total bias and uncertainty is added to the k-effective value from Case KU1D03 to obtain the maximum borated k-effective value of 0.93966, which is less than the 10 CFR 50.68 regulatory value of 0.95. (If credit is taken for soluble boron, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with borated water, and the k-effective must remain below 1.0 (subcritical) at a 95% probability, 95% confidence level, if flooded with unborated water.)

(12.E.1) Cases KU1E01 and KU1E03 model an infinite radial but finite axial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of upper and lower end fitting composition (unborated water, smeared composition) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. The 0.93696 k-effective of Case KU1E03 (smeared UEF and LEF) exceeds the 0.93568 k-effective of Case KU1E01 (unborated water in lieu of UEF and LEF); however, both are less than the 0.93955 k-effective of the infinite axial case KU1D12.

(12.E.2) Cases KU1E02 and KU1E04 model an unborated infinite radial but finite axial array of 10x10 storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of upper and lower end fitting composition (unborated water, smeared composition) at the worst case temperature of 40°F for a fuel clad material composed of optin. The 0.97605 k-effective of Case KU1E02 (unborated water in lieu of UEF and LEF) slightly exceeds the 0.97531 k-effective of Case KU1E04 (smeared UEF and LEF); however, both are less than the 0.97872 k-effective of the infinite axial case KU1A12.

(12.F.1) Case KU1F01 models a finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. The purpose of this calculation is to determine the amount of conservatism inherent in an infinite versus finite SFP model. The 0.92835 k-effective value of Case KU1F01 is 1.13% Δk less than the 0.93966 k-effective value of KU1D03.

(12.F.2) Case KU1F02 models an unborated finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of optin. The purpose of this calculation is to determine the amount of conservatism inherent in an infinite versus finite SFP model. The 0.96683 k-effective value of Case KU1F02 is 1.17% Δk less than the 0.97852 k-effective value of KU1A02.

(12.G.1) Cases KU1G01 and KU1G03 model a finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at the worst case soluble boron concentration of 300 ppm. KU1G01 models the reconstitution of alternate assemblies in the row closest to the SFP wall. KU1G03 models the reconstitution of all of the assemblies in the row closest to the SFP wall. The 0.92990 k-effective value of Case KU1G01 is 0.98% Δk less than the 0.93966 k-effective value of KU1D03. The 0.92814 k-effective value of Case KU1G03 is 1.15% Δk less than the 0.93966 k-effective value of KU1D03. Thus sufficient margin exists in going from a two to three dimensional model to counteract any effect of raising a row of assemblies on spacers. In addition, there is no reactivity penalty between reconstituting an entire row of assemblies or alternate assemblies in a row.

(12.G.2) Cases KU1G02 and KU1G04 model an unborated finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F for a fuel clad material composed of optin. KU1G02 models the reconstitution of alternate assemblies in the row closest to the SFP wall. KU1G04 models the reconstitution of all of the assemblies in the row closest to the SFP wall. The 0.96661 k-effective value of Case KU1G02 is 1.19% Δk less than the 0.97852 k-effective value of KU1A02. The 0.96920 k-effective value of Case KU1G04 is 0.93% Δk less than the 0.97852 k-effective value of KU1A02. Thus sufficient margin exists in going from a two to three dimensional model to counteract any effect of raising a row of assemblies on spacers. In addition, there is only a slight reactivity penalty between reconstituting an entire row of assemblies or alternate assemblies in a row.

(12.H.1) Per Ref.4, the double contingency principle shall be applied. It shall require two unlikely, independent, concurrent events to produce a criticality accident. The double-contingency principle means that realistic conditions may be assumed. For example, if soluble boron is normally present in the SFP water, the loss of soluble boron is considered as one

accident condition and a second concurrent accident need not be assumed. Therefore, total credit for the presence of soluble boron may be assumed in evaluating this accident condition. Per Technical Assumption 7.I, the normal SFP boron concentration is conservatively assumed to be 2000 ppm. Cases KU1H01-KU1H03 model a finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F as a function of soluble boron concentration (300, 0, 2000 ppm) for the dropped assembly accident. The 0.92835 k-effective value of Case KU1F01 is approximately equal to the 0.92914 k-effective value of Case KU1H01, while the 0.96683 k-effective value of Case KU1F02 is approximately equal to the 0.96528 k-effective value of Case KU1H02. Thus the dropped assembly is effectively decoupled from the assemblies stored in the SFP storage racks as was previously noted in Ref.32. Taking credit for 2000 ppm per the double contingency principle drops the k-effective value to 0.77446 (Case KU1H03), well below the regulatory requirement.

(12.I.1) Per Ref.4, the double contingency principle shall be applied. It shall require two unlikely, independent, concurrent events to produce a criticality accident. The double-contingency principle means that realistic conditions may be assumed. For example, if soluble boron is normally present in the SFP water, the loss of soluble boron is considered as one accident condition and a second concurrent accident need not be assumed. Therefore, total credit for the presence of soluble boron may be assumed in evaluating this accident condition. Per Technical Assumption 7.I, the normal SFP boron concentration is conservatively assumed to be 2000 ppm. Cases KU1I01-KU1I03 model a finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F as a function of soluble boron concentration (300, 0, 2000 ppm) for the dropped assembly accident and assuming reconstitution of all of the assemblies in the row closest to the SFP wall. The 0.92814 k-effective value of Case KU1G03 is approximately equal to the 0.92835 k-effective value of Case KU1I01, while the 0.96920 k-effective value of Case KU1G04 is approximately equal to the 0.96328 k-effective value of Case KU1I02. Thus the dropped assembly is effectively decoupled from the assemblies stored in the SFP storage racks as was previously noted in Ref.32. Taking credit for 2000 ppm per the double contingency principle drops the k-effective value to 0.77471 (Case KU1I03), well below the regulatory requirement.

(12.LXA.1) Cases KU1A02LX and KU1A02LXu model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell B_{10} density (0.0177 gm/cm^2 B_{10} and 0.01593 gm/cm^2 B_{10}) at the worst case temperature of 40°F for a fuel clad material composed of optin at a soluble boron concentration of 0 ppm. A 40-70 yr bias (LX cases) of 0.00466 is indicated for the 0 ppm case. An uncertainty (LXu cases) of 0.00607 is indicated for the 0 ppm case.

(12.LXD.1) Cases KU1D03LX and KU1D03LXu model an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel as a function of storage cell B_{10} density (0.0177 gm/cm^2 B_{10} and 0.01593 gm/cm^2 B_{10}) at the worst case temperature of 40°F for a fuel clad material composed of zirc4 at a soluble boron concentration of 300 ppm. A 40-70 yr bias (LX cases) of 0.00504 is indicated for the 300 ppm case. An uncertainty (LXu cases) of 0.00466 is indicated for the 300 ppm case.

13. CONCLUSIONS

For an infinite axial and radial array of storage cells of nominal dimensions containing the maximum enrichment of 5.0 w/o VAP fuel at the worst case temperature of 40°F, the maximum unborated k-effective value of 0.986 is calculated with all biases and uncertainties, which is less than the 10 CFR 50.68 regulatory value of 1.0. The maximum k-effective value of 0.947 at a moderator boron concentration of 300 ppm with all biases and uncertainties is less than the 10 CFR 50.68 regulatory value of 0.95. (If credit is taken for soluble boron, the k-effective of the spent fuel storage racks loaded with fuel of the maximum fuel assembly reactivity must not exceed 0.95, at a 95% probability, 95% confidence level, if flooded with borated water, and the k-effective must remain below 1.0 (subcritical) at a 95% probability, 95% confidence level, if flooded with unborated water.). Note that 300 ppm is a minimum boron concentration requirement. Per Technical Assumption 7J, 15% should be added to this value to account for all uncertainties. Thus a boron level of 350 ppm with uncertainties is required to credit soluble boron in the SFP and to safely store 5 w/o VAP fuel in the SFP.

A finite radial and axial model of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o VAP fuel at the worst case temperature of 40°F at a soluble boron concentration of 0 and 300 ppm was modeled with alternate and sequential assemblies in the row closest to the SFP wall on spacers to simulate the reconstitution/inspection process. Sufficient margin exists in going from a two to three dimensional model to counteract any increase in reactivity from raising a row of assemblies on spacers. In addition, there is no reactivity penalty between reconstituting an entire row of assemblies or alternate assemblies in a row.

Dropping an assembly of 5.0 w/o VAP fuel onto the SFP racks was analyzed, even though it is not a credible accident. Per Ref.4, the double contingency principle was applied. It required two unlikely, independent, concurrent events to produce a criticality accident. The double contingency principle means that realistic conditions may be assumed. For example, if soluble boron is normally present in the SFP water, the loss of soluble boron is considered as one accident condition and a second concurrent accident need not be assumed. Therefore, total credit for the presence of soluble boron may be assumed in evaluating this accident condition. Per Technical Assumption 7.I, the normal SFP boron concentration is conservatively assumed to be 2000 ppm. A finite radial and axial configuration of the Unit 1 SFP of nominal dimensions containing the maximum enrichment of 5.0 w/o fuel at the worst case temperature of 40°F was modeled as a function of soluble boron concentration (300, 0, 2000 ppm) for the dropped assembly accident with and without reconstitution. The dropped assembly is effectively decoupled from the assemblies stored in the SFP storage racks as was previously noted in Ref.32. Taking credit for 2000 ppm per the double contingency principle drops the k-effective value to well below the regulatory requirement for all cases.

ATTACHMENT A
CALCULATION LIST

	A	B	C	D	E	F	G	H	I	J
1	KENO Reactivity Results									
2										
3	Case	Enr(w/o)	T(K)	SHD(%)	Pitch(in)	Steel(cm)	Clad	PPM	Planar Geom	Axial
4	KU1A01	5 0	**277.15**	0.945	10.09375	0.1524	**zirlo**	0	Single assembly	Infinite
5	**KU1A02**	**5.0**	**277.15**	**0.945**	**10.09375**	**0.1524**	**optin**	**0**	Single assembly	Infinite
6	KU1A03	5.0	**277.15**	0.945	10.09375	0.1524	**zirc4**	0	Single assembly	Infinite
7	KU1A04	5.0	**341.48**	0.945	10.09375	0.1524	**zirlo**	0	Single assembly	Infinite
8	KU1A05	5.0	**341.48**	0.945	10.09375	0.1524	**optin**	0	Single assembly	Infinite
9	KU1A06	5.0	**341.48**	0.945	10.09375	0.1524	**zirc4**	0	Single assembly	Infinite
10	KU1A07	5.0	277.15	**0.965**	10.09375	0.1524	optin	0	Single assembly	Infinite
11	KU1A08	5.0	277.15	0.945	**10.125**	0.1524	optin	0	Single assembly	Infinite
12	KU1A09	5.0	277.15	0.945	**10.0625**	0.1524	optin	0	Single assembly	Infinite
13	KU1A10	5.0	277.15	0.945	10.09375	**0.1270**	optin	0	Single assembly	Infinite
14	KU1A11	5.0	277.15	0.945	10.09375	**0.1778**	optin	0	Single assembly	Infinite
15	KU1A12	**5.0**	277.15	0.945	10.09375	0.1524	optin	0	10x10	Infinite
16	KU1A13	**5.0 ecc**	277.15	0.945	10.09375	0.1524	optin	0	10x10 ecc in	Infinite
17	KU1A14	**5.0 ecc**	277.15	0.945	10.09375	0.1524	optin	0	10x10 ecc out	Infinite
18	KU1B01	**4.9**	277.15	0.945	10.09375	0.1524	optin	0	Single assembly	Infinite
19	KU1B02	**4.8**	277.15	0.945	10.09375	0.1524	optin	0	Single assembly	Infinite
20	KU1B03	**4.7**	277.15	0.945	10.09375	0.1524	optin	0	Single assembly	Infinite
21	KU1B04	**4.6**	277.15	0.945	10.09375	0.1524	optin	0	Single assembly	Infinite
22	KU1B05	**4.5**	277.15	0.945	10.09375	0.1524	optin	0	Single assembly	Infinite
23	KU1B06	**4.4**	277.15	0.945	10.09375	0.1524	optin	0	Single assembly	Infinite
24	KU1B07	**4.3**	277.15	0.945	10.09375	0.1524	optin	0	Single assembly	Infinite
25	KU1B08	**4.2**	277.15	0.945	10.09375	0.1524	optin	0	Single assembly	Infinite
26	KU1B09	**4.1**	277.15	0.945	10.09375	0.1524	optin	0	Single assembly	Infinite
27	KU1C01	5.0	277.15	0.945	10.09375	0.1524	optin	**100**	Single assembly	Infinite
28	KU1C02	5.0	277.15	0.945	10.09375	0.1524	optin	**200**	Single assembly	Infinite
29	**KU1C03**	**5.0**	**277.15**	**0.945**	**10.09375**	**0.1524**	**optin**	**300**	Single assembly	Infinite
30	KU1C04	5.0	277.15	0.945	10.09375	0.1524	optin	**400**	Single assembly	Infinite
31	KU1C05	5.0	277.15	0.945	10.09375	0.1524	optin	**500**	Single assembly	Infinite
32	KU1D01	5.0	**277.15**	0.945	10 09375	0.1524	**zirlo**	300	Single assembly	Infinite
33	KU1D02	5 0	**277.15**	0.945	10.09375	0.1524	**optin**	300	Single assembly	Infinite
34	**KU1D03**	**5.0**	**277.15**	**0.945**	**10.09375**	**0.1524**	**zirc4**	**300**	Single assembly	Infinite
35	KU1D04	5.0	**341.48**	0.945	10.09375	0.1524	**zirlo**	300	Single assembly	Infinite
36	KU1D05	5.0	**341.48**	0.945	10 09375	0.1524	**optin**	300	Single assembly	Infinite

	A	B	C	D	E	F	G	H	I	J
37	KU1D06	5.0	**341.48**	0.945	10.09375	0.1524	**zirc4**	300	Single assembly	Infinite
38	KU1D07	5.0	277.15	**0.965**	10.09375	0.1524	zirc4	300	Single assembly	Infinite
39	KU1D08	5.0	277.15	0.945	**10.125**	0.1524	zirc4	300	Single assembly	Infinite
40	KU1D09	5.0	277.15	0.945	**10.0625**	0 1524	zirc4	300	Single assembly	Infinite
41	KU1D10	5.0	277.15	0.945	10.09375	**0.1270**	zirc4	300	Single assembly	Infinite
42	KU1D11	5.0	277.15	0.945	10.09375	**0.1778**	zirc4	300	Single assembly	Infinite
43	KU1D12	**5.0**	277.15	0.945	10.09375	0.1524	zirc4	300	10x10	Infinite
44	KU1D13	**5.0 ecc**	277.15	0.945	10.09375	0.1524	zirc4	300	10x10 ecc in	Infinite
45	KU1D14	**5.0 ecc**	277.15	0.945	10.09375	0.1524	zirc4	300	10x10 ecc out	Infinite
46	KU1E01	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	10x10	Finite-H2O
47	KU1E02	5.0	277.15	0.945	10.09375	0.1524	optin	0	10x10	Finite-H2O
48	KU1E03	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	10x10	Finite
49	KU1E04	5.0	277.15	0.945	10.09375	0.1524	optin	0	10x10	Finite
50	KU1F01	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	Unit 1 SFP	Finite
51	KU1F02	5.0	277.15	0.945	10.09375	0.1524	optin	0	Unit 1 SFP	Finite
52	KU1G01	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	U1SFP-Recon-alternate	Finite
53	KU1G02	5.0	277.15	0.945	10.09375	0.1524	optin	0	U1SFP-Recon-alternate	Finite
54	KU1G03	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	U1SFP-Recon-sequential	Finite
55	KU1G04	5.0	277.15	0.945	10.09375	0.1524	optin	0	U1SFP-Recon-sequential	Finite
56	KU1H01	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	U1SFP Drop Assm	Finite
57	KU1H02	5.0	277.15	0.945	10 09375	0.1524	optin	0	U1SFP Drop Assm	Finite
58	KU1H03	5.0	277.15	0.945	10.09375	0.1524	zirc4	2000	U1SFP Drop Assm	Finite
59	KU1I01	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	U1SFP-Drop Assm-Recon sequential	Finite
60	KU1I02	5.0	277.15	0 945	10.09375	0.1524	optin	0	U1SFP-Drop Assm-Recon sequential	Finite
61	KU1I03	5.0	277.15	0.945	10 09375	0.1524	zirc4	2000	U1SFP-Drop Assm-Recon sequential	Finite
62	KU1A02LX	5.0	277.15	0.945	10.09375	0.1524	optin	0	Single assembly-0.0177g/cm2 B10	Infinite
63	KU1A02LXu	5.0	277.15	0.945	10.09375	0.1524	optin	0	Single assembly-0.01593 g/cm2 B10	Infinite
64	KU1D03LX	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	Single assembly-0 0177g/cm2 B10	Infinite
65	KU1D03LXu	5 0	277.15	0.945	10.09375	0.1524	zirc4	300	Single assembly-0.01593 g/cm2 B10	Infinite

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ATTACHMENT B
REACTIVITY RESULTS

	A	B	C	D	E	F	G	H	I	J	K
1	KENO Reactivity Results										
2									unbiased		biased
3	Case	Enr(w/o)	T(K)	SHD(%)	Pitch(in)	Steel(cm)	Clad	PPM	k-effective	delta-k	k-effective
4	KU1A01	5.0	277.15	0 945	10.09375	0.1524	zirlo	0	0.96505	0.00107	
5	KU1A02	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.96623	0.00113	0.98524
6	KU1A03	5 0	277.15	0.945	10.09375	0.1524	zirc4	0	0.96427	0.00103	
7	KU1A04	5.0	341.48	0 945	10.09375	0.1524	zirlo	0	0.95812	0.00106	
8	KU1A05	5.0	341.48	0.945	10.09375	0.1524	optin	0	0.95904	0.0011	
9	KU1A06	5.0	341.48	0.945	10.09375	0.1524	zirc4	0	0.96087	0.00109	
10	KU1A07	5.0	277.15	0.965	10.09375	0.1524	optin	0	0.96811	0.00116	
11	KU1A08	5.0	277.15	0.945	10.125	0.1524	optin	0	0.96127	0.00125	
12	KU1A09	5 0	277.15	0.945	10.0625	0.1524	optin	0	0.96968	0 00117	
13	KU1A10	5.0	277.15	0.945	10.09375	0.1270	optin	0	0.96180	0.00105	
14	KU1A11	5.0	277.15	0.945	10 09375	0.1778	optin	0	0.96968	0.00111	
15	KU1A12	5.0	277.15	0.945	10.09375	0 1524	optin	0	0.96643	0 00109	0.98544
16	KU1A13	5.0 ecc	277.15	0.945	10.09375	0.1524	optin	0	0.96486	0.00101	
17	KU1A14	5.0 ecc	277.15	0.945	10.09375	0.1524	optin	0	0.96648	0.00111	
18	KU1B01	4.9	277.15	0.945	10.09375	0.1524	optin	0	0.96320	0.00111	0.98221
19	KU1B02	4.8	277.15	0.945	10.09375	0.1524	optin	0	0.95721	0.00111	0 97622
20	KU1B03	4.7	277.15	0.945	10.09375	0.1524	optin	0	0.95405	0.00110	0.97306
21	KU1B04	4.6	277.15	0.945	10.09375	0.1524	optin	0	0.95089	0.00103	0.96990
22	KU1B05	4.5	277.15	0.945	10.09375	0.1524	optin	0	0.94661	0.00102	0.96562
23	KU1B06	4.4	277.15	0.945	10.09375	0.1524	optin	0	0.94284	0.00099	0.96185
24	KU1B07	4.3	277.15	0.945	10 09375	0.1524	optin	0	0 93789	0.00125	0.95690
25	KU1B08	4.2	277.15	0.945	10.09375	0.1524	optin	0	0.93282	0 00107	0.95183
26	KU1B09	4.1	277.15	0.945	10 09375	0.1524	optin	0	0.92834	0.00107	0.94735
27	KU1C01	5.0	277.15	0.945	10.09375	0.1524	optin	100	0.95113	0.00120	0.97014
28	KU1C02	5.0	277.15	0.945	10.09375	0.1524	optin	200	0.93922	0.00104	0.95823
29	KU1C03	5.0	277.15	0.945	10.09375	0.1524	optin	300	0.92714	0.00110	0.94615
30	KU1C04	5.0	277.15	0.945	10.09375	0.1524	optin	400	0.91420	0.00102	0.93321
31	KU1C05	5 0	277.15	0.945	10 09375	0.1524	optin	500	0.90613	0.00101	0.92514
32	KU1D01	5.0	277.15	0.945	10.09375	0.1524	zirlo	300	0.92624	0.00110	
33	KU1D02	5 0	277.15	0.945	10.09375	0.1524	optin	300	0.92714	0.00110	
34	KU1D03	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	0.92737	0.00105	0.94638
35	KU1D04	5 0	341.48	0.945	10.09375	0.1524	zirlo	300	0.92284	0.00112	
36	KU1D05	5 0	341.48	0.945	10.09375	0.1524	optin	300	0.92161	0.00103	

	A	B	C	D	E	F	G	H	I	J	K
37	KU1D06	5.0	**341.48**	0.945	10.09375	0.1524	**zirc4**	300	0.92173	0.00103	
38	KU1D07	5.0	277.15	**0.965**	10.09375	0.1524	zirc4	300	0.92788	0.00104	
39	KU1D08	5.0	277.15	0.945	**10.125**	0.1524	zirc4	300	0.92195	0.00108	
40	KU1D09	5.0	277.15	0.945	**10.0625**	0.1524	zirc4	300	0.92977	0.00105	
41	KU1D10	5.0	277.15	0.945	10.09375	**0.1270**	zirc4	300	0.92062	0.00106	
42	KU1D11	5.0	277.15	0.945	10.09375	**0.1778**	zirc4	300	0.92809	0.00114	
43	KU1D12	**5.0**	277.15	0.945	10.09375	0.1524	zirc4	300	0 92726	0.00105	0.94627
44	KU1D13	**5.0 ecc**	277.15	0.945	10.09375	0.1524	zirc4	300	0.92418	0.00111	
45	KU1D14	**5.0 ecc**	277.15	0.945	10.09375	0.1524	zirc4	300	0.92236	0.00108	
46	KU1E01	5.0	277.15	0.945	10 09375	0.1524	zirc4	300	0.92339	0.00104	0.94240
47	KU1E02	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.96376	0.00107	0.98277
48	KU1E03	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	0.92467	0.00119	0.94368
49	KU1E04	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.96302	0.00105	0.98203
50	KU1F01	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	0.91606	0.00112	0.93507
51	KU1F02	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.95454	0.00120	0.97355
52	KU1G01	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	0.91761	0.00108	0.93662
53	KU1G02	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.95432	0.00115	0.97333
54	KU1G03	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	0.91585	0.00100	0.93486
55	KU1G04	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.95691	0.00097	0.97592
56	KU1H01	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	0.91685	0.00126	0.93586
57	KU1H02	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.95299	0.00114	0.97200
58	KU1H03	5.0	277.15	0.945	10.09375	0.1524	zirc4	2000	0.76217	0.00098	0.78118
59	KU1I01	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	0.91606	0.00102	0.93507
60	KU1I02	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.95099	0.00120	0.97000
61	KU1I03	5.0	277.15	0.945	10.09375	0.1524	zirc4	2000	0.76242	0.00094	0.78143
62	KU1A02LX	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.96875	0.00101	
63	KU1A02LXu	5.0	277.15	0.945	10.09375	0.1524	optin	0	0.97279	0.00102	
64	KU1D03LX	5.0	277.15	0.945	10 09375	0.1524	zirc4	300	0.93031	0.00105	
65	KU1D03LXu	5.0	277.15	0.945	10.09375	0.1524	zirc4	300	0.93281	0.00111	
66											
67											
68											
69											
70											
71											
72											

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	A	B	C	D	E	F	G	H	I	J	K
73	Summary of Bias and Uncertainty Results for Zero Soluble Boron:										
74					Bias	Uncertainty					
75	Calculational Methodology				0.00080	0.00760					
76	Temperature						Worst Case - 4C				
77	Fuel Cladding Composition						Worst Case - optin				
78	Stack Height Density					0.00417	Nominal				
79	Storage Cell Pitch					0.00575	Nominal				
80	Fuel Enrichment						Worst Case - 5.0 w/o				
81	Soluble Boron Concentration						Worst Case - 0 ppm				
82	Steel Thickness					0.00569	Nominal				
83	Poison Loading				0.00466	0.00607	Nominal				
84	Eccentric Positioning					0.00249	Nominal				
85	Fuel Depletion						NA				
86	Axial Burnup Distribution						NA				
87	Total				0.00546	0.01355					
88						0.01901	Bias and Uncertainty				
89	Summary of Bias and Uncertainty Results for 300 PPM Soluble Boron:										
90					Bias	Uncertainty					
91	Calculational Methodology				0.00080	0.00760					
92	Delta-K					0.00101					
93	Temperature						Worst Case - 4C				
94	Fuel Cladding Composition						Worst Case - zirc4				
95	Stack Height Density					0.00260	Nominal				
96	Storage Cell Pitch					0.00450	Nominal				
97	Fuel Enrichment						Worst Case - 5.0 w/o				
98	Soluble Boron Concentration						Worst Case - 0 ppm				
99	Steel Thickness					0.00291	Nominal				
100	Poison Loading				0.00504	0.00466	Nominal				
101	Eccentric Positioning					0.00000	Nominal				
102	Fuel Depletion						NA				
103	Axial Burnup Distribution						NA				
104	Total				0.00584	0.01072					
105						0.01656	Bias and Uncertainty				

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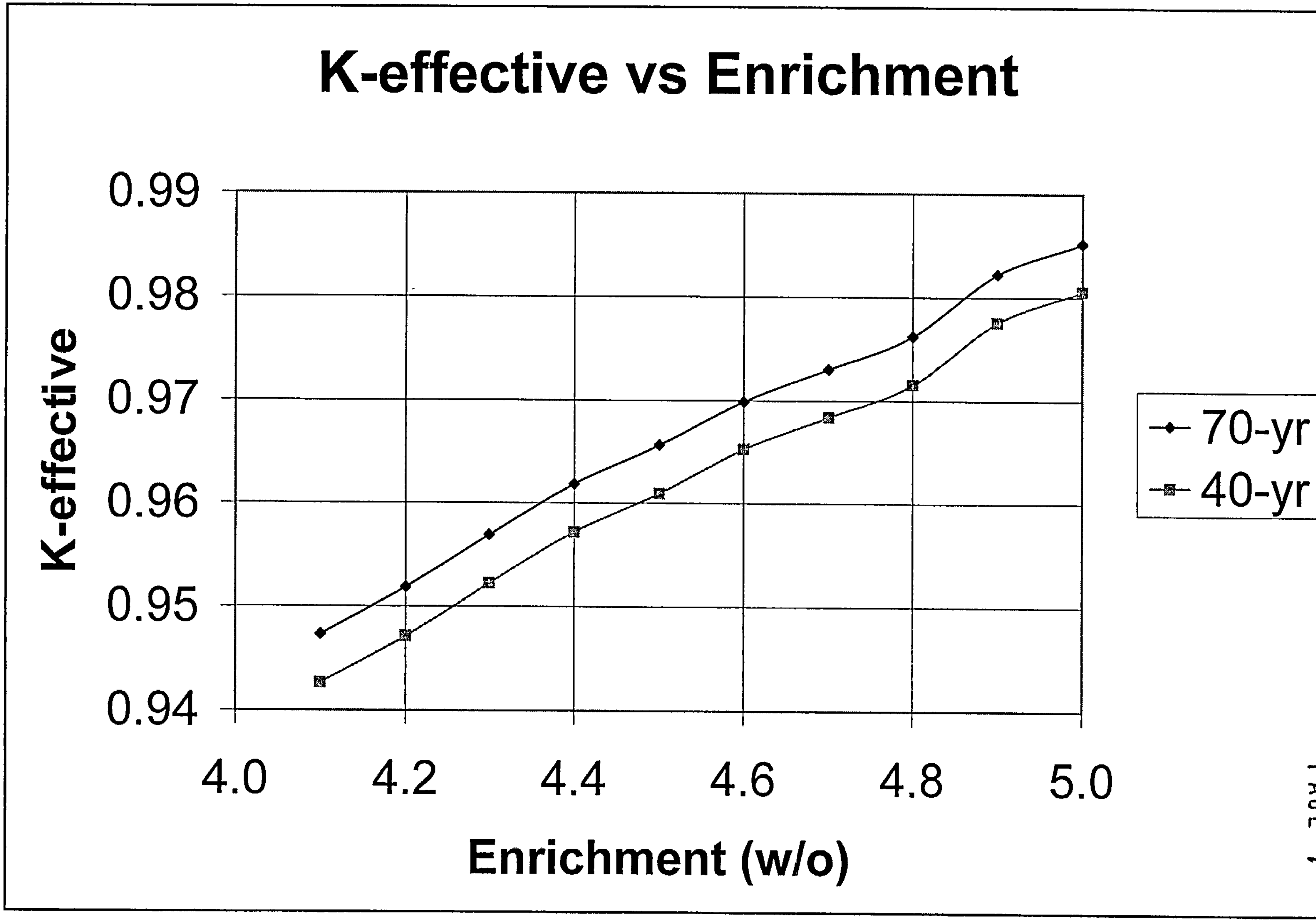

K-effective vs Enrichment
K-effective
0.99
0.98
0.97
0.96
0.95
0.94
4.0
4.2
4.4
4.6
4.8
5.0
Enrichment (w/o)
70-yr
40-yr

ATTACHMENT C
DENSITY CALCULATIONS

	A	B	C	D	E	F	G	H
1	**Carborundum Material Densities:**							
2								
3	F =	B4C density fraction = B10L / PST / B10A * MWB4C / AWB4 / DB4C						
4	F =				0 240685	0 213007	0 191706	
5								
6	B10L = B10 Loading (gm/cm2)				0.020	0 017700	0 015930	Ref.15
7	PST = Poison Sheet Thickness (cm) = 0.090" * 2.54 =				0 2286	0.2286	0 2286	Ref.15
8	B10A = Abundance of B10 in a/f				0.19900	0.19900	0.19900	Ref.19
9	B11A = B11 abundance in a/f				0.80100	0.80100	0 80100	Ref.19
10	AWB10 = B10 atomic weight in gm/mole				10.012937	10.012937	10.012937	Ref.19
11	AWB11 = B11 atomic weight in gm/mole				11.009306	11.009306	11.009306	Ref.19
12	AWB = B atomic weight in gm/mole				10 81103	10.81103	10.81103	calculated
13	AWC = Atomic Weight of C				12 01100	12 01100	12 01100	Ref.19
14	MWB4C = Molecular Weight of B4C				55 2551	55.2551	55.2551	calculated
15	AWB4 = Atomic Weight of Natural B in B4C				43.2441	43 2441	43 2441	calculated
16	DB4C = Density of B4C in gm/cc				2.52	2.52	2.52	Ref 21
17	B10W = B10 abundance in w/f				0.18431	0.18431	0 18431	Ref 21
18								
19								
20	**ZIRLO Material Densities**							
21								
22	N(ATOMS/B-CM) = DZ * f * NA / AW / C							
23								
24		f(w/o)	AW(gm/mole)	N				
25	Sn	1.00	118.71	3.2594E-04				
26	Fe	0.11	55.847	7.6211E-05				
27	Nb	1.00	92.90638	4.1647E-04				
28	Zr	97.89	91.224	4.1520E-02				
29		100 00						
30								
31	f = Zirlo composition in w/o							Refs 17-18
32	DZ = Zirlo density in gm/cc				6.425			Ref.18
33	AW = Atomic weight in gm/mole							Ref.19
34	NA = Avogadro's Number in atoms/mole				6.022E+23			Ref.20
35	C = barns/cm2				1.00E+24			Ref 20
36								
37								
38								
39								
40								
41								
42								
43								
44								
45								
46								
47								
48								
49								
50								

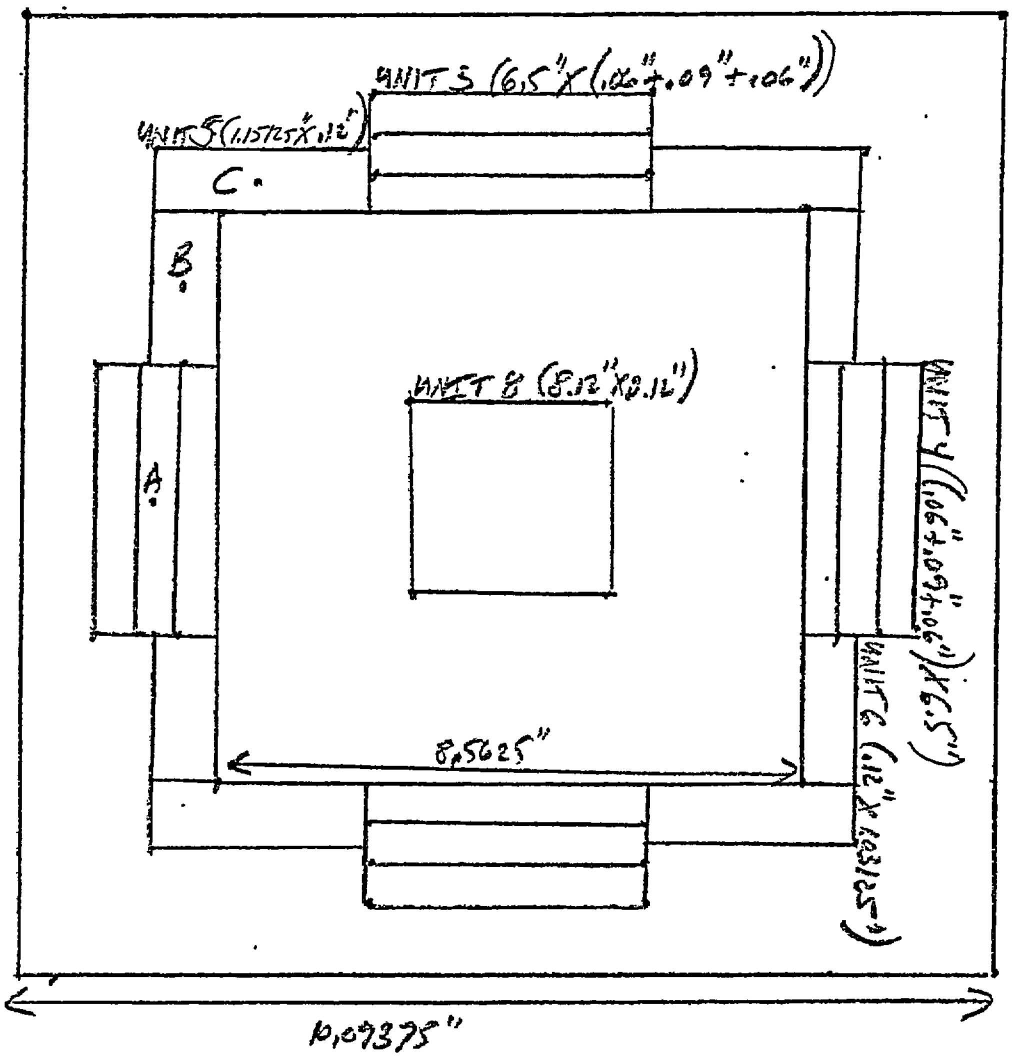
	A	B	C	D	E	F	G	H
51	**OPTIN Material Densities**							
52								
53	N(ATOMS/B-CM) = DZ * f * NA / AW / C							
54								
55		f(w/o)	AW(gm/mole)	N				
56	Sn	1.25	118 71	4.1535E-04				
57	Fe	0 21	55.847	1.4832E-04				
58	Cr	0.10	51.996	7.5862E-05				
59	O	0 12	15.9994	2.9585E-04				
60	Zr	98.32	91.224	4.2514E-02				
61		100.00						
62								
63	f = Optin composition in w/o							Refs 17-18
64	DZ = Optin density in gm/cc				6.550			Ref.18
65	AW = Atomic weight in gm/mole							Ref.19
66	NA = Avogadro's Number in atoms/mole				6.022E+23			Ref.20
67	C = barns/cm2				1.00E+24			Ref.20
68								
69								
70	**Soluble Boron Density**							
71								
72	D(H3BO3) = f * D(H2O) * MW(H3BO3) / AWB = Density of H3BO3 in gm/cc							
73								
74	B10A = B10 abundance in w/o				19 9			Ref.19
75	B11A = B11 abundance in w/o				80 1			Ref.19
76	AWB10 = B10 atomic weight in gm/mole				10 012937			Ref.19
77	AWB11 = B11 atomic weight in gm/mole				11 009306			Ref 19
78	AWB = B atomic weight in gm/mole				10 81103			calculated
79	AWH = H atomic weight in gm/mole				1.00780			Ref.19
80	AWO = O atomic weight in gm/mole				15 99940			Ref.19
81	MWH3BO3 = H3BO3 molecular weight in gm/mole				61.83263			calculated
82								
83	f	DH2O	DH3BO3					
84	0.000100	1.0000	0.00057194					
85	0 000200	1.0000	0.001143881					
86	0.000300	1.0000	0 001715821					
87	0 000400	1.0000	0.002287761					
88	0.000500	1.0000	0.002859702					
89	0.002000	1.0000	0.011438806					
90	0 000100	1.0000	0.00057194					
91	0.000200	0.9785	0.001119287					
92	0.000300	0 9785	0.001678931					
93	0.000400	0.9785	0.002238574					
94	0.000500	0 9785	0.002798218					
95	0.002000	0.9785	0.011192872					
96								
97								
98								
99								
100								

	A	B	C	D	E	F	G	H
101	**Upper End Fitting:**							
102	Length	8.12	in	20 6248	cm	UFSAR Fig.3 3-1		
103	Width	8 12	in	20.6248	cm	UFSAR Fig 3.3-1		
104	Height	15 295	in	38 8493	cm	Ref.25		
105	Total Volume	1008 46665	in3	16525 8075	cc			
106	Inconel X-750	1100	gm			Ref.26		
107	SS-304	5080	gm			Ref 26		
108	Zirc-4	680	gm			Ref.26		
109	SS-302	7980	gm			Ref.26		
110	Inconel X-750	8 30	gm/cc-ref			Ref.21		
111	SS-304	7.94	gm/cc-ref			Ref.21		
112	Zirc-4	6.56	gm/cc-ref			Ref.21		
113	SS-302	7.94	gm/cc-ref			Ref.21		
114	Inconel X-750	132 5301	cc	0.008020	vol frac			
115	SS-304	639 7985	cc	0.038715	vol frac			
116	Zirc-4	103 6585	cc	0.006273	vol frac			
117	SS-302	1005.0378	cc	0.060816	vol frac			
118	Water Vol	14644.7826	cc	0 886177	vol frac			
119								
120								
121	**Lower End Fitting:**							
122	Length	8.12	in	20.6248	cm	UFSAR Fig 3 3-1		
123	Width	8.12	in	20.6248	cm	UFSAR Fig.3.3-1		
124	Height	5 246	in	13 32484	cm	Ref 25		
125	Volume	345 89186	in3	5668 152086	cc			
126	Inconel-625	1360	gm			Ref 26		
127	SS-304	5000	gm			Ref.26		
128	Inconel	8.30	gm/cc-ref			Ref.21		
129	SS-304	7.94	gm/cc-ref			Ref.21		
130	Inconel	163.8554	cc	0.028908	vol frac			
131	SS-304	629.7229	cc	0.111098	vol frac			
132	Water Vol	4874 5737	cc	0.859993	vol frac			

ATTACHMENT D
FUEL DATA SPREADSHEET

217			Assemblies per core	UFSAR 3.1
77			CEAs per core	UFSAR 3.1
176			Rods per assembly	UFSAR 3.1
5			Guide tubes per assembly	UFSAR 3.1
136.7	347.218	in-cm	Active core height	UFSAR 3.1
1.035	2.6289	in-cm	Guide tube ID	BGE Drwg E-550-701-303 - Ref.27
1.115	2.8321	in-cm	Guide tube oD	BGE Drwg E-550-701-303 - Ref.27
0.580	1.4732	in-cm	Fuel rod pitch	UFSAR Figure 3.3-1
0.20	0.508	in-cm	Assembly spacing, fuel ros surface-surface	UFSAR Table 3.3-5
8.12	20.6248	in-cm	Assembly pitch (14*0.58")	UFSAR Figure 3.3-1
0.06	0.1524	in-cm	Assembly gap (8.18"-8.12")	UFSAR Figure 3.3-1
548		deg F	Tcold	UFSAR Figure 4-9
572.5		deg F	Tave	UFSAR Figure 4-9
599.4		deg F	Thot	UFSAR Figure 4-9
532		deg F	Thzp	UFSAR Figure 4-9
Standard Fuel Design				
0.3795	0.96393	in-cm	Pellet diameter (A-C U1)	UFSAR Table 3.3-1
15.4626		in3	Pin fuel volume	
0.3805	0 96647	in-cm	Pellet diameter (A-C U2)	UFSAR Table 3 3-2
15.5442		in3	Pin fuel volume	
0.3765	0.95631	in-cm	Pellet diameter (D-S U1, D-R U2)	UFSAR Table 3.3-1/2
15.2191		in3	Pin fuel volume	
0.388	0.98552	in-cm	Clad ID (A-C U1-U2)	UFSAR Table 3.3-1/2
0.384	0.97536	in-cm	Clad ID	UFSAR Table 3.3-1/2
0.440	1.1176	in-cm	Clad OD	UFSAR Table 3.3-1/2
10.170		gm/cc	Stack height density (max)	UFSAR Table 3.3-1/2
0.9279			Stack height density (% TD)	
VAP Fuel Design				
0.381	0.96774	in-cm	Pellet diameter	UFSAR Table 3.3-1/2
15.585		in3	Pin fuel volume	
0.388	0.98552	in-cm	Clad ID	UFSAR Table 3.3-1/2
0.440	1.1176	in-cm	Clad OD	UFSAR Table 3.3-1/2
10.310		gm/cc	Stack height density	UFSAR Table 3.3-1/2
0.9407			Stack height density (% TD)	
SAS2H Larger Unit Cell Effective Radii for 176 pin assembly (Standard and VAP Fuel Design)				
1.31445		cm	Clad ID/2 = 1.035"/2 = 0.5175" (H2O)	
1.41605		cm	Clad OD/2 = 1.115"/2 = 0.5575" (Zirc)	
1.66233		cm	SQRT[4*(0.58)^2/pi] = 0.65446" (H2O)	
5.20391		cm	SQRT[196*(0.58)^2/5/pi] = 2.04878" (Fuel)	
5.22314		cm	SQRT[(8.15)^2/5/pi] = 2.05635" (H2O)	In ORNL/TM-12667, uses 8.18".
SAS2H Larger Unit Cell Effective Radii for 172 pin assembly (Standard and VAP Fuel Design)				
1.31445		cm	Clad ID/2 = 1.035"/2 = 0.5175" (H2O)	
1.41605		cm	Clad OD/2 = 1.115"/2 = 0.5575" (Zirc)	
1.66233		cm	SQRT[4*(0.58)^2/pi] = 0.65446" (H2O)	
5.15054		cm	SQRT[192*(0.58)^2/5/pi] = 2.02777" (Fuel)	
5 22314		cm	SQRT[(8.15)^2/5/pi] = 2.05635" (H2O)	In ORNL/TM-12667, uses 8.18".

ATTACHMENT E
SFP SINGLE RACK PLANAR GEOMETRY



A: $X = 8.5625''/2 + .06'' + .09''/2 = 4.38625'' = 11.141075$ CM

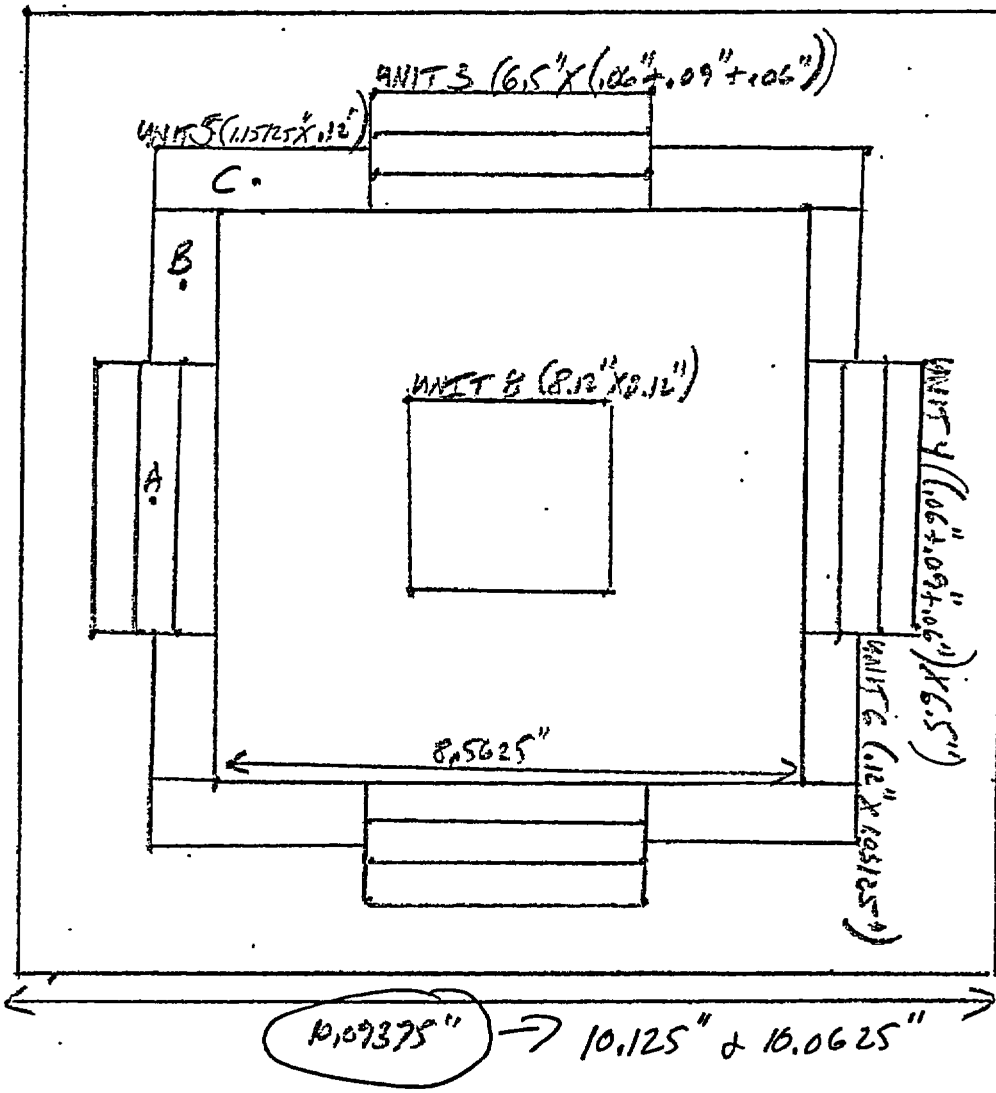
B: $X = 8.5625''/2 + .12''/2 = 4.34125'' = 11.026775$ CM

$Y = (8.5625'' + 6.5'')/4 = 3.765625'' = 9.5646875$ cm

C: $X = (8.5625'' + 6.5'' + .24'')/4 = 3.825625'' = 9.7170875$ CM

$Y = 8.5625''/2 + .06'' = 4.34125'' = 11.026775$ CM

STORAGE CELL PITCH UNCERTAINTY



A: $X = 8.5625''/2 + .06'' + .09''/2 = 4.38625'' = 11.141075$ CM

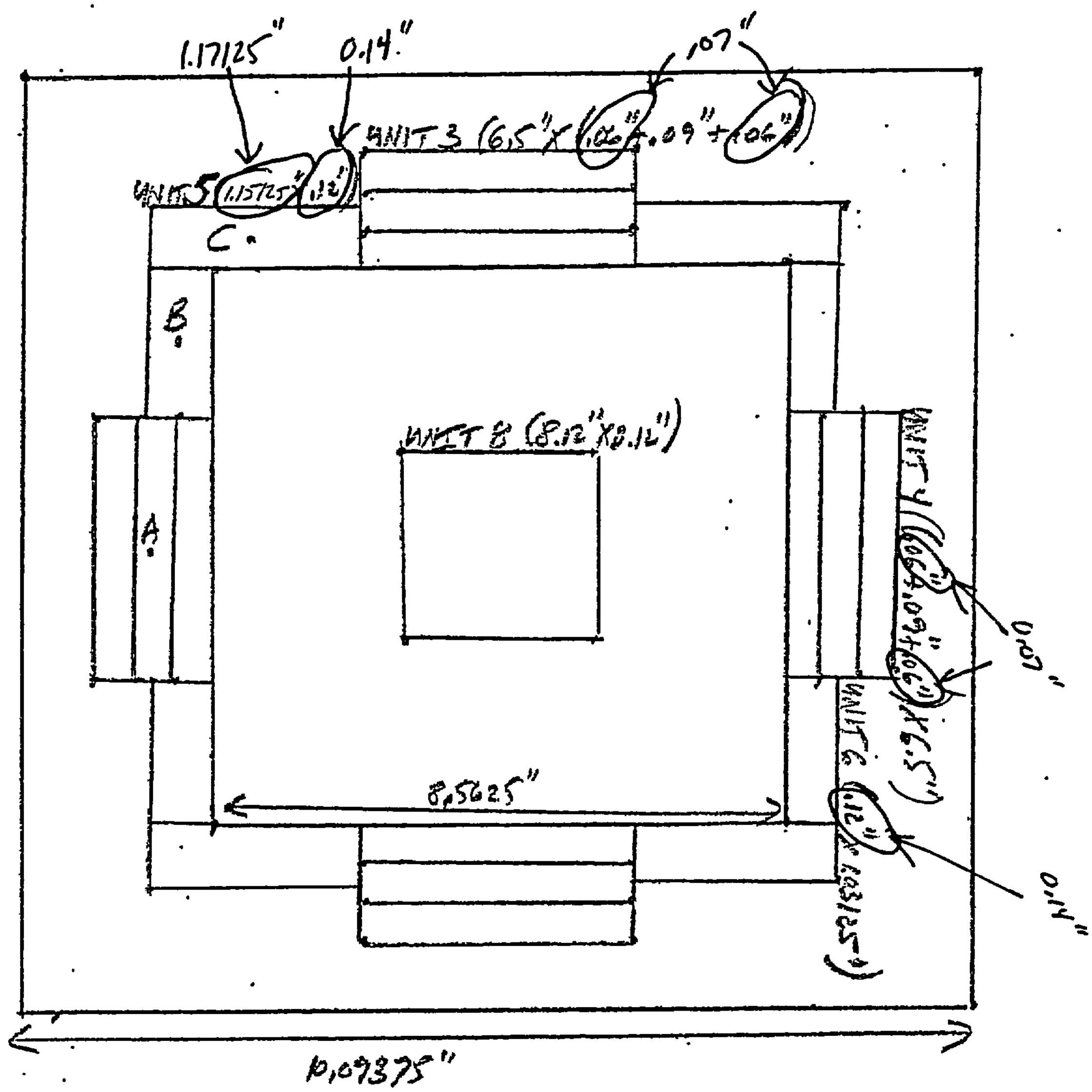
B: $X = 8.5625''/2 + .12''/2 = 4.34125'' = 11.026775$ CM

$Y = (8.5625'' + 6.5'')/4 = 3.765625'' = 9.5646875$ cm

C: $X = (8.5625'' + 6.5'' + .24'')/4 = 3.825625'' = 9.7170875$ CM

$Y = 8.5625''/2 + .06'' = 4.34125'' = 11.026775$ CM

STEEL THICKNESS UNCERTAINTY (+0.010)



A: $X = 8.5625''/2 + .06''\ [.07''] + .09''/2 = 4.38625''\ [4.39625''] = 11.141075\ [11.166475]$ CM

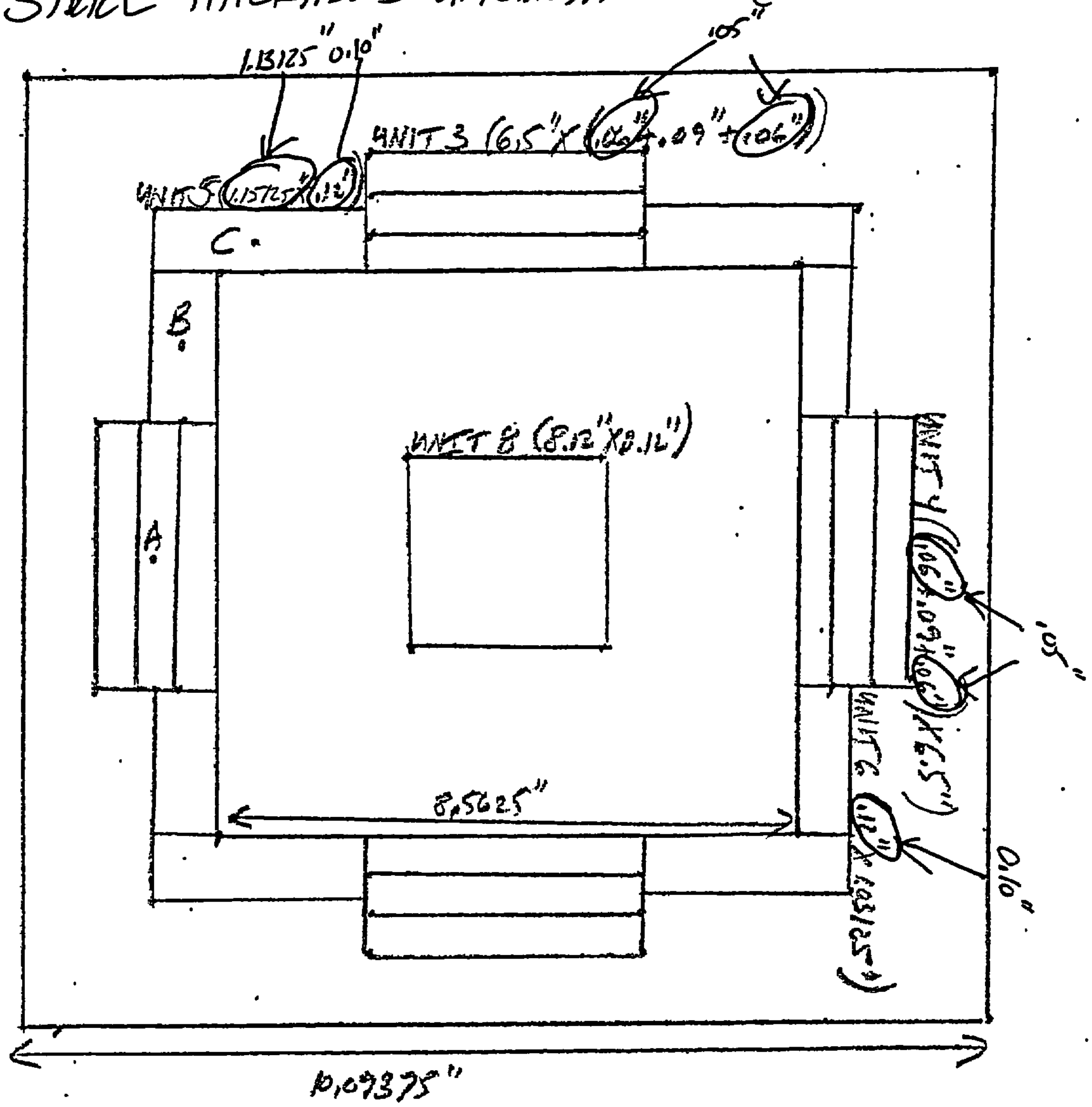
B: $X = 8.5625''/2 + .12''\ [0.14'']/2 = 4.34125''\ [4.35125''] = 11.026775\ [11.052175]$ CM

$Y = (8.5625'' + 6.5'')/4 = 3.765625'' = 9.5646875$ CM

C: $X = (8.5625'' + 6.5'' + .24''\ [0.28''])/4 = 3.825625''\ [3.835625''] = 9.716875\ [9.7424875]$ CM

$Y = 8.5625''/2 + .06''\ [.07''] = 4.34125''\ [4.351250] = 11.026775\ [11.052175]$ CM

STEEL THICKNESS UNCERTAINTY (−0.010)



A: X = 8.5625"/2 + .06" (.05") + .09"/2 = 4.38625" (4.37625") = 11.141075 CM (11.115675)

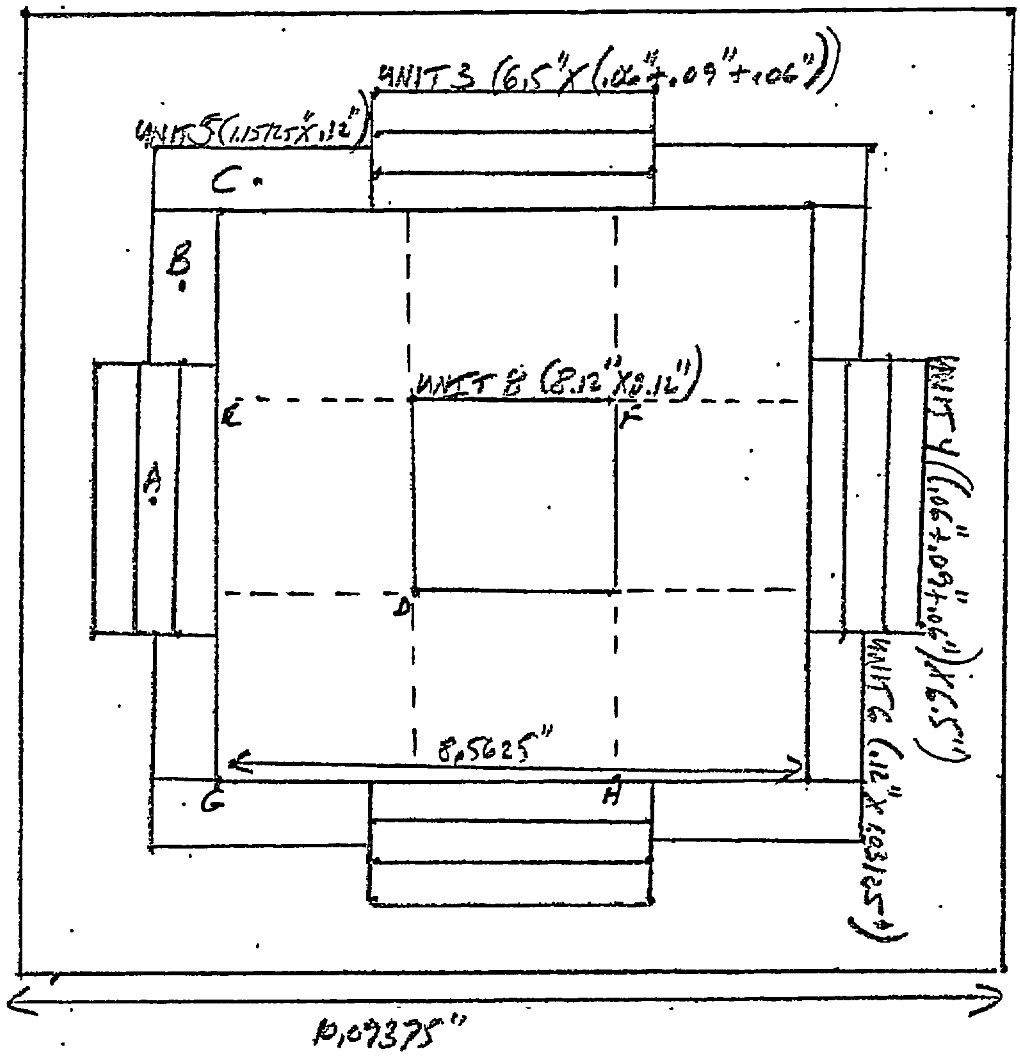
B: X = 8.5625"/2 + .11" (.10")/2 = 4.34125" (4.33125) = 11.026775 CM (11.001375)

Y = (8.5625" + 6.5")/4 = 3.765625" = 9.5646875 CM

C: X = (8.5625" + 6.5" + .21" (.20"))/4 = 3.825625" (3.815625) = 9.7170875 CM (9.6916875)

Y = 8.5625"/2 + .06" (.05") = 4.34125" (4.33125") = 11.026775 CM (11.001375)

ECCENTRIC POSITIONING



A: X = 8.5625"/2 + .06" + .09"/2 = 4.38625" = 11.141075 CM

B: X = 8.5625"/2 + .12"/2 = 4.34125" = 11.026775 CM

Y = (8.5625" + 6.5")/4 = 3.765625" = 9.5646875 CM

C: X = (8.5625" + 6.5" + .24")/4 = 3.825625" = 9.7170875 CM

Y = 8.5625"/2 + .06" = 4.34125" = 11.026775 CM

D X = Y = -10.3124

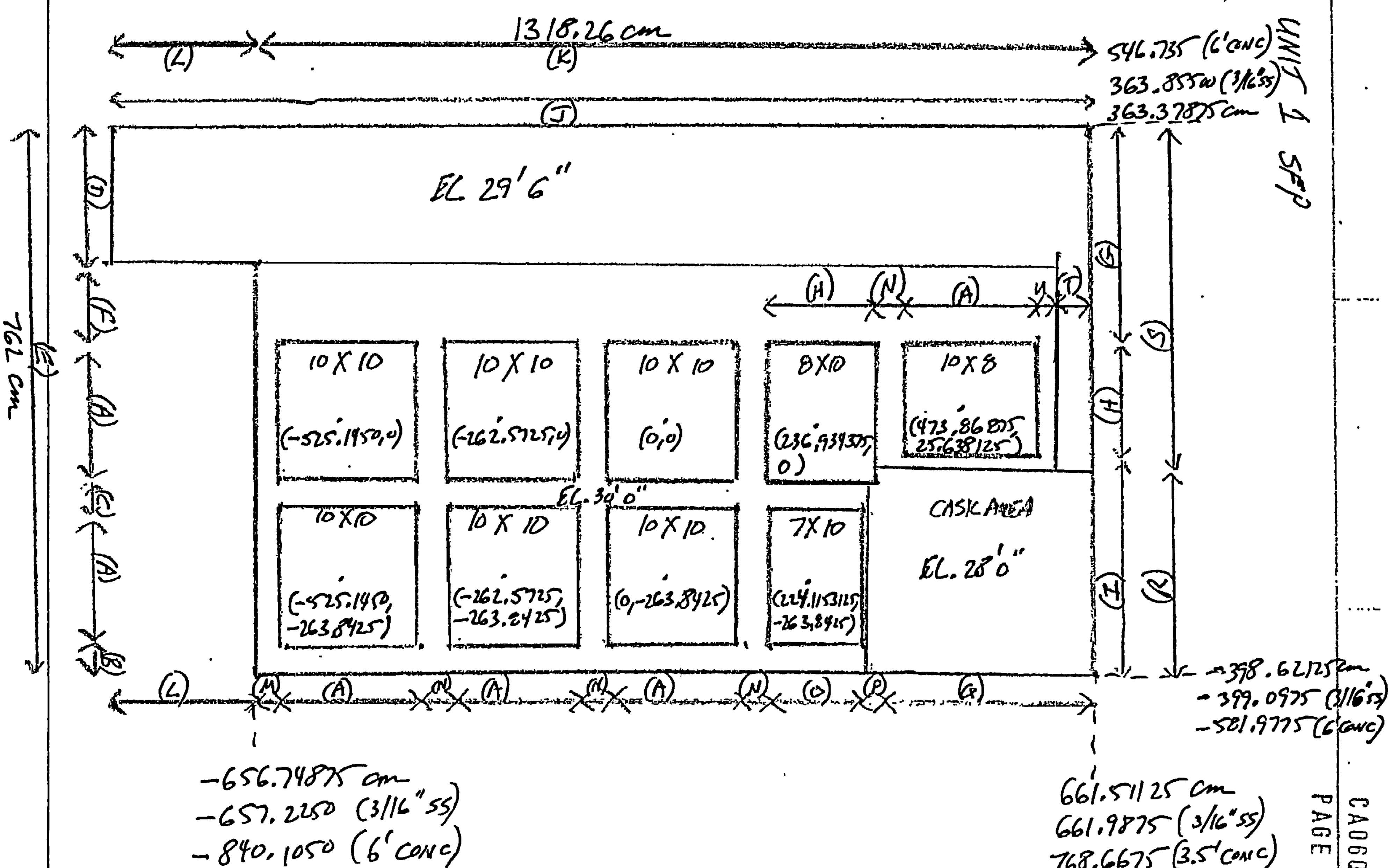
E X = -10.874375 Y = -9.750425

F X = Y = -9.750425

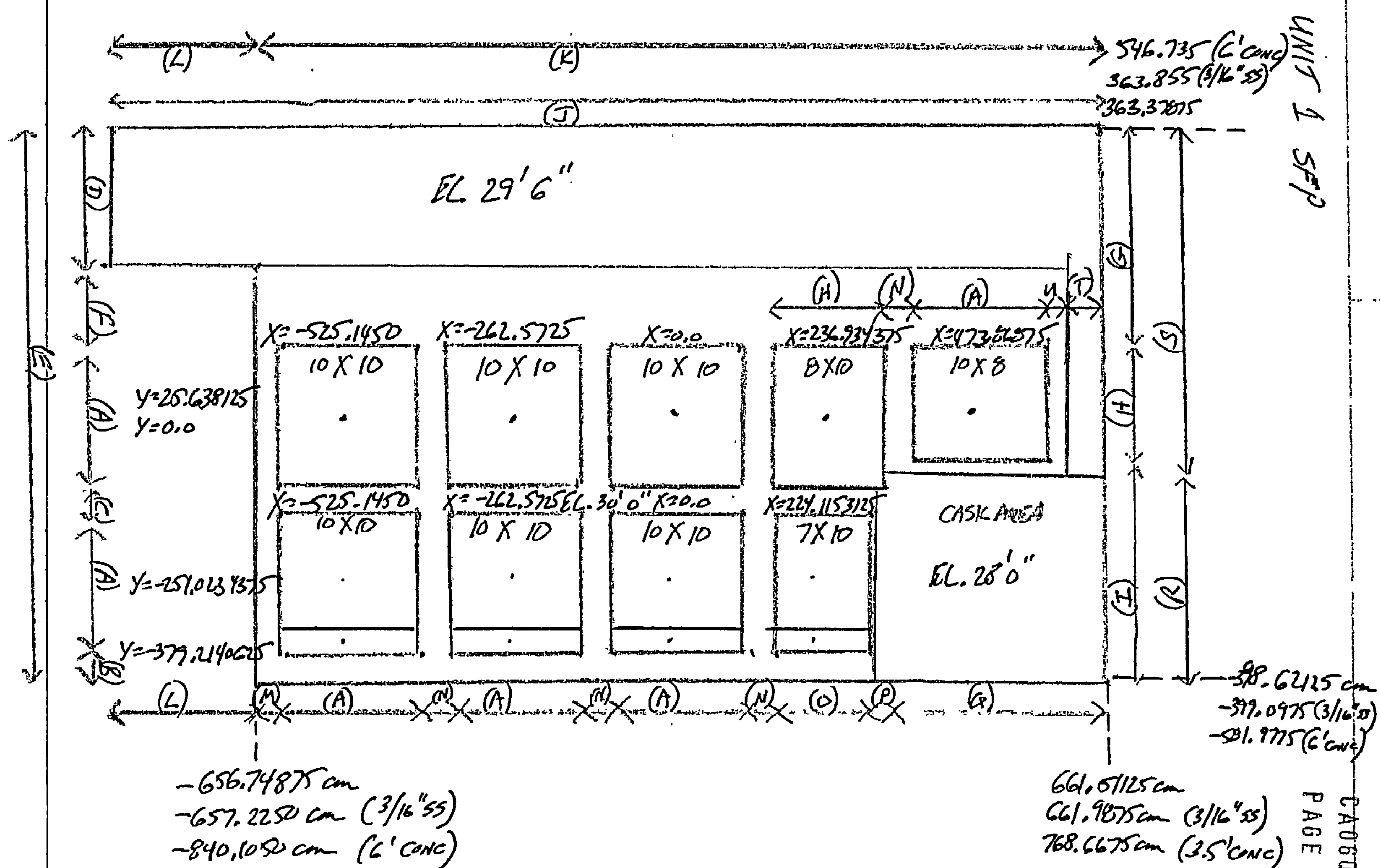
G X = Y = -10.874375

H X = -9.750425 Y = -10.874375

ATTACHMENT F
UNIT 1 SFP PLANAR GEOMETRY



1318.26 cm
(L)
(K)
546.735 (6' CONC)
363.8550 (3/16" SS)
363.37875 cm
UNIT 1 SFP
(J)
EL. 29'6"
762 Cm
(E)
(D)
(F)
(A)
(C)
(A)
(B)
(H)
(N)
(A)
(T)
(G)
(S)
(H)
(I)
(R)
10 X 10
(-525.1950,0)
10 X 10
(-262.57125,0)
10 X 10
(0,0)
8 X 10
(236.939375, 0)
10 X 8
(473.86875, 25.638125)
EL. 30'0"
10 X 10
(-525.1950, -263.8425)
10 X 10
(-262.5725, -263.8425)
10 X 10
(0,-263.8425)
7 X 10
(224.115312, -263.8425)
CASK AREA
EL. 28'0"
(L)
(M)
(A)
(N)
(A)
(N)
(A)
(N)
(O)
(P)
(Q)
-398.62125 cm
-399.0975 (3/16" SS)
-581.9775 (6' CONC)
-656.74875 cm
-657.2250 (3/16" SS)
-840.1050 (6' CONC)
661.51125 cm
661.9875 (3/16" SS)
768.6675 (3.5' CONC)


UNIT 1 SFP
546.735 (6' CONC)
363.855 (3/16" SS)
363.37875
EL 29'6"
X=-525.1450
X=-262.5725
X=0.0
X=236.934375
X=473.86875
10 X 10
10 X 10
10 X 10
8X10
10 X 8
Y=256.638125
Y=0.0
X=-525.1450
X=-262.5725
EL. 30'0"
X=0.0
X=224.1153125
10X10
10 X 10
10X10
7X10
CASK AREA
EL. 28'0"
Y=-257.0234375
Y=-379.2140625
-378.62125 cm
-379.0975 (3/16" SS)
-581.9775 (6' CONC)
-656.74875 cm
-657.2250 cm (3/16" SS)
-840.1050 cm (6' CONC)
661.51125 cm
661.9875 cm (3/16" SS)
768.6675 cm (3.5' CONC)

(A) 10 * 10.09375" = 100.9375" Ref. 15

(B) 2.5" + 0.09375" = 2.59375" Refs. 15 & 22

(C) 2.75" + 2 * 0.09375" = 2.9375" Refs 15 & 22

(D) 83.625" Ref. 22

(E) 25' 0" Ref. 22

(F) E − 2A − B − C − D = 8.96875" Refs. 15 & 22

(G) D + F = 92.59375" Refs. 15 & 22

(H) 8 * 10.09375" = 80.75" Ref. 15

(I) E − G − H = 126.65625" Refs. 15 & 22

(J) 54' 0" Ref. 23

(K) 43' 3" Refs. 22-23

(L) J − K = 10' 9" Refs. 22-23

(M) 1.25" + 0.09375" = 1.34375" Refs. 22-23

(N) 2.25" + 2 * 0.09375" = 2.4375" Refs. 22-23

(O) 7 * 10.09375" = 70.65625" Refs. 15 & 22

(P) K − 3A − M − 3N − O − Q = 4.875" Refs. 15-22-23

(Q) 11' 0" Ref. 23

(R) 9' 0" Ref. 23

(S) E − R = 16' 0" Refs. 22-23

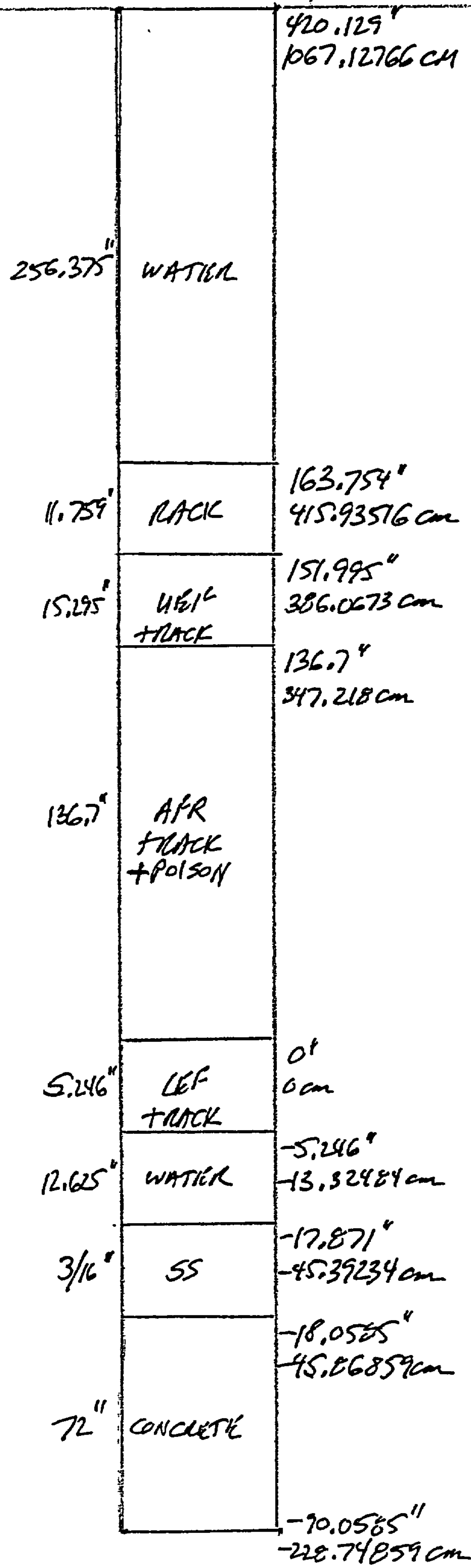
(T) 1' 6" Ref. 23

(U) O + P + Q − H − A − N − T = 5.40625" Ref. 23

(V) ELEVATIONS Ref. 23

ATTACHMENT G
UNIT 1 SFP AXIAL GEOMETRY

AXIAL GEOMETRY
(Reference 25)



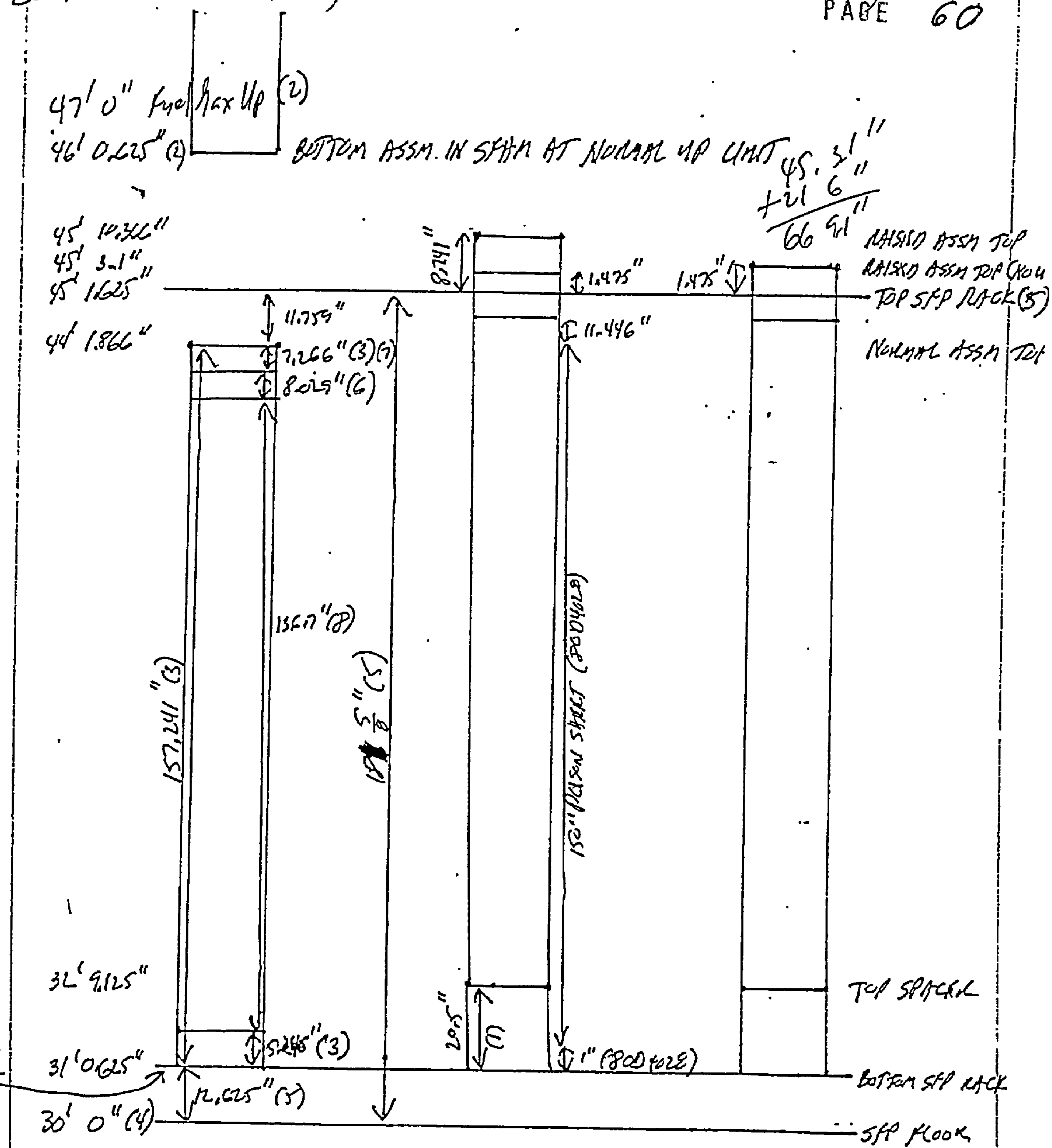
RECONSTITUTION AXIAL GEOMETRY

(Reference 25)

Thickness	Region	Elevation at top of region
247.634"	Water	420.129" / 1067.12766 cm
8.741"	Water + UEF	172.495" / 438.1373 cm
6.554"	Rack + UEF	163.754" / 415.93516 cm
20.5"	Rack + APR	157.20" / 399.288 cm
116.200"	Rack + Poison + APR	136.70" / 347.218 cm
5.246"	Rack + Poison + LEF	20.5" / 52.0700 cm
15.254"	Rack + Poison + Spacer	15.254" / 38.74516 cm
5.246"	Rack + Spacer	0" / 0 cm
12.625"	Water	-5.246" / -13.32484 cm
3/16"	SS	-17.871" / -45.39234 cm
72"	Concrete	-18.0585" / -45.86859 cm
	(bottom)	-90.0585" / -228.74859 cm

OP LIMIT – 67'
LL MSVM – 66.5'

SPENT FUEL POOL DIAGRAM



(1) E-FHST-501-099 Sh.1 Rev.1
(2) 15534-0001 Sh.3 Rev.7
(3) 12131-0250 Rev.0
(4) C284 Rev 1
(5) 13939-37 Rev.4
(6) 0-114-E000-003 Rev.2
NK4-52-374
(8) UFSAR T85 3.3-1