# Attachment J

(Spent Fuel Pool Dilution Analysis)

# SPENT FUEL POOL DILUTION ANALYSIS

## SAN ONOFRE NUCLEAR GENERATING STATION
## UNITS 2 AND 3

**DECEMBER, 2001**

**SOUTHERN CALIFORNIA EDISON COMPANY**

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## 1.0 INTRODUCTION

A boron dilution analysis has been completed for crediting soluble boron in the San Onofre Nuclear Generating Station (SONGS) Units 2 and 3 spent fuel rack criticality analysis. The boron dilution analysis includes an evaluation of the following plant specific features:

- Dilution Sources
- Dilution Flow Rates
- Boration Sources
- Instrumentation
- Administrative Controls
- Piping
- Loss of Offsite Power Impact
- Boron Dilution Initiating Events
- Boron Dilution Times and Volumes

The boron dilution analysis was performed to ensure that sufficient time, administrative procedures, and instrumentation are available to detect and mitigate the boron dilution before the spent fuel racks criticality analysis 0.95 $K_{eff}$ design basis is exceeded.

This analysis demonstrates that the final minimum boron concentration following a boron dilution event is 1,700 ppm. This soluble boron concentration is more conservative than the minimum boron concentration of 970 ppm required to maintain the spent fuel rack $K_{eff}$ less than 0.95 assuming normal plant operations during the dilution event. No other accidents, such as misloading a fuel assembly, are assumed to occur during the dilution accident.

## 2.0 SPENT FUEL POOL AND RELATED SYSTEM FEATURES

This section provides background information on the SONGS Units 2 and 3 spent fuel pool and its related systems and features.

### 2.1 Spent Fuel Pool

The purpose of the Spent Fuel Pool (SFP) is to provide safe storage for irradiated fuel assemblies. The SFP is filled with borated water. The water functions as a sink for decay heat generated by the irradiated fuel, as a shield to reduce personnel radiation exposure and to reduce the quantity of radioactive gases released to the environment following a fuel handling accident. Evaporation of SFP water occurs on a continuous basis due to the decay heat from irradiated fuel, and periodic SFP makeup is required. Because the evaporation process does not remove boron, makeup may be from an unborated water source. If the SFP is filled with borated water, evaporation may increase the boron concentration in the pool.

Each SONGS Unit has a separate SFP. The SFP is a reinforced concrete structure lined with 3/16" thick stainless steel welded liner plate. Behind the watertight liner plates are multiple horizontal and vertical chases which are connected by their individual drains to a leak detection sump. Observation of the leakage from the drains allows identification of the approximate location of the leak. The fuel handling building (FHB) and the SFP are designed as seismic Class I structures.

The SFP operating deck is located above grade at the 63.5 feet elevation of the fuel handling building. The nominal SFP water depth is 43.5 feet, which corresponds to the plant elevation of 61 feet or the level of 28 feet on the SFP ruler. The high water level alarm is at an elevation 61'-4", the low level alarm is at an elevation 59'-6" and the minimum water level is at an elevation 55'-11 15/16", which is 23 feet above the top of the stored fuel assemblies at an elevation 32'-11 15/16".

The plant elevations and water levels are summarized in Table 2-1.

Both of the SONGS Units 2 and 3 SFPs are divided into three areas which are thermally and hydraulically coupled, but are separated by gates. The larger area (the main SFP) is used primarily for the storage of fuel. One smaller area, the cask storage pool (CP) is used primarily for loading of fuel storage or transportation casks. Another smaller area is the fuel transfer pool, used during refueling.

The refueling canal (cavity) lies adjacent to the fuel transfer pool, and is connected to it by a transfer tube. The transfer tube is normally closed by an installed blind flange and a manually operated gate valve. If draining the refueling canal is desired following the completion of refueling operations, a gate is closed to isolate the refueling canal and the fuel transfer pool from the main SFP. A gate may also be closed to isolate the cask loading area from the main SFP; these gates are normally open to ensure SFP water quality. The elevation of both keyway bottoms is 35'-5 ½", which is above the top of the stored fuel assemblies at an elevation of 32'-11 15/16" (Table 2-1).

Considering the volume displaced by a full loading of irradiated fuel, the volume contained in the SFP (with the CP isolated) corresponding to the low level of 59'-6" is 349,931 gallons.

### 2.1.1 Spent Fuel Pool Overflow

The main SFP overflow line S2(3)1219ML041 is connected to the overflow line S2(3)1219ML021 from the fuel transfer pool which is connected to the overflow line S2(3)1219ML022 from the cask storage pool. All the above overflows are directed into the fuel handling building sump. The sump is provided with a HI-HI level switch S2(3)LSHH5827, which alarms in the control room (CR).

The Fuel Handling Building Sump is located at the elevation 17.5 ft, has an overall length of 4.8 ft by 3.9 ft wide by 6 ft deep. The sump houses two fuel handling building sump pumps, S2(3)2426MP328 and -329, with a nominal flowrate of 50 gpm. The sump pumps are operated by a hand-switch. The evaluation of line and sump volumes (Reference 1) identified the total volume up to the sump level switch setpoint to be 600 gallons.

The fuel building sump pumps are normally not in operation and are started manually after the HI-HI alarm. The response to the HI-HI alarm is per Alarm Response Instruction SO23-15-56.C, item 56C56 (Fuel Hdlg Bldg Sump Level HI-HI), which describes the Operations activity after that alarm. Specifically, alarm response instruction SO23-15-56.C requires inspection for leakage and performing a tour of the Fuel Handling Building to uncover the cause of the HI-HI level. Investigation showed that Operations personnel need about 30 minutes to perform this search. The time needed to uncover the real cause of the overflow has been identified by Operations to be 1 hour, based on the walkdown of the area. Thus, SFP overflow would cause HI-HI level after a transient volume of 600 gallons is filled, and the Operations can isolate the inflow 1.5 hours after the alarm sounds in the control room.

### 2.1.2 Required hydraulic head at the SFP overflow pipe

The top of the overflow elbow is at the elevation of 61'-5". To this elevation we will add a hydraulic head due to the flow into the elbow derived in Reference 1.

## 2.2 Spent Fuel Pool Storage Racks

The spent fuel storage racks provide for storage of new and spent fuel assemblies in the spent fuel pool, while maintaining a coolable geometry, preventing criticality, and protecting the fuel assemblies from excess mechanical or thermal loadings. Storage is divided into two regions within the pool. Region I has 312 locations and is generally reserved for temporary storage of new fuel or partially irradiated fuel which would not qualify for Region II storage. Region II has 1230 locations and is generally used for long term storage of permanently discharged fuel that has achieved qualifying burnup levels.

## 2.3 Spent Fuel Pool Cooling System

The SFP cooling system is designed to remove the decay heat generated by the irradiated fuel assemblies stored in the pool. The fuel pool cooling system consists of two pumps and two SFP heat exchangers (HXs) arranged in parallel with each pump capable of directing flow to either heat exchanger. Each SFP heat exchanger rejects heat to the component cooling water system which is cooled by the ultimate heat sink. Piping for the SFP cooling system is Seismic Category I and is arranged so that a piping failure will not drain the SFP below the top of the stored fuel assemblies. The SFP cooling system has piping ties with the safety injection system (shutdown cooling heat exchanger), which provides an alternate means of cooling the SFP.

The fuel pool cooling system suction line penetrates the pool liner at an elevation of 54'-10". The operating deck elevation is at 63.5 feet. The fuel pool cooling return line S2(3)-031-10"-D-LL0 enters the pool from above on the west side of the pool. The fuel pool cooling return line is equipped with an anti-siphon pipe S2(3)-080-1.5"-D-LL0, which has open ends at the elevation 58'-11". The top of the stored fuel assemblies is at 32' - 11 15/16".

The fuel pool cooling system is capable of removing the design basis heat loads as described in UFSAR Section 9.1.3.

## 2.4 Spent Fuel Pool Purification System

The SFP cleanup or purification system is designed to remove soluble and insoluble foreign matter from the SFP water and dust from the pool surface. This maintains the SFP water purity and clarity, permitting visual observation of underwater operations. The purification system interfaces with the SFP separate from the SFP cooling system and consists of a purification pump, a filter, an ion exchanger, an ion exchanger strainer, a surface debris skimmer, and various valves and instrumentation. Purification is conducted on an intermittent basis as required by SFP conditions. The fuel pool purification pump has a design flowrate of 150 gpm.

In addition to purifying the SFP water, the SFP makeup water from the refueling water tank(s) may be cleaned through connections to the purification loop.

## 2.5 Dilution Sources and Flowrates

Table 2-2 summarizes the credible dilution sources and associated flowrates. The listed events will be used in Section 3 for numerical evaluation of SFP boron dilution times and SFP boron concentration values. The dilution sources are discussed below.

### 2.5.1 Spent Fuel Pool Makeup System

The makeup which is evaluated here is the unborated water makeup, as that one has the potential for diluting the SFP. Makeup from the refueling water storage tank (RWST) would not result in dilution of the SFP, as RWST contains borated water with a minimum concentration of 2,350 ppm per Technical Specification 3.5.4.

The demineralized water makeup is proceduralized to assure that dilution will not occur. Procedure SO23-3-2.11.1 describes three ways of adding demineralized water to the SFP:

a) SFP makeup using primary makeup water (demineralized water) from SA1415MT055 and -056 to the SFP cooling pump.
b) SFP makeup (potentially demineralized water) from Radwaste Primary Tanks (RPTs) SA1901MT065 and -066.
c) SFP makeup (potentially demineralized water) from RPTs SA1901MT067 and -068.

Procedure SO23-3-2.11.1 uses a rigorous method for adding demineralized (unborated) makeup to the SFP. Prior to such makeup, the boron concentration in the SFP must be sampled, and an initial and final boron concentration determined by a calculation performed in the procedure, based on SFP initial and final water levels. Due to the rigorous nature of this administrative procedure, a potential operator error is eliminated. Thus the probability of transferring more than the required quantity of unborated makeup to the SFP is judged to be extremely low. However, for this evaluation, it is assumed that the operators will not isolate the primary makeup. This case is shown on Table 3-1, which shows that for an initial boron concentration of 2,000 ppm and when the SFP reaches the high level, and consequent high level alarm, the operators will have 280 minutes before the SFP boron concentration reaches the 1,700 ppm limit to verify that the possible makeup sources are closed. The Operations personnel will be able to isolate the makeup within this time.

### 2.5.1.1 Makeup from the Primary Plant Makeup Storage Tank(s)

Prior to the system alignment for makeup from the Primary Plant Makeup Storage Tank(s) SA1415MT055 and -056, procedure SO23-3-2.11.1 requires performing calculations of SFP volumes and boron concentration, as a result of the makeup. If these calculations show that SFP boron concentration following makeup would be ≥ 2,650 ppm, plant procedures permit SFP makeup to originate from the Primary Plant Makeup Storage Tanks. In this evaluation, the primary makeup water is assumed to contain 0 ppm soluble boron.

The makeup requires a specific valve alignment (opening normally closed valves, etc.). The Primary Makeup Storage Tank Pumps SA1415MP200, -201, -202 and -203 draw suction from the 300,000 gallon capacity Primary Makeup Storage Tanks SA1415MT055 and -056 (SO23-407-3-61). These tanks have high and low level alarms which annunciate locally and in the control room. The Unit 2 and 3 primary plant makeup storage tanks are filled by a flow from the radwaste deborating ion exchangers SA1415ME083 and -084.

Normally, one primary makeup tank pump is in service; the second pump remains in standby. Either pump is started manually by a handswitch and the pumps are prevented from starting (or are stopped) when low-low level takes place in the Primary Plant Makeup Storage Tank (at either Units 2 or 3). Each pump has a design flowrate of 160 gpm and provides flow to the coolant polishing demineralizer, from where the condensate is distributed to a variety of plant equipment. Thus, 160 gpm would be assumed to be directed to the SFP.

Prior to the makeup operation, the makeup mode selector hand switch is first selected to be in the manual mode. Then, for the demineralized makeup to be lined-up to the SFP, manual valves SA1901MU572 (Unit 2) or SA1901MU584 (Unit 3) need to be opened, in addition to manual valve S2(3)1901MU574. The primary makeup water pump is then manually started.

The contents of the Primary Plant Makeup Storage Tank(s) SA1415MT055(-056) can be transferred to the SFP through a single 3-inch branch line using the primary makeup tank pump(s) as motive force. The makeup line S2(3)1219ML071 connects to the SFP cooling pump(s) suction line S2(3)1219ML010 at approximately 38 foot elevation. Makeup to the SFP through this 3-inch line may be accomplished by opening the normally closed valves S2(3)1901MU574 and S2(3)1219MU096, which is the procedurally specified makeup path.

Normal Operating Procedure SO23-3-2.11.1 specifies that primary makeup flow is established by manually opening (2 - 4 turns) the 3" ASME Section III isolation valve S2(3)1219MU096 located by SFP HX at the elevation 30' of the FHB. The valve is then gradually opened. The primary makeup flow is indicated on CR flow indicator. The flow path is directed to the suction side of SFP Cooling Pumps.

Due to the rigorous administrative procedure used for adding makeup to the SFP, the probability of SFP dilution is very low.

#### 2.5.1.2 Makeup from the Radwaste Primary Tank(s) SA1901MT065/066

Makeup to the SFP from the Radwaste Primary Tanks (RPTs) is done through the SFP Purification Ion Exchanger S2(3)1219ME071, SFP purification discharge line, and into the SFP Cooling system. The SFP Purification pump S2(3)1219MP014 will be stopped (due to lack of miniflow during the transfer) and then restarted after the transfer.

Prior to the makeup, the Chemistry division will obtain a sample from the RPTs, to verify the boron concentration. If the boron concentration of the water in the RPTs is higher than 2,650 ppm, no additional calculation of the SFP final boron concentration is required, and, the makeup operation can proceed. If, however, the boron concentration in the RPTs is < 2,650 ppm, the calculation of final (after makeup) boron concentration in the SFP is required per procedure SO23-3-2.11.1. The makeup is only allowed, if the final SFP boron concentration is higher than 1,900 ppm with the SFP not connected to the Refueling Cavity, or, is ≥ 2,650 ppm with the SFP connected to the Refueling Cavity.

If the makeup to the SFP is allowed per the procedure, a crosstie path alignment is then established. The discharge valve S2(3)1219MU021 from the SFP purification pump S2(3)1219MP014 is closed, the pump miniflow isolation valve S2(3)1219MU098, the recirculation isolation valve SA1901MU410 to Radwaste Primary Tank SA1901MT065 and the recirculation isolation valve SA1901MU411 to Radwaste Primary Tank SA1901MT066 are closed. The RPT crosstie to Unit 2 (throttle valve S2(3)1219MU173) is opened. RPT crosstie to Unit 2 (isolation valve S2(3)1219MU172) is unlocked and opened.

Likewise, the valves in the RPT crosstie to Unit 3 are opened. To start the transfer of water, valve SA1901MU476 is opened and the RPT pump SA1901MP169 is started. The transfer flow is about 60 gpm. Communications must be established to communicate SFP level changes to the control room.

As the design flow of the RPT pump is 140 gpm, this case is bounded by the previous case in Section 2.5.1.1. Due to the rigorous administrative procedure for adding makeup to the SFP (plant procedure SO23-3-2.11.1), the probability of SFP dilution using this path is very low.

#### 2.5.1.3 Makeup from the Radwaste Primary Tank(s) SA1901MT067/068

The makeup from Primary Radwaste Tank(s) SA1901MT067/068 is similar to the makeup from tanks SA1901MT065/066 and the same rigor is used for the makeup alignment as outlined above. This case is bounded by the case described in Section 2.5.1.1. Due to the rigorous administrative procedure of adding makeup to the SFP, the probability of SFP dilution using this path is very low.

### 2.5.2 Nuclear Service Water Systems

Nuclear service water (NSW) is a demineralized water and it is used at both units for water service stations (hoses) and washdown stations. The NSW is delivered to the system by NSW pumps SA1415MP138 or -139, which take suction from the nuclear service water storage tank SA1415MT104. The NSW storage tank has a gross capacity of 26,550 gallons.

The makeup to the NSW storage tank is supplied from the demineralized water makeup, supplied by the Makeup Demineralizer (MUD) tanks SA1417MT266, -267, -268. Each MUD tank has a nominal capacity of 535,000 gallons, with a level controlled at a minimum of 75%. Procedure SO23-11-6, specifies that High Flow MUD system is operated when the level drops to 75%, to replenish the tank. Based on the above data, sufficient capacity exists in these tanks to provide makeup in case of postulated outflow from the NSW system.

There are 2 NSW pumps of nominal 200 gpm capacity, one in operation and one in standby, actuated by a low pressure signal in the pump discharge header. This double-pump NSW system is common to both Units 2 and 3 and the NSW is supplied throughout both Units 2 and 3. There are dedicated 1.5 inch pipe headers leading into each unit's fuel handling building.

The NSW piping is routed in the vicinity of the SFPs, specifically 1.5 inch line S2(3)1415-223-1.5"-R-LL1, which serves several water stations and is finally reduced to a 1 inch size (similar at both units).

In this case it is postulated that an operator forgets to close one hose station, thus allowing the hose to continue flowing at an estimated flowrate of 50 gpm.

Also, the NSW header will be evaluated for a pipe break flow. As the NSW piping is routed in the direct vicinity of the SFPs, and, the system is normally pressurized, this system is considered to a be viable source of boron dilution.

### 2.5.3 Component Cooling Water

Component cooling water (CCW) is the cooling medium for the SFP cooling heat exchangers. The CCW contains zero (0) boron. The portion of CCW that interacts with the SFP heat exchangers is seismic Category I. There is no direct connection between the component cooling water system and the SFP cooling water system. However, if a leak were to develop in either of the SFP heat exchangers (S2(3)1219ME003 or S2(3)1219ME004) while in service, a connection between the two systems would be made. As the CCW system operating pressure (110 psig) is higher than the SFP cooling system operating pressure (35 psig), the flow would be from the CCW to the SFP.

The CCW system contains a surge tank (S2(3)1203MT003/004) which is designed to accommodate fluid volumetric changes and to maintain a static pressure head at each CCW pump suction. Any leakage path between the fuel pool heat exchanger shell and tube sides will result in a reduction in the surge tank level and will cause demineralized water to be automatically added to the CCW surge tank via an automatic water level control system, with makeup from the nuclear service water.

Although the CCW surge tank has an automatic level control, should a major leakage occur, beyond the capacity of the makeup (200 gpm), low level would trigger a low level alarm in the control room. A calculation performed in Reference 1 has shown that the upper bound leak rate from a single failed tube is approximately 90 gpm. As the leak rate associated with the rupture of one tube is smaller than 200 gpm, a CCW surge tank low level alarm may not sound in the control room as a result of one broken heat exchanger tube.

Based on the above, the credible dilution scenario for the CCW is the rupture of the SFP Heat Exchanger tube.

### 2.5.4 Back-flushing the Fuel Pool Filter

Fuel Pool Filter S2(3)1219MF016 is backflushed periodically by using procedure SO23-8-3. The backflushing can be automatic or manual. Upstream/downstream process isolation valves must be closed prior to the backflushing. After that, nitrogen is used for backflushing the filter into the backflush filter crud tank T-073. The process of filter backflushing does not require the use of nuclear condensate, however, a connection is provided on the return line to the crud tank T-073 to allow flushing that line. The backflusing valves must be closed before the process valves are open, otherwise the system would not operate properly.

Specifically, during the back-flushing process, the process flow, i.e. the SFP purification flow, is isolated by closing the air-operated inlet/outlet valves 2(3)HV-7733A and 2(3)HV-7733B. The back-flush inlet/outlet valves 2(3)HV-7733C and 2(3)HV-7733D are then opened to allow the back-flushing to take place.

Based on the fact that backflushing of the filter uses nitrogen as the motive fluid, there is no boron dilution path during this alignment.

### 2.5.5 Resin Flush Line/Resin Fill for Spent Fuel Pool Ion Exchanger E-071

The resin transfer operation is performed approximately once each fuel cycle (18-24 months), to flush spent resin from the ion exchanger.

SFP ion exchanger S2(3)1219ME071 is equipped with resin charge/flush lines. Nuclear condensate is used for flushing the ion exchanger during this flushing operation. The nuclear condensate system is supplied by the nuclear service water system, by line SA1415-703-2"-J-LL0. The resin transfer is performed in accordance with procedure SO23-8-12. The procedure requires closing the process isolation valves upstream/downstream of the exchanger S2(3)1219MU028/032, thus the dilution with condensate would be limited only to the piping around the ion exchanger and the ion exchanger itself.

The opening as well as the closing of the nuclear condensate valve is done with administrative verification of valve alignment (an operator initial is required in the procedure to verify that the alignment has been made). In the case of this procedure there is a high degree of certainty that the alignment is performed, due to the structure of the procedure. Specifically, not only an alignment must be verified, but there are three valves (S2(3)1219MU056, S2(3)1219MU057 and S2(3)1219MU058) that are aligned (opened or closed) at the same time at specific steps of the procedure, and those valve numbers are displayed prominently in a special text box in the procedure.

The volume of condensate is thus limited to the volume of the exchanger and the associated process piping up to the isolation valves. This volume has been derived in Reference 1 to be 2000 gallons. Calculations documented for other dilution paths (see for example Table 3-7) show a very minimal dilution with dilution volume of 7,800 gallons. Thus, this dilution path need not be evaluated separately as it is bounded by all other evaluated dilution events.

### 2.5.6 Fire Protection System

In addition to the primary makeup water, the SFP room is served by two fire hose stations, fed by the plant fire protection system pumps, which take suction at the plant fire tanks. The quality of the fire tank water is similar to the domestic water, which contains zero boron. Two fire protection hose stations are located in the vicinity of the SFP (FHS 118 and 119 in Unit 2 and FHS 128 and 129 in Unit 3). These hose stations are supplied by the fire water system through a 4 inch header, that branches to 2.5 inch lines to each hose station. Normally closed isolation valves are used to control the delivery of water to the hoses, however in case of fire, it is assumed that both hoses will be deployed. Any discharge from the fire hose to the SFP would require its manual removal from the reel and operation by fire fighting personnel. A flow rate of 150 gpm is assumed to result from initiation of one fire hose flow. With 2 hoses, the total flow is 300 gpm.

A SFP dilution through a deployed fire hose is an evolution that is easily observable by operations personnel. As the fire loading in the SFP room is less than 1E7 Btu, the duration of the fire is only 0.02 hours (per SONGS 2 and 3 Fire Hazard Analysis, fire hazard area 2FH17-123) thus the quantity of fire water discharged into the SFP is only 360 gallons. Even if we assume more than twice the volume (1000 gallons), the dilution volume is too low to affect the boron concentration in the SFP significantly. The easy visibility combined with the operator involvement and low volume mean that fire water supplied to the SFP through the two hose stations is not a credible dilution path to dilute the SFP. Based on the above, the dilution source from fire fighting activities is bounded by all other evaluated dilution events, and will not be evaluated separately.

Another concern is a potential dilution stream due to leakage and/or crack in the fire protection header, which would divert unborated water into the SFP. As the fire water piping is routed in the direct vicinity of the SFPs, and, the fire protection water system is normally pressurized, this system is considered to be a viable source of boron dilution and is discussed in the next section.

### 2.5.7 Dilution from Pipe / Component Break Events

The fuel handling building is a seismic category I reinforced concrete structure containing the SFP, spent fuel cask area, refueling canal, spent fuel cooling and purification pumps, heat exchangers, filters and ventilation equipment. The FHB exterior walls, floors and partitions are designed to protect the equipment inside from the effects of hurricane and tornado winds, external missiles and flooding. The SFP portion of the FHB, including the walls and roof directly above the pool, is designed to withstand, without penetration, the impact of external missiles that might occur during the passage of a tornado. The SFP is located above grade with a pool floor elevation of 17.5 feet and an operating deck elevation of 63.5 feet.

The below Sections evaluate the relevant pipe/component break flows at Unit 2 (U3 is similar) piping in the vicinity of the SFP.

#### 2.5.7.1 Pipe Break in the Fire Water Header

SA-2301-051-4"-W-LS1 - Fire Water. This header branches off to other pipes/hose stations; however, for conservatism it is postulated that there is one pipe break in this main header. As the fire water has moderate pressure, a critical crack will be postulated. The pipe is 4 inch standard (std) weight (schedule 40), 4.026 inch internal diameter (ID), with 0.237 inch wall.

The critical crack flow has been determined in Reference 1 to be 110 gpm.

#### 2.5.7.2 Pipe Break in the Nuclear Service Water Header

S2-1415-223-1.5"-R-LL4 - Nuclear Service Water. This header branches off to other pipes/hose stations; however, for conservatism it is postulated that there is one pipe break in this main header. The pipe is stainless steel, schedule 40S, 1.61 inch ID, with 0.145 inch wall.
The critical crack flow has been determined in Reference 1 to be 30 gpm.

#### 2.5.7.3 Pipe Break in the SFP Cooling Water Return Header

S2-1219-025-12"-D-LL0 - SFP Cooling water return header. This header branches off to other smaller diameter pipes; however, for conservatism it is postulated that there is one pipe break in this main header. As the SFP cooling water has moderate pressure, a critical crack will be assumed in this piping. The pipe is schedule 10S, with 12.39" ID, and wall thickness of 0.18".
The critical crack flow has been determined in Reference 1 to be 130 gpm.

#### 2.5.7.4 Pipe Break in the SFP Cooling Water Suction Header

S2-1219-010-14"-D-LL0 - SFP Cooling water suction header. A critical crack will be assumed in this piping. The pipe is schedule 10S, with 13.624" ID, and wall thickness of 0.188". The critical crack flow has been determined in Reference 1 to be 107.2 gpm.

#### 2.5.7.5 Pipe Break in the Fuel Pool Purification Pump P-014 Discharge Header

S2-1219-018-3"-J-LL0, SFP Purification pump discharge header. A critical crack will be assumed in this piping. The pipe is schedule 10S, with 3.26" ID, and wall thickness of 0.12". The critical crack flow has been determined in Reference 1 to be 38 gpm.

#### 2.5.7.6 Tube Break in the SFP Heat Exchanger

SFP Heat Exchangers S2(3)1219ME005, -ME006 tube bundle features 490 3/4" tubes 22 gage of 304 stainless steel (S/S) material. Rupture of only 1 tube will be assumed.

The tube outside diameter (OD)= 0.75", and the tube wall is 0.028". The design pressure of the SFP cooling piping is 50 psi, and the operating pressure is 35 psi. The flow through a ruptured tube has been derived in Reference 1 to be 90 gpm.

#### 2.5.7.7 Pipe Break in the Demineralized Water Makeup

This makeup pipe (S2-1219-029-3"-J-LL0) is connected to the SFP cooling line at an elevation 20.75'. The effects of rupture of demineralized water makeup pipe S2-1219-029-3"-J-LL0 need not be considered, as they are bounded by the break in the 12" SFP cooling water return header line.

#### 2.5.7.8 Pipe Breaks due to Tornado Events

The effects of tornado or hurricane events have been reviewed and found to not result in any rupture of piping adjacent/associated with the SFP or related systems. As a result, dilution resulting from a tornado or hurricane is not a credible event.

#### 2.5.7.9 Crack in the SFP Liner Plate

The SFP liner plate is a 3/16" thick stainless steel welded plate. Behind the watertight liner plates are multiple horizontal and vertical chases which are connected by their individual drains to a leak detection sump. Observation of the leakage from the drains allows identification of the approximate location of the leak. Thus the liner plate leakage ends up directly in the Fuel Handling Building Sump, which is equipped with a HI-HI alarm. The transient volume of the leakage to result in the sump HI-HI level is conservatively estimated at 1000 gallons.

The leakage rate associated with SFP liner plate damage has been evaluated before in the licensing submittal for the SONGS 2 and 3 SFP re-racking (Licensing Amendment Applications 146 and 130, dated July 29, 1996 ) and it was identified as 49 gpm.

### 2.5.7.10 Leakage through the SFP Gates

As mentioned above, the SFP is connected to two other cavities, i.e. the cask pool and the fuel transfer pool. These cavities can be isolated from the SFP by bulkhead gates. The bulkhead gates are normally open in the SONGS Units 2 and 3 SFPs. However, this evaluation assumes that these two gates are closed (thus isolating the two cavities from the SFP), as that condition provides a smaller SFP initial volume. This is more conservative from the boron dilution standpoint, than the situation with the gates open. Leakage through the closed gates would require subsequent makeup, which represents a potential dilution scenario.

Each SFP bulkhead seal consists of 3'-5" wide by 28'-7.5" high gate with two independent pressurized bladders which provide redundant means for sealing the surfaces between the bulkhead gates and the SFP walls. These pressurized seals are constructed from heavy radiation resistant reinforced fabric. Both seals on each gate are held in place by a total of 174 two inch wide clips. Eighty-seven of these clips are welded to the gate and 87 clips are held in place by 174 screws.

The normal operating pressure of the seal is 20 psig and the motive air is the service air, backed-up by compressed air bottles. Low pressure switches at the south gate inner seal (2(3)PSL-7777A) and outer seal (2(3)PSL-7777B) alarm at the local SFP panel. Likewise, low pressure switches at the north gate inner seal (2(3)PSL-7778A) and outer seal (2(3)PSL-7778B) alarm at the local SFP panel.

The potential for the SFP gate leakage was a subject of NRC IE Bulletin 84-03 dated August 24, 1984. SCE responded to this IE Bulletin in a letter from M.D. Medford to USNRC dated October 26, 1984, which concluded that due to the redundant nature of the motive gas, and the seals, as well as low pressure alarms, it is not credible to postulate a leak in these pneumatic water seals, which would exceed the normal makeup capacity to the SFP.

### 2.5.8 Evaluation of Infrequent Spent Fuel Pool Configurations

### 2.5.8.1 Dilution of SFP with Cask Storage Area Isolated

Although unlikely, it is possible that the main SFP could be unintentionally isolated from the cask storage area. But as noted above, this evaluation already assumes the cask pool isolated, as this lineup is more conservative. Based on that, no additional calculations need to be done for this lineup.

### 2.5.8.2 Filling the Refueling Canal and Pool

To prepare for refueling activities, the fuel transfer (refueling) canal must be filled with borated water with at least 2,650 ppm boron, per procedure SO23-3-2.11.1. As noted previously, a bulkhead between the SFP and the transfer canal is normally open. However, prior to the refueling operations, the gate at the fuel transfer pool is closed, and, the borated water pumped out to a holding tank (such as Radwaste Primary Tank(s) SA1901MT067, 068), to facilitate the installation of the refueling equipment. The transfer pool is then refilled typically from the refueling pool side, which is filled from the RWST. Otherwise, plant procedures used for filling the transfer canal specify that makeup is taken directly from the RWST, which is a borated tank. Also, per plant procedures, the bulkheads between the pools may not be open until the water level in the corresponding areas is approximately equal to the water level in the SFP. Opening the bulkheads when the adjacent area is empty is thus precluded by plant operation procedures. Based on the fact that the boron concentration during refueling is higher than 2,600 ppm, this case is bounded by previous SFP boron dilution cases.

### 2.5.8.3 SFP Dilution During Fuel Shipment

Fuel shipment out of the SFP (to dry cask storage or other destinations) is an infrequent operation, and during this operation the SFP low level is lower than during normal operation. The water levels during fuel shipment will not be used except for the worst-case scenario (Case 7), which will be verified (Table 3-7A) with the SFP LL setpoint lowered to 57.667 ft from the normal 59.5 ft.

It should be noted that the likelyhood of SFP overflow during this operation is extremely low, as operation personnel are present during the fuel trans-shipment, and, this operation requires a specially lowered water level. Thus rising water level in the pool would not go un-noticed, and using the operator response times, as used in the other scenarios, is extremely conservative.

Due to the operators' presence, this evaluation assumes that the makeup would be isolated within 60 minutes after the SFP HI level alarm.

## 2.6 Boration Sources

The normal source of borated water to the SFP is from the RWST. It is also possible to borate the SFP through the addition of dry boric acid directly to the SFP water. The boration sources are listed here for information only, and as such they will not be considered as boron dilution sources in this evaluation, because the boron concentration of these sources is higher than the boron concentration of the SFP.

### 2.6.1 Refueling Water Storage Tank(s)

There are two 245,000 gallon Refueling Water Storage Tanks (RWSTs) per unit, S2(3)1204MT005, 006. Both tanks are cross-connected by a 24 inch cross-connecting pipe, resulting in the combined nominal volume of 490,000 gallons. The RWST(s) are connected to the SFP purification loop through a three inch feed line (S2(3)1219ML018) via the SFP Makeup Pump S2(3)1219MP011 and a four inch return line (S2(3)1219ML036). These connections are used as a flow path for makeup to the SFP from the RWST and also may be used to process the contents of the RWST through the purification filters and ion exchanger. Using the makeup flow path, the makeup pump can supply a makeup flow rate to the SFP of approximately 160 gpm. Technical Specification 3.5.4 requires that the boron concentration in the RWST be maintained at least 2,350 ppm (in the range from 2,350 ppm to 2,800 ppm). The RWST boron is normally maintained ≥2,650 ppm, for refueling purposes.

### 2.6.2 Boric Acid Makeup Tanks

The contents of either BAMU tank (S2(3)1218MT071 or S2(3)1218MT72) can be directed to the RWST S2(3)1204MT006 by using a blending tee which mixes demineralized water with the borated water from the BAMU pumps S2(3)1218MP174 or S2(3)1218MP175 to a selected mix concentration. From the RWST, this fluid may be used to borate the SFP. To pass flow from the BAMU tanks to the RWST, a number of valves must be repositioned to utilize this non-standard lineup. To be in service (operable), LCS 3.1.104 requires the BAMU tanks to contain at least 4150 gallons of water with a concentration of greater than 4371 ppm boron.

### 2.6.3 Direct Addition of Boric Acid

If necessary, the boron concentration of the SFP can be increased by emptying barrels of dry boric acid directly into the SFP. The dry boric acid will dissolve in the SFP water and will be mixed throughout the pool by the SFP cooling system flow and by the thermal convection created by the SFP decay heat.

## 2.7 Loss of Offsite Power (LOOP)

Of the dilution sources listed in Section 2.5, only the fire water and CCW piping are capable of providing non-borated water to the SFP during a loss of offsite power (LOOP), coincident with a postulated pipe break. This is because the fire water system is equipped with a diesel-driven fire pump (SA2301MP220), and, the CCW pumps are automatically loaded on the emergency diesel generators (S2(3)2420MG002/003). Plant annunciators, including the control room (such as for SFP level and temperature annunciation) are powered by 125 Volt DC non-1E power supply, so they should be operable following a LOOP.

A LOOP would also affect the ability to respond to a dilution event. The fuel pool purification pump S2(3)1219MP014 is not automatically loaded on the emergency diesel generators. Manual boron addition could be used if it became necessary to increase spent fuel boron concentration during a LOOP.

The SONGS Unit 2 and 3 SFP cooling pumps S2(3)1219MP009 and S2(3)1219MP010 are not automatically loaded onto the emergency diesel generators in the event of a LOOP.

In conclusion, the only potential dilution sources after the LOOP will be the fire water and the CCW water, which are already addressed in Sections 2.5.6 and 2.5.3, and, the affects thereoff are evaluated.

## 2.8 Piping

There are no systems (other than those listed in Sections 2.5.6 and 2.5.7) identified which have piping in the vicinity of the SFP which could result in a dilution of the spent fuel pool if they were to fail.

Fire protection and nuclear service water, if damaged, could provide a source of SFP dilution. However, the effects of these dilutions are bounded by the effects of primary water system makeup into the SFP, associated with postulated operator errors.

## 2.9 Spent Fuel Pool Instrumentation

Instrumentation is available at SONGS Units 2 and 3 to monitor SFP water level and temperature. Additional instrumentation is available to monitor the status of each SFP cooling pump, the pump discharge line pressure and the upstream/downstream temperatures of the SFP heat exchangers. Local instrumentation is available to indicate the purification pump discharge pressure and temperature.

The instrumentation provided to monitor the SFP water level and temperature has a local indication and is annunciated in the control room. The SFP water level is maintained at a nominal elevation between 59'-6"(low) and 61'-4"(high). High level alarm (at 61'-4") annunciates in the control room. Low level alarm (at 59'-6") is annunciated locally.

## 2.10 Administrative Controls

The following administrative controls are in place to control and monitor the SFP boron concentration and water inventory:

A. The SFP boron concentration must be verified in accordance with LCS 3.7.116 at least every 30 days. This is done per chemistry procedure SO123-III-1.1.23 on a weekly basis.

B. The SFP water level must be verified in accordance with LCS 3:7.117 at least every 7 days. This is done on a weekly basis by plant procedures per SO23-3-3.27 and SO23-3-3.27.1.

C. Plant procedure SO23-3-2.11.1 requires sampling the SFP for boron concentration following makeup with a un-borated water source (e.g. step 2.4.7 in Attachment 1 of the procedure).

D. Administrative controls on the use of the primary makeup dilution paths are present. Administrative controls are also present for the positioning of the valves in the lines connecting the RWST and SFP (see procedure SO23-3-2.11.1).

**Table 2-1: SFP Elevations**

| Condition | Water level | Plant Elevation |
|---|---|---|
| SFP operating deck | N.A. | 63.5 ft |
| nominal level | 43.5 ft | 61 ft |
| high level alarm | 43.833 ft | 61'-4" |
| low level alarm | 42 ft | 59'-6" |
| minimum level | 38.4375 ft | 55'-11 15/16" |
| top of stored fuel assemblies | 15.4375 ft | 32'-11 15/16" |

| Table 2-2: Dilution Summary | | | |
|---|---|---|---|
| **Dilution Source** | | **Break Flow** | **Max Dilution** |
| 1. | Normal Primary Water System makeup from T-055/-056 | NA | 160 gpm |
| 2. | Primary Water System makeup from T-055/-056 | 1 gpm | 160 gpm |
| 3. | NSW Addition through (1) service hose | NA | 50 gpm |
| 4. | NSW pipe break near the SFP | 30 gpm | 30 gpm |
| 5. | Rupture of 1 tube in the SFP Heat Exchanger | 90 gpm | 90 gpm |
| 6. | Pipe Break in the Fire Water Header | 110 gpm | 160 gpm |
| 7. | Pipe Break in the SFP Cooling Water Return Header | 130 gpm | 160 gpm |
| 7A. | Same as case 7, but during fuel shipment | 130 gpm | 160 gpm |

# 3.0 SPENT FUEL POOL DILUTION EVALUATION

## 3.1 Calculation of Boron Dilution Times and Volumes

This evaluation uses only the volume of the SFP (while the cask pool gate and transfer pool gate are normally open, they are assumed closed for conservatism), as this results in conservative boron concentration values after dilution as compared to the volumes with the cask pool and transfer pool connected with the SFP. The total pool volume at the start of the dilution is 349,931 gallons, which corresponds to the LL level in the SFP, when the cask pit is isolated. The low level represents the volume of the SFP filled to the low elevation of 59.5'. This value of pool volume is derived by using the procedure SO23-3-2.11.1, which accounts for the water displaced by the fuel storage racks and the contained fuel assemblies.

For the purposes of identifying the dilution times and volumes, the initial SFP boron concentration is assumed to be at the proposed Technical Specification 3.7.17 limit of 2,000 ppm. This evaluation assumes thorough mixing of all non-borated water added to the SFP.

The time to dilute depends on the initial volume of the SFP and the postulated rate of dilution. The dilution times and required volumes for the considered dilution events will be calculated based on the below methodology.

### 3.1.1 Boron Concentration Derivations When the Makeup Does Not Result in an Overflow

For SFP water levels up to the SFP overflow, the boron concentration is calculated based on mix correlations, as follows:

$$Cfinal = (V1 * Cinit) / (V1 + dV) \quad [ppm] \qquad \ldots (1)$$

where:
V1 ... Initial volume of SFP [gal]
dV ... Added volume of unborated makeup [gal]
Cinit ... Initial boron concentration in the SFP (relative to volume V1) [ppm]
Cfinal ... Final boron concentration after unborated makeup with volume dV [ppm]

### 3.1.2 Boron Concentration Derivations When the Makeup Results in an Overflow

When the SFP overflows as a result of unborated makeup, this is considered to be a 'feed and bleed' process, with the SFP volume to remain essentially same. The water head required for the overflow is neglected in this evaluation, thus the volume at the overflow would be assumed to be equal to the SFP volume at the overflow level.

The rate of change of boron concentration in the SFP is then described by the following equation

$V * dC/dt = -QC$ [ppm] ... (2)

where:

V -SFP volume corresponding to overflow level (365,075 gallons for SFP only ) [gal]
C -SFP boron concentration [ppm]
Q -Volumetric flowrate of unborated water [gpm] (assumed constant)
t - Dilution time [min]

The solution of Equation 2 can be written as:

$C(t) = Cinit * e^{-t/tau}$ [ppm] ... (3)

where:

Cinit -Initial boron concentration [ppm]
C(t) -Boron concentration after t minutes [ppm]
tau = V/Q = boron dilution time constant [min]

In terms of the total added makeup, the Equation 3 can be expressed in terms of the initial SFP volume V, added makeup volume, say Vmakeup and initial and final concentrations, as follows:
Vmakeup = Q * t

thus, $C(t) = Cinit * e^{-t/(V/(Vmakeup/t))}$

and, $C(t) = Cinit * e^{-(Vmakeup/V)}$ [ppm] ... (4)

To calculate the time required to reach a specific boron value, the original Equation 3 can be re-written as:

$t = \ln(Cinit / C(t)) * V/Q$

or

$t = \ln(Cinit / C(t)) * tau$ [min] ... (5)

### 3.1.3 Dilution Calculation Example

Determine SFP volumes in the range of concern (from LL to OVFL) per page 91 of SO23-3-2.11.1:

In the range of LL-OVFL: Volume of 1 ft. of SFP = 7,572 gallons

As an example, a dilution by unborated makeup at 160 gpm is evaluated. The operator is assumed to start makeup after the SFP low level alarm is annunciated in the control room. The low level setpoint is 59.5 ft. and the alarm is assumed to sound after a 0.25 inch band.

Thus the makeup is started when the SFP is at the following level:

59.5 - 0.25/12 = 59.479 ft.

The SFP volume corresponding to elevation 59.479 ft is 349,773 gallons.

The overflow elevation is 61'-5" ft. The hydraulic head associated with the overflow (per Reference 1) is:

Hofl = $Q^2$ / 162,844 = 0.157 ft.

Thus the overflow elevation will be:

61.417 + .157 = 61.574 ft.

Adding 2.095 ft. of water from elevation of 59.479 ft. to 61.574 ft. represents adding 15,863 gallons of unborated water to the SFP. If the initial boron concentration was 2,000 ppm, the final concentration is calculated as follows:

V1 = 349,773 gallons
dV = 15,863 gallons
Cinit = 2,000 ppm
Cfinal = (V1 * Cinit) / (V1 + dV) = 1,913 ppm

The SFP volume corresponding to the elevation 61.574 ft is 365, 636 gallons.

Now, adding 7,935 gallons of unborated water to the volume of 365,636 gallons with initial concentration of 1,913 ppm would result in following final concentration:

V1 = 365,636 gallons
dV = 7,935 gallons
Cinit = 1,913 ppm

Cfinal = Cinit * $e^{-(dV/V1)}$ = 1,872 ppm

### 3.2 Evaluation of Boron Dilution Events

The SFP boron concentrations for bounding boron dilution events at SONGS Units 2 and 3 (Table 2-2), are derived by using the methodology described above in Section 3.1.

The dilution flowrates from Table 2-2 are used as an input in specific boron concentration calculations, which are documented in Tables 3-1 through 3-7A.

The minimum final boron concentration after dilution is 1700 ppm (Reference 2). Also, the gallons required to dilute to 970 ppm will be calculated to show the available margin.

The selected dilution flows are considered to be added (not simultaneously) until the time when they are isolated (either 60 minutes from SFP HI level alarm, or 90+ minutes from SFP overflow, based on Fuel Handling Building Sump HI-HI level alarm).

The dilution calculations are performed in spreadsheet tables as summarized below:

| Dilution Source (Table 2-2) | Table |
|---|---|
| 1. Normal Primary Water System makeup from T-055/-056 | Table 3-1 |
| 2. Primary Water System makeup from T-055/-056 after minor SFP outflow | Table 3-2 |
| 3. NSW Addition through (1) service hose | Table 3-3 |
| 4. NSW pipe break near the SFP | Table 3-4 |
| 5. Rupture of 1 tube in the SFP Heat Exchanger | Table 3-5 |
| 6. Pipe Break in the Fire Water Header | Table 3-6 |
| 7. Pipe Break in the SFP Cooling Water Return Header | Table 3-7 |
| 7A. Same as case 7, but during fuel shipment | Table 3-7A |

### 3.3 Summary of Boron Dilution Events

The boron dilution results are summarized in Table 3-8.

It is concluded that an unplanned or inadvertent event which would result in the dilution of the SFP boron concentration below 1,700 ppm from an initial concentration of 2,000 ppm is a not a credible event.

The following discussion applies:

A. Boron dilution during normal primary make-up (flowrate = 160 gpm) would have to continue for 4.6 hours after the SFP HI level alarm is sounded in the control room for the boron concentration to be diluted from initial 2,000 ppm to 1,700 ppm (see Table 3-1). This would be adequate time for the operators to isolate the makeup.

B During normal primary makeup, in the unlikely event that the Operators neglect or do not get the SFP HI level alarm, the primary make-up flowrate of 160 gpm will continue and the water will reach an overflow level. After the SFP overflows, water will spill into the fuel handling building sump, which is equipped with a HI-HI alarm. This alarm will be triggered and annunciated in the control room about 4 minutes after the SFP starts to overflow. The alarm response procedure SO23-15-56.C requires the operators to determine the cause of the sump HI-HI level. The operating staff have concluded that this activity can be accomplished within half an hour after the HI-HI alarm is sounded. Another 1 hour would be needed to isolate the inflow, thus the total time to isolate the in-leakage would be 94 minutes after the SFP starts to overflow. Based on the above, the inflow would be isolated when the boron concentration in the SFP reaches about 1,836 ppm.

C. The above discussions illustrate that there are two separate opportunities for the operators to isolate the SFP unborated inflow, based on two different alarms. The alarm associated with the SFP HI level is annunciated in the control room at panel 61, while the Fuel Handling Building Sump HI-HI level alarm is annunciated in the control room at panel 56. This alarm multiplicity prevents further long-term dilution of the SFP (longer than about 193 minutes during the above mentioned normal primary makeup per Table 3-1). This multiple alarm is applicable to all evaluated scenarios in this evaluation, because the SFP dilution means extended inflow of unborated water to the pool.

D. The normal makeup paths to the SFP from the primary makeup water system and the nuclear service water system are maintained closed.

E. In-place administrative controls on the primary letdown path from the SFP (return line to the RWST) ensure that any prolonged, inadvertent SFP makeup would result in pool overflow.

F. Besides documenting the required dilution volumes to dilute the SFP to 1,700 ppm boron, the following tables show for information the dilution volumes which would dilute the SFP to 970 ppm boron, to illustrate the dilution margin.

## Table 3-1: SFP Boron Dilution Due To Primary Makeup

**Makeup Flow= 160 [gpm]**

**Makeup is started after SFP LL alarm sounds in the control room**

**Makeup can be isolated 60 minutes after SFP HL alarm, or**

**Makeup can be isolated 90 minutes after sump HI-HI alarm, which is,**

**94 [min] after SFP overflow**

**SFP dilution (from LL level to >OFL) from Cinit= 2,000 [ppm]**

| SFP Condition | Total Makeup added [Gal] | Makeup Flow [gpm] | Time after SFP LL alarm [min] | Time after SFP HL alarm [min] | Time after SFP overflow [min] | Final boron conc. [ppm] |
|---|---|---|---|---|---|---|
| SFP overflowing | 264,100 | 160 | 1,711 | 1,562 | 1,551 | **970** |
| SFP overflowing | 58,980 | 160 | 429 | 280 | **269** | **1,700** |
| SFP overflowing | 30,929 | 160 | 253 | 105 | **94** | **1,836** |
| SFP overflowing | 23,858 | 160 | 209 | **60** | 50 | **1,872** |
| SFP overflowing | 15,861 | 160 | 159 | 10 | 0 | **1,913** |
| OFL pipe level | 14,671 | 160 | 152 | 3 | | **1,919** |
| HL alarm | 14,198 | 160 | 149 | 0 | | **1,922** |
| HL setpoint | 14,040 | 160 | 148 | | | **1,923** |
| LL setpoint | 158 | 160 | 61 | | | **1,999** |
| LL alarm | 0 | 160 | 60 | | | **2,000** |
| OP starts MU | 0 | 160 | 60 | | | **2,000** |

Note: It would take 264,100 gallons of unborated water to dilute the SFP to 970 ppm boron.

## Table 3-2: SFP Boron Dilution Due To Primary Makeup After Minor Leak

**Leak Flow=** 1 [gpm]
**Makeup Flow=** 160 [gpm]

**Leakage results in SFP level reduction below LL alarm,**
**60 minutes after LL alarm, makeup is started at a full makeup flow of 160 gpm.**
**Makeup can be isolated 60 minutes after SFP HL alarm, or**
**Makeup can be isolated 90 minutes after sump HI-HI alarm, which is,**
**94 [min] after SFP overflow**

**SFP dilution (from LL level to >OFL) from Cinit= 2,000 [ppm]**

| SFP Condition | Total Makeup added [Gal] | Makeup Flow [gpm] | Time after SFP LL alarm [min] | Time after SFP HL alarm [min] | Time after SFP overflow [min] | Final boron conc. [ppm] |
|---|---|---|---|---|---|---|
| SFP overflowing | 264,100 | 160 | 1,711 | 1,562 | 1,551 | **970** |
| SFP overflowing | 58,980 | 160 | 429 | 280 | **269** | **1,700** |
| SFP overflowing | 30,929 | 160 | 253 | 104 | **94** | **1,836** |
| SFP overflowing | 23,858 | 160 | 209 | **60** | 50 | **1,872** |
| SFP overflowing | 15,921 | 160 | 160 | 10 | 0 | **1,913** |
| OFL pipe level | 14,731 | 160 | 152 | 3 | | **1,919** |
| HL alarm | 14,258 | 160 | 149 | 0 | | **1,922** |
| HL setpoint | 14,100 | 160 | 148 | | | **1,922** |
| LL setpoint | 218 | 160 | 61 | | | **1,999** |
| LL alarm | 60 | 160 | 60 | | | **2,000** |
| OP starts MU | 0 | 160 | 60 | | | **2,000** |

Note: It would take 264,100 gallons of unborated water to dilute the SFP to 970 ppm boron.

## Table 3-3: SFP Boron Dilution Due To One Flowing NSW Hose

**Hose Flow= 50 [gpm]**

**Inflow results in SFP level increase from LL**

**Inflow can be isolated 60 minutes after SFP HL alarm, or**

**Inflow can be isolated 90 minutes after sump HI-HI alarm, which is,**

**102 [min] after SFP overflow**

**SFP dilution (from LL level to >OFL) from Cinit= 2,000 [ppm]**

| SFP Condition | Total Inflow added [Gal] | SFP Inflow [gpm] | Time after SFP LL alarm [min] | Time after SFP HL alarm [min] | Time after SFP overflow [min] | Final boron conc. [ppm] |
|---|---|---|---|---|---|---|
| SFP overflowing | 263,400 | 50 | 5,268 | 4,984 | 4,972 | **970** |
| SFP overflowing | 59,000 | 50 | 1,180 | 896 | **884** | **1,700** |
| SFP overflowing | 19,887 | 50 | 398 | 114 | **102** | **1,892** |
| SFP overflowing | 17,198 | 50 | 344 | **60** | 48 | **1,906** |
| SFP overflowing | 14,787 | 50 | 296 | 12 | 0 | **1,919** |
| OFL pipe level | 14,671 | 50 | 293 | 9 | | **1,919** |
| HL alarm | 14,198 | 50 | 284 | 0 | | **1,922** |
| HL setpoint | 14,040 | 50 | 281 | | | **1,923** |
| LL setpoint | 158 | 50 | 3 | | | **1,999** |
| LL alarm | 0 | 50 | 0 | | | **2,000** |
| Inflow starts | 0 | 50 | 0 | | | **2,000** |

Note: It would take 263,400 gallons of unborated water to dilute the SFP to 970 ppm boron.

# Table 3-4: SFP Boron Dilution Due To Cracked NSW Header

**Break Flow= 30 [gpm]**

**Inflow results in SFP level increase from LL**

**Inflow can be isolated 60 minutes after SFP HL alarm, or**

**Inflow can be isolated 90 minutes after sump HI-HI alarm, which is,**

**110 [min] after SFP overflow**

**SFP dilution (from LL level to >OFL) from Cinit= 2,000 [ppm]**

| SFP Condition | Total Inflow added [Gal] | SFP Inflow [gpm] | Time after SFP LL alarm [min] | Time after SFP HL alarm [min] | Time after SFP overflow [min] | Final boron conc. [ppm] |
|---|---|---|---|---|---|---|
| SFP overflowing | 263,300 | 30 | 8,777 | 8,303 | 8,286 | **970** |
| SFP overflowing | 59,000 | 30 | 1,967 | 1,493 | **1,476** | **1,700** |
| SFP overflowing | 18,013 | 30 | 600 | 127 | **110** | **1,902** |
| SFP overflowing | 15,998 | 30 | 533 | **60** | 43 | **1,913** |
| OFL* | 14,713 | 30 | 490 | 17 | 0 | **1,919** |
| OFL pipe level | 14,671 | 30 | 489 | 16 | | **1,919** |
| HL alarm | 14,198 | 30 | 473 | 0 | | **1,922** |
| HL setpoint | 14,040 | 30 | 468 | | | **1,923** |
| LL setpoint | 158 | 30 | 5 | | | **1,999** |
| LL alarm | 0 | 30 | 0 | | | **2,000** |
| Inflow starts | 0 | 30 | 0 | | | **2,000** |

Note: It would take 263,300 gallons of unborated water to dilute the SFP to 970 ppm boron.

# Table 3-5: SFP Boron Dilution Due To One Failed SFP H-X Tube

**Break Flow= 90 [gpm]**

**Inflow results in SFP level increase from LL**

**Inflow can be isolated 60 minutes after SFP HL alarm, or**

**Inflow can be isolated 90 minutes after sump HI-HI alarm, which is,**

**97 [min] after SFP overflow**

**SFP dilution (from LL level to >OFL) from Cinit= 2,000 [ppm]**

| SFP Condition | Total Inflow added [Gal] | SFP Inflow [gpm] | Time after SFP LL alarm [min] | Time after SFP HL alarm [min] | Time after SFP overflow [min] | Final boron conc. [ppm] |
|---|---|---|---|---|---|---|
| SFP overflowing | 263,500 | 90 | 2,928 | 2,770 | 2,761 | **970** |
| SFP overflowing | 59,000 | 90 | 656 | 498 | **488** | **1,700** |
| SFP overflowing | 23,750 | 90 | 264 | 106 | **97** | **1,872** |
| SFP overflowing | 19,598 | 90 | 218 | **60** | 51 | **1,894** |
| SFP overflowing | 15,047 | 90 | 167 | 9 | 0 | **1,918** |
| OFL pipe level | 14,671 | 90 | 163 | 5 | | **1,919** |
| HL alarm | 14,198 | 90 | 158 | 0 | | **1,922** |
| HL setpoint | 14,040 | 90 | 156 | | | **1,923** |
| LL setpoint | 158 | 90 | 2 | | | **1,999** |
| LL alarm | 0 | 90 | 0 | | | **2,000** |
| Inflow starts | 0 | 90 | 0 | | | **2,000** |

Note: It would take 263,500 gallons of unborated water to dilute the SFP to 970 ppm boron.

# Table 3-6: SFP Boron Dilution Due To Cracked Fire Water Header

**Break Flow= 110 [gpm]**

**Inflow results in SFP level increase from LL**

**Inflow can be isolated 60 minutes after SFP HL alarm, or**

**Inflow can be isolated 90 minutes after sump HI-HI alarm, which is,**

**95 [min] after SFP overflow**

**SFP dilution (from LL level to >OFL) from Cinit= 2,000 [ppm]**

| SFP Condition | Total Inflow added [Gal] | SFP Inflow [gpm] | Time after SFP LL alarm [min] | Time after SFP HL alarm [min] | Time after SFP overflow [min] | Final boron conc. [ppm] |
|---|---|---|---|---|---|---|
| SFP overflowing | 263,700 | 110 | 2,397 | 2,268 | 2,259 | **970** |
| SFP overflowing | 59,000 | 110 | 536 | 407 | **398** | **1,700** |
| SFP overflowing | 25,738 | 110 | 234 | 105 | **95** | **1,862** |
| SFP overflowing | 20,797 | 110 | 189 | **60** | 51 | **1,888** |
| SFP overflowing | 15,233 | 110 | 138 | 9 | 0 | **1,917** |
| OFL pipe level | 14,671 | 110 | 133 | 4 | | **1,919** |
| HL alarm | 14,198 | 110 | 129 | 0 | | **1,922** |
| HL setpoint | 14,040 | 110 | 128 | | | **1,923** |
| LL setpoint | 158 | 110 | 1 | | | **1,999** |
| LL alarm | 0 | 110 | 0 | | | **2,000** |
| Inflow starts | 0 | 110 | 0 | | | **2,000** |

Note: It would take 263,700 gallons of unborated water to dilute the SFP to 970 ppm boron.

# Table 3-7: SFP Boron Dilution Due To Cracked SFP Cooling Header

**Break Flow= 130 [gpm]**
**Makeup Flow= 160 [gpm]**

**Break flow results in SFP level reduction below LL alarm,**
**60 minutes after LL alarm, makeup is started at a full makeup flow of 160 gpm.**
**Makeup can be isolated 60 minutes after SFP HL alarm, or**
**Makeup can be isolated 90 minutes after sump HI-HI alarm, which is,**
**94 [min] after SFP overflow**

**SFP dilution (from LL level to >OFL) from Cinit= 2,000 [ppm]**

| SFP Condition | Total Makeup added [Gal] | Makeup Flow [gpm] | Time after SFP LL alarm [min] | Time after SFP HL alarm [min] | Time after SFP overflow [min] | Final boron conc. [ppm] |
|---|---|---|---|---|---|---|
| SFP overflowing | 263,600 | 160 | 1,708 | 1,510 | 1,500 | **970** |
| SFP overflowing | 58,700 | 160 | 427 | 229 | **219** | **1,700** |
| SFP overflowing | 38,669 | 160 | 302 | 104 | **94** | **1,795** |
| SFP overflowing | 31,598 | 160 | 257 | **60** | 50 | **1,830** |
| SFP overflowing | 23,661 | 160 | 208 | 10 | 0 | **1,871** |
| OFL pipe level | 22,471 | 160 | 200 | 3 | | **1,877** |
| HL alarm | 21,998 | 160 | 197 | 0 | | **1,879** |
| HL setpoint | 21,840 | 160 | 196 | | | **1,880** |
| LL setpoint | 7,958 | 160 | 110 | | | **1,955** |
| LL alarm | 7,800 | 160 | 109 | | | **1,955** |
| OP starts MU | 0 | 160 | 60 | | | **2,000** |

Note: It would take 263,600 gallons of unborated water to dilute the SFP to 970 ppm boron.

# Table 3-7A: SFP Boron Dilution Due To Cracked SFP Cooling Header During Fuel Shipment

**Break Flow= 130 [gpm]**
**Makeup Flow= 160 [gpm]**

**Break flow results in SFP level reduction below LL alarm,**
**(The LL alarm during fuel trans-shipment is lowered below normal setpoint)**
**60 minutes after LL alarm, makeup is started at a full makeup flow of 160 gpm.**
**Due to operators presence, M-U can be isolated 60 minutes after SFP HL alarm.**

**SFP dilution (from LL level to >OFL) from Cinit= 2,000 [ppm]**

| SFP Condition | Total Makeup added [Gal] | Makeup Flow [gpm] | Time after SFP LL alarm [min] | Time after SFP HL alarm [min] | Time after SFP overflow [min] | Final boron conc. [ppm] |
|---|---|---|---|---|---|---|
| SFP overflowing (2) | 262,400 | 160 | 1,700 | 1,416 | 1,405 | **970** |
| SFP overflowing | 57,300 | 160 | 418 | 134 | **123** | **1,700** |
| SFP overflowing | 52,600 | 160 | 389 | 105 | **(1) 94** | **1,722** |
| SFP overflowing | 45,480 | 160 | 344 | **60** | 50 | **1,756** |
| SFP overflowing | 37,541 | 160 | 295 | 10 | 0 | **1,795** |
| OFL pipe level | 36,350 | 160 | 287 | 3 | | **1,801** |
| HL alarm | 35,877 | 160 | 284 | 0 | | **1,803** |
| HL setpoint | 35,719 | 160 | 283 | | | **1,804** |
| LL setpoint | 7,958 | 160 | 110 | | | **1,953** |
| LL alarm | 7,800 | 160 | 109 | | | **1,954** |
| OP starts MU | 0 | 160 | 60 | | | **2,000** |

## Notes:

(1) Data for information only, if M-U isolated 90 minutes after sump HI-HI alarm, which is: 94 [min] after SFP overflow

(2) It would take 262,400 gallons of unborated water to dilute the SFP to 970 ppm boron.

## Table 3-8: SFP Boron Dilution Summary

**SFP dilution (from LL level to >OFL) from initial boron conc. = 2,000 [ppm]**

| Dilution Scenario | See Table | Break/ Leak'g Flow [gpm] | Dil.'n Flow [gpm] | Time after alarms when M-U is isolated [min] | | SFP Boron Conc. when M-U is isolated after below alarms | |
|---|---|---|---|---|---|---|---|
| | | | | SFP HI | Sump HI-HI | SFP HI | Sump HI-HI |
| Normal Primary SFP Makeup | 3-1 | N/A | 160 | 60 | 94 | 1,872 | 1,836 |
| Primary SFP MU after minor leak | 3-2 | 1 | 160 | 60 | 94 | 1,872 | 1,836 |
| Flow from 1 NSW Hose | 3-3 | 50 | 50 | 60 | 102 | 1,906 | 1,892 |
| Cracked NSW Header | 3-4 | 30 | 30 | 60 | 110 | 1,913 | 1,902 |
| Failed SFP H-X Tube | 3-5 | 90 | 90 | 60 | 97 | 1,894 | 1,872 |
| Cracked Fire Water Header | 3-6 | 110 | 110 | 60 | 95 | 1,888 | 1,862 |
| Cracked SFP Cooling Header | 3-7 | 130 | 160 | 60 | 94 | 1,830 | 1,795 |
| Case per 3-7 w/ fuel shipment | 3-7A | 130 | 160 | 60 | 94 | 1,756 | 1,722 |

## 4.0 CONCLUSIONS

A boron dilution analysis has been completed for the spent fuel pool. As a result of this spent fuel pool boron dilution analysis, it is concluded that an unplanned or inadvertent event which would result in the dilution of the spent fuel pool boron concentration from 2,000 ppm to 1,700 ppm is not a credible event.

An operator would have to initiate dilution flow, then abandon monitoring of pool level, ignore tagged valves, violate administrative procedures, and ignore spent fuel pool and building sump level alarms.

A spent fuel pool dilution event would be readily detected by plant personnel via alarms, flooding in the fuel handling building, or by normal operator rounds through the spent fuel pool area.

It should be noted that this boron dilution analysis was conducted by evaluating the time and water volumes required to dilute the spent fuel pool from 2,000 ppm to 1,700 ppm. Under normal, non-accident conditions, only 970 ppm is required to keep $K_{eff}$ less than 0.95. This is a margin of 730 ppm. As shown in Tables 3-1 through 3-7A, a minimum of 262,400 gallons of unborated water would have to be added to dilute from 2,000 ppm to 970 ppm. Plant instrumentation and administrative procedures are in place to prevent the inadvertent dilution of this magnitude.

Finally, the criticality analyses show that on a 95/95 basis the spent fuel rack $K_{eff}$ remains less than 1.0 with non-borated water in the pool. Thus, even if the spent fuel pool were diluted to zero ppm, the spent fuel would remain subcritical and the health and safety of the public would be assured.

## 5.0 REFERENCES

1. M-0022-019, Rev. 0, SFP Boron Dilution Analysis

2. "Spent Fuel Pool Criticality Analysis (With No Boraflex And Credit For Soluble Boron)", Southern California Edison Company, San Onofre Nuclear Generating Station, Units 2 And 3, Revision 0, November 2001.

# Attachment K

(Spent Fuel Pool Criticality Analysis)

# SPENT FUEL POOL CRITICALITY ANALYSIS

(WITH NO BORAFLEX
AND
CREDIT FOR SOLUBLE BORON)

SOUTHERN CALIFORNIA EDISON
SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 AND 3

REVISION 0
NOVEMBER 2001

TABLE OF CONTENTS

## EXECUTIVE SUMMARY

This report describes the criticality analyses performed for San Onofre Nuclear Generating Station (SONGS) Units 2 and 3, Facility Operating Licenses NPF-10 and NPF-15, respectively.

The results of the criticality analyses show that the existing spent fuel storage racks with no Boraflex, and supporting systems and components, have been adequately designed to accommodate the storage and handling of SONGS Units 2 and 3 fuel with a maximum nominal fuel pin enrichment of 4.8 weight percent (w/o). For all normal and postulated accident conditions (with the exception of boron dilution) in the spent fuel pool, a minimum concentration of 1,700 ppm soluble boron is required. A soluble boron level of 2,000 ppm in the spent fuel pool is required for all postulated accident conditions and a concurrent boron dilution event.

To compensate for no Boraflex, SONGS Units 2 and 3 will use the following storage patterns and guide tube inserts as needed:

(1) unrestricted storage, minimum discharge burnup and cooling time requirements vs initial enrichment,
(2) SFP Peripheral storage, minimum discharge burnup and cooling time requirements vs initial enrichment,
(3) 2x2 storage patterns, minimum discharge burnup and cooling time requirements vs initial enrichment,
(4) 3x3 storage patterns, minimum discharge burnup and cooling time requirements vs initial enrichment,
(5) credit for inserted Control Element Assemblies (CEAs)
(6) credit for erbia in fresh assemblies,
(7) credit for cooling time (Pu-241 decay), and,
(8) credit for borated stainless steel and borated aluminum guide tube inserts.

The criticality analyses also show that San Onofre Nuclear Generating Station (SONGS) Unit 1 fuel assemblies can be safely stored in the SONGS Units 2 and 3 spent fuel storage racks with no Boraflex. The maximum nominal enrichment of the SONGS Unit 1 assemblies is 4.0 w/o.

The analyses documented herein use methodologies and computer programs previously reviewed and approved by the NRC. In particular, credit for soluble boron in the spent fuel pool water is taken. This means that the acceptance criteria for the spent fuel storage racks are $K_{eff}$ less than 1.0 with unborated water, and have $K_{eff}$ less than or equal to 0.95 with borated water.

On the basis of the information and evaluations presented in this report, Edison concludes that the proposed changes (no Boraflex and credit for soluble boron) in fuel storage for the SONGS Units 2 and 3 spent fuel storage facilities will provide safe fuel storage and are in conformance with NRC requirements. The changes will have no significant impact on the health and safety of the general public.

# 1. INTRODUCTION

The criticality analyses documented in this report show that the SONGS Units 2 and 3 spent fuel storage racks meet the NRC's acceptance criteria for criticality (1) assuming no Boraflex, and (2) taking credit for 1,700 ppm soluble boron in the spent fuel pool water.

The methodology and computer programs employed herein have been previously reviewed and approved by the NRC. [3,4,5,6,7]

When credit for soluble boron is taken, the acceptance criteria are:[5]

(1) Under normal conditions, the 95/95 neutron multiplication factor ($K_{eff}$), including all uncertainties, shall be less than 1.0 when flooded with unborated water.

(2) Under normal and accident conditions, the 95/95 neutron multiplication factor ($K_{eff}$), including all uncertainties, shall be less than or equal to 0.95 when flooded with borated water.

To compensate for no Boraflex, SONGS Units 2 and 3 will use the following storage patterns and guide tube inserts as needed:

(1) unrestricted storage, minimum discharge burnup and cooling time requirements vs initial enrichment,
(2) SFP Peripheral storage, minimum discharge burnup and cooling time requirements vs initial enrichment,
(3) 2x2 storage patterns, minimum discharge burnup and cooling time requirements vs initial enrichment,
(4) 3x3 storage patterns, minimum discharge burnup and cooling time requirements vs initial enrichment,
(5) credit for inserted Control Element Assemblies (CEAs)
(6) credit for erbia in fresh assemblies,
(7) credit for cooling time (Pu-241 decay), and,
(8) credit for borated stainless steel and borated aluminum guide tube inserts.

Boraflex erosion/dissolution is an industry problem, and SONGS Units 2 and 3 are affected. Silica levels in the SONGS Units 2 and 3 spent fuel pools are increasing, and this indicates the Boraflex is eroding/dissolving. Although there is currently sufficient Boraflex, it is prudent to plan for the long term. Taking no credit for Boraflex for SONGS Units 2 and 3 will totally eliminate any Boraflex concerns in the future, and monitoring programs will not be required to ensure that an adequate amount of Boraflex is present.

## 2. FUEL STORAGE DESCRIPTION

This section presents a description of the SONGS Units 2 and 3 spent fuel storage racks, the SONGS Units 1, 2, and 3 fuel assemblies currently stored in the SONGS Units 2 and 3 spent fuel storage racks, and guide tube inserts which will be used as needed.

### 2.1 FUEL ASSEMBLY DESCRIPTIONS

Two fuel assembly designs are currently licensed for storage in the SONGS Units 2 and 3 fuel storage racks (UFSAR Sections 4.2 and 9.1.2):

(1) Westinghouse-Combustion Engineering (W/CE), Zircaloy-clad, 16x16 Fuel Assemblies, 4.8 w/o maximum nominal enrichment

Note: Westinghouse-Combustion Engineering was formerly ABB-Combustion Engineering was formerly Combustion Engineering.

(2) Westinghouse, Stainless-steel-clad, 14x14 Fuel Assemblies transhipped from Unit 1, 4.0 w/o maximum nominal enrichment

The characteristics of the W/CE SONGS Units 2 and 3 and Westinghouse SONGS Unit 1 fuel assembly designs are given in Table 2-1.

### 2.2 GUIDE TUBE INSERTS

#### 2.2.1 Control Element Assemblies (CEAs)

Full length, 5-finger CEAs may be used in W/CE fuel assemblies stored in Regions I and II. Use of CEAs allows flexibility in fuel assembly placement and greater utilization of the spent fuel pool by lowering fuel assembly reactivity, which is expressed as a lower required discharge burnup. The characteristics of the CEAs assumed in the criticality analyses documented herein are described in Section 4.2 of the UFSAR. No CEA insert will be used in the Westinghouse SONGS Unit 1 fuel assemblies.

The control elements of a full- length CEA consist of an Inconel 625 tube loaded with a stack of cylindrical absorber pellets. The absorber material is boron carbide ($B_4C$), with the exception of the lower portion (2 inches) which is silver-indium-cadmium (Ag-In-Cd) alloy cylinders and Inconel end plug.

This robust design reduces the neutron exposure to the $B_4C$ pellets by at least a factor of 10 compared to the CEA design at Palo Verde Units 1, 2, and 3 which has $B_4C$ pellets to the bottom of the CEA. Because of this design difference, the CEAs at SONGS Units 2 and 3 are not susceptible to the failure mechanism recently observed at Palo Verde Units 1, 2, and 3.

### 2.2.2 Borated Stainless Steel (SS) And Aluminum Inserts

Three or five borated SS or Aluminum guide tube inserts may be used in fuel assemblies stored in Region II. Use of inserts allows flexibility in fuel assembly placement and greater utilization of the spent fuel pool by lowering fuel assembly reactivity, which is expressed as a lower required discharge burnup.

The characteristics assumed for the inserts in the criticality analyses documented herein are described below.

The inserts are 0.75 inches O.D. minimum, and must cover the entire active fuel length of 150.0 inches. The inserts must have a minimum boron loading of:

0.02434 grams of B-10 per $cm^3$ — Stainless Steel
0.06890 grams of B-10 per $cm^3$ — Aluminum

When 3 guide tube inserts are used, the orientation shall be the same in every assembly in the spent fuel pool (Figure 3-3).

## 2.3 SPENT FUEL STORAGE RACK DESCRIPTION

The spent fuel storage racks [1,2] provide for storage of new and spent fuel assemblies in the spent fuel pool, while maintaining a coolable geometry, preventing criticality, and protecting the fuel assemblies from excess mechanical or thermal loadings. SONGS Units 1, 2, and 3 fuel may be stored in the SONGS Units 2 and 3 racks, as well as miscellaneous storage items (e.g., trash baskets, dummy fuel assemblies, neutron sources), and the failed rod storage baskets.

Fuel is stored in two regions within each pool (Table 2-2, Figure 2-1):
(1) Region I (312 locations)
(2) Region II (1230 locations)

As originally installed and currently licensed, both regions use Boraflex, a neutron absorbing material. Boraflex consists of fine boron carbide particles distributed in a polymeric silicone encapsulant.

The criticality analyses documented herein assume no Boraflex. Conservatively, it is assumed that the Boraflex has completely dissolved/eroded, and the pocket is filled with spent fuel pool water.

### 2.3.1 Materials

The Region I and Region II racks are constructed from Type 304LN stainless steel except the leveling screws which are SA-564 Type 630 stainless steel and some leveling pads which are either SA-182 Type F-304 stainless steel or SA-240 (or SA-479) Type 304 stainless steel. The floor plates under the rack support pads are made from SA-240 Type 304 stainless steel, which has the same corrosion resistance characteristics as the rack materials.

The Region I and Region II racks are neither anchored to the floor nor braced to the pool walls or each other. Also, the pool floor plates are not attached to the pool floor.

### 2.3.2 Region I Spent Fuel Storage Rack Description

Region I (312 locations) consists of two high density fuel racks, each with 12x13 cells. The nominal dimensions of each rack are 125.5 inches by 135.9 inches. The cells within a rack are interconnected by grid assemblies and stiffener clips to form an integral structure as shown in Figure 2-2. The cells in Region I are separated from each other by a minimum water gap of about 1.1 inches.

Region I is generally reserved for temporary storage of new fuel or partially irradiated fuel which would not qualify for Region II storage.

### 2.3.3 Region II Spent Fuel Storage Rack Description

Region II (1230 locations) has six high density fuel racks, four with 14x15 cells and two with 13x15 cells and provides normal storage for spent fuel assemblies. The nominal dimensions of the 14x15 rack are 124.82 inches by 133.67 inches; the nominal dimensions of the 13x15 rack are 115.97 inches by 133.67 inches. The cells in Region II do not have a water gap.

The six Region II storage racks consist of stainless steel cells assembled in a checkerboard pattern, producing the structure shown in Figure 2-3. Cells are located in every other location and are welded together at the cell corners. This results in "non-cell" storage locations, each one formed by one outside wall of four checkerboard cells.

Region II is generally used for long term storage of permanently discharged fuel that has achieved qualifying burnup levels.

Table 2-1
FUEL ASSEMBLY DATA FOR SONGS UNITS 1, 2, AND 3

| | SONGS 1 | SONGS 2&3 |
|---|---|---|
| Maximum Fuel Pin Enrichment (w/o) | 4.0 | 4.8 |
| Cladding Type | SS | Zr |
| Rod Array | 14x14 | 16x16 |
| Fuel Rod Pitch (in.)* | 0.556 | 0.506 |
| Number of Rods Per Assembly | 180 | 236 |
| Fuel Rod Outer Diameter (in.) | 0.422 | 0.382 |
| Fuel Pellet Diameter (in.) | 0.3835 | 0.3250- 0.3255 |
| Active Fuel Length (in.) | 120.0 | 150.0 |
| Cladding Thickness (in.) | 0.0165 | 0.025 |
| Number of Guide Tubes | 16 | 5 |
| Guide Tube Outer Diameter (in.) | 0.535 | 0.980 |
| Guide Tube Inner Diameter (in.) | 0.511 | 0.900 |
| Guide Tube Material | SS | Zr |

* Fuel rod pitch is the spacing between fuel rods measured as the distance from centerline to centerline of the rod. Both assembly types are square pitch arrays.

Table 2-2

SPENT FUEL RACK DATA
(Each Unit)

| | Region I | Region II |
|---|---|---|
| Number of Storage Locations | 312 | 1230 |
| Number of Rack Arrays | Two 12x13 | Four 14x15<br>Two 13x15 |
| Center-to-Center Spacing (inches) | 10.40 | 8.85 |
| Cell Inside Width (inches) | 8.64 | 8.63 |
| Type of Fuel | SONGS 2 and 3 16x16 and/or SONGS 1 14x14 | SONGS 2 and 3 16x16 and/or SONGS 1 14x14 |
| Rack Assembly Outline Dimensions (inches) | 126 x 136 x 198.5 | 125 x 134 x 198.5 (14 x 15)<br><br>116 x 134 x 198.5 (13 x 15) |

**Figure 2-1**
**SAN ONOFRE UNITS 2 AND 3**
**SPENT FUEL POOL LAYOUT (NOMINAL DIMENSIONS in INCHES)**

**RI = Region I**
**RII = Region II**

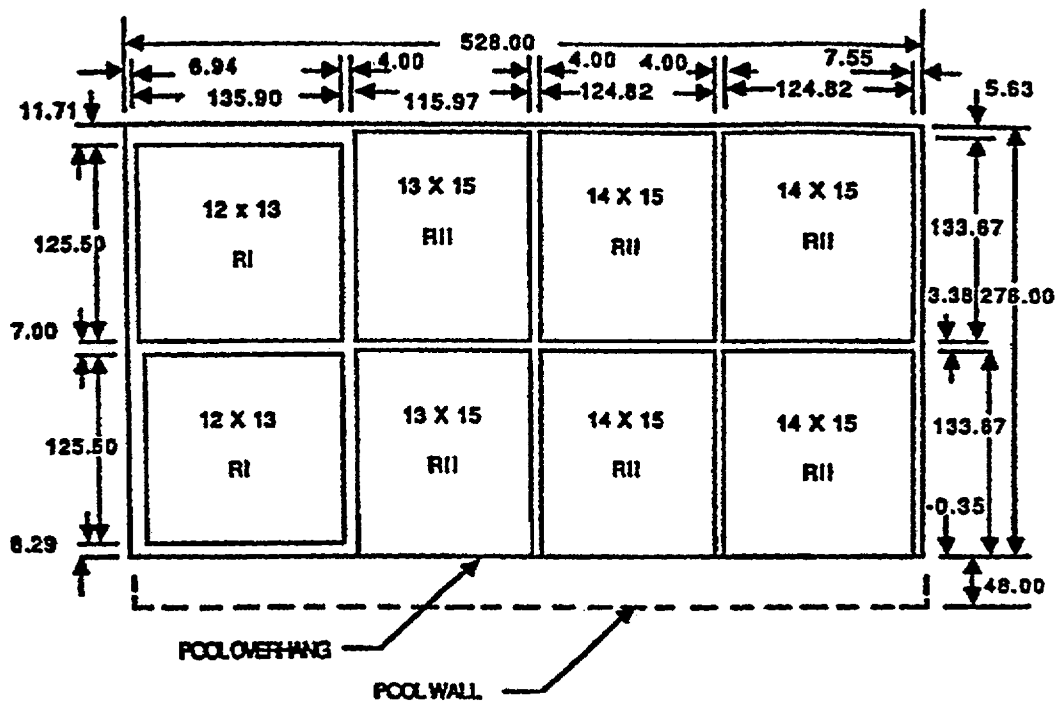


**Figure 2-2**
**SAN ONOFRE UNITS 2 AND 3**
**REGION I SPENT FUEL STORAGE CELLS**

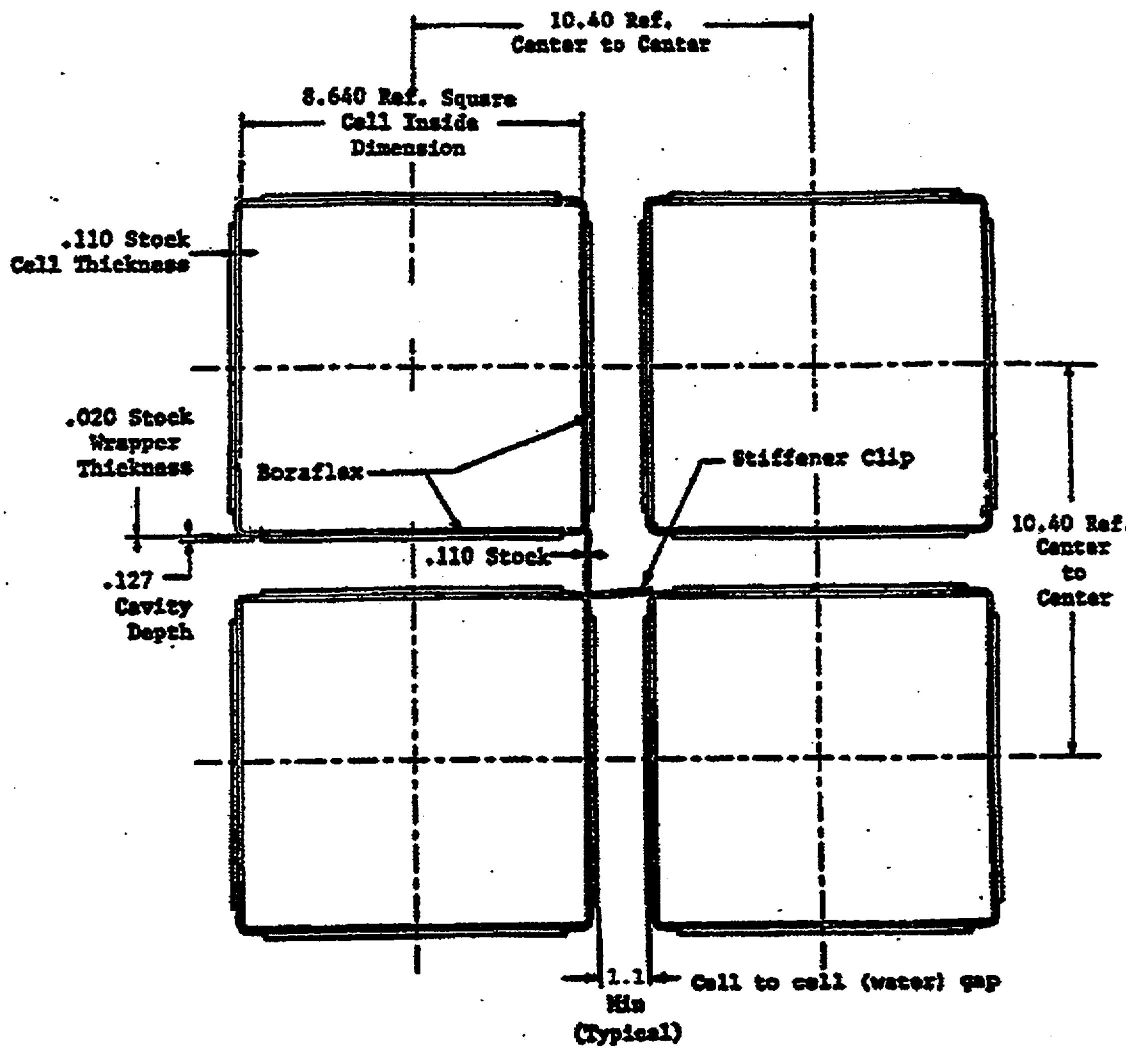
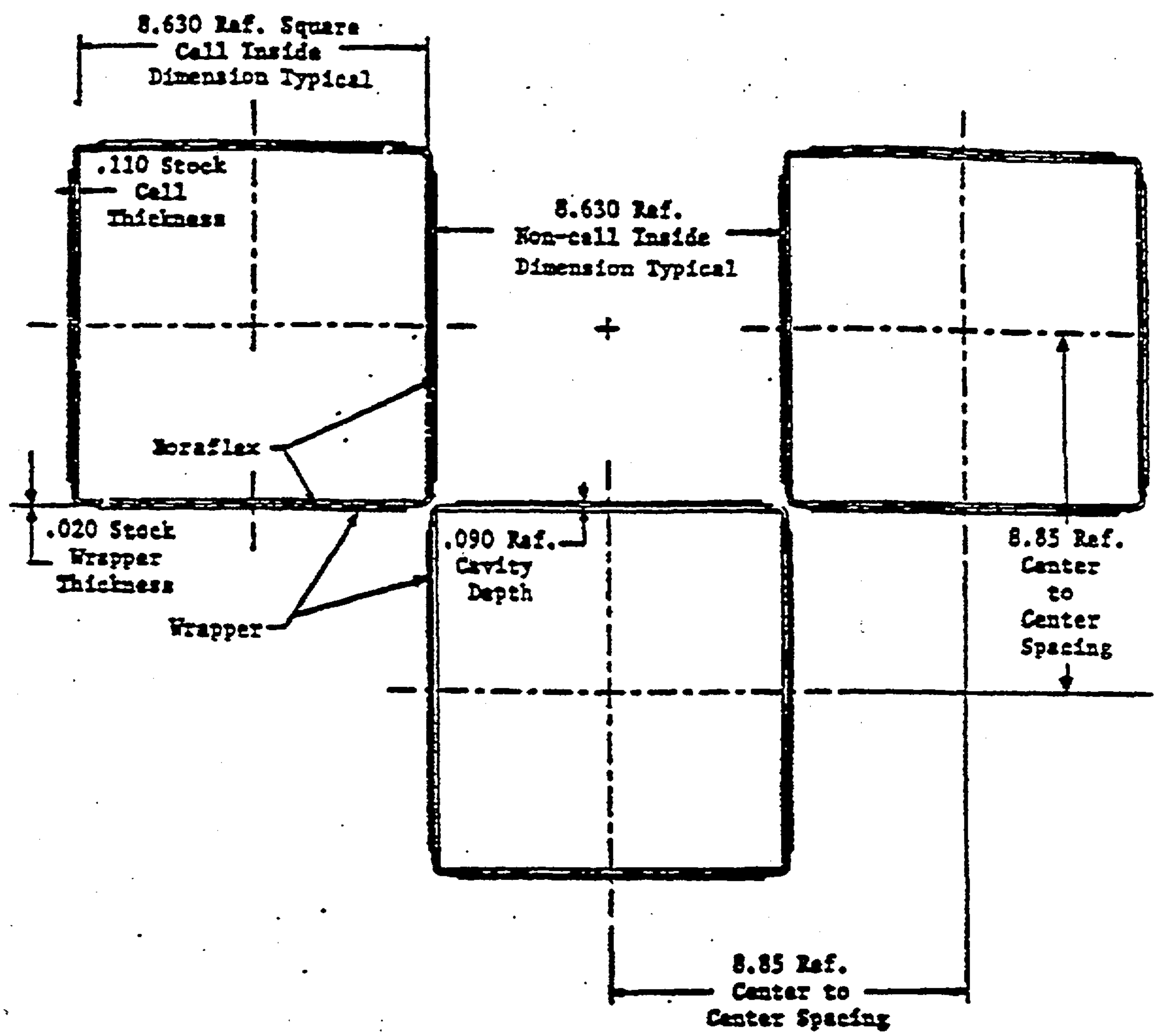


**Figure 2-3**
**SAN ONOFRE UNITS 2 AND 3**
**REGION II SPENT FUEL STORAGE CELLS**



# 3. COMPUTER PROGRAMS AND METHODOLOGY

This section describes the computer programs and methodology used for the criticality analyses of the SONGS Units 2 and 3 spent fuel storage racks.

## 3.1 COMPUTER PROGRAMS

### 3.1.1 Computer Program Descriptions

CELLDAN, NITAWL-II, KENO-Va, CASMO-3, and SIMULATE-3 are the computer programs used in the analyses. [10,11,12]

CELLDAN, NITAWL-II, KENO-Va, and CASMO-3 have been used in previous SCE spent fuel pool criticality analyses approved by the NRC.[7]

SCE has NRC approval[17] to use CASMO-3 and SIMULATE-3 for reactor physics analyses.

CELLDAN calculates the atoms/barn-cm of U235, U238, and Oxygen in the $UO_2$ fuel. CELLDAN also calculates the atoms/barn-cm of Hydrogen, Oxygen, B-10, and B-11 in the water. Finally, CELLDAN calculates the Dancoff factor, and U235 and Oxygen scattering cross-sections per U238 atom for NITAWL-II.

NITAWL-II generates a binary cross-section library for KENO-Va. The library contains 27 group cross-section data for every nuclide in the KENO-Va problem. Using the U238 number density, Dancoff factor, and U235/Oxygen scattering cross-sections per U238 atom from CELLDAN, NITAWL-II uses the Nordheim Method to do resonance shielding of the U238 cross-section.

KENO-Va is the nuclear industry standard program for criticality analyses. KENO-Va is a three-dimensional, multi-group, Monte Carlo program.

CASMO-3 is a multi-group two-dimensional transport theory program for calculations on BWR and PWR fuel assemblies. It is extensively used by utilities in the U.S. In these analyses, CASMO-3 is used for three purposes. First, CASMO-3 is used to evaluate the reactivity variations (Delta-k) due to the rack manufacturing tolerances and normal pool temperature variation. Second, CASMO-3 is used to generate the initial enrichment versus discharge burnup criteria. Thirdly, CASMO-3 is used to evaluate the pool heat up accident, and determine the required soluble boron concentration for the fuel mishandling accident.

SIMULATE-3 is the computer program used by SCE to model the San Onofre reactor cores to calculate power distribution, Boron letdown curve, MTC, rod worths, etc. In this analysis, SIMULATE-3 is used to evaluate the axial burnup bias.

### 3.1.2 Computer Program Benchmarking

KENO-Va has been benchmarked by SCE against industry standard critical experiments performed by B&W .(13,14) The bias and 95/95 uncertainty in the bias for CELLDAN, NITAWL-II, and KENO-Va and the 27 group cross-section library is 0.00814 $\pm$ 0.00172. (Table 3-1)

The criticality experiments examined have similar nuclear characteristics to spent fuel storage and are applicable to conditions encountered during the handling of LWR fuel outside reactors. This B&W critical experiment case set has been previously used by SCE for spent fuel pool criticality analyses reviewed and approved by the NRC.(7) The number of benchmarking cases used by SCE (16 cases) compared to Reference 4 (32 cases) is conservative and results in a higher bias for SCE's analyses.

Since the enrichment in the B&W critical experiments was 2.46 w/o, additional comparisons(15,16) were done at 4.30 w/o and 4.75 w/o. The bias and uncertainty determined at 2.46 w/o was found to be applicable for these higher enrichments.

CASMO-3 and SIMULATE-3 have been validated by accurately predicting SONGS Units 2 and 3 startup physics test data and core follow results.(17) CASMO-3 U and Pu isotopic predictions agree quite well with measurements for all measured isotopes (Yankee Core) throughout the burnup range. CASMO-3 has also been compared to industry critical experiments and other measured data* with good agreement.

* $28_{Rho}$ = Ratio of epithermal to thermal $U^{238}$ capture rates
$25_{Delta}$ = Ratio of epithermal to thermal $U^{235}$ fission rates
$28_{Delta}$ = Ratio of $U^{238}$ to $U^{235}$ fission rates
CR = Ratio of $U^{238}$ capture to $U^{235}$ fission rates (Conversion Ratio)

Table 3-1
KENO-Va Analyses Of Critical Experiments
For The Determination
Of Calculational Bias And Uncertainty

| B&W Core | Measured k-eff | KENO-Va k-eff | Difference |
|---|---|---|---|
| I | 1.0002 | 0.99037 | 0.00983 |
| II | 1.0001 | 0.99278 | 0.00732 |
| III | 1.0000 | 0.99346 | 0.00654 |
| IX | 1.0030 | 0.99044 | 0.01256 |
| X | 1.0001 | 0.99039 | 0.00971 |
| XI | 1.0000 | 0.99441 | 0.00559 |
| XII | 1.0000 | 0.99362 | 0.00638 |
| XIII | 1.0000 | 0.99868 | 0.00132 |
| XIV | 1.0001 | 0.99382 | 0.00628 |
| XV | 0.9998 | 0.98833 | 0.01147 |
| XVI | 1.0001 | 0.98892 | 0.01118 |
| XVII | 1.0000 | 0.99234 | 0.00766 |
| XVIII | 1.0002 | 0.99119 | 0.00901 |
| XIX | 1.0002 | 0.99146 | 0.00874 |
| XX | 1.0003 | 0.99085 | 0.00945 |
| XXI | 0.9997 | 0.99256 | 0.00714 |

Mean = 0.00814
Standard Deviation = 0.00273

$$\text{Bias} \pm \text{Uncertainty} = \text{Mean} \pm \frac{\text{k95/95} * \text{Standard Deviation}}{\text{SQRT(Number Of Cases)}}$$

$$= 0.00814 \pm (2.524)(0.00273)/\text{SQRT}(16)$$

$$= 0.00814 \pm 0.00172$$

## 3.2 METHODOLOGY

The methodology used for this analysis is consistent with methods previously reviewed and approved by the NRC.[3,4,5,6,7]

The methodology of this analysis follows NRC guidance and the Westinghouse Owners Group (WOG) methodology for spent fuel storage rack criticality analyses. This methodology includes credit for soluble boron and burnable poison integral with the fuel rods. The WOG methodology has been found non-conservative for the axial burnup bias.[6] In this analysis, SCE evaluates a SONGS specific axial burnup bias.

Reference 7 is NRC approval of SCE's methodology for fuel rack criticality analyses using KENO-Va and CASMO-3. The SCE methodology does not include soluble boron or burnable poison credit. Otherwise, the SCE and WOG methodologies are essentially the same (except for axial burnup bias) and follow well established industry guidance.[8]

Reference 9 documents that an equivalent fresh enrichment determined at 0 ppm is under-estimated if used in a KENO-Va model which includes dissolved boron. SCE's analyses ensured that the conditions under which equivalent fresh enrichments were determined remained unchanged in the down-stream analyses which used the equivalent fresh enrichments. As an example, enrichment equivalence determined for 500 ppm soluble boron used for downstream cases which assumed 500 ppm soluble boron.

The following methodology elements are discussed below:

(1) Reference Reactivity

(2) Manufacturing Tolerances And Pool Temperature Bias

(3) Eccentric Placement in Storage Cells

(4) Fuel Assembly Burnup Credit (Reactivity Equivalencing)

(5) Axial Burnup Bias

(6) Control Element Assembly (CEA) Bias

(7) Integral Fuel Burnable Absorber Credit

(8) Borated Stainless Steel (SS) And Aluminum Inserts

(9) Postulated Accidents

(10) Soluble Boron Credit Methodology

The relationship between these methodology elements is shown in Figure 3-1.

### 3.2.1 Reference Reactivity

KENO-Va is used to establish a nominal reference reactivity, using fresh assemblies and nominal rack dimensions.

The following input parameters/assumptions are consistent with the WOG and SCE methodologies[4,7] approved by the NRC.

(a) Nominal spent fuel storage rack and fuel assembly dimensions are used.

(b) The $UO_2$ stack density is 96 % of theoretical.
This bounds the small tolerances in fuel rod/assembly dimensions, including the two fuel pellet ODs of 0.325 inches and 0.3255 inches.

(c) The temperature of all materials is 68 degrees F.

(d) Axially, 150 inches of active fuel are modeled.
A 30 centimeter water reflector is used above and below the active fuel region.

(e) Storage box walls above the active fuel are conservatively not modeled.

(f) Only the storage cell box wall and Boraflex wrapper are modeled.
Storage rack structural materials, braces, or supports are not modeled.
Boraflex is not modeled, and is conservatively replaced with spent fuel pool water.

(g) Fuel assembly grids and end fittings are conservatively not modeled.

(h) In the KENO-Va models, at least 503 neutron generations will be run with at least 2000 neutrons per generation. $K_{eff}$ will be taken after skipping the first 3 generations.

(i) The following formula is used to determine the final $K_{eff}$:

$$K_{eff} = k_{nominal} + B_{method} + B_{temp} + B_{uncert} + B_{CEA} + B_{Axial}$$

where:
$k_{nominal}$ = KENO-Va $K_{eff}$
$B_{method}$ = method bias determined from benchmark critical experiments
$B_{temp}$ = temperature bias (68°F to 160°F)
$B_{uncert}$ = statistical summation of uncertainty components
$B_{CEA}$ = CEA bias for rodded cases only
$B_{Axial}$ = Axial Burnup Bias

Representative Region I and Region II KENO-Va models, and the whole pool KENO-Va model used for this analysis are shown in Appendix A.

All steps for calculating the Region I and Region II zero burnup enrichment for unrestricted storage at 0 ppm ($K_{eff} < 1.0$) are shown in Appendices B and C.

### 3.2.2 Manufacturing Tolerances And Pool Temperature Bias

The reactivity effects of possible variations in material characteristics and construction dimensions must be evaluated and included in the final neutron multiplication factor ($K_{eff}$) of the spent fuel racks. The reactivity effects of the following tolerances are evaluated using CASMO-3:

Enrichment – The standard DOE enrichment tolerance of $\pm$ 0.05 w/o $U^{235}$ is used
Stainless steel thickness (cell wall thickness and Boraflex wrapper thickness)
Minimum cell inner dimension
Storage cell pitch (Region I only)

The delta $K_{eff}$'s due to these tolerances are calculated with CASMO-3 because the delta $K_{eff}$'s are small and can be lost in the statistical uncertainty in KENO-Va results ($K_{eff}$ +/- sigma).
The variations in material characteristics due to manufacturing tolerances are random. These random variations both increase and decrease $K_{eff}$, but on the average there is no net effect. Therefore, the CASMO-3 tolerance delta-k results are conservatively combined statistically (Square root of the sum of the squares) with the methodology bias uncertainty, reference KENO-Va $K_{eff}$ uncertainty, and eccentric placement of fuel assemblies in the storage cells. Manufacturing tolerance delta-k's are conventionally reported as positive values, because the value is squared when combined statistically with other tolerances and uncertainties.

Rather than analyze tolerances on $UO_2$ stack density, the fuel is analyzed at a bounding value of 96% of theoretical density with no pellet dishing.

The normal fuel pool temperature range is 68°F to 160°F. CASMO-3 is used to evaluate the fuel pool temperature bias. Since the pool temperature has no random variation, the pool temperature bias is added directly to the reference KENO-Va result. The pool temperature bias may be either positive or negative depending on boron concentration and storage rack geometry (absence or presence of a water gap around the storage cells)

The manufacturing tolerance and pool temperature results are in Section 4.1.

### 3.2.3 Eccentric Placement in Storage Cells

For eccentric placement of fuel assemblies in the storage cells, a KENO-Va model is set up with four assemblies moved as close together as possible in the corner where four storage locations meet. The results may depend on spent fuel rack region and enrichment.

The results for eccentric placement of fuel assemblies is in Section 4.2.

### 3.2.4 Fuel Assembly Burnup Credit (Reactivity Equivalencing)

Spent fuel storage in the Region I and II spent fuel storage racks is achievable by means of "reactivity equivalencing". The concept of "reactivity equivalencing" is based on the fact that reactivity decreases with fuel assembly burnup. A series of reactivity calculations are performed to generate a set of "enrichment - fuel assembly discharge burnup" pairs which all give the equivalent $K_{eff}$ when the fuel is stored in the Region I and II racks.

The "enrichment - burnup pairs" were generated with CASMO-3. CASMO-3 allows a fuel assembly to be depleted at hot full power reactor conditions, and then placed into fuel storage rack geometry at 20 degrees C, 0 ppm soluble boron concentration, and no Xenon. The most reactive point in time for a fuel assembly after discharge is conservatively approximated by removing the Xenon. Samarium buildup after shutdown is conservatively not modelled.

To eliminate axial burnup effects, the CASMO-3 depletions are performed at the following extreme reactor operating conditions which enhance plutonium buildup:

(1) Reactor Outlet Temperature = 600°F
(2) Constant BOC Fuel Temperature = 1200°F
(3) Constant Soluble Boron = 1000 ppm

Because the burnup history is not known exactly for the discharged fuel assemblies, the fuel assembly isotopic content (U, Pu, etc) and distribution is not known exactly. Therefore, a bounding uncertainty is applied to CASMO-3 calculational results which is zero at zero burnup and increases linearly with burnup, passing through 0.01 delta-k at 30,000 MWD/T. This uncertainty is covered by an amount of soluble boron.

As part of the reactivity equivalencing process, Pu-241 decay is also credited for up to 20 years of cooling.

3.2.5 Axial Burnup Bias

Curves of discharge burnup vs initial enrichment are generated with 2D axially infinite models (CASMO-3) which gives the modeled assembly a uniform axial burnup. However, physical fuel assemblies have a non-uniform axial burnup caused by neutron leakage from the ends of the finite length fuel assembly. Thus, the ends of the assembly have a lower burnup than the assembly average. The delta-k difference between the 3D axially dependent burnup distribution with a given average burnup and the 2D uniform burnup distribution at the same average burnup is the axial burnup bias. The bias may be either positive or negative.

The axial burnup bias is evaluated with two SIMULATE-3 Cases:

(1) All-rods-out (ARO) 2D depletion at constant $T_{mod}$ = 600 F, constant $T_{fuel}$ = 1200 F, constant 1000 ppm, and burnup from 0 to 60 GWD/T.

At 0, 10, 20, 30, 40, 50, and 60 GWD/T, the 2D depleted assembly is expanded to 3D at 68 F, 0 ppm, no Xenon, and with top and bottom reflectors ( from the SIMULATE-3 models used for core follow, physics databook, and startup test predictions).

(2) ARO 3D depletion at constant $T_{inlet}$ = 553 F, $T_{fuel}$ = f(Tmod, Burnup), 1000 ppm, top and bottom reflectors, and burnup from 0 to 60 GWD/T. A $T_{inlet}$ of 553 F bounds lower inlet temperatures.

At 0, 10, 20, 30, 40, 50, and 60 GWD/T, the 3D depleted assembly is restarted at 68 F, 0 ppm, no Xenon, and with top and bottom reflectors (from the SIMULATE-3 models used for core follow, physics databook, and startup test predictions).

If the 2D case has higher assembly k-inf than the 3D case, the bias is zero. Therefore CASMO-3 reactivity equivalencing cases run at constant $T_{mod}$ = 600 F, constant $T_{fuel}$ = 1200 F, and constant 1000 ppm are conservative. If the 3D case has higher assembly k-inf than the 2D case, an appropriate bias will be determined and included in the final calculational results. The axial burnup bias results are in Section 4.4.

3.2.6 Control Element Assembly (CEA) Bias

Full length, 5-finger CEAs may be used in SONGS Units 2 and 3 fuel assemblies stored in Region I and II. Since CEAs will be modeled in KENO-Va, the need for a CEA bias to apply to the KENO-Va results will be investigated.

The potential KENO-Va bias when CEAs are present will be determined by comparison of calculated CEA worth between KENO-Va and CASMO-3. CASMO-3 (through SIMULATE-3) has accurately predicted SONGS Units 2 and 3 CEA bank worth measurements.[17] The bias between CASMO-3 and measured CEA worth data is 0.0 delta-k.

The CEA bias result is in Section 4.3.

CEA tip depletion is not a concern for the following reasons:

- SONGS Units 2 and 3 operation history is essentially unrodded.
- The bottom portion of the CEA finger is composed of non-depleting Silver-Indium-Cadmium.
- The CEA tip is in a low importance region. At shutdown, the flux shifts to the top of the assembly; the CEA tip is at the bottom of the assembly.
- During the lifetime of the CEAs , the rod worth is measured at the beginning of each cycle and no depletion effects are discernible.
- The W/CE CEA design has a much larger cross sectional area than the Westinghouse RCCA design, which significantly reduces CEA depletion.

### 3.2.7 Integral Fuel Burnable Absorber Credit

Credit for burnable absorbers integral with the fuel (Erbia) includes:

- The fuel assembly is modeled at its most reactive point in life. (BOC)
- The nominal burnable poison loading is decreased by 5% to conservatively account for manufacturing tolerances.

In this analysis, fresh fuel assemblies containing 40 and 80 Erbium rods are considered. Conservatively, enrichment zoning in the assembly is not modeled. Every fuel rod is at a nominal 4.80 w/o, including the fuel rods with the erbia. Normally, the erbia containing fuel rods would be 0.4 w/o less enriched. The erbia cutback region is modeled as 4.80 w/o instead of 4.40 w/o.

The presence of erbia is converted to an equivalent fresh enrichment:

(1) Run an assembly with erbia in CASMO-3 to determine a zero burnup enrichment rack k-inf. The fresh fuel assembly is modeled as follows:
4.80% U-235 in all pins (No zoning)
40 or 80 erbia rods
2.0 wt% Erbia (Reduced from 2.1 wt%)

(2) Run an assembly containing only $UO_2$ fuel rods with a single U-235 enrichment. There are NO erbia fuel rods, and there is no enrichment zoning. The U-235 enrichment shall be iterated until the rack k-inf of this case matches (1) above.

### 3.2.8 Borated Stainless Steel (SS) And Aluminum Inserts

Three or five borated SS or Aluminum guide tube inserts may be used in fuel assemblies stored in Region II. Use of inserts allows flexibility in fuel assembly placement and greater utilization of the spent fuel pool by lowering fuel assembly reactivity, which is expressed as a lower required discharge burnup.

The inserts are 0.75 inches O.D. minimum, and must cover the entire active fuel length of 150.0 inches. The inserts must have a minimum boron loading of:

0.02434 grams of B-10 per $cm^3$ — Stainless Steel
0.06890 grams of B-10 per $cm^3$ — Aluminum

When 3 guide tube inserts are used, the orientation shall be the same in every assembly in the spent fuel pool (Figure 3-3 and Section 4.5).

### 3.2.9 Postulated Accidents

Two accident conditions must be addressed: [4,18]

Pool Water Temperature Accident
Fuel Assembly Misplacement

#### 3.2.9.1 Pool Water Temperature Accident

For the Pool Water Temperature Accident, CASMO-3 is used to determine the amount of reactivity associated with an increase or decrease in spent fuel pool water temperature.

The normal operating temperature range is 68 F to 160 F. This range is covered by a bias added to KENO-Va results.

The accident range is 50 F to 248 F + 10% void. At the bottom of the racks where pressure is greater than atmospheric, 248 F (120 C) is the approximate boiling temperature. Ten percent voiding is an additional conservatism in the SCE methodology.

3.2.9.2 Fuel Assembly Misplacement

The following fuel assembly misplacement accidents are considered:[4,18]

Fuel Assembly Dropped Horizontally On Top Of The Racks

Fuel Assembly Dropped Vertically Into A Storage Location Already Containing A Fuel Assembly

Fuel Assembly Dropped To The SFP Floor

Fuel Misloading in either Region I or Region II

3.2.9.2.1 Fuel Assembly Dropped Horizontally On Top Of The Racks

In a previous submittal,[18] SCE has shown that more than 12 inches of water separates the active fuel region of the dropped assembly lying on top of the racks from the active fuel region of assemblies in the storage racks. A SONGS Units 2 and 3 fuel assembly is 176.8 inches long. A storage cell is about 190 inches deep. Therefore the storage cell extends about 13 inches above the top of the upper end fitting of the fuel assembly in storage. The active fuel is about 21 inches below the top of the upper end fitting. Thus the active fuel regions of the dropped and stored fuel assemblies are neutronically isolated and reactivity does not increase.

A single un-irradiated, 5.1 w/o fuel assembly, with no burnable absorbers, in water at 68 degrees F and 0 ppm has $K_{eff} = 0.92$,[18] which is less than the acceptance crierion of 0.95.

3.2.9.2.2 Fuel Assembly Dropped Vertically Into A Storage Location Already Containing A Fuel Assembly

In a previous submittal,[18] SCE has shown that more than 12 inches of water, steel, and zircaloy (fuel rod end cap and lower end fitting of dropped assembly; upper end fitting plus fuel rod end caps and plenum region of stored assembly) separates the active fuel region of the dropped assembly from the active fuel region of assemblies in the storage racks. Thus the active fuel regions of the dropped and stored fuel assemblies are neutronically isolated and reactivity does not increase.

3.2.9.2.3 Fuel Assembly Dropped To The SFP Floor

A dropped fuel assembly can not fit between rack modules. However, a fuel assembly can fit between a Region I module and the pool wall.

Therefore, this case is analyzed in Section 3.2.9.2.4 below.

3.2.9.2.4 Fuel Misloading in either Region I or Region II

Misloading a single fresh 4.8 w/o fuel assembly in Regions I and II is analyzed.

The following misplacement locations were considered:

Region I:
- Center Of Module 1
- Periphery Of Module 1
- Periphery Of Module 2
- Module 1-3 Interface (Center)
- Module 1-3 Interface (Periphery)
- Next to Module 1 (Outside Racks)
- Checkerboard Patterns In Module 1

Region II:
- Center Of Module 5
- Periphery Of Module 5
- Periphery Of Module 6
- Module 1-3 Interface (Center)
- Module 1-3 Interface (Periphery)
- Checkerboard Patterns In Module 5
- 3 Out of 4 Patterns In Module 5
- 1 Out Of 9 patterns In Module 5

These locations are shown in Figure 3-2.

The amount of reactivity increase caused by each possible accident scenario is calculated using KENO-Va.

For these accident conditions, the presence of soluble boron can be assumed as a realistic initial condition.

Using the results of KENO-Va or CASMO-3 soluble boron worth calculations, the amount of soluble boron needed to offset the highest reactivity increase caused by all accident conditions and maintain $K_{eff}$ less than or equal to 0.95 is determined.

3.2.10 Soluble Boron Credit Methodology

The soluble boron credit methodology has four steps which determine three soluble boron concentrations. The four steps are:

(a) Determine the storage configuration of the spent fuel racks using no soluble boron 95/95 k-eff conditions such that the final KENO $K_{eff}$, including all uncertainties, is less than 1.0.

(b) Using the configuration from Step (a), determine the soluble boron concentration which maintains $K_{eff}$ less than or equal to 0.95. This step is performed with either CASMO-3 or KENO-Va.

(c) Since soluble boron is now credited, uncertainties in reactivity equivalencing and discharge burnup are now off-set with soluble boron. This step is performed with either CASMO-3 or KENO-Va.

(d) Determine the increase in reactivity caused by postulated accidents and the corresponding additional amount of soluble boron needed to off-set these reactivity increases. The increase in reactivity is determined with KENO-Va (fuel mishandling) and CASMO-3 (pool heat up). The amount of soluble boron needed to off-set the reactivity increase for the pool heatup accident is calculated with CASMO-3. The amount of soluble boron needed to off-set the reactivity increase for the fuel mishandling accident is calculated with both CASMO-3 and KENO-Va to compare results.

The final soluble boron requirement is the sum of the requirements determined in steps (b), (c), and (d) above.

The total soluble boron credit requirement along with the storage configuration specified for no soluble boron shows that the spent fuel racks will always maintain $K_{eff}$ less than or equal to 0.95. Further, the no soluble boron storage configuration will ensure that $K_{eff}$ remains less than 1.0 with no soluble boron in the spent fuel pool.

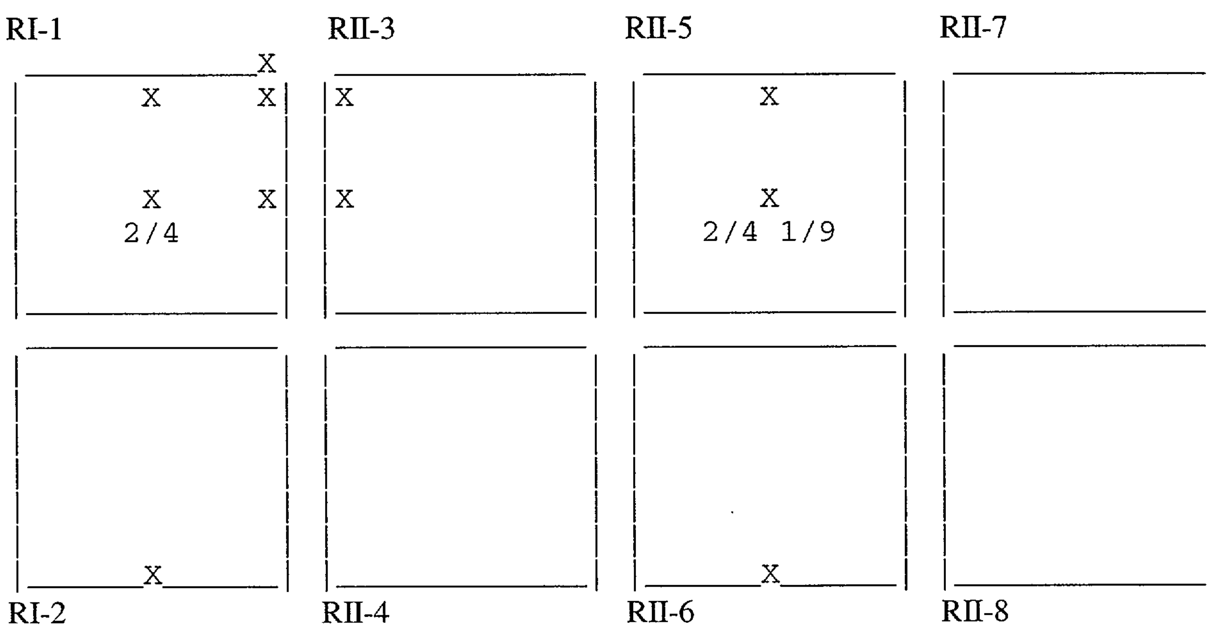
Finally, Reference 9 documents that an equivalent fresh enrichment determined at 0 ppm is under-estimated if used in a KENO-Va model which includes dissolved boron. SCE's analyses ensured that the conditions under which equivalent fresh enrichments were determined remained unchanged in the down-stream analyses which used the equivalent fresh enrichments.

Figure 3-1
SFP Criticality Methodology

```
 ---------
| CELLDAN |
 ---------
     |
 -----------
| NITAWL-II |
 -----------
     |
 -------------------------------        -------------------------------
|           KENO-Va             |      |           CASMO-3             |
|                               |      |                               |
| (1) Reference Reactivity      |      | (1) Manufacturing Tolerances  |
| (2) Eccentric Placement In    |      |     Pool Temp Bias            |
|     Storage Cells             |      | (2) Reactivity Equivalencing  |
| (3) CEA Bias                  |      |     (Burnup/Cooling Time Tables)|
| (4) Integral Fuel Burnable    |      | (3) CEA Bias                  |
|     Absorber Credit           |      | (4) Integtral Fuel Burnable   |
| (5) Borated SS And Al Inserts |      |     Absorber Credit           |
| (6) Postulated Accidents      |      | (5) Borated SS And Al Inserts |
| (7) Soluble Boron Credit      |      | (6) Postulated Accidents      |
 -------------------------------       | (7) Soluble Boron Credit      |
                                        -------------------------------

                  -----------
                 |  CASMO-3  |
                 |           |
                 | X-Sections|
                  -----------
                       |
             ------------------------
            |       SIMULATE-3       |
            |                        |
            |    Axial Burnup Bias   |
            | (2D vs 3D Comparison)  |
             ------------------------
```

Figure 3-2
Fuel Mishandling Analysis Locations




Ry-z = Region y, Module z
x = Misload Location

Figure 3-3
Orientation Of 3 Guide Tube Inserts

```
 --------------------------------------
|                                  xxx |  <--- Serial
|                                    x |       Number
|                                    x |
|      XX                      OO      |
|      XX                      OO      |
|                                      |
|                                      |
|                                      |
|                  XX                  |
|                  XX                  |
|                                      |
|                                      |
|                                      |
|      OO                     XX       |
|      OO                     XX       |
|                                      |
|                                      |
|                                      |
 --------------------------------------
```

```
XX = Guide Tube With Insert
XX

OO = Empty Guide Tube
OO
```

# 4. CRITICALITY SAFETY ANALYSES

This section summarizes the results of the criticality analyses preformed for the SONGS Units 2 and 3 spent fuel storage racks assuming no Boraflex. The analyses were performed at 0 ppm. The acceptance criteria is $K_{eff} < 1.0$, including all uncertainties.

First, results are presented for :
- Manufacturing Tolerances
- Pool Temperature Bias
- Eccentric Placement Bias
- CEA Bias
- Axial Burnup Bias

The delta-k's from these analyses (and the bias and uncertainty from Section 3.1.2) are needed to calculate a spent fuel storage rack $K_{eff}$ which includes all biases and uncertainties.

Then, permissible storage patterns for both Region I and Region II are given. SONGS Unit 1 assembly results are given. Finally, results are given for:
- Inter-module Spacing
- Reconstitution Station
- Failed Fuel Rod Storage Basket
- Fuel Handling Equipment
- Non-fuel components

## 4.1 MANUFACTURING TOLERANCES AND POOL TEMPERATURE BIAS

The manufacturing tolerance and normal pool temperature range results are shown in Table 4-1. These results were calculated with CASMO-3. The manufacturing tolerances are combined statistically (square root of the sum of the squares). The pool temperature bias is added directly to the KENO-Va result.

## 4.2 ECCENTRIC PLACEMENT BIAS

Eccentric Placement of fuel assemblies in the storage cells has been evaluated with KENO-Va. The results are:

| | | | |
|---|---|---|---|
| Region I Delta-k | = | 0.01383 | (4.80 w/o) |
| | | 0.00767 | (2.47 w/o) |
| Region II Delta-k | = | 0.0 | (No enrichment dependence) |

As discussed in Section 3.2.3, this result is combined statistically with the manufacturing tolerance results.

## 4.3 CONTROL ELEMENT ASSEMBLY (CEA) BIAS

The bias for 5-finger, full-length CEAs in SONGS Units 2 and 3 fuel assemblies is 0.007 delta-k. This bias is independent of enrichment and was determined by inter-comparison of CASMO-3 and KENO-Va for rodded and unrodded cases. The CEA bias is added directly to the KENO-Va results.

## 4.4 AXIAL BURNUP BIAS

The axial burnup bias for SONGS fuel assemblies is 0.0 delta-k at all burnups from 0 to 60 GWD/T. This bias is added directly to the KENO-Va results.

SCE's analyses have determined that an assembly with a uniform axial burnup of X GWD/T (X = 0 to 60 GWD/T) has higher reactivity than an assembly with a 3D burnup profile with average burnup of X GWD/T provided:

(1) The mode of operation is ARO.

(2) The uniform axial burnup results from depletion at constant $T_{mod}$ = 600 F, $T_{fuel}$ = 1200 F.

(3) The 3D axial burnup distribution results from depletion at actual reactor conditions of $T_{inlet} \leq 553$ F, $T_{fuel} = f(T_{mod}, \text{Burnup})$, and axial variation of these temperatures.

The SIMULATE-3 results are shown in Table 4-2. The axial burnup bias is 0.0 delta-k. In fact, there is a small credit which increases with burnup. Conservatively, this credit is not taken.

## 4.5 SONGS UNITS 2 AND 3 FUEL ASSEMBLIES

### 4.5.1 Region I

The non-accident neutron multiplication factor ($K_{eff}$) for the Region I spent fuel storage racks is less than 1.0, including all uncertainties, assuming a soluble boron concentration of 0 ppm.

The permissible Region I storage patterns are shown in Tables 4-3 through 4-10 and Figures 4-1 through 4-6.

4.5.2 Region II

The non-accident neutron multiplication factor ($K_{eff}$) for the Region II spent fuel storage racks is less than 1.0, including all uncertainties, assuming a soluble boron concentration of 0 ppm.

The permissible Region II storage patterns are shown in Tables 4-11 through 4-25 and Figures 4-7 through 4-21. When 3 guide tube inserts are used, the orientation shall be the same in every assembly in the spent fuel pool (Figure 3-3). A 5-finger, full-length CEA may be used in place of 3 or 5 borated SS or Aluminum guide tube inserts.

4.5.3 Region I And Region II Checkerboard Pattern Interface requirements

The boundary between checkerboard zones and the boundary between a checkerboard zone and all cell storage must be controlled to prevent an undesirable increase in reactivity. This is accomplished by examining each 2x2 assembly matrix interface and ensuring that each matrix conforms to restrictions for both regions.

For example, consider a fuel assembly location E in the following matrix of storage cells.

| | | |
|---|---|---|
| A | B | C |
| D | E | F |
| G | H | I |

Four 2x2 matrices of storage cells which include cell E are created in the above figure. They include (A, B, D, E), (B, C, F, E), (E, F, I, H), and (D, E, H, G). Each of these 2x2 matrices of storage cells must meet the requirements for both regions.

A row of empty storage cells can also be used at the interface to separate different storage patterns.

The interface requirements are shown in Figures 4-22 through 4-27.

4.5.4 Region II One Out Of Nine Pattern Interface requirements

The boundary between One Out of Nine and the boundary between all cell storage must be controlled to prevent an undesirable increase in reactivity. A specific KENO-Va case was run to determine the interface requirement.

A row of empty storage cells can also be used at the interface to separate different storage patterns.

The interface requirement is shown in Figure 4-28.

## 4.6 SONGS UNIT 1 FUEL ASSEMBLIES

Unit 1 Fuel has not been analyzed to be stored in Region I.

### 4.6.1 Unrestricted Storage in Region II

SONGS Unit 1 nominal 3.40 w/o assemblies can be stored in the Region II Racks (unrestricted) if:

> the burnup is greater than 25,000 MWD/T, and
> the cooling time is greater than 5 years.

SONGS Unit 1 nominal 4.00 w/o assemblies can be stored in the Region II Racks (unrestricted) if:

> the burnup is greater than 26,300 MWD/T, and
> the cooling time is greater than 20 years.
>
> or
>
> the burnup is greater than 27,100 MWD/T, and
> the cooling time is greater than 15 years.
>
> or
>
> the burnup is greater than 28,200 MWD/T, and
> the cooling time is greater than 10 years.

### 4.6.2 SFP Peripheral Storage in Region II

SONGS Unit 1 nominal 4.00 w/o assemblies can be stored in the Region II Racks (SFP periphery) if:

> the burnup is greater than 20,000 MWD/T, and
> the cooling time is greater than 0 years.

## 4.7 INTER-MODULE SPACING

A full pool KENO-Va model (Figure A-3 in Appendix A) was used to evaluate the inter-module spacing assuming no Boraflex. The inter-module spacing needed when Boraflex is present is conservatively unchanged when there is no Boraflex.

## 4.8 RECONSTITUTION STATION

A fuel assembly reconstitution station is a special case of a checkerboard pattern.

A reconstitution station is permitted anywhere in the Region I racks. The empty cells in the checkerboard pattern do not need to be blocked. A reconstitution station is permitted anywhere in the Region II racks provided that empty cells in the checkerboard pattern are blocked to make it impossible to misload a fuel assembly during reconstitution activities.

## 4.9 FAILED FUEL ROD STORAGE BASKET

The failed fuel rod storage basket (FFRSB) is less reactive than an intact fuel assembly.

Therefore, for storage of the FFRSB in the SFP storage racks, the FFRSB shall be treated as if it were an assembly with enrichment and burnup of the rod in the basket with the most limiting combination of enrichment and burnup. Alternatively, explicit analyses using the methodology of Section 3.2 may be performed to determine storage requirements for the FFRSB.

## 4.10 FUEL HANDLING EQUIPMENT

This equipment (Upenders, Transfer Baskets, Refueling Machine Mast) is not affected by the presence or absence of Boraflex.

## 4.11 NON-FUEL COMPONENTS

Neutron sources and non-fuel bearing assembly components (thimble plugs, CEAs, etc) may be stored in fuel assemblies without affecting the storage requirements of these assemblies. The neutron source material is an absorber which reduces reactivity. Thus, a neutron source may be stored in an empty cell or in an assembly. A storage basket containing no fissile material can be stored in any storage location, and can be used as a storage cell blocker for reactivity control.

**Table 4-1**
**Manufacturing Tolerance And Pool Temperature Results**

**REGION I DELTA-$K_{inf}$**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 5.10 w/o | | | | 1.85 w/o | |
| **Tolerance** | **0 ppm** | **500 ppm** | **1000 ppm** | | **0 ppm** | **500 ppm** | **1000 ppm** |
| **Enrichment** | 0.00179 | 0.00201 | 0.00216 | | 0.00757 | 0.00772 | 0.00774 |
| **SS Thickness** | 0.00518 | 0.00370 | 0.00283 | | 0.00460 | 0.00291 | 0.00215 |
| **Cell ID** | 0.00531 | 0.00518 | 0.00502 | | 0.00360 | 0.00350 | 0.00335 |
| **Cell Pitch** | 0.00796 | 0.00807 | 0.00790 | | 0.00620 | 0.00586 | 0.00560 |
| **40 C (104 F)** | 0.00383 | 0.00344 | 0.00314 | | 0.00182 | 0.00152 | 0.00144 |
| **71 C (160 F)** | 0.00914 | 0.00862 | 0.00829 | | 0.00389 | 0.00438 | 0.00454 |

**REGION II DELTA-$K_{inf}$**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1.85 w/o | | | | 1.20 w/o | |
| **Tolerance** | **0 ppm** | **500 ppm** | **1000 ppm** | | **0 ppm** | **500 ppm** | **1000 ppm** |
| **Enrichment** | 0.00907 | 0.00959 | 0.00976 | | 0.01543 | 0.01547 | 0.01510 |
| **SS Thickness** | 0.00174 | 0.00107 | 0.00062 | | 0.00165 | 0.00100 | 0.00058 |
| **Cell ID** | 0.00244 | 0.00304 | 0.00331 | | 0.00223 | 0.00267 | 0.00286 |
| **Cell Pitch** | N/A | N/A | N/A | | N/A | N/A | N/A |
| **40 C (104 F)** | -0.00040 | 0.00031 | 0.00077 | | -0.00076 | 0.00000 | 0.00043 |
| **71 C (160 F)** | -0.00099 | 0.00147 | 0.00285 | | -0.00160 | 0.00083 | 0.00215 |

Note: Region II does not have a water gap between storage cells. Therefore, cell pitch is not applicable in the Region II racks

**Table 4-2**
**Axial Burnup Bias**

| Burnup | 1.87 w/o 2D $K_{eff}$ | 1.87 w/o 3D $K_{eff}$* | Delta-k (2D - 3D) |
|---|---|---|---|
| 0 | 1.24454 | 1.24454 | 0.00000 |
| 10 | 1.11561 | 1.10809 | 0.00752 |
| 20 | 1.01562 | 1.00765 | 0.00797 |
| 30 | 0.94019 | 0.93183 | 0.00836 |
| 40 | 0.88513 | 0.87637 | 0.00876 |
| 50 | 0.84777 | 0.83876 | 0.00901 |
| 60 | 0.82274 | 0.81284 | 0.00990 |

| Burnup | 4.45 w/o 2D $K_{eff}$ | 4.45 w/o 3D $K_{eff}$* | Delta-k (2D - 3D) |
|---|---|---|---|
| 0 | 1.45672 | 1.45671 | 0.00001 |
| 10 | 1.34135 | 1.33404 | 0.00731 |
| 20 | 1.25052 | 1.24275 | 0.00777 |
| 30 | 1.16868 | 1.16048 | 0.00820 |
| 40 | 1.08984 | 1.08169 | 0.00815 |
| 50 | 1.01564 | 1.00736 | 0.00828 |
| 60 | 0.94916 | 0.93970 | 0.00946 |

* 3D Axial Burnup Profile

**Table 4-3**

# Region I

**Category I-1**
**Unrestricted Storage**

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 5.00 | 22.84 | 21.47 | 20.59 | 20.04 | 19.67 |
| 4.50 | 18.61 | 17.57 | 16.89 | 16.45 | 16.17 |
| 4.00 | 14.30 | 13.58 | 13.09 | 12.78 | 12.57 |
| 3.50 | 9.84 | 9.40 | 9.11 | 8.92 | 8.79 |
| 3.00 | 5.24 | 5.02 | 4.91 | 4.84 | 4.79 |
| 2.47 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2.47 w/o | 2.47 w/o | 2.47 w/o | . . . | 2.47 w/o | 2.47 w/o | 2.47 w/o |

**Table 4-4**

# Region I

**Category I-2**
**SFP Peripheral Storage**

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 12.55 | 12.15 | 11.82 | 11.61 | 11.47 |
| 4.50 | 9.09 | 8.85 | 8.63 | 8.49 | 8.40 |
| 4.00 | 5.58 | 5.43 | 5.33 | 5.25 | 5.21 |
| 3.50 | 2.22 | 2.13 | 2.09 | 2.05 | 2.03 |
| 3.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **3.20 w/o** | 2.47 w/o | 2.47 w/o | . . . | 2.47 w/o | 2.47 w/o | **3.20 w/o** |

**Table 4-5**

# Region I

**Category I-3**
**Filler Assembly For 1-out-of-4 Pattern**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/T) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 5.00 | 39.99 | 36.28 | 34.27 | 33.04 | 32.22 |
| 4.50 | 34.95 | 31.71 | 29.94 | 28.84 | 28.12 |
| 4.00 | 29.71 | 26.99 | 25.46 | 24.51 | 23.89 |
| 3.50 | 24.22 | 22.03 | 20.79 | 20.02 | 19.52 |
| 3.00 | 18.37 | 16.84 | 15.91 | 15.34 | 14.97 |
| 2.50 | 12.21 | 11.30 | 10.72 | 10.37 | 10.13 |
| 2.00 | 5.28 | 5.05 | 4.85 | 4.72 | 4.62 |
| 1.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| **4.80 w/o Fresh** | 1.71 w/o |
| 1.71 w/o | 1.71 w/o |

**Table 4-6**

# Region I

**4.80 w/o Fresh Fuel**

**Checkerboard**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/T) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 4.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| ( Empty) | **4.80 w/o** |
| **4.80 w/o** | (Empty) |

**Table 4-7**

# Region I

**4.80 w/o Fresh Fuel
With
Full-length, 5-finger CEA**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 4.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| 4.80 w/o Fresh With CEA | 4.80 w/o Fresh With CEA |
| 4.80 w/o Fresh With CEA | 4.80 w/o Fresh With CEA |

**Table 4-8**

# Region I

**Category I-4**
**Filler Assembly For 1-out-of-4 Pattern**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 26.57 | 24.71 | 23.59 | 22.90 | 22.44 |
| 4.50 | 22.12 | 20.62 | 19.73 | 19.17 | 18.80 |
| 4.00 | 17.54 | 16.46 | 15.78 | 15.35 | 15.07 |
| 3.50 | 12.84 | 12.12 | 11.66 | 11.37 | 11.18 |
| 3.00 | 7.95 | 7.56 | 7.31 | 7.15 | 7.05 |
| 2.50 | 2.76 | 2.64 | 2.56 | 2.50 | 2.46 |
| 2.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| **4.80 w/o Fresh 80 Erbia** | 2.27 w/o |
| 2.27 w/o | 2.27 w/o |

**Table 4-9**

# Region I

**Category I-5**
**Filler Assembly For 1-out-of-4 Pattern**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 30.81 | 28.40 | 27.00 | 26.14 | 25.57 |
| 4.50 | 26.17 | 24.17 | 22.99 | 22.26 | 21.78 |
| 4.00 | 21.32 | 19.77 | 18.84 | 18.27 | 17.88 |
| 3.50 | 16.32 | 15.22 | 14.55 | 14.13 | 13.85 |
| 3.00 | 11.11 | 10.45 | 10.05 | 9.79 | 9.61 |
| 2.50 | 5.55 | 5.30 | 5.14 | 5.04 | 4.98 |
| 2.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| **4.80 w/o Fresh 40 Erbia** | 2.07 w/o |
| 2.07 w/o | 2.07 w/o |

**Table 4-10**

# Region I

**Category I-6**
**4.80 w/o Assembly Depleted to 18.0 GWD/MTU**

| Initial Enrichment (w/o) | MinimumBurnup(GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 19.82 | 18.84 | 18.12 | 17.67 | 17.37 |
| 4.50 | 15.83 | 15.11 | 14.58 | 14.24 | 14.01 |
| 4.00 | 11.75 | 11.28 | 10.92 | 10.69 | 10.54 |
| 3.50 | 7.56 | 7.23 | 7.04 | 6.91 | 6.83 |
| 3.00 | 3.28 | 3.15 | 3.07 | 3.03 | 2.99 |
| 2.65 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

## Category I-4
## Checkerboard Partner For Category I-6 Fuel

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 26.57 | 24.71 | 23.59 | 22.90 | 22.44 |
| 4.50 | 22.12 | 20.62 | 19.73 | 19.17 | 18.80 |
| 4.00 | 17.54 | 16.46 | 15.78 | 15.35 | 15.07 |
| 3.50 | 12.84 | 12.12 | 11.66 | 11.37 | 11.18 |
| 3.00 | 7.95 | 7.56 | 7.31 | 7.15 | 7.05 |
| 2.50 | 2.76 | 2.64 | 2.56 | 2.50 | 2.46 |
| 2.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| **2.65 w/o** | 2.27 w/o |
| 2.27 w/o | **2.65 w/o** |

Table 4-11

# Region II

Category II-1
Unrestricted Storage

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 5.00 | 53.76 | 47.77 | 44.75 | 43.00 | 41.86 |
| 4.50 | 48.43 | 42.93 | 40.15 | 38.52 | 37.47 |
| 4.00 | 42.91 | 37.94 | 35.40 | 33.92 | 32.96 |
| 3.00 | 30.99 | 27.26 | 25.30 | 24.16 | 23.43 |
| 2.00 | 17.05 | 14.97 | 13.90 | 13.25 | 12.83 |
| 1.87 | 14.93 | 13.23 | 12.26 | 11.68 | 11.31 |
| 1.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.23 w/o | 1.23 w/o | 1.23 w/o | . . . | 1.23 w/o | 1.23 w/o | 1.23 w/o |

**Table 4-12**

# Region II

**Category II-2**
**SFP Peripheral Storage**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 5.00 | 36.95 | 33.68 | 31.89 | 30.81 | 30.10 |
| 4.50 | 32.29 | 29.44 | 27.87 | 26.91 | 26.28 |
| 4.00 | 27.44 | 25.04 | 23.70 | 22.88 | 22.35 |
| 3.00 | 16.95 | 15.62 | 14.83 | 14.34 | 14.03 |
| 2.00 | 4.93 | 4.67 | 4.52 | 4.42 | 4.35 |
| 1.87 | 3.04 | 2.87 | 2.76 | 2.69 | 2.64 |
| 1.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **1.70 w/o** | 1.23 w/o | 1.23 w/o | . . . | 1.23 w/o | 1.23 w/o | **1.70 w/o** |

**Table 4-13**

# Region II

**Category II-4**
**Checkerboard Partner For Category II-3 Fuel**

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 75.42 | 61.90 | 56.85 | 54.18 | 52.60 |
| 4.50 | 68.08 | 56.12 | 51.65 | 49.25 | 47.76 |
| 4.00 | 60.74 | 50.35 | 46.44 | 44.19 | 42.78 |
| 3.00 | 46.06 | 38.80 | 35.41 | 33.52 | 32.31 |
| 2.00 | 31.38 | 25.71 | 23.12 | 21.65 | 20.71 |
| 1.87 | 29.19 | 23.83 | 21.34 | 19.91 | 19.08 |
| 0.94 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Category II-3**
**Checkerboard Pattern**

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 41.18 | 37.27 | 35.18 | 33.93 | 33.12 |
| 4.50 | 36.34 | 32.87 | 31.01 | 29.88 | 29.15 |
| 4.00 | 31.29 | 28.31 | 26.69 | 25.70 | 25.06 |
| 3.00 | 20.32 | 18.50 | 17.47 | 16.84 | 16.42 |
| 2.00 | 7.81 | 7.25 | 6.91 | 6.71 | 6.58 |
| 1.87 | 5.90 | 5.53 | 5.30 | 5.17 | 5.09 |
| 1.56 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| 0.94 w/o | **1.56 w/o** |
| **1.56 w/o** | 0.94 w/o |

**Table 4-14**

# Region II

**Category II-6**
**Checkerboard Partner For Category II-5 Fuel**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 5.00 | 62.37 | 53.95 | 50.33 | 48.25 | 46.91 |
| 4.50 | 56.21 | 48.90 | 45.51 | 43.56 | 42.31 |
| 4.00 | 50.04 | 43.67 | 40.54 | 38.73 | 37.57 |
| 3.00 | 37.71 | 32.56 | 29.97 | 28.52 | 27.58 |
| 2.00 | 23.30 | 19.80 | 18.13 | 17.14 | 16.50 |
| 1.87 | 21.11 | 18.02 | 16.42 | 15.48 | 14.88 |
| 1.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Category II-5**
**Checkerboard Pattern**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 5.00 | 47.50 | 42.58 | 40.03 | 38.53 | 37.55 |
| 4.50 | 42.40 | 37.95 | 35.64 | 34.26 | 33.37 |
| 4.00 | 37.10 | 33.16 | 31.10 | 29.86 | 29.06 |
| 3.00 | 25.64 | 22.89 | 21.40 | 20.52 | 19.95 |
| 2.00 | 12.29 | 11.10 | 10.42 | 10.01 | 9.75 |
| 1.87 | 10.24 | 9.35 | 8.80 | 8.46 | 8.25 |
| 1.38 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| 1.08 w/o | **1.38 w/o** |
| **1.38 w/o** | 1.08 w/o |

**Table 4-15**

# Region II

**Checkerboard Storage**

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 4.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| Empty (Blocked) | **4.80 w/o** |
| **4.80 w/o** | Empty (Blocked) |

**Table 4-16**

# Region II

**Category II-7**
**3 Out of 4 Storage**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 34.20 | 31.35 | 29.74 | 28.76 | 28.12 |
| 4.50 | 29.67 | 27.21 | 25.82 | 24.97 | 24.41 |
| 4.00 | 24.94 | 22.92 | 21.75 | 21.05 | 20.59 |
| 3.00 | 14.79 | 13.76 | 13.13 | 12.73 | 12.47 |
| 2.00 | 3.16 | 3.00 | 2.90 | 2.83 | 2.79 |
| 1.87 | 1.21 | 1.14 | 1.09 | 1.06 | 1.04 |
| 1.80 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | |
|---|---|
| **1.80 w/o** | **1.80 w/o** |
| **1.80 w/o** | Empty (Blocked) |

**Table 4-17**

# Region II

**Category II-8**
**Unrestricted Storage**
**With**
**5 Borated SS Or Aluminum Inserts In Every Assembly**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 5.00 | 37.68 | 34.53 | 32.72 | 31.61 | 30.88 |
| 4.50 | 32.61 | 29.90 | 28.33 | 27.36 | 26.72 |
| 4.00 | 27.33 | 25.10 | 23.78 | 22.97 | 22.43 |
| 3.00 | 15.86 | 14.76 | 14.06 | 13.61 | 13.32 |
| 2.00 | 2.04 | 1.97 | 1.89 | 1.84 | 1.81 |
| 1.90 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1.90 w/o<br>5 Inserts | 1.90 w/o<br>5 Inserts | 1.90 w/o<br>5 Inserts | . . . | 1.90 w/o<br>5 Inserts | 1.90 w/o<br>5 Inserts | 1.90 w/o<br>5 Inserts |

**Table 4-18**

# Region II

**Category II-9**
**Unrestricted Storage**
**With**
**3 Borated SS Or Aluminum Inserts In Every Assembly**

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 44.16 | 39.95 | 37.68 | 36.31 | 35.42 |
| 4.50 | 38.99 | 35.25 | 33.22 | 31.99 | 31.18 |
| 4.00 | 33.61 | 30.38 | 28.60 | 27.52 | 26.81 |
| 3.00 | 21.92 | 19.86 | 18.72 | 18.01 | 17.56 |
| 2.00 | 8.28 | 7.72 | 7.34 | 7.11 | 6.96 |
| 1.87 | 6.18 | 5.83 | 5.58 | 5.43 | 5.34 |
| 1.59 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1.59 w/o<br>3 Inserts | 1.59 w/o<br>3 Inserts | 1.59 w/o<br>3 Inserts | . . . | 1.59 w/o<br>3 Inserts | 1.59 w/o<br>3 Inserts | 1.59 w/o<br>3 Inserts |

**Table 4-19**

# Region II

**Category II-10**
**Filler Assembly With 5 Borated SS Or Aluminum Inserts**

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) | | | | |
|---|---|---|---|---|---|
| | 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
| 5.00 | 80.09 | 65.66 | 60.12 | 57.45 | 55.68 |
| 4.50 | 72.13 | 59.43 | 54.55 | 52.02 | 50.33 |
| 4.00 | 64.18 | 53.19 | 48.98 | 46.58 | 44.98 |
| 3.00 | 48.27 | 40.72 | 37.16 | 35.03 | 33.75 |
| 2.00 | 32.35 | 26.59 | 23.79 | 22.25 | 21.25 |
| 1.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | |
|---|---|---|
| 1.03 w/o<br>5 Inserts | 1.03 w/o<br>5 Inserts | 1.03 w/o<br>5 Inserts |
| 1.03 w/o<br>5 Inserts | **4.80 w/o<br>Fresh** | 1.03 w/o<br>5 Inserts |
| 1.03 w/o<br>5 Inserts | 1.03 w/o<br>5 Inserts | 1.03 w/o<br>5 Inserts |

Table 4-20

# Region II

Category II-11
Filler Assembly With 5 Borated SS Or Aluminum Inserts

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 47.04 | 42.52 | 40.05 | 38.57 | 37.60 |
| 4.50 | 41.62 | 37.58 | 35.36 | 34.02 | 33.14 |
| 4.00 | 35.97 | 32.46 | 30.50 | 29.32 | 28.54 |
| 3.00 | 23.70 | 21.42 | 20.09 | 19.31 | 18.79 |
| 2.00 | 9.17 | 8.54 | 8.09 | 7.81 | 7.62 |
| 1.59 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | |
|---|---|---|
| 1.59 w/o<br>5 Inserts | 1.59 w/o<br>5 Inserts | 1.59 w/o<br>5 Inserts |
| 1.59 w/o<br>5 Inserts | **4.80 w/o<br>Fresh<br>5 Inserts** | 1.59 w/o<br>5 Inserts |
| 1.59 w/o<br>5 Inserts | 1.59 w/o<br>5 Inserts | 1.59 w/o<br>5 Inserts |

**Table 4-21**

# Region II

**Category II-12**
**Filler Assembly With 3 Borated SS Or Aluminum Inserts**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 54.33 | 48.48 | 45.46 | 43.67 | 42.51 |
| 4.50 | 48.81 | 43.45 | 40.67 | 39.02 | 37.95 |
| 4.00 | 43.07 | 38.24 | 35.72 | 34.22 | 33.26 |
| 3.00 | 30.65 | 27.11 | 25.18 | 24.05 | 23.33 |
| 2.00 | 16.01 | 14.23 | 13.22 | 12.62 | 12.22 |
| 1.87 | 13.82 | 12.35 | 11.47 | 10.94 | 10.60 |
| 1.32 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | |
|---|---|---|
| 1.32 w/o<br>3 Inserts | 1.32 w/o<br>3 Inserts | 1.32 w/o<br>3 Inserts |
| 1.32 w/o<br>3 Inserts | **4.80 w/o<br>Fresh<br>5 Inserts** | 1.32 w/o<br>3 Inserts |
| 1.32 w/o<br>3 Inserts | 1.32 w/o<br>3 Inserts | 1.32 w/o<br>3 Inserts |

**Table 4-22**

# Region II

**Category II-13**
**Filler Assembly With No Borated SS Or Aluminum Inserts**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 64.24 | 55.51 | 51.59 | 49.41 | 48.03 |
| 4.50 | 57.99 | 50.23 | 46.73 | 44.67 | 43.38 |
| 4.00 | 51.75 | 44.94 | 41.71 | 39.79 | 38.59 |
| 3.00 | 39.25 | 33.75 | 31.05 | 29.48 | 28.50 |
| 2.00 | 24.76 | 20.95 | 19.07 | 18.01 | 17.33 |
| 1.87 | 22.64 | 19.10 | 17.38 | 16.37 | 15.72 |
| 1.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | |
|---|---|---|
| 1.05 w/o | 1.05 w/o | 1.05 w/o |
| 1.05 w/o | **4.80 w/o Fresh 5 Inserts** | 1.05 w/o |
| 1.05 w/o | 1.05 w/o | 1.05 w/o |

**Table 4-23**

# Region II

**Category II-14**
**4.80 w/o Assembly Depleted to 18.0 GWD/MTU**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 19.59 | 18.61 | 17.96 | 17.54 | 17.27 |
| 4.50 | 15.93 | 15.17 | 14.68 | 14.36 | 14.15 |
| 4.00 | 12.18 | 11.64 | 11.29 | 11.07 | 10.93 |
| 3.00 | 4.28 | 4.12 | 4.05 | 4.00 | 3.98 |
| 2.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Category II-13**
**Filler Assembly For Category II-14 Fuel**

| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 64.24 | 55.51 | 51.59 | 49.41 | 48.03 |
| 4.50 | 57.99 | 50.23 | 46.73 | 44.67 | 43.38 |
| 4.00 | 51.75 | 44.94 | 41.71 | 39.79 | 38.59 |
| 3.00 | 39.25 | 33.75 | 31.05 | 29.48 | 28.50 |
| 2.00 | 24.76 | 20.95 | 19.07 | 18.01 | 17.33 |
| 1.87 | 22.64 | 19.10 | 17.38 | 16.37 | 15.72 |
| 1.05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | |
|---|---|---|
| 1.05 w/o | 1.05 w/o | 1.05 w/o |
| 1.05 w/o | **2.51 w/o** | 1.05 w/o |
| 1.05 w/o | 1.05 w/o | 1.05 w/o |

**Table 4-24**

# Region II

**Category II-14**
**4.80 w/o Assembly Depleted to 18.0 GWD/MTU**

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 19.59 | 18.61 | 17.96 | 17.54 | 17.27 |
| 4.50 | 15.93 | 15.17 | 14.68 | 14.36 | 14.15 |
| 4.00 | 12.18 | 11.64 | 11.29 | 11.07 | 10.93 |
| 3.00 | 4.28 | 4.12 | 4.05 | 4.00 | 3.98 |
| 2.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Category II-11**
**Filler Assembly With 5 Borated SS Or Aluminum Inserts**

| Initial Enrichment (w/o) | Minimum Burnup(GWD/MTU) 0 Years Cooling | 5 Years Cooling | 0 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 47.04 | 42.52 | 40.05 | 38.57 | 37.60 |
| 4.50 | 41.62 | 37.58 | 35.36 | 34.02 | 33.14 |
| 4.00 | 35.97 | 32.46 | 30.50 | 29.32 | 28.54 |
| 3.00 | 23.70 | 21.42 | 20.09 | 19.31 | 18.79 |
| 2.00 | 9.17 | 8.54 | 8.09 | 7.81 | 7.62 |
| 1.59 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | |
|---|---|---|
| 1.59 w/o<br>5 Inserts | 1.59 w/o<br>5 Inserts | 1.59 w/o<br>5 Inserts |
| 1.59 w/o<br>5 Inserts | **2.51 w/o** | 1.59 w/o<br>5 Inserts |
| 1.59 w/o<br>5 Inserts | 1.59 w/o<br>5 Inserts | 1.59 w/o<br>5 Inserts |

**Table 4-25**

# Region II

**Category II-15**
**Unrestricted Storage**
**With**
**A Full-Length, 5-Finger CEA In Every Assembly**

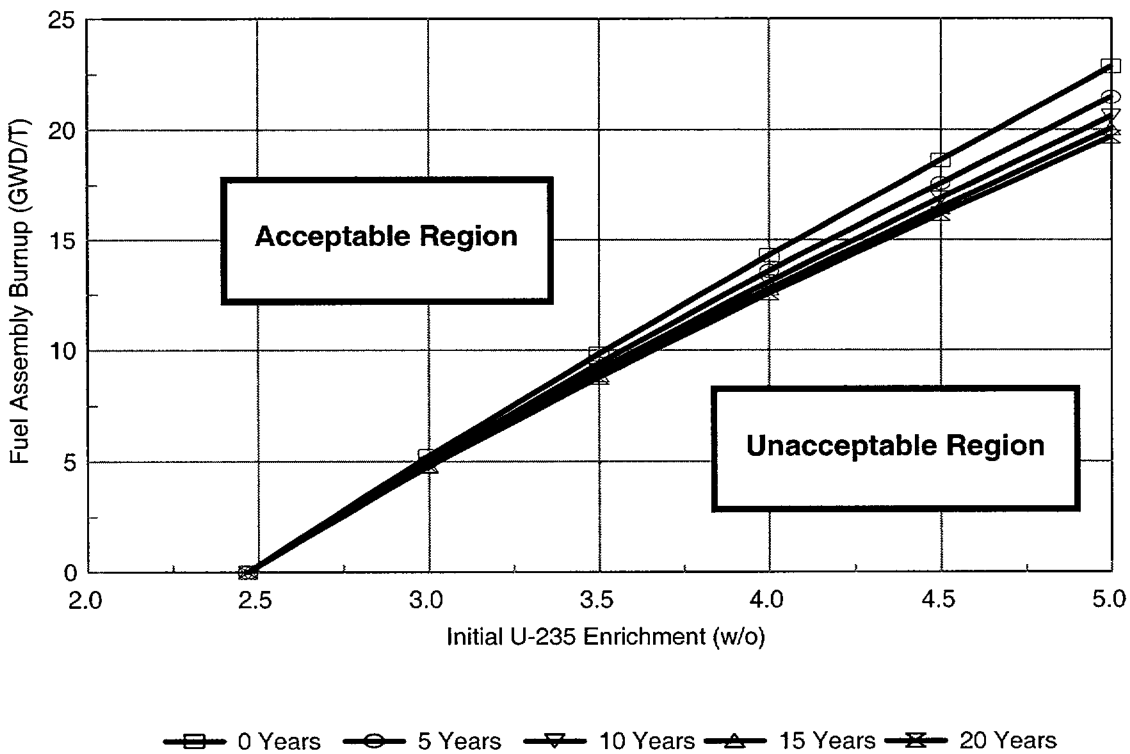
| Initial Enrichment (w/o) | Minimum Burnup (GWD/MTU) 0 Years Cooling | 5 Years Cooling | 10 Years Cooling | 15 Years Cooling | 20 Years Cooling |
|---|---|---|---|---|---|
| 5.00 | 29.24 | 27.24 | 26.00 | 25.22 | 24.70 |
| 4.50 | 24.44 | 22.84 | 21.81 | 21.17 | 20.75 |
| 4.00 | 19.41 | 18.26 | 17.49 | 17.00 | 16.68 |
| 3.00 | 8.83 | 8.47 | 8.19 | 8.02 | 7.90 |
| 2.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2.30 w/o CEA | 2.30 w/o CEA | 2.30 w/o CEA | . . . | 2.30 w/o CEA | 2.30 w/o CEA | 2.30 w/o CEA |

Figure 4-1

REGION I

MINIMUM BURNUP FOR CATEGORY I-1 FUEL
(UNRESTRICTED STORAGE)

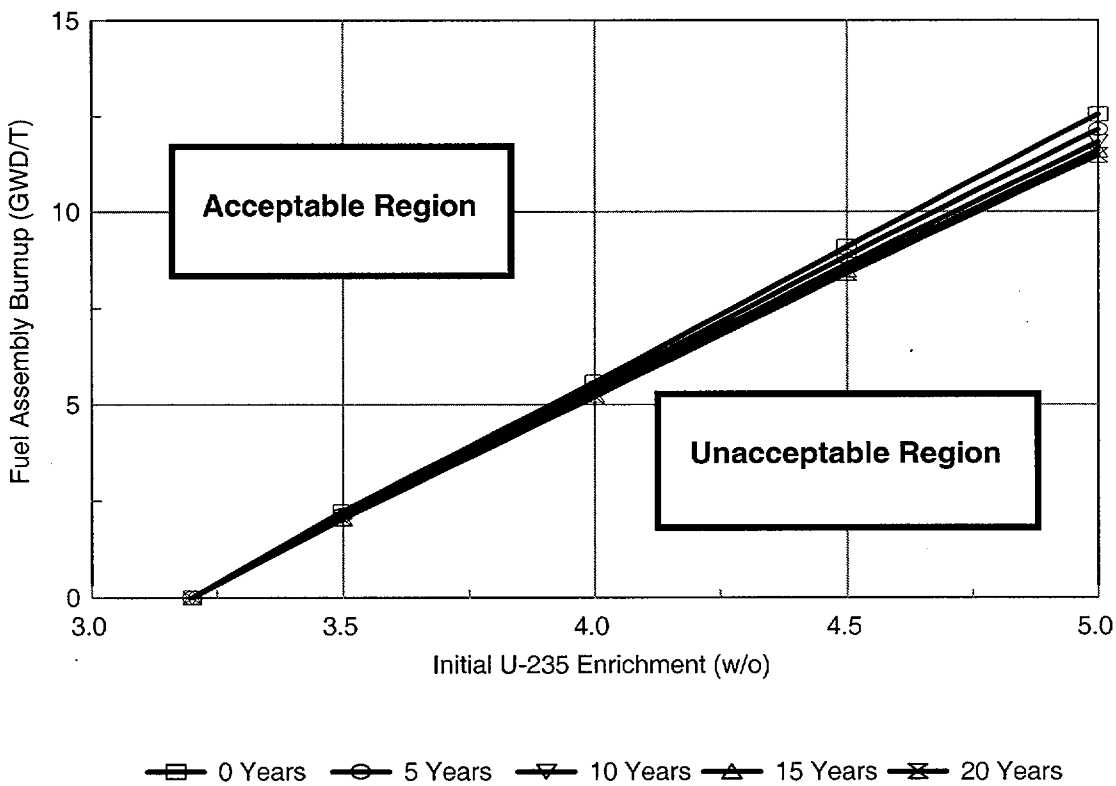



(Figure data points are from Table 4-3)

Figure 4-2

REGION I

MINIMUM BURNUP FOR CATEGORY I-2 FUEL
(SFP PERIPHERAL STORAGE)

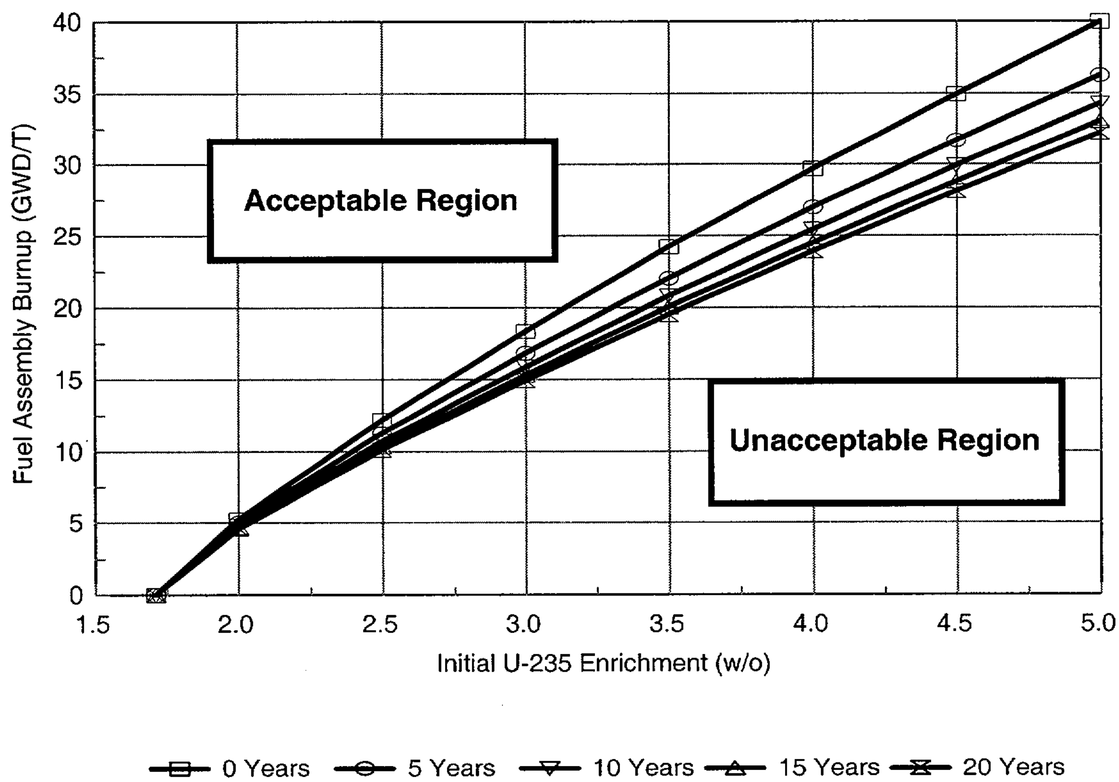



(Figure data points are from Table 4-4)

Figure 4-3

REGION I

MINIMUM BURNUP FOR CATEGORY I-3 FUEL
(FILLER ASSEMBLY FOR 1-OUT-OF-4 PATTERN)

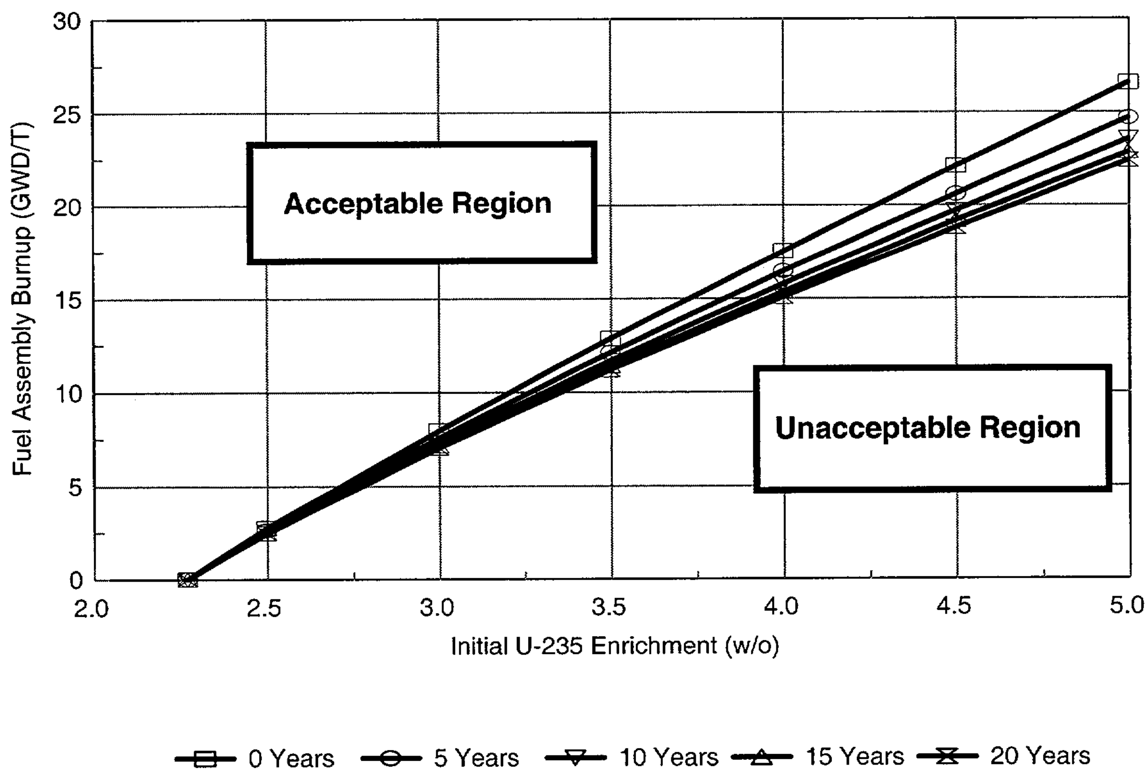



(Figure data points are from Table 4-5)

Figure 4-4

REGION I

MINIMUM BURNUP FOR CATEGORY I-4 FUEL
(FILLER ASSEMBLY FOR 1-OUT-OF-4 PATTERN)

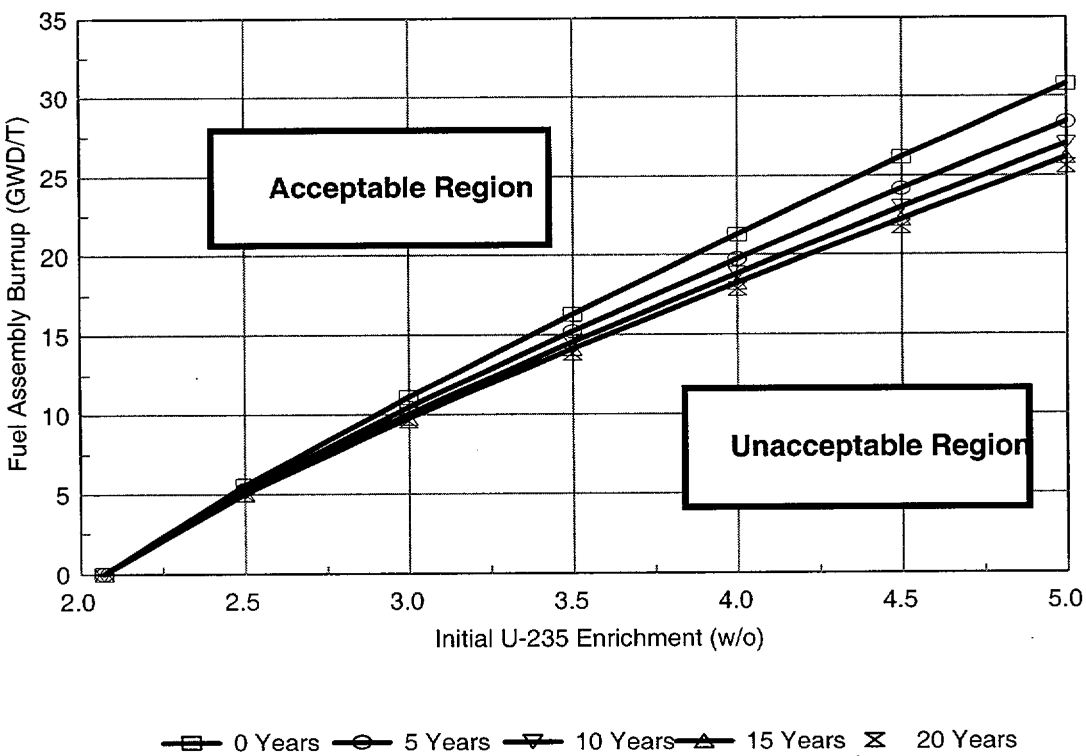



(Figure data points are from Table 4-8)

Figure 4-5

REGION I

MINIUMUM BURNUP FOR CATEGORY I-5 FUEL
(FILLER ASSEMBLY FOR 1-OUT-OF-4 PATTERN)

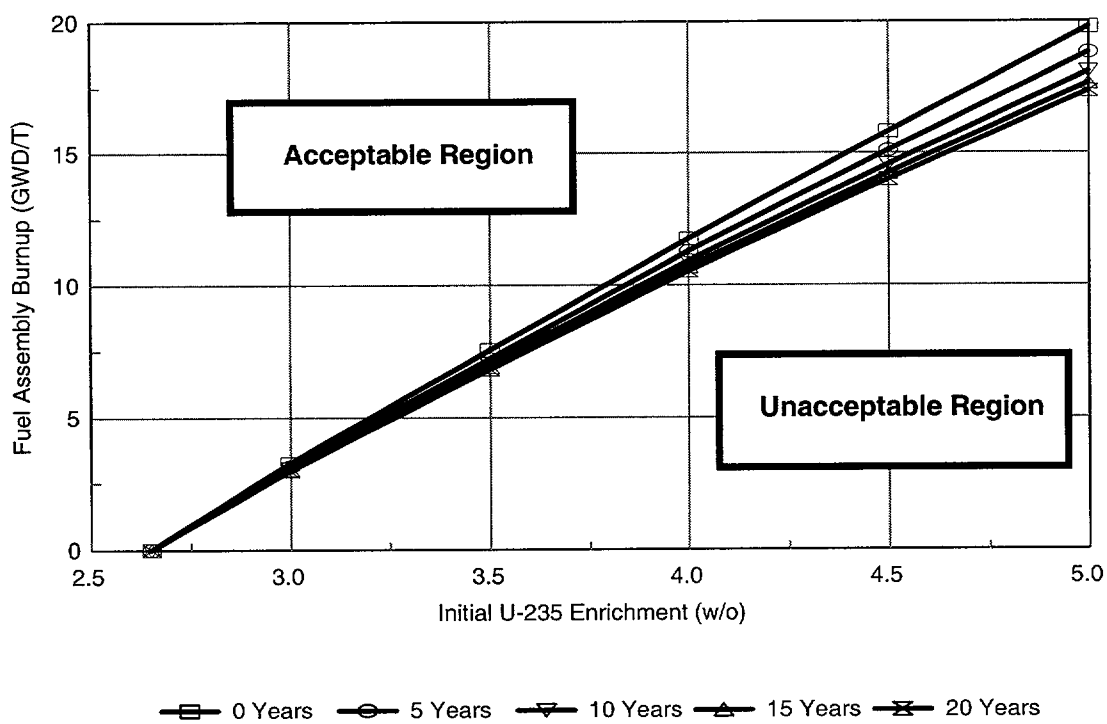



(Figure data points are from Table 4-9)

Figure 4-6

REGION I

MINIMUM BURNUP FOR CATEGORY I-6 FUEL
(4.80 W/O ASSEMBLY DEPLETED TO 18.0 GWD/T)

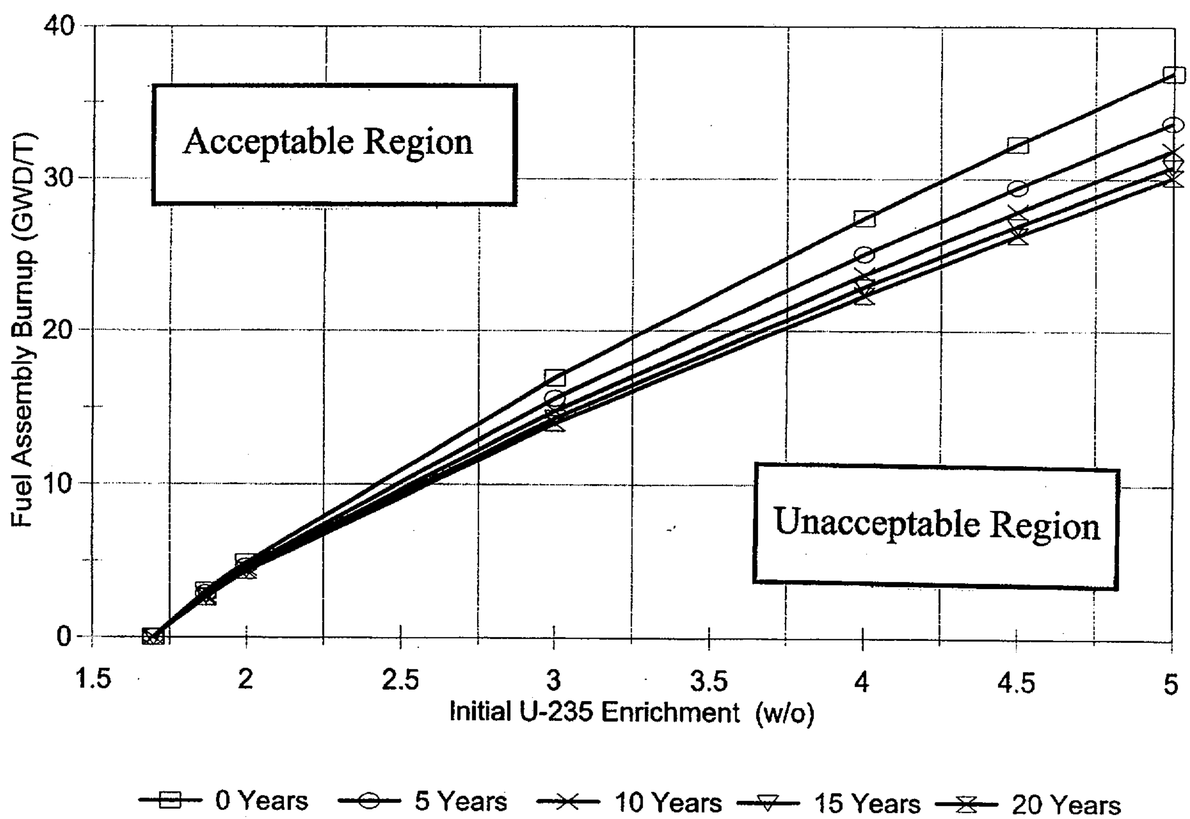



(Figure data points are from Table 4-10)

Figure 4-7

REGION II

MINIMUM BURNUP FOR CATEGORY II-1 FUEL
(UNRESTRICTED STORAGE)

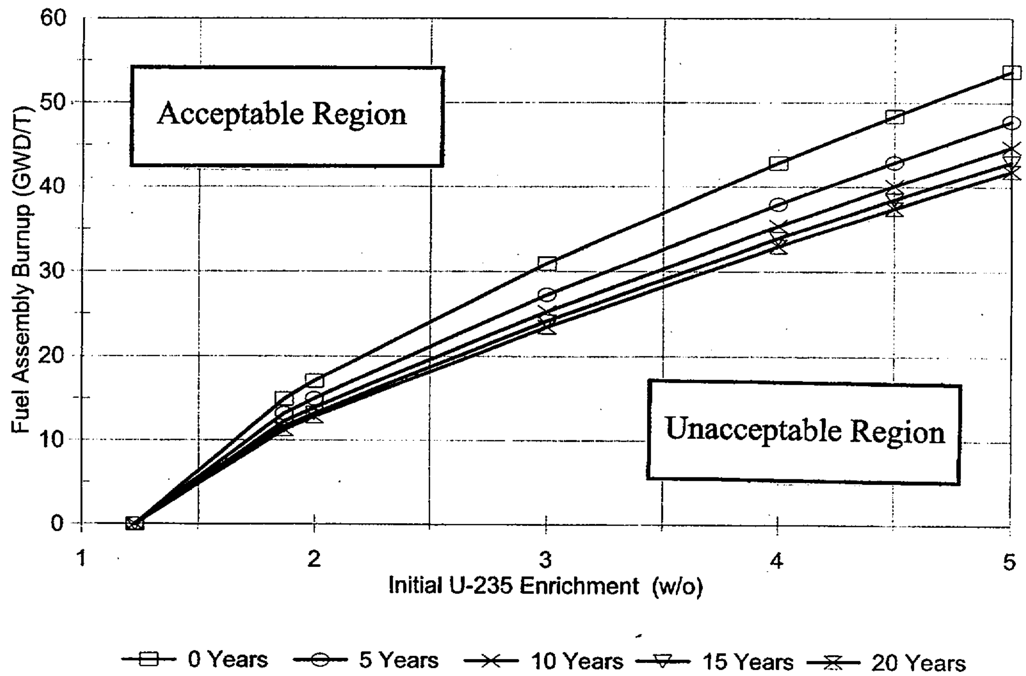



(Figure data points are from Table 4-11)

Figure 4-8

REGION II

MINIMUM BURNUP FOR CATEGORY II-2 FUEL
(SFP PERIPHERAL STORAGE)

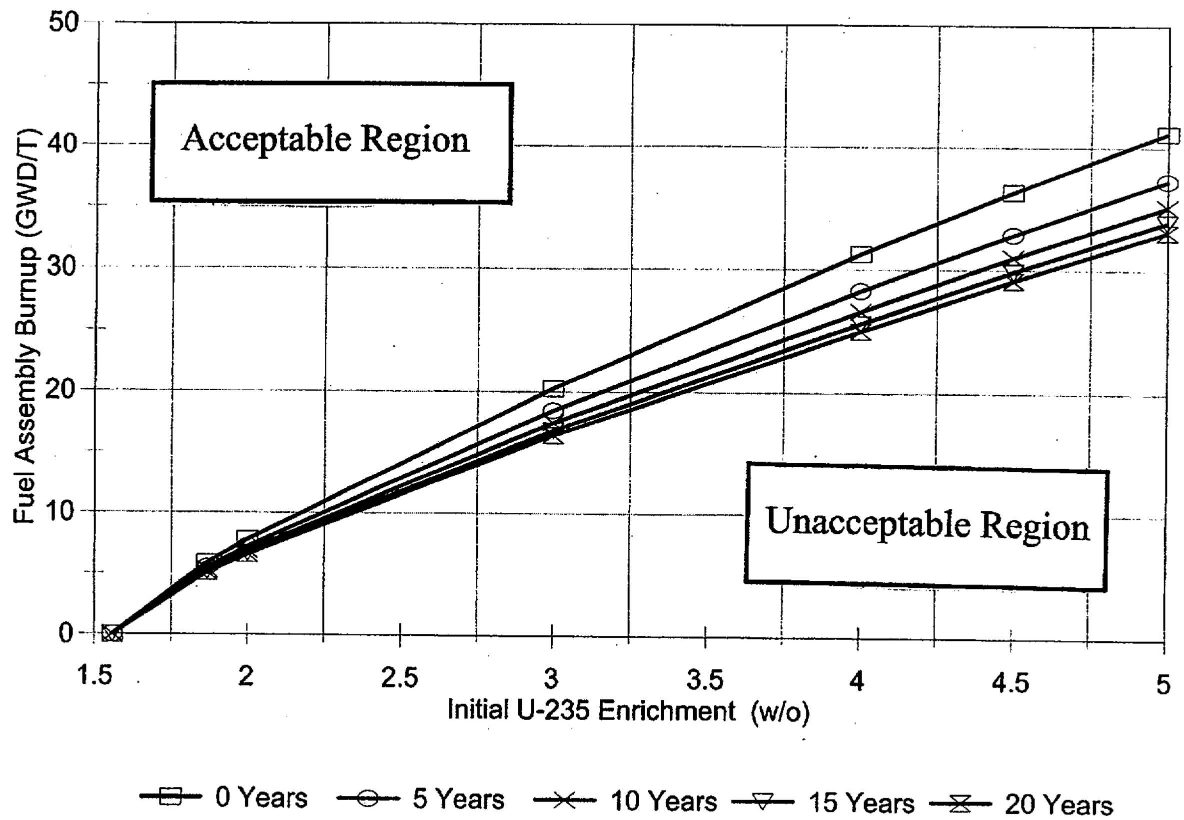



(Figure data points are from Table 4-12)

Figure 4-9

REGION II

MINIMUM BURNUP FOR CATEGORY II-3 FUEL
(CHECKERBOARD PARTNER FOR CATEGORY II-4)

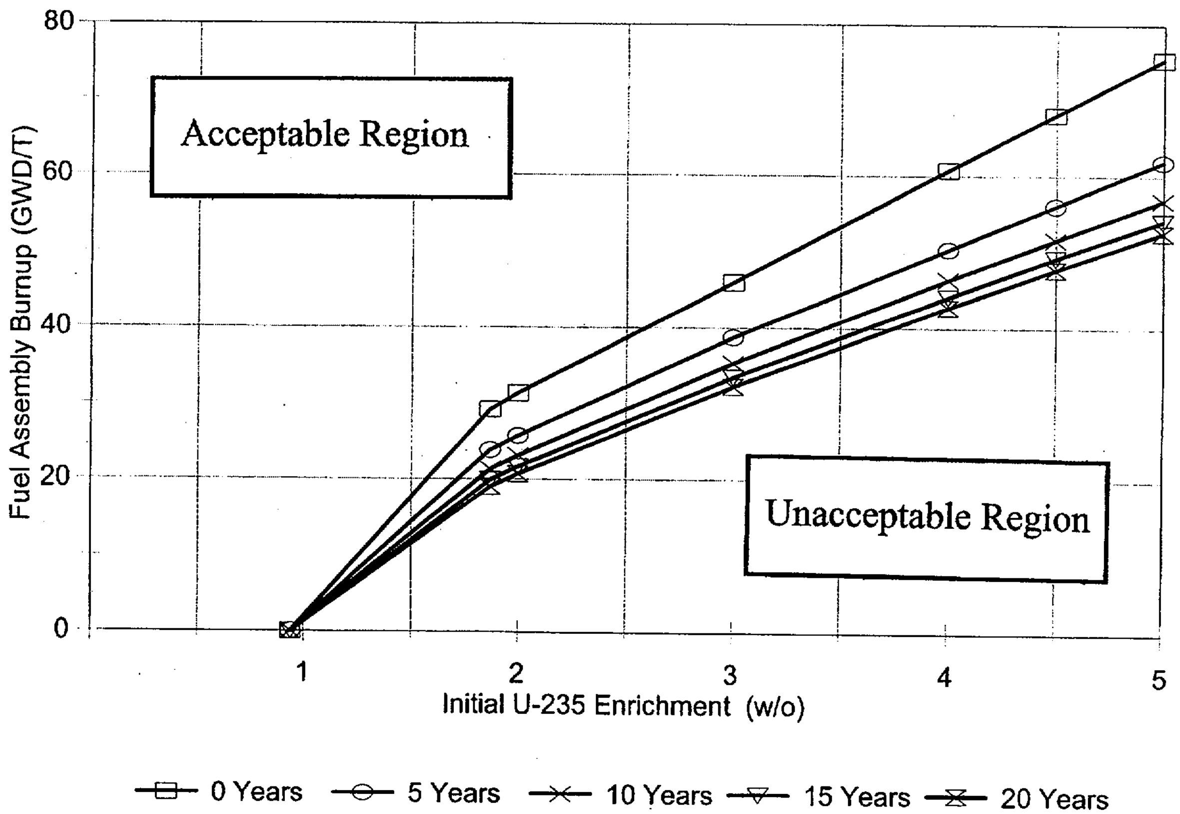



(Figure data points are from Table 4-13)

Figure 4-10

REGION II

MINIMUM BURNUP FOR CATEGORY II-4 FUEL
(CHECKERBOARD PARTNER FOR CATEGORY II-3)

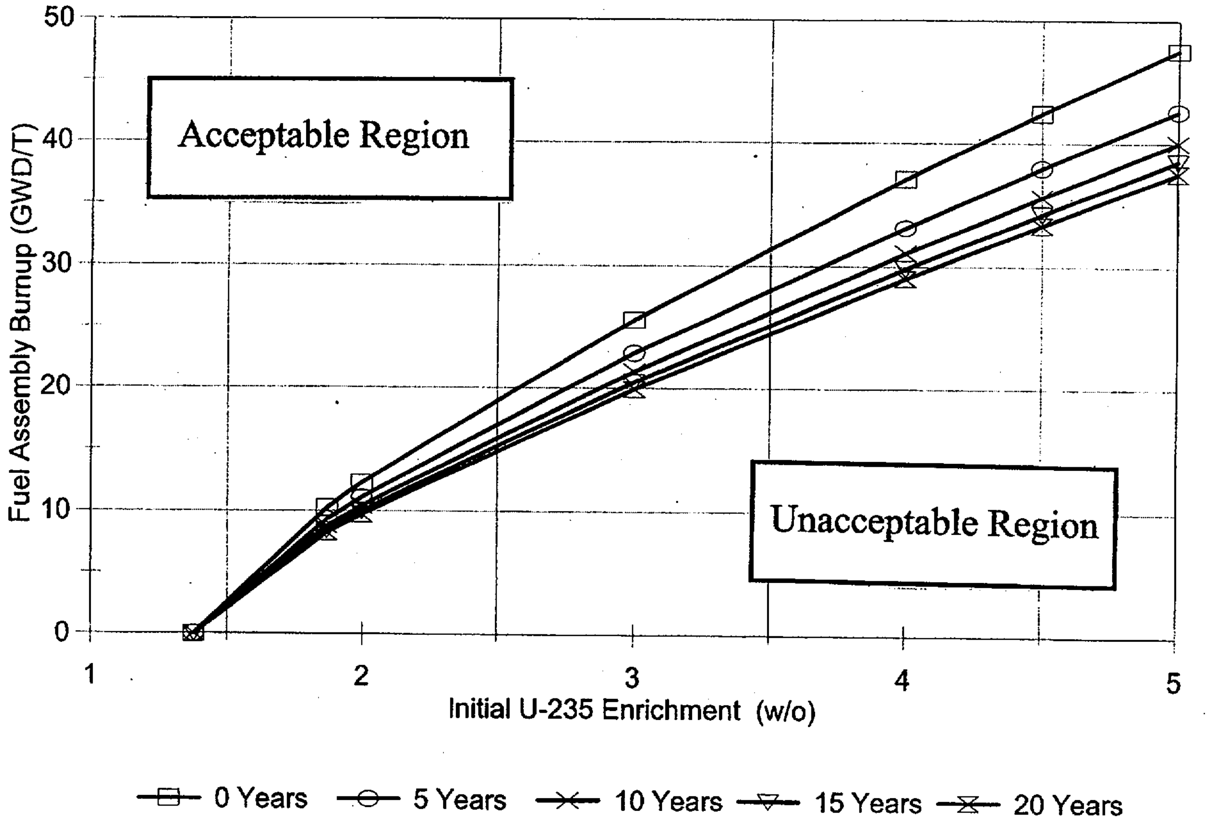



(Figure data points are from Table 4-13)

Figure 4-11

REGION II

MINIMUM BURNUP FOR CATEGORY II-5 FUEL
(CHECKERBOARD PARTNER FOR CATEGORY II-6)

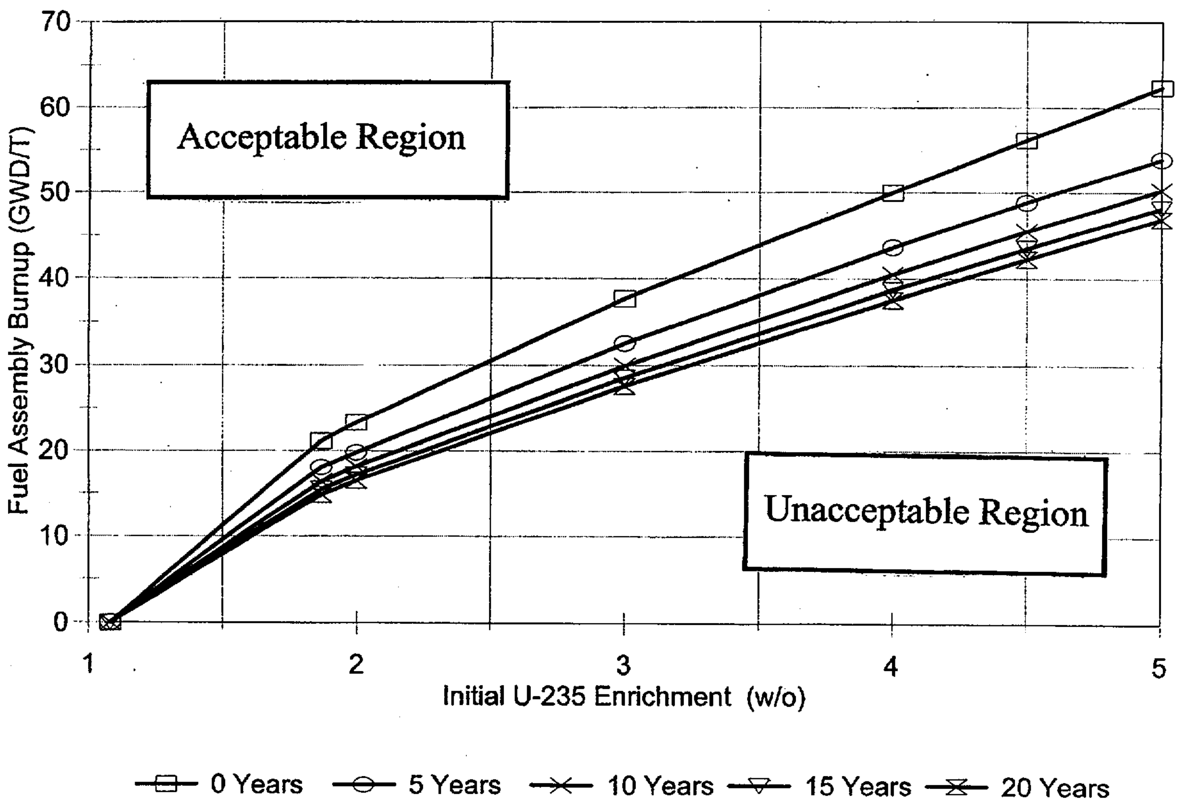



(Figure data points are from Table 4-14)

Figure 4-12

REGION II

MINIMUM BURNUP FOR CATEGORY II-6 FUEL
(CHECKERBOARD PARTNER FOR CATEGORY II-5)

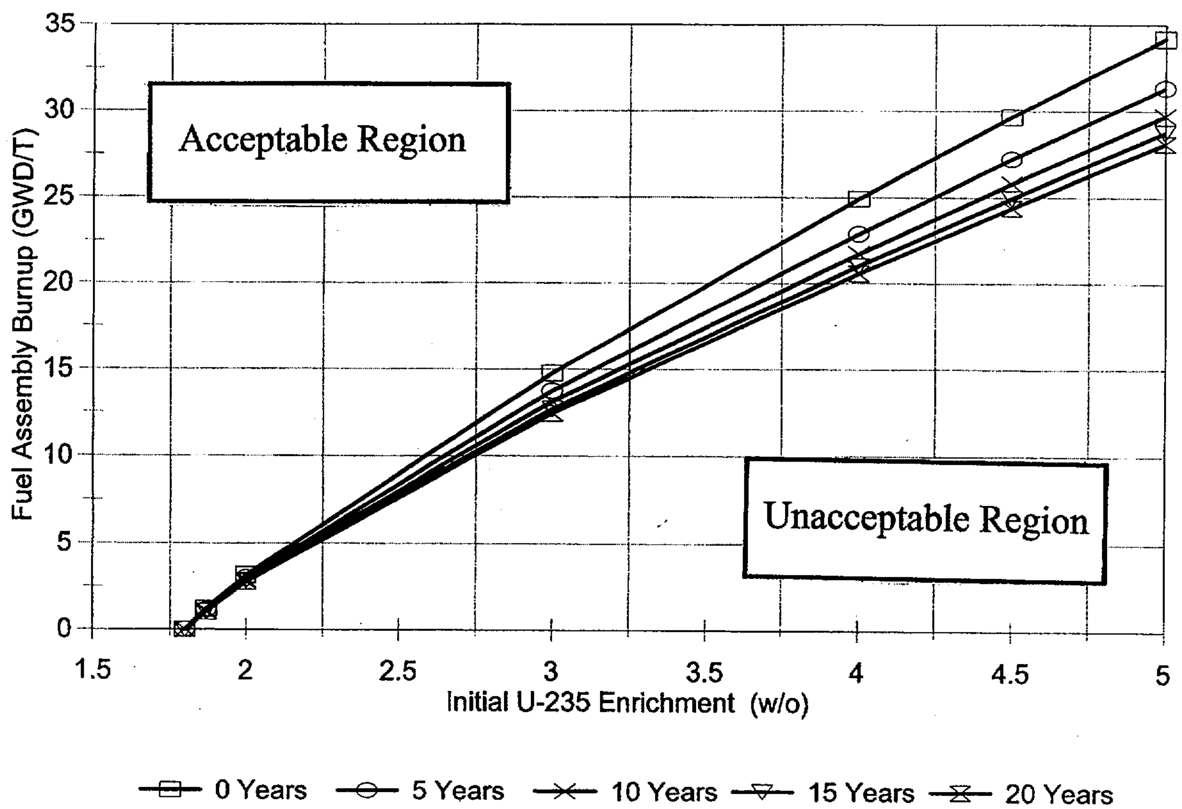



(Figure data points are from Table 4-14)

Figure 4-13

REGION II

MINIMUM BURNUP FOR CATEGORY II-7 FUEL
(3-OUT-OF-4 STORAGE)

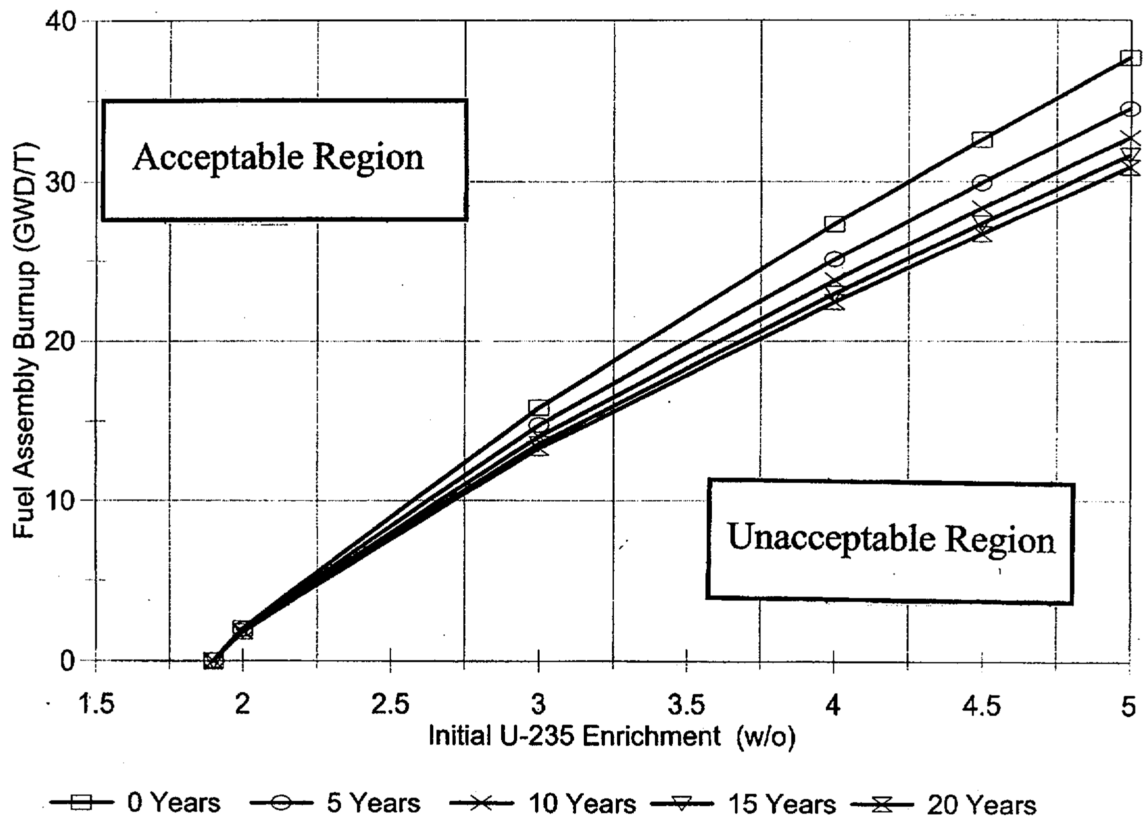



(Figure data points are from Table 4-16)

Figure 4-14

REGION II

MINIMUM BURNUP FOR CATEGORY II-8 FUEL
(UNRESTRICTED STORAGE WITH 5 BORATED SS OR ALUMINUM INSERTS)

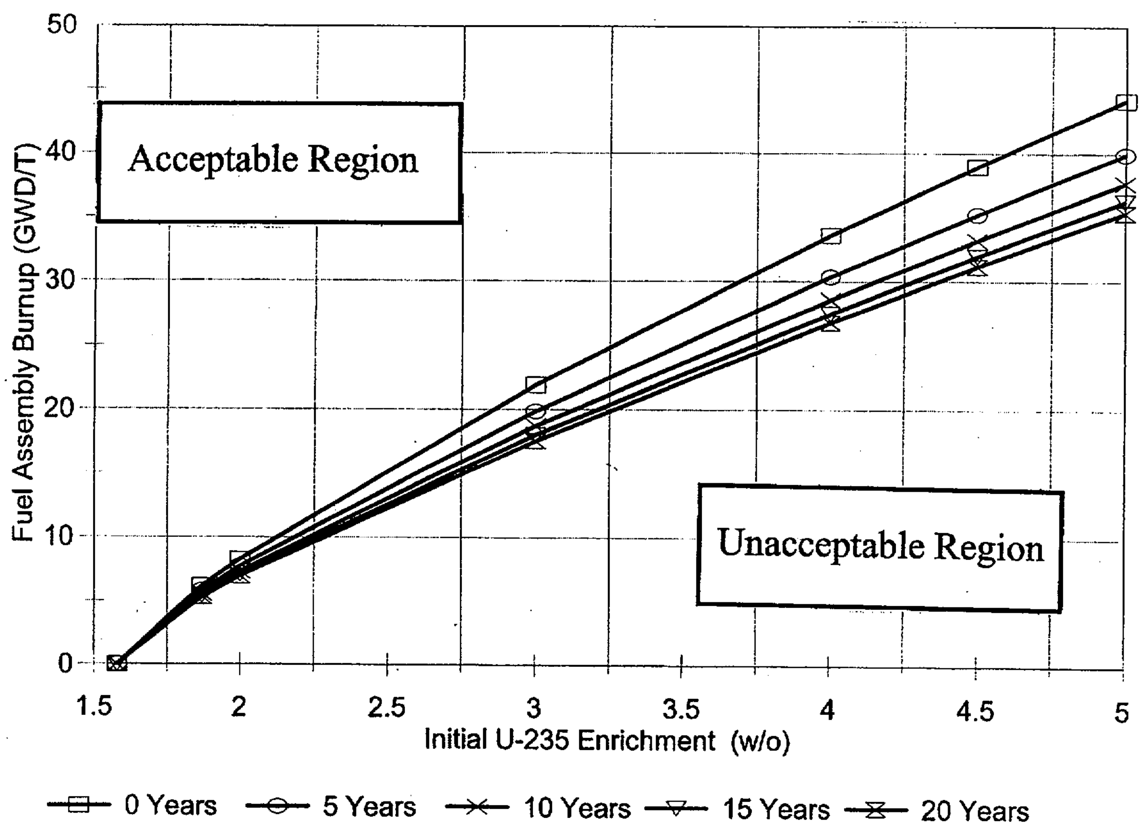



(Figure data points are from Table 4-17)

Figure 4-15

REGION II

MINIMUM BURNUP FOR CATEGORY II-9 FUEL
(UNRESTRICTED STORAGE WITH 3 BORATED SS OR ALUMINUM INSERTS)

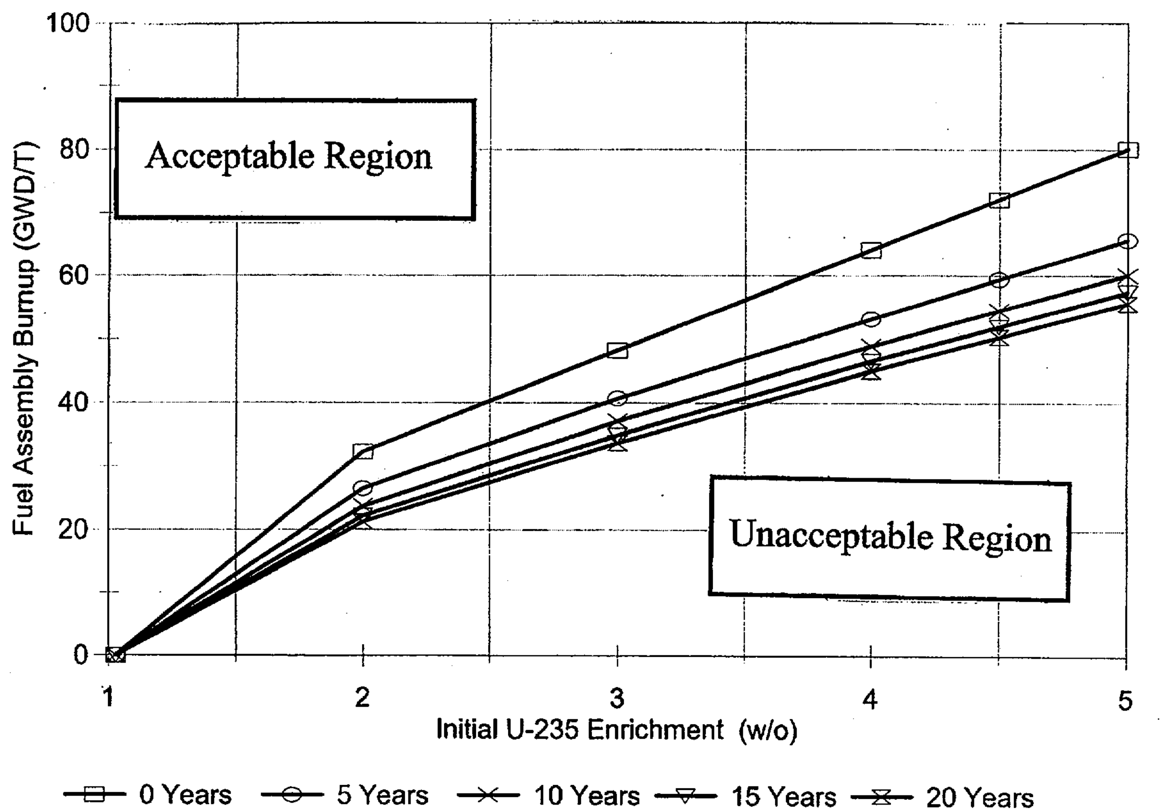



(Figure data points are from Table 4-18)

Figure 4-16

REGION II

MINIMUM BURNUP FOR CATEGORY II-10 FUEL
(FILLER ASSEMBLY WITH 5 BORATED SS OR ALUMINUM INSERTS)

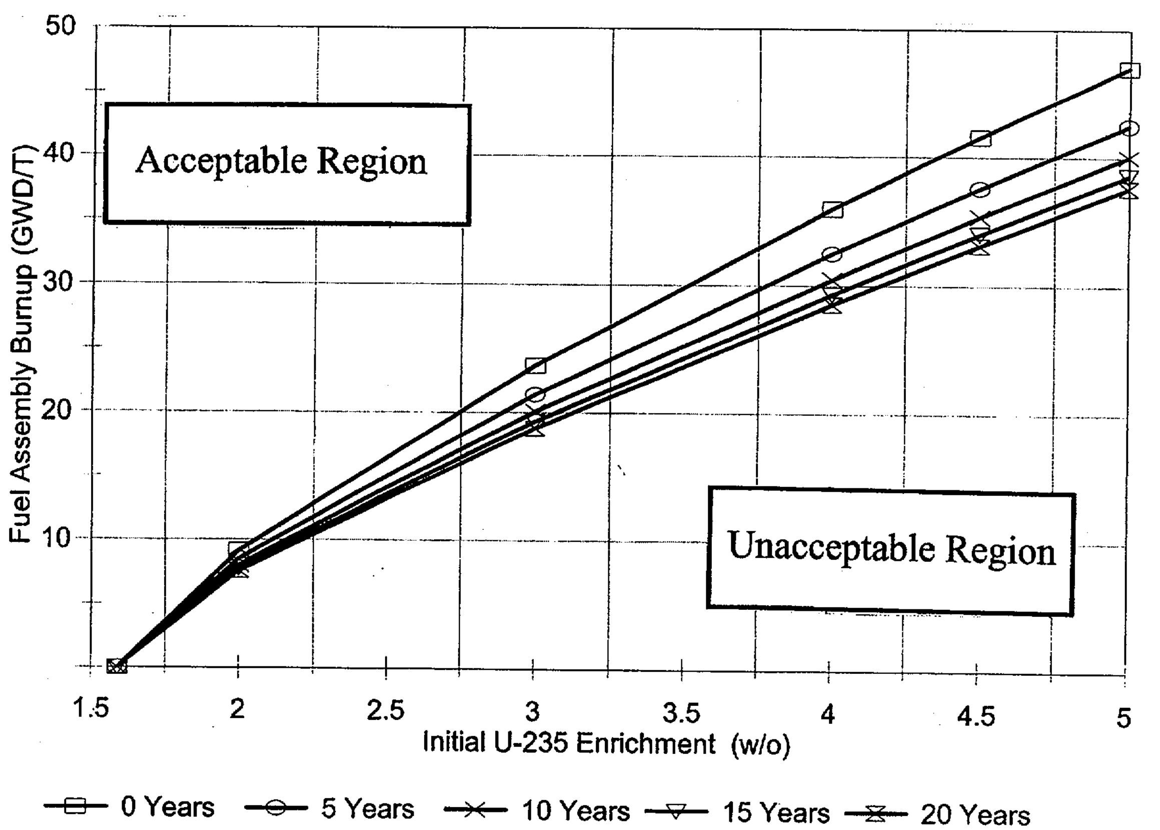



(Figure data points are from Table 4-19)

Figure 4-17

REGION II

MINIMUM BURNUP FOR CATEGORY II-11 FUEL
(FILLER ASSEMBLY WITH 5 BORATED SS OR ALUMINUM INSERTS)

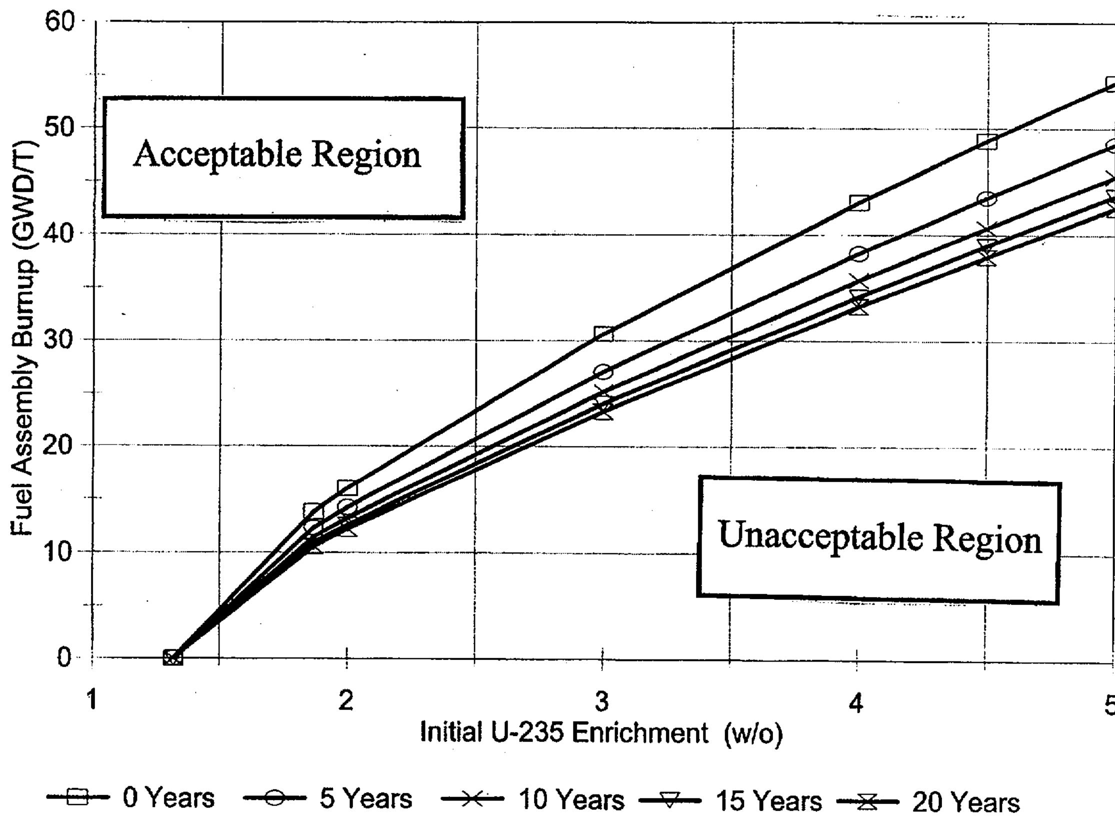



(Figure data points are from Table 4-20)

Figure 4-18

REGION II

MINIMUM BURNUP FOR CATEGORY II-12 FUEL
(FILLER ASSEMBLY WITH 3 BORATED SS OR ALUMINUM INSERTS)

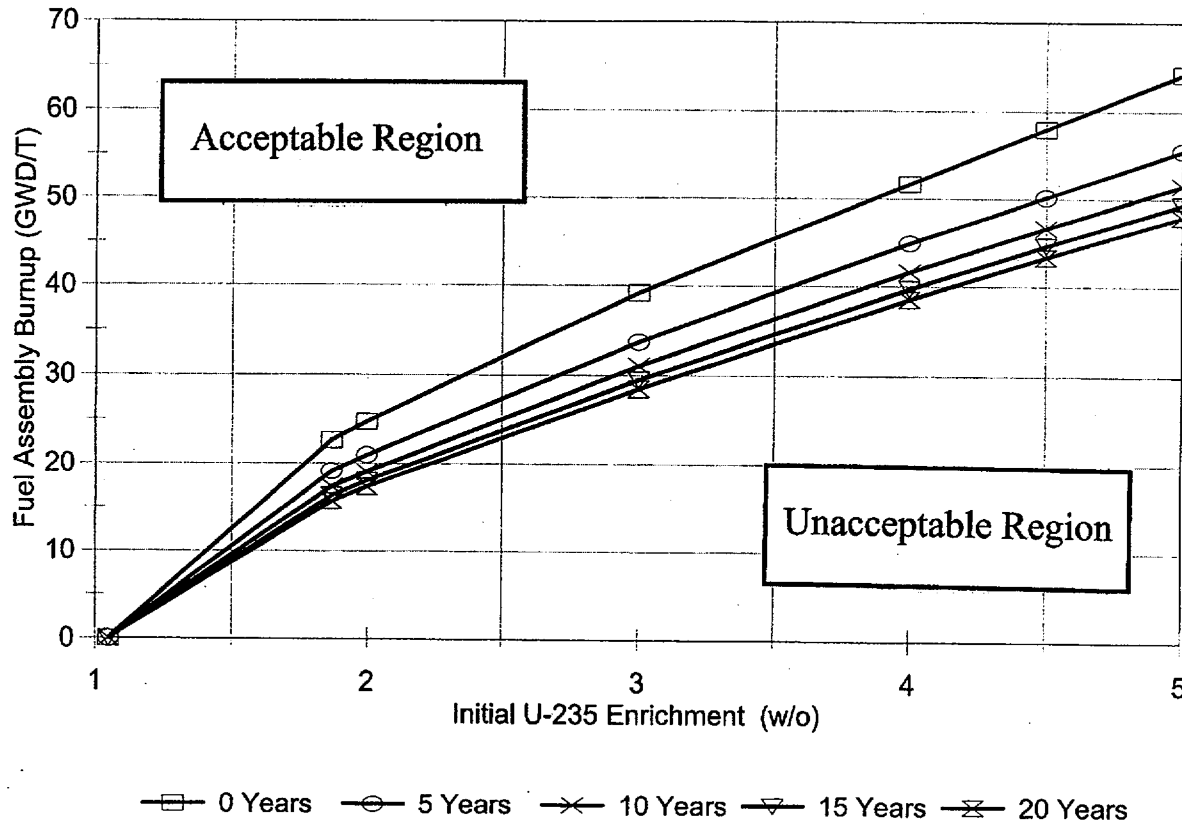



(Figure data points are from Table 4-21)

Figure 4-19

REGION II

MINIMUM BURNUP FOR CATEGORY II-13 FUEL
(FILLER ASSEMBLY WITH NO INSERTS)

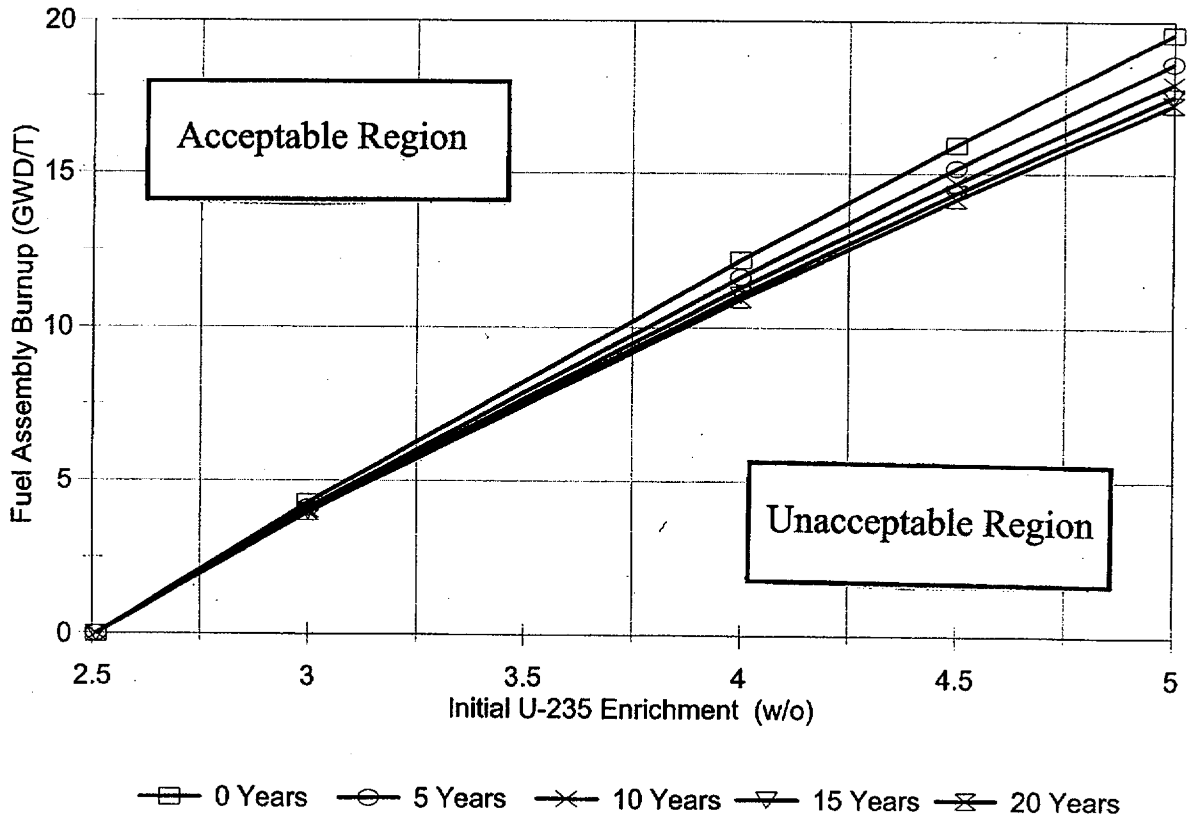



(Figure data points are from Table 4-22)

Figure 4-20

REGION II

MINIMUM BURNUP FOR CATEGORY II-14 FUEL
(4.80 W/O ASSEMBLY DEPLETED TO 18.0 GWD/T)

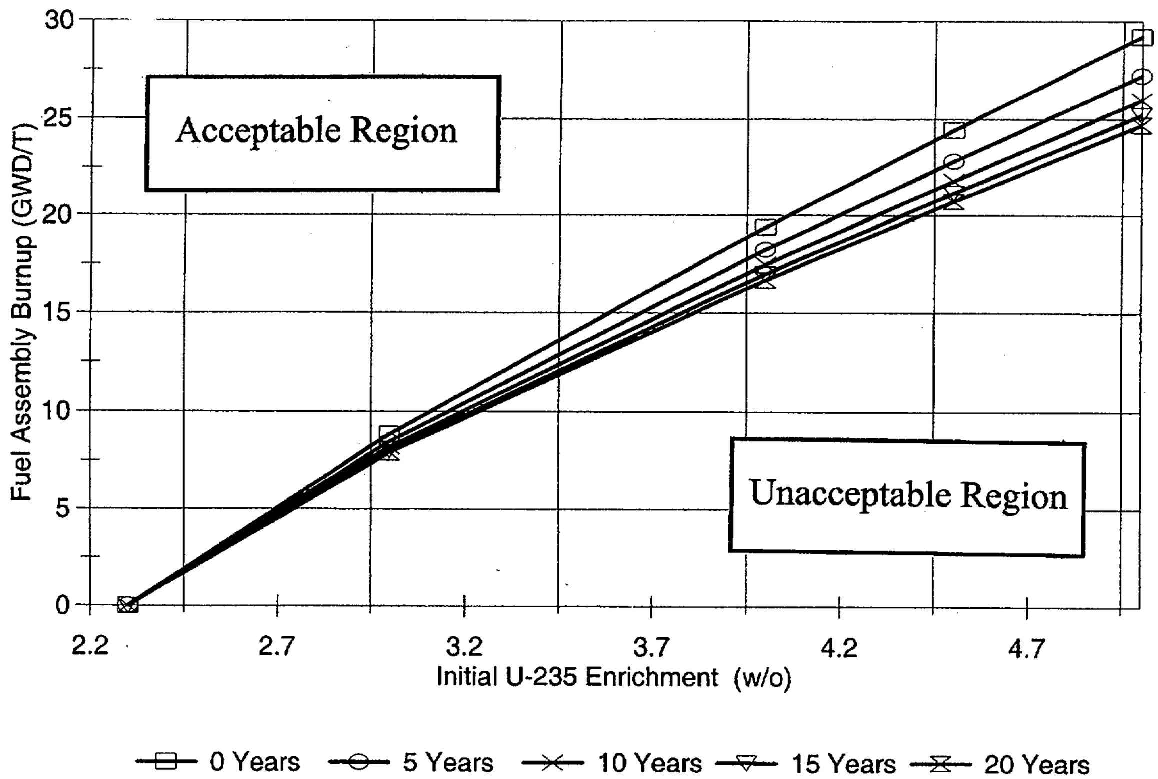



(Figure data points are from Table 4-23)

Figure 4-21

REGION II

MINIMUM BURNUP FOR CATEGORY II-15 FUEL
(ASSEMBLY WITH FULL-LENGTH, 5-FINGER CEA)




(Figure data points are from Table 4-25)

Figure 4-22

REGION I

BOUNDARY BETWEEN ALL CELL STORAGE AND CHECKERBOARD STORAGE
(VALUES ARE U-235 W/O)

| | | | | | |
|---|---|---|---|---|---|
| 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| 2.47 | Empty | 2.47 | 2.47 | 2.47 | 2.47 |
| Empty | 4.80 | Empty | 2.47 | 2.47 | 2.47 |
| 4.80 | Empty | 2.47 | 2.47 | 2.47 | 2.47 |

||
Interface

| | | | | | |
|---|---|---|---|---|---|
| 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| 2.47 | 2.27 | 2.47 | 2.47 | 2.47 | 2.47 |
| 2.27 | 2.65 | 2.27 | 2.47 | 2.47 | 2.47 |
| 2.65 | 2.27 | 2.47 | 2.47 | 2.47 | 2.47 |

||
Interface

Note: (1) A row of empty cells can be used at the interface to separate the configurations
(2) It is acceptable to replace an assembly with an empty cell.

Figure 4-23

REGION I

BOUNDARY BETWEEN ALL CELL STORAGE AND 1 OUT OF 4 STORAGE
(VALUES ARE U-235 W/O)

| | | | | | |
|---|---|---|---|---|---|
| 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| 2.47 | 2.47 | 2.47 | 2.47 | 2.47 | 2.47 |
| 1.71 | 1.71 | 1.71 | 2.47 | 2.47 | 2.47 |
| 1.71 | 4.80 | 1.71 | 2.47 | 2.47 | 2.47 |
| 1.71 | 1.71 | 1.71 | 2.47 | 2.47 | 2.47 |

Interface

Note: (1) A row of empty cells can be used at the interface to separate the configurations
(2) It is acceptable to replace an assembly with an empty cell.

Figure 4-24

REGION I

BOUNDARY BETWEEN CHECKERBOARD STORAGE AND 1 OUT OF 4 STORAGE
(VALUES ARE U-235 W/O)

| | | | | | |
|---|---|---|---|---|---|
| 4.80 | Empty | 4.80 | Empty | 4.80 | Empty |
| Empty | 4.80 | Empty | 4.80 | Empty | 4.80 |
| 4.80 | Empty | 4.80 | Empty | 4.80 | Empty |
| Empty | 1.71 | Empty | 4.80 | Empty | 4.80 |
| 1.71 | 4.80 | 1.71 | Empty | 4.80 | Empty |
| 1.71 | 1.71 | Empty | 4.80 | Empty | 4.80 |

Interface

| | | | | | |
|---|---|---|---|---|---|
| 2.65 | 2.27 | 2.65 | 2.27 | 2.65 | 2.27 |
| 2.27 | 2.65 | 2.27 | 2.65 | 2.27 | 2.65 |
| 2.65 | 2.27 | 2.65 | 2.27 | 2.65 | 2.27 |
| 1.71 | 1.71 | 1.71 | 2.65 | 2.27 | 2.65 |
| 1.71 | 4.80 | 1.71 | 2.27 | 2.65 | 2.27 |
| 1.71 | 1.71 | 1.71 | 2.65 | 2.27 | 2.65 |

Interface

Note: (1) A row of empty cells can be used at the interface to separate the configurations
(2) It is acceptable to replace an assembly with an empty cell.

Figure 4-25

REGION II

BOUNDARY BETWEEN ALL CELL STORAGE AND CHECKERBOARD STORAGE
(VALUES ARE U-235 W/O)

| | | | | | |
|---|---|---|---|---|---|
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | Empty | 1.23 | 1.23 | 1.23 | 1.23 |
| Empty | 4.80 | Empty | 1.23 | 1.23 | 1.23 |
| 4.80 | Empty | 1.23 | 1.23 | 1.23 | 1.23 |

Interface

| | | | | | |
|---|---|---|---|---|---|
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | 0.94 | 1.23 | 1.23 | 1.23 | 1.23 |
| 0.94 | 1.56 | 0.94 | 1.23 | 1.23 | 1.23 |
| 1.56 | 0.94 | 1.23 | 1.23 | 1.23 | 2.47 |

Interface

Note: (1) A row of empty cells can be used at the interface to separate the configurations
(2) It is acceptable to replace an assembly with an empty cell.

Figure 4-26

REGION II

BOUNDARY BETWEEN ALL CELL STORAGE AND 3 OUT OF 4 STORAGE
(VALUES ARE U-235 W/O)

| | | | | | |
|---|---|---|---|---|---|
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| Blocked | 1.80 | Blocked | 1.23 | 1.23 | 1.23 |
| 1.80 | 1.80 | 1.80 | 1.23 | 1.23 | 1.23 |
| Blocked | 1.80 | Blocked | 1.23 | 1.23 | 1.23 |

||
Interface

Note: (1) A row of empty cells can be used at the interface to separate the configurations

(2) It is acceptable to replace an assembly with an empty cell.

Figure 4-27

REGION II

BOUNDARY BETWEEN CHECKERBOARD STORAGE AND 3 OUT OF 4 STORAGE
(VALUES ARE U-235 W/O)

| | | | | | |
|---|---|---|---|---|---|
| 1.80 | Blocked | 1.80 | Blocked | 1.80 | Blocked |
| 1.80 | 1.80 | 1.80 | 1.80 | 1.80 | 1.80 |
| 1.80 | Blocked | 1.80 | Blocked | 1.80 | Blocked |
| Blocked | 4.80 | Blocked | 1.80 | 1.80 | 1.80 |
| 4.80 | Blocked | 4.80 | Blocked | 1.80 | Blocked |
| Blocked | 4.80 | Blocked | 1.80 | 1.80 | 1.80 |

||
Interface

Note: (1) A row of empty cells can be used at the interface to separate the configurations
(2) It is acceptable to replace an assembly with an empty cell.

Figure 4-28

REGION II

BOUNDARY REQUIREMENTS FOR 1 OUT OF 9 STORAGE
(VALUES ARE U-235 W/O)

| | | | | | |
|---|---|---|---|---|---|
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| 1.23 | 1.23 | 1.23 | 1.23 | 1.23 | 1.23 |
| Filler | Filler | Filler | 1.23 | 1.23 | 1.23 |
| Filler | A | Filler | 1.23 | 1.23 | 1.23 |
| Filler | Filler | Filler | 1.23 | 1.23 | 1.23 |

Interface

Where:
(1) If A = 2.51 w/o, Filler = 1.05 w/o or 1.59 w/o + 5 Inserts.
(2) If A = 4.80 w/o, Filler = 1.03 w/o + 5 Inserts.
(3) If A = 4.80 w/o + 5 Inserts, Filler = 1.59 w/o + 5 Inserts.
(4) If A = 4.80 w/o + 5 Inserts, Filler = 1.32 w/o + 3 Inserts.
(3) If A = 4.80 w/o + 5 Inserts, Filler = 1.05 w/o.

## 5. SOLUBLE BORON REQUIREMENTS

This analysis takes credit for soluble boron in the spent fuel pool for both normal and accident conditions.

The total soluble boron required to maintain $K_{eff}$ less than 0.95, including all biases and uncertainties, under non-accident conditions, is 970 ppm. This result has the following components:

| | | | | |
|---|---|---|---|---|
| (Section 5.1) | (1) | $K_{eff}$ less than or equal to 0.95 | — | 370 ppm |
| (Section 5.2) | (2) | Reactivity equivalencing uncertainty | — | 178 ppm |
| (Section 5.3) | (3) | Discharge burnup uncertainty | — | 218 ppm |
| (Section 5.4) | (4) | Soluble boron measurement uncertainty | — | 50 ppm |
| (Section 5.5) | (5) | Margin for future requirements | — | 154 ppm |
| | | | TOTAL | 970 ppm |

(Section 5.6) The total soluble boron required to maintain $K_{eff}$ less than 0.95, including all biases and uncertainties, under accident conditions, is 1,700 ppm, with the exception of boron dilution. A spent fuel pool boron concentration of 2000 ppm is used to cover both accident conditions and a concurrent boron dilution.

### 5.1 $K_{eff}$ LESS THAN OR EQUAL TO 0.95

The soluble boron concentration needed to maintain $K_{eff}$ less than or equal to 0.95, including biases and uncertainties, under non-accident conditions is 370 ppm. This amount of soluble boron does not include uncertainties in reactivity equivalencing, discharge burnup, and soluble boron measurement. This value was determined from a whole-pool (8 modules) KENO-Va model. Region I and II unrestricted and SFP peripheral fresh enrichments from Section 4 above were used.

### 5.2 REACTIVITY EQUIVALENCING UNCERTAINTY

The soluble boron needed to compensate for reactivity equivalencing uncertainties is 178 ppm. The reactivity equivalencing uncertainty is 0.00 Delta-k at 0 GWD/T and 0.01 Delta-k at 30 GWD/T, linear with burnup.

In previous SCE analyses, which did not credit soluble boron, the reactivity equivalencing uncertainty was used to adjust the reactivity acceptance criteria. Since this analysis credits soluble boron, the reactivity equivalencing uncertainty is expressed in ppm units. This reactivity equivalencing uncertainty is the industry standard practice submitted to and approved by the NRC.

## 5.3 DISCHARGE BURNUP UNCERTAINTY

The soluble boron needed to compensate for the fuel assembly discharge burnup uncertainty is 218 ppm.

This result is based on a discharge burnup uncertainty of 7% for SONGS Units 2 and 3 fuel assemblies.

For SONGS Unit 1 assemblies, the discharge burnup uncertainty is 10%. However, the higher discharge burnups of SONGS Units 2 and 3 assemblies make these the assemblies to use to evaluate the soluble boron requirement.

## 5.4 SOLUBLE BORON MEASUREMENT UNCERTAINTY

Previous SONGS spent fuel pool criticality analyses have assumed the soluble boron measurement uncertainty is 50 ppm. This conservative assumption is used in this analysis also.

## 5.5 MARGIN FOR FUTURE REQUIREMENTS

The total soluble boron requirement from Sections 5.1 through 5.4 above is 1,546 ppm. This result is conservatively rounded up to 1,700 ppm. This allows a margin of 154 ppm for future requirements.

## 5.6 ACCIDENT CONDITIONS

The total soluble boron concentration needed to maintain $K_{eff}$ less than or equal to 0.95, including all biases and uncertainties, under accident conditions is 1,700 ppm. This is based on misloading a single 4.8 w/o fresh fuel assembly in Region II. The fuel misloading accident is more severe than the pool heat up accident.

### 5.6.1 Pool Heat-Up Accident

The amount of soluble boron required for the pool heat up accident is 125 ppm.

The pool heat-up accident was evaluated using CASMO-3. Infinitely large Regions I and II were separately considered, and the larger of the two region results is the final result.

The pool heat up accident considers the temperature range from 50 degrees F to 248 degrees F + 10% void.

### 5.6.2 Fuel Mishandling Accident

The amount of soluble boron required for the fuel mishandling accident is 730 ppm.

The fuel mishandling accident was evaluated with a whole-pool model. A single fresh 4.8 w/o fuel assembly was placed in different rack locations and storage patterns. It was discovered that Region II storage patterns which include an empty storage location into which the misload might occur would have un-acceptably large soluble boron requirements.

Thus it was decided to only allow these patterns if the empty cell is blocked to preclude the misloading accident. (Region I empty cell patterns are acceptable.)

After excluding Region II empty cell patterns, the fuel misloading event which produces the largest increase in spent fuel pool $K_{eff}$ is misloading in Region II , 1.56 w/o x 0.94 w/o checkerboard pattern (Table 4-13). Starting at $K_{eff} = 0.95$ with 370 ppm, this accident requires an additional 730 ppm to maintain $K_{eff}$ less than or equal to 0.95, including all biases and uncertainties.

## 6. REFERENCES


1. San Onofre Nuclear Generating Station Units 2 and 3 Updated Final Safety Analysis Report, Revision 16, Chapter 9, Docket Nos. 50-361 and 50-362.

2. Spent Fuel Pool Reracking Licensing Report, Revision 6, Southern California Edison, San Onofre Nuclear Generating Station Units 2 and 3, February 16, 1990.

3. (A) Nuclear Regulatory Commission, Letter to All Power Reactor Licensees, B. K. Grimes, April 14, 1978, "OT Position for Review and Acceptance of Spent Fuel Storage and Handling Applications," as amended by the NRC letter dated January 18, 1979

   (B) USNRC, Office Of Nuclear Reactor Regulation, Reactor Systems Branch, 1998, "Guidance On The Regulatory Requirements For Criticality Analysis Of Fuel Storage At Light-Water Reactor Power Plants"

4. WCAP-14416-NP-A, Rev 1, Westinghouse Electric Corporation, November 1996, "Westinghouse Spent Fuel Rack Criticality Analysis Methodology"

5. NRC Letter to Westinghouse Owners Group, October 25, 1996, "Acceptance For Referencing Of Licensing Topical Report WCAP-14416-P, 'Westinghouse Spent Fuel Rack Criticality Analysis Methodology (TAC No. M93254)' "

6. NRC To Westinghouse Letter Dated July 27, 2001 "Non-Conservatisms In Axial Burnup Biases For Spent Fuel Rack Criticality Analysis Methodology"

7. NRC to SCE Letter Dated October 3, 1996, "Issuance Of Amendment For San Onofre Nuclear Generating Station, Unit No. 2 (TAC No. M94624) and Unit No. 3 (TAC No. M94625)"

8. ANSI/ANS-57.2-1983, "American National Standard Design Requirements For Light Water Reactor Spent Fuel Storage Facilities At Nuclear Power Plants"

9. NUREG/CR-6683, ORNL/TM-2000/230, Oak Ridge National Laboratory, September 2000 "A Critical Review of the Practice of Equating the Reactivity of Spent Fuel to Fresh Fuel in Burnup Credit Criticality Safety Analyses for PWR Spent Fuel Pool Storage"

10. CCC-545, RSIC Computer Code Collection, Oak Ridge National Laboratory "SCALE 4.3 Modular Code System for Performing Standardized Computer Analysis for Licensing Evaluation for Workstations and Personal Computers"

11. STUDSVIK/NFA-89/3, User's Manual, Studsvik AB, 1989
"CASMO-3 Fuel Assembly Burnup Program"

12. STUDSVIK/SOA-92/01, User's Manual, Studsvik AB, 1992
"SIMULATE-3 Advanced Three-Dimensional Two-Group Reactor Analysis Code"

13. BAW-1484-7, The Babcock & Wilcox Company, July, 1979
"Critical Experiments Supporting Close Proximity Water Storage of Power Reactor Fuel,"

14. SCR-607, Sandia Corporation, March 1963
"Factors For One-Sided Tolerance Limits And For Variables Sampling Plans"

15. Nuclear Technology, Volume 50, September 1980,
"Dissolution And Storage Experiment With 4.75-wt% $^{235}U$-Enriched $UO_2$ Rods"

16. NUREG/CR-0073, Battelle Pacific Northwest Laboratories, 1978,
"Critical Separation Between Subcritical Clusters of 4.29 wt% $^{235}U$ Enriched $UO_2$ Rods In Water With Fixed Neutron Poisons"

17. SCE-9001-A, Southern California Edison Company, September 1992,
"Southern California Edison Company PWR Reactor Physics Methodology Using CASMO-3/SIMULATE-3"

18. SCE to NRC Letter dated December 6, 1995,
"Docket Nos. 50-361 And 50-362
Amendment Application Nos. 153 and 137
Storing Nuclear Fuel, San Onofre Nuclear Generating Station, Units 2 And 3"
Attachment E – "Evaluation Of The Handling And Storage Of 4.8 w/o Enriched Fuel", October 18, 1995

# APPENDIX A

# SPENT FUEL RACK DIAGRAMS

Figure A-1
REGION 1

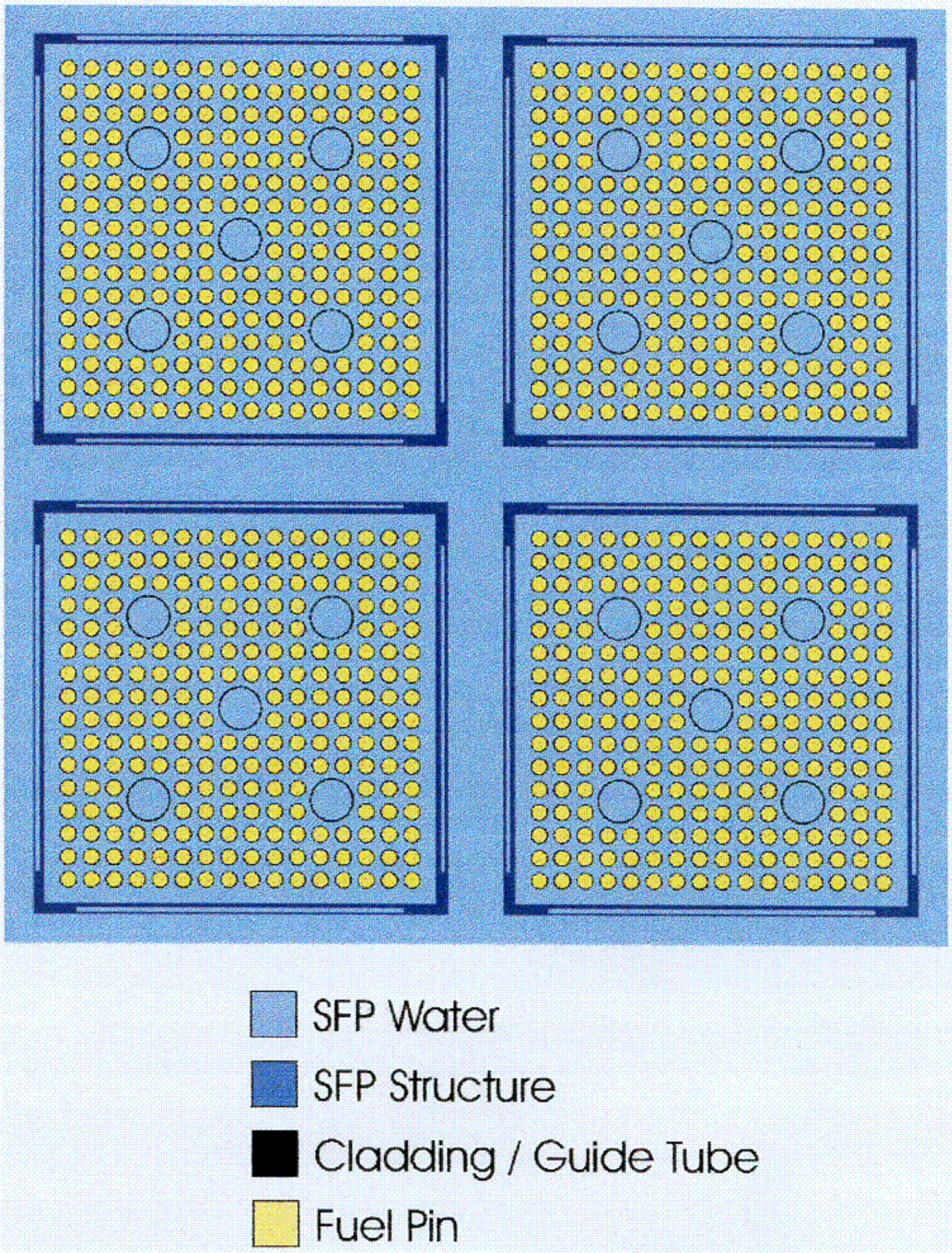
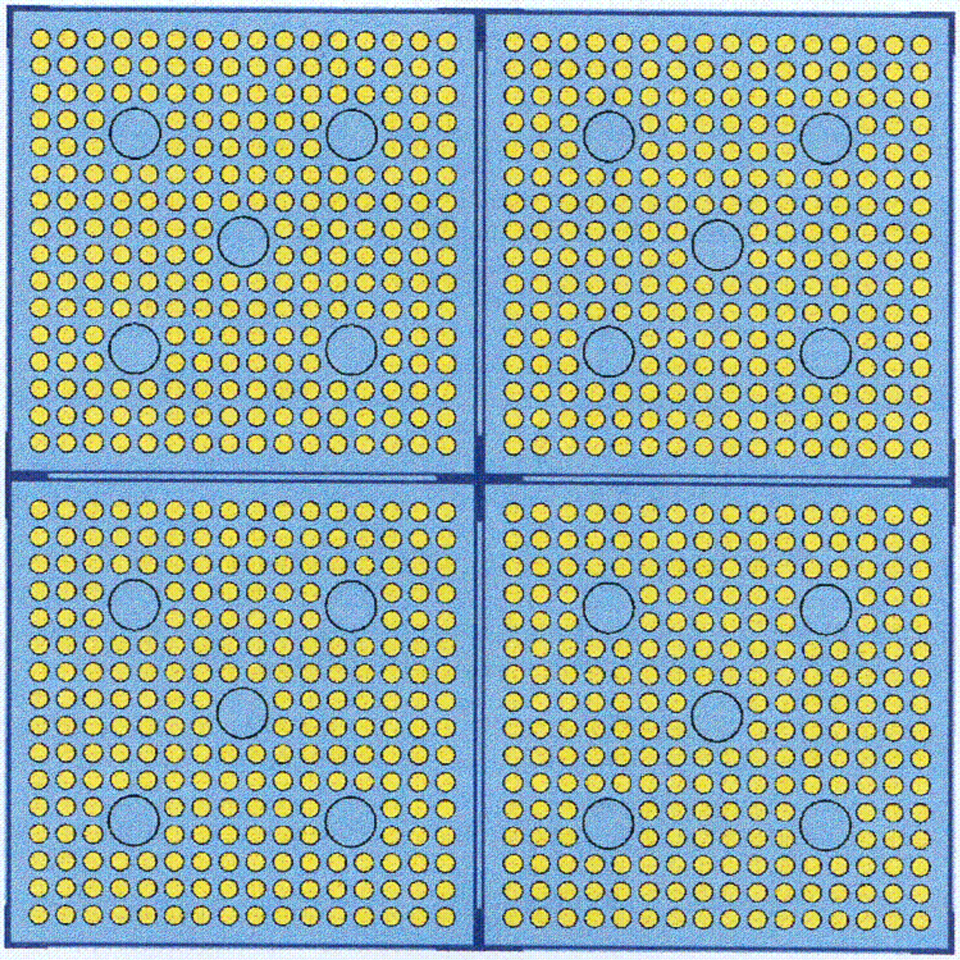
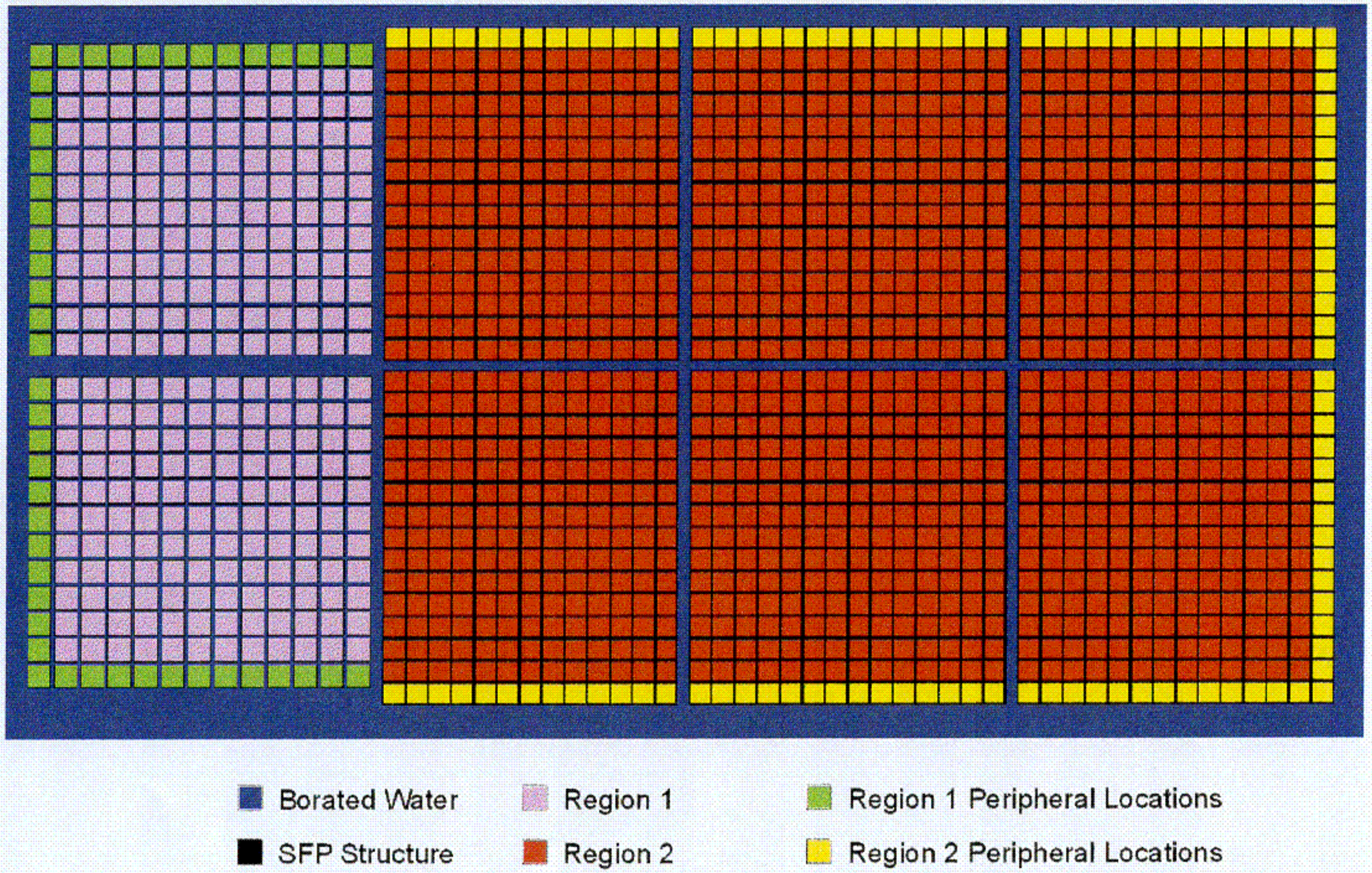


Figure A-2
REGION 2




C02

Figure A-3
WHOLE POOL




C03

# APPENDIX B

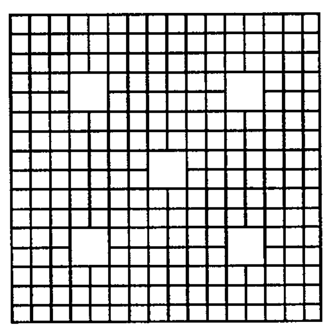
# REGION I KENO-Va MODEL

## SONGS UNITS 2 AND 3 FUEL ASSEMBLY DATA

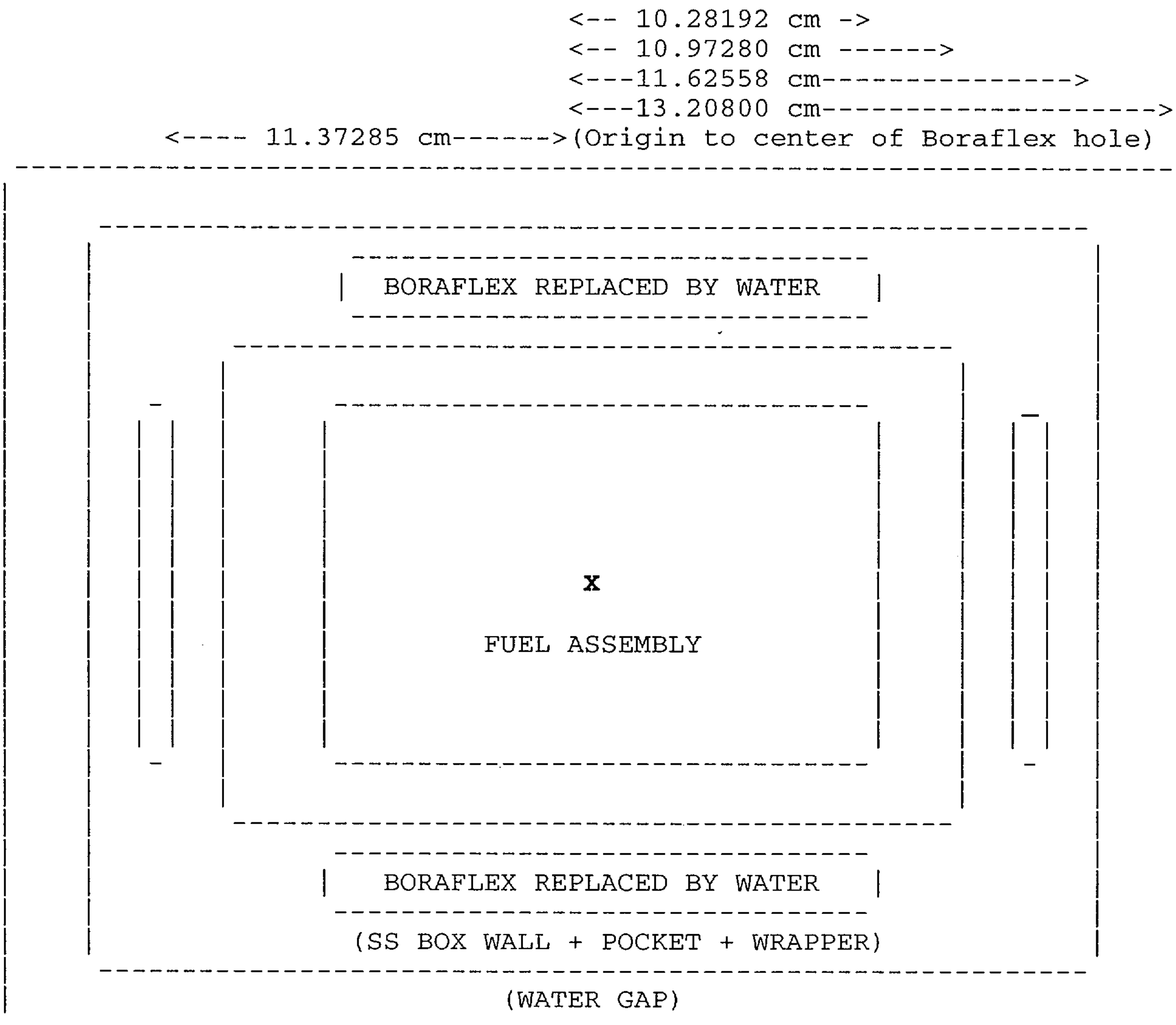
```
Fuel Pellet O.D.      = 0.325 inches
Fuel Pellet Density = 10.5216 gms/cc   (0.96 * 10.96 gms/cc)
Clad I.D.             = 0.332 inches
Clad O.D.             = 0.382 inches
Clad material         = Zircaloy

Guide Tube I.D.         = 0.90 inches
Guide Tube O.D.         = 0.98 inches
Guide Tube Material     = Zircaloy
Number Of Guide Tubes = 5

Fuel Rod Array = 16x16
Fuel Rod Pitch = 0.506 inches
```



## REGION I KENO-Va MODEL




```
1/2(Center-to-center)       = (2.54)(10.40)/2           = 13.20800 cm

1/2(Cell+Wall+Pocket+Wrap) = (2.54)(8.64/2 + 0.11
                                  + 0.127 +0.02)        = 11.62558 cm
1/2(Storage cell Id)   = (2.54)(8.64)/2                 = 10.97280 cm
1/2(Fuel Assembly)     = (2.54)(16)(0.506)/2            = 10.28192 cm
1/2(BFLX thick)   = (2.54)(0.095)/2                     =  0.12065 cm

1/2(BFLX width)   = (2.54)(7.522)(0.96)/2               =  9.17082 cm
Origin to BFLX Hole = (2.54)(8.64/2 + 0.11 + 0.095/2)   = 11.37285 cm
```

```
          CELLDAN PROGRAM - CELL CONSTANTS AND DANCOFF FACTOR
                        SCE VERSION R1 10-09-97

                  DATE OF RUN -    12:50:47   05/01/**

                  CE 16 X 16 FUEL

     FUEL OD .... .3250 IN.   .8255 CM   RADIUS =     .4127 CM
     CLAD ID .... .3320 IN.   .8433 CM   RADIUS =     .4216 CM
     CLAD OD .... .3820 IN.   .9703 CM   RADIUS =     .4851 CM
     ROD PITCH .. .5060 IN. 1.2852 CM   1/2 PITCH = .6426 CM

               ZIRCONIUM  CLAD    -   SQUARE     GEOMETRY

            FUEL DENSITY ...........    10.522 G/CC UO2
            ENRICHMENT .............     2.470 WT% U-235
            MODERATOR TEMPERATURE ..    20 DEGREES C
            DENSITY FACTOR .........     1.000
            WATER DENSITY ..........      .99823 G/CC

               HYDROGEN NUMBER DENSITY =  .066740
                OXYGEN  NUMBER DENSITY =  .033370 IN MODERATOR


                 U-235  NUMBER DENSITY =  5.87114E-04
                 U-238  NUMBER DENSITY =   .022890
                OXYGEN  NUMBER DENSITY =   .046954 IN FUEL

  NO OF FUEL RODS            236      NO THIM AND GUIDE TUBES   5
OVERALL CELL DIM, IN.     8.0960      THIMBLE ID, INCHES     .9000
DANCOFF HOMOG FACTOR-1    3.5590      THIMBLE OD, INCHES     .9800
DANCOFF HOMOG FACTOR-2    3.2200      ID/OD IN CM 1.1430/1.2446

  HOMOGENIZED DENSITIES AT A WATER-TO-FUEL VOL RATIO OF  1.936

  U235    = 1.7537E-04   U238   = 6.8371E-03  CLAD = 4.6736E-03
HYDROGEN = 3.8598E-02  OXYGEN = 3.3324E-02

 U-235  SCAT/A-238 =     .2693   MOD  MEAN FREE PATH =    .6689
 OXYGEN SCAT/A-238 =    7.6924   CLAD MEAN FREE PATH =   3.7925
      SIG-P0       =   17.4617

      DANCOFF FACTORS:

FIRST ROW (PER ROD)      .0490   SECOND ROW (PER ROD)       .0133
CORR. - OUTER ROWS     .013618   DANCOFF FACTOR             .2229
```

```
#
#  Execute SCALE43 Driver
#
cat <<'eof' >input
=nitawl
' REGION 1 RACKS  - 2.47 W% - 96% T.D.  -  PITCH=1.28524 CM'
0$$ 82 E
1$$ 0 13 0 4R0 1 E T
2$$ 92235 92238
    40302
    1001  8016
    5010  5011  6012  14000
    24304 25055 26304 28304
3** 92238  293.0  2  0.4127  0.2229  0.0   .022890  1
    15.994  7.6924  1     235.04  0.2693  1        1.0   T
end
=kenova
REGION I RACKS -- 2.47 W% -- NOMINAL MODEL -- CIRCULAR GUIDE TUBES
READ PARAM  TME=1000  GEN=503 NPG=2000 NSK=3 LIB=4 TBA=1.0   END PARAM
READ BOUNDS   ALL=REFLECT   END BOUNDS
READ MIXT     SCT=2
MIX=1    92235 5.87114-4  92238 2.28900-2   8016 4.69540-2
MIX=2    40302 4.32444-2
MIX=3     1001 6.67400-2   8016 3.33700-2   5010 0.0000000   5011 0.0000000
MIX=4     6012 3.16910-4  24304 1.64710-2  25055 1.73210-3  26304 6.03600-2
         28304 6.48340-3  14000 1.69400-3
MIX=5     5010 0.74493-2   5011 0.29749-1
          1001 0.24250-1   6012 0.18314-1   8016 0.12288-1  14000 0.77566-2
END MIXT
READ GEOM
UNIT      1
'FUEL ROD'
CYLINDER  1   1  0.41275                                   381.0    0.0
CYLINDER  0   1  0.42164                                   381.0    0.0
CYLINDER  2   1  0.48514                                   381.0    0.0
CUBOID    3   1  0.64262 -0.64262 0.64262 -0.64262  381.0    0.0
UNIT      2
```

```
'GUIDE TUBE'
CYLINDER  3   1  1.14300                                   381.0    0.0
CYLINDER  2   1  1.24460                                   381.0    0.0
CUBOID    3   1  1.28524 -1.28524 1.28524 -1.28524  381.0    0.0
UNIT      3
'GUIDE TUBE + INSERTED CEA (FUTURE)'
CYLINDER  3   1  1.14300                                   381.0    0.0
CYLINDER  2   1  1.24460                                   381.0    0.0
CUBOID    3   1  1.28524 -1.28524 1.28524 -1.28524  381.0    0.0
UNIT      4
'FUEL ROD ONLY -- NO SURROUNDING WATER'
CYLINDER  1   1  0.41275                                   381.0    0.0
CYLINDER  0   1  0.42164                                   381.0    0.0
CYLINDER  2   1  0.48514                                   381.0    0.0
UNIT      5
'TWO HORIZONTAL FUEL RODS + SURROUNDING WATER'
CUBOID    3   1  1.28524 -1.28524 0.64262 -0.64262  381.0    0.0
HOLE      4     -0.64262  0.0     0.0
HOLE      4      0.64262  0.0     0.0
UNIT      6
'TWO VERTICAL FUEL RODS + SURROUNDING WATER'
CUBOID    3   1  0.64262 -0.64262 1.28524 -1.28524  381.0    0.0
HOLE      4      0.0     -0.64262 0.0
HOLE      4      0.0      0.64262 0.0
UNIT      7
'FOUR FUEL RODS + SURROUNDING WATER'
CUBOID    3   1  1.28524 -1.28524 1.28524 -1.28524  381.0    0.0
HOLE      4      0.64262  0.64262 0.0
HOLE      4      0.64262 -0.64262 0.0
HOLE      4     -0.64262 -0.64262 0.0
HOLE      4     -0.64262  0.64262 0.0
UNIT      8
'VERTICAL BORAFLEX PANEL REPLACED WITH WATER'
CUBOID    3   1  0.12065 -0.12065 9.17082 -9.17082  381.0   0.0
UNIT      9
'HORIZONTAL BORAFLEX PANEL REPLACED WITH WATER'
CUBOID    3   1  9.17082 -9.17082 0.12065 -0.12065  381.0   0.0
```

```
UNIT      10   ARRAY 1    -10.28192   -10.28192   0.0
'FUEL ASSEMBLY IN REGION 1 SPENT FUEL RACK'
CUBOID     3   1   10.97280  -10.97280  10.97280  -10.97280  381.0  0.0
CUBOID     4   1   11.62558  -11.62558  11.62558  -11.62558  381.0  0.0
HOLE       8      -11.37285    0.0        0.0
HOLE       8       11.37285    0.0        0.0
HOLE       9         0.0       11.37285   0.0
HOLE       9         0.0      -11.37285   0.0
CUBOID     3   1   13.20800  -13.20800  13.20800  -13.20800  411.0  -30.0
END GEOM
READ ARRAY
ARA=1        NUX=9 NUY=9 NUZ=1
'FULL SONGS 2 AND 3 FUEL ASSEMBLY'
FILL
1  5  5  5  5  5  5  5  1
6  7  7  7  7  7  7  7  6
6  7  2  7  7  7  2  7  6
6  7  7  7  7  7  7  7  6
6  7  7  7  2  7  7  7  6
6  7  7  7  7  7  7  7  6
6  7  2  7  7  7  2  7  6
6  7  7  7  7  7  7  7  6
1  5  5  5  5  5  5  5  1
END FILL
ARA=2        NUX=1 NUY=1 NUZ=1
GBL=2
'FINAL ARRAY OF PROBLEM'
FILL
 10
END FILL
END ARRAY
END DATA
end
eof
```

REGION I KENO-Va RESULTS

| no. of initial generations skipped | average k-effective | | deviation | 67 per cent confidence interval | 95 per cent confidence interval | 99 per cent confidence interval | number of histories |
|---|---|---|---|---|---|---|---|
| 3 | .96400 | + or - | .00063 | .96337 to .96463 | .96274 to .96526 | .96211 to .96589 | 1000000 |
| 4 | .96405 | + or - | .00063 | .96342 to .96468 | .96279 to .96531 | .96216 to .96594 | 998000 |
| 5 | .96403 | + or - | .00063 | .96340 to .96467 | .96277 to .96530 | .96214 to .96593 | 996000 |
| 6 | .96405 | + or - | .00063 | .96342 to .96469 | .96279 to .96532 | .96216 to .96595 | 994000 |
| 7 | .96407 | + or - | .00063 | .96344 to .96471 | .96281 to .96534 | .96217 to .96597 | 992000 |
| 8 | .96407 | + or - | .00063 | .96344 to .96470 | .96280 to .96534 | .96217 to .96597 | 990000 |
| 9 | .96409 | + or - | .00064 | .96346 to .96473 | .96282 to .96536 | .96219 to .96600 | 988000 |
| 10 | .96412 | + or - | .00064 | .96349 to .96476 | .96285 to .96539 | .96221 to .96603 | 986000 |

# CALCULATION OF REGION I FINAL $K_{eff}$ FOR UNRESTRICTED STORAGE

KENO-Va Result = 0.96400 ± 0.00063 ($K_{eff}$ ± sigma)

Bias = 0.00814 Delta-k
Bias Uncertainty = 0.000172 Delta-k

K95/95 For 500 Cases = 1.763

Pool Temperature Bias = 0.00914 Delta-k

| Tolerances: | | |
|---|---|---|
| | SS Thickness | = 0.00518 Delta-k |
| | Storage Cell ID | 0.00531 |
| | Storage Cell Pitch | 0.00807 |
| | Enrichment | 0.00774 |
| | Eccentric Loading | 0.00767 |

$$\text{Final } K_{eff} = 0.96400 + 0.00814 + 0.00914 + \text{SQRT}[(1.763*0.00063)^2 + (0.00518)^2 + (0.00531)^2 + (0.00807)^2 + (0.00774)^2 + (0.00767)^2]$$

$$= 0.99687$$

# APPENDIX C

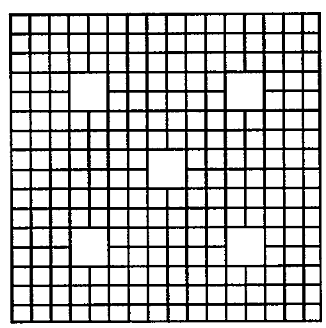
# REGION II KENO-Va MODEL

## SONGS UNITS 2 AND 3 FUEL ASSEMBLY DATA

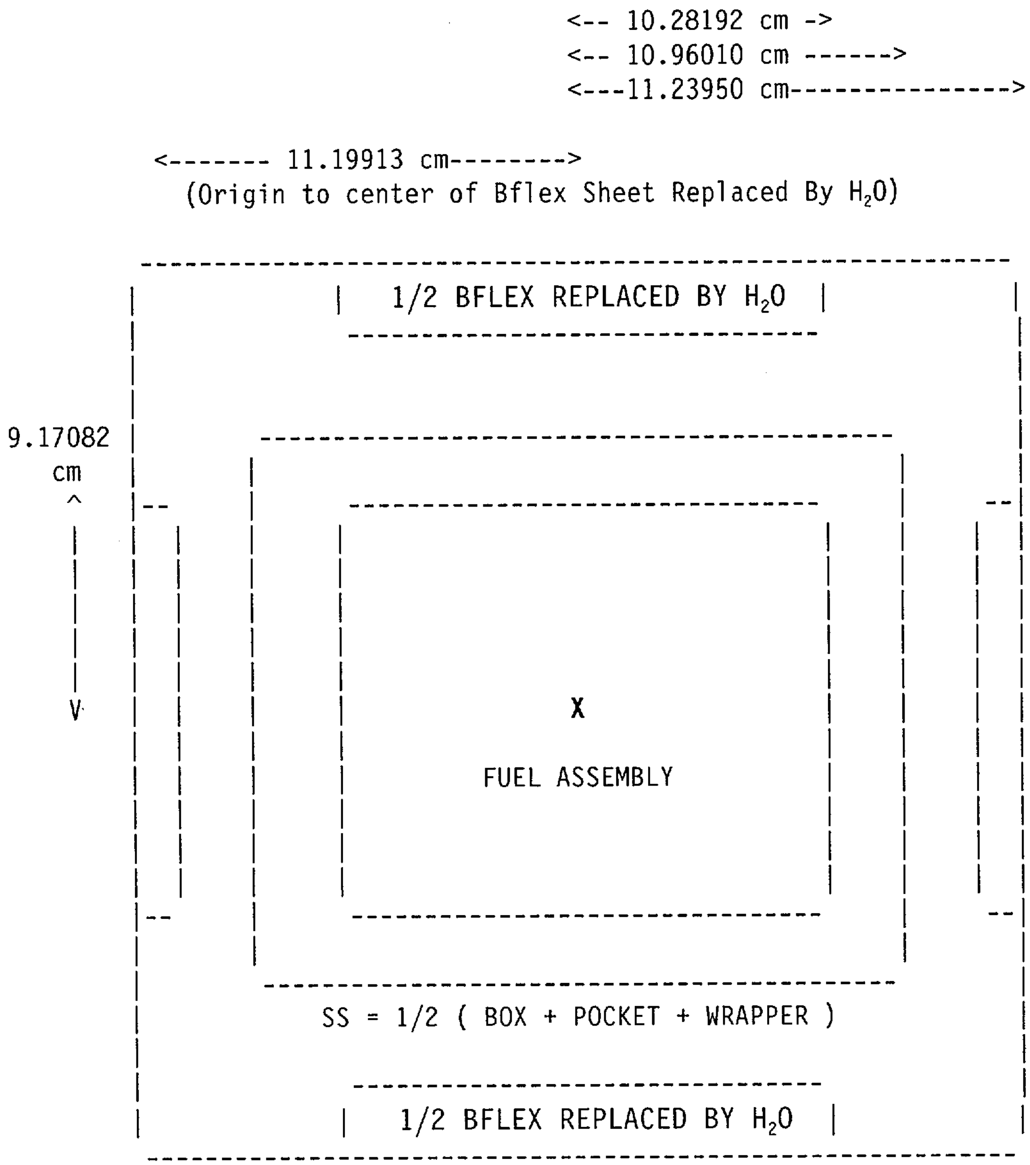
```
Fuel Pellet O.D.      = 0.325 inches
Fuel Pellet Density = 10.5216 gms/cc   (0.96 * 10.96 gms/cc)
Clad I.D.             = 0.332 inches
Clad O.D.             = 0.382 inches
Clad material         = Zircaloy

Guide Tube I.D.         = 0.90 inches
Guide Tube O.D.         = 0.98 inches
Guide Tube Material     = Zircaloy
Number Of Guide Tubes = 5

Fuel Rod Array = 16x16
Fuel Rod Pitch = 0.506 inches
```



# REGION II KENO-Va MODEL




<--> = 1/2 (Boraflex thickness) = 0.07874 cm

1/2(Center-to-center) = (2.54)(8.85)/2 = 11.23950 cm
1/2(Storage cell Id) = (2.54)(8.63)/2 = 10.96010 cm
1/2(Fuel Assembly) = (2.54)(16)(0.506)/2 = 10.28192 cm

1/2(BFLX thick) = (2.54)(0.062)/2 = 0.07874 cm
1/2(BFLX width) = (2.54)(7.522)(0.96)/2 = 9.17082 cm

Origin to BFLX Hole = 11.23950 - 0.07874/2 - **0.001** = 11.19913 cm

```
CELLDAN PROGRAM - CELL CONSTANTS AND DANCOFF FACTOR
               SCE VERSION R1 10-09-97

          DATE OF RUN -   08:03:26      04/27/**

          CE 16 X 16 FUEL

   FUEL OD .... .3250 IN.  .8255 CM   RADIUS =     .4127 CM
   CLAD ID .... .3320 IN.  .8433 CM   RADIUS =     .4216 CM
   CLAD OD .... .3820 IN.  .9703 CM   RADIUS =     .4851 CM
   ROD PITCH .. .5060 IN. 1.2852 CM   1/2 PITCH = .6426 CM

           ZIRCONIUM  CLAD    -   SQUARE     GEOMETRY

        FUEL DENSITY ...........    10.522 G/CC UO2
        ENRICHMENT .............     1.230 WT% U-235
        MODERATOR TEMPERATURE ..    20 DEGREES C
        DENSITY FACTOR .........     1.000
        WATER DENSITY ..........      .99823 G/CC

          HYDROGEN NUMBER DENSITY =  .066740
           OXYGEN  NUMBER DENSITY =  .033370 IN MODERATOR


            U-235  NUMBER DENSITY =  2.92374E-04
            U-238  NUMBER DENSITY =   .023181
           OXYGEN  NUMBER DENSITY =   .046947 IN FUEL

  NO OF FUEL RODS          236     NO THIM AND GUIDE TUBES   5
OVERALL CELL DIM, IN.    8.0960    THIMBLE ID, INCHES    .9000
DANCOFF HOMOG FACTOR-1   3.5590    THIMBLE OD, INCHES    .9800
DANCOFF HOMOG FACTOR-2   3.2200    ID/OD IN CM 1.1430/1.2446

HOMOGENIZED DENSITIES AT A WATER-TO-FUEL VOL RATIO OF  1.936

  U235     = 8.7331E-05   U238   = 6.9241E-03  CLAD = 4.6736E-03
HYDROGEN = 3.8598E-02  OXYGEN = 3.3322E-02

  U-235  SCAT/A-238 =     .1324   MOD  MEAN FREE PATH =    .6689
  OXYGEN SCAT/A-238 =    7.5946   CLAD MEAN FREE PATH =   3.7925
       SIG-P0       =   17.2270

       DANCOFF FACTORS:

 FIRST ROW (PER ROD)        .0490   SECOND ROW (PER ROD)       .0133
 CORR. - OUTER ROWS       .013618   DANCOFF FACTOR             .2229
```

```
#
#  Execute SCALE43 Driver
#
cat <<'eof' >input
=nitawl
' REGION 2 RACKS  - 1.23 W% - 96% T.D.  -  PITCH=1.28524 CM
0$$ 82 E
1$$ 0 13 0 4R0 1 E T
2$$ 92235 92238
    40302
    1001  8016
    5010  5011  6012  14000
    24304 25055 26304 28304
3** 92238  293.0  2  0.4127  0.2229  0.0  0.023181  1
    15.994  7.5946  1     235.04  0.1324  1        1.0   T
end
=kenova
REGION II RACKS -- 1.23 W% FUEL -- CIRCULAR GUIDE TUBES
READ PARAM  TME=1000  GEN=503 NPG=2000 NSK=3 LIB=4 TBA=1.0   END PARAM
READ BOUNDS   ALL=REFLECT   END BOUNDS
READ MIXT     SCT=2
MIX=1   92235 2.92374-4  92238 2.3181-2  8016 4.6947-2
MIX=2   40302 4.32444-2
MIX=3    1001 6.6740-2   8016 3.3370-2  5010 0.00000    5011 0.00000
MIX=4    6012 3.16910-4  24304 1.64710-2  25055 1.73210-3  26304 6.036-2
        28304 6.48340-3  14000 1.69400-3
MIX=5    5010 0.74493-2   5011 0.29749-1
         1001 0.24250-1   6012 0.18314-1  8016 0.12288-1 14000 0.77566-2
END MIXT
READ GEOM
COM= '                                                                    '
COM= '  NOMINAL DIMENSIONS AND BORAFLEX COMPOSITION                       '
COM= '                                                                    '
COM= '  SAME MODEL AS IN CASMO3 FOR COMPARISON:                           '
COM= '  (1) POCKET WATER MODELED AS SS-304                                '
COM= '  (2) BOX WALL THICKENED TO INCLUDED WRAPPER                        '
COM= '                                                                    '
COM= '  0000 PPM                                                          '
```

```
COM= '  20 DEG C                                                               '
COM= '                                                                         '
COM= '  C-E ZR-CLAD FUEL :  1.23 W%                                            '
COM= '                      96 % T.D.                                          '
COM= '                                                                         '
COM= '  3 - D KENO MODEL: MODEL ACTIVE FUEL + 1 FEET OF WATER                  '
COM= '                    REFLECTIVE BOUNDARY CONDITIONS ON EACH END           '
COM= '                                                                         '
COM= '  SYMMETRICALLY CENTERED ASSEMBLY                                        '
COM= '                                                                         '
COM= '  INFINITE ARRAY ASSUMED RADIALLY                                        '
COM= '                                                                         '
COM= '  ONE FULL ASSEMBLY IS MODELED                                           '
COM= '                                                                         '
COM= '  STRUCTURAL STEEL BETWEEN STORAGE CELLS NOT MODELLED                    '
COM= '                                                                         '
UNIT      1
COM=     "FUEL ROD"
CYLINDER  1   1  0.41275                                    381.0    0.0
CYLINDER  0   1  0.42164                                    381.0    0.0
CYLINDER  2   1  0.48514                                    381.0    0.0
CUBOID    3   1  0.64262 -0.64262 0.64262 -0.64262          381.0    0.0
UNIT      2
COM=     "GUIDE TUBE"
CYLINDER  3   1  1.14300                                    381.0    0.0
CYLINDER  2   1  1.24460                                    381.0    0.0
CUBOID    3   1  1.28524 -1.28524 1.28524 -1.28524          381.0    0.0
UNIT      3
COM=     "GUIDE TUBE + INSERTED CEA"
CYLINDER  3   1  1.14300                                    381.0    0.0
CYLINDER  2   1  1.24460                                    381.0    0.0
CUBOID    3   1  1.28524 -1.28524 1.28524 -1.28524          381.0    0.0
UNIT      4
COM=     "FUEL ROD ONLY -- NO SURROUNDING WATER"
CYLINDER  1   1  0.41275                                    381.0    0.0
CYLINDER  0   1  0.42164                                    381.0    0.0
CYLINDER  2   1  0.48514                                    381.0    0.0
UNIT      5
```

```
COM=      "TWO HORIZONTAL FUEL RODS + SURROUNDING WATER"
CUBOID     3   1  1.28524 -1.28524 0.64262 -0.64262  381.0    0.0
HOLE       4     -0.64262  0.0     0.0
HOLE       4      0.64262  0.0     0.0
UNIT       6
COM=      "TWO VERTICAL FUEL RODS + SURROUNDING WATER"
CUBOID     3   1  0.64262 -0.64262 1.28524 -1.28524  381.0    0.0
HOLE       4      0.0     -0.64262 0.0
HOLE       4      0.0      0.64262 0.0
UNIT       7
COM=      "FOUR FUEL RODS + SURROUNDING WATER"
CUBOID     3   1  1.28524 -1.28524 1.28524 -1.28524  381.0    0.0
HOLE       4      0.64262  0.64262 0.0
HOLE       4      0.64262 -0.64262 0.0
HOLE       4     -0.64262 -0.64262 0.0
HOLE       4     -0.64262  0.64262 0.0
UNIT       8
COM=      "VERTICAL BORAFLEX PANEL REPLACED WITH WATER"
CUBOID     3   1  0.03937 -0.03937 9.17082 -9.17082  381.0   0.0
UNIT       9
COM=      "HORIZONTAL BORAFLEX PANEL REPLACED WITH WATER"
CUBOID     3   1  9.17082 -9.17082 0.03937 -0.03937  381.0   0.0
UNIT      10   ARRAY 1    -10.28192   -10.28192   0.0
COM=      "FUEL ASSEMBLY IN REGION 2 SPENT FUEL RACK -- CASMO-3 MODEL"
CUBOID     3   1   10.96010  -10.96010  10.96010  -10.96010  381.0  0.0
CUBOID     4   1   11.23950  -11.23950  11.23950  -11.23950  381.0  0.0
HOLE       8      -11.19913    0.0         0.0
HOLE       8       11.19913    0.0         0.0
HOLE       9         0.0        11.19913   0.0
HOLE       9         0.0       -11.19913   0.0
CUBOID     3   1   11.23950  -11.23950  11.23950  -11.23950  411.0 -30.0
END GEOM
READ ARRAY
ARA=1       NUX=9 NUY=9 NUZ=1
COM=     "FULL SONGS 2 AND 3 FUEL ASSEMBLY"
FILL
1  5  5  5  5  5  5  5  1
6  7  7  7  7  7  7  7  6
```

```
6  7  2  7  7  7  2  7  6
6  7  7  7  7  7  7  7  6
6  7  7  7  2  7  7  7  6
6  7  7  7  7  7  7  7  6
6  7  2  7  7  7  2  7  6
6  7  7  7  7  7  7  7  6
1  5  5  5  5  5  5  5  1
END FILL
ARA=2        NUX=1 NUY=1 NUZ=1
COM=    "FINAL ARRAY OF PROBLEM"
FILL
 10
END FILL
END ARRAY
END DATA
end
eof
```

REGION II KENO-Va RESULTS

| no. of initial generations skipped | average k-effective | | deviation | 67 per cent confidence interval | 95 per cent confidence interval | 99 per cent confidence interval | number of histories |
|---|---|---|---|---|---|---|---|
| 3 | .97086 | + or - | .00048 | .97038 to .97134 | .96989 to .97183 | .96941 to .97231 | 1000000 |
| 4 | .97088 | + or - | .00048 | .97039 to .97136 | .96991 to .97185 | .96943 to .97233 | 998000 |
| 5 | .97087 | + or - | .00048 | .97039 to .97136 | .96990 to .97184 | .96942 to .97233 | 996000 |
| 6 | .97087 | + or - | .00049 | .97038 to .97135 | .96990 to .97184 | .96941 to .97232 | 994000 |
| 7 | .97085 | + or - | .00049 | .97036 to .97134 | .96988 to .97182 | .96939 to .97231 | 992000 |
| 8 | .97083 | + or - | .00049 | .97034 to .97132 | .96986 to .97180 | .96937 to .97229 | 990000 |
| 9 | .97083 | + or - | .00049 | .97034 to .97132 | .96985 to .97180 | .96936 to .97229 | 988000 |
| 10 | .97082 | + or - | .00049 | .97033 to .97131 | .96984 to .97180 | .96935 to .97229 | 986000 |

# CALCULATION OF REGION II FINAL $K_{eff}$ FOR UNRESTRICTED STORAGE

KENO-Va Result = 0.97086 ± 0.00048 ($K_{eff}$ ± sigma)

Bias = 0.00814 Delta-k
Bias Uncertainty = 0.000172 Delta-k

K95/95 For 500 Cases = 1.763

Pool Temperature Bias = 0.00300 Delta-k

| | | |
|---|---|---|
| Tolerances: | SS Thickness | = 0.00174 Delta-k |
| | Storage Cell ID | 0.00331 |
| | Enrichment | 0.01547 |
| | Eccentric Loading | 0.00000 |

$$\text{Final } K_{eff} = 0.97086 + 0.00814 + 0.00300 + \text{SQRT}[(1.763*0.00048)^2 + (0.00174)^2 + (0.00331)^2 + (0.01547)^2 + (0.00000)^2]$$

$$= 0.99803$$