LA-SUB--95-175-A:1

SEA No. 90-500-02-A:1

HFBR:

REVIEW OF THE TECHNICAL SPECIFICATIONS AGAINST THE FSAR

January 12, 1990
(Revised January 25, 1990)

Prepared for:

Mr. P. R. Shire
Los Alamos National Laboratory
N-Division, MS K557
P.O. Box 1663
Los Alamos, NM 87545

Prepared by:

Dasari V. Rao, Steven B. Ross, Eddie R. Claiborne, John L. Darby, Robert A. Clark
Science and Engineering Associates, Inc.
SEA Plaza
6100 Uptown Blvd. NE, Suite 700
Albuquerque, NM 87110

Science & Engineering Associates, Inc.

SEA No. 90-500-02-A:1

HFBR:

REVIEW OF THE TECHNICAL SPECIFICATIONS AGAINST THE FSAR

January 12, 1990
(Revised January 25, 1990)

Prepared for:

Mr. P. R. Shire
Los Alamos National Laboratory
N-Division, MS K557
P.O. Box 1663
Los Alamos, NM 87545

Prepared by:

Dasari V. Rao, Steven B. Ross, Eddie R. Claiborne, John L. Darby, Robert A. Clark
Science and Engineering Associates, Inc.
SEA Plaza
6100 Uptown Blvd. NE, Suite 700
Albuquerque, NM 87110

I. EXECUTIVE SUMMARY

The purpose of this review is to determine the adequacy of the High Flux Beam Reactor (HFBR) Technical Specifications for 40 MW operation by comparison with the HFBR Final Safety Analysis Report, particularly the accident analyses chapter. Specifically, the Technical Specifications were compared against the Design Basis Accident (DBA) Analyses presented in the Addendum to the HFBR FSAR for 60 MW Operation. The 60 MW DBA analyses was used since it is more current and complete than the analyses presented in the original FSAR which is considered obsolete . A listing of the required systems and equipment was made for each of the accidents analyzed. Additionally, the Technical Specification instrument setpoints were compared to the DBA analyses parametric values.

Also included in this review was a comparison of the Technical Specification Bases against the FSAR and the identification of any differences. The HFBR Operations Procedures Manual (OPM) was also reviewed for any inconsistencies between the FSAR or the Technical Specifications.

Upon completion of this review it was determined that the Technical Specifications are well written and the items commented on should not delay the low power restart (40 MW). Additionally, the OPM is also well written and does not require further modification before restart.

The review also indicates that the systems and components required to mitigate the DBA discussed in HFBR-FSAR are automated, in almost all cases. The systems/components that are controlled manually from the control room provide first and second level redundancy. Thus operator actions provide a backup that is only needed in case of failure of the automated systems. The only exception to this is a LOCA in the primary system where the operator actions are essential to isolate the break and mitigate the accident. From the accident analysis is is clear that the HFBR is equipped with systems and equipment that are capable of mitigating a wide variety of accidents. Consequently, no major modifications are suggested for low power restart. The only modification suggested pertains to steam vent valves P-300 A&B. It is recommended that for low power restart (40 MW) steam vent valves P-300 A&B be modified for remote manual operation and for 60 MW operation they be modified to be fully automated in the event of a vessel or beam tube break. However, it is important to note that in spite of full automation of valves P-300 A&B at 60 MW, the control room and operations level may be inaccessible during accidents for any manual mitigating actions (poison solution addition) due to the high radiation levels; therefore core damage may result. Additionally, although the pony motors are not required for low power restart they should be included as another level of forced cooling redundancy.

II. SCOPE OF THE REVIEW

The purpose of this task is to perform a review of the HFBR Technical Specifications to determine their adequacy for 40 MW operation. This review involved the following activities:

- Development of a listing of all systems and equipment required by the FSAR Design Basis Accident (DBA).
- Comparison of the HFBR Technical Specifications with the list in item 1.
- Identification of cases where the Technical Specifications are not in agreement with the DBA analyses parametric values.
- Review of the HFBR Technical Specifications against the FSAR to determine any inconsistencies.
- Review of the HFBR Operations Procedure Manual (OPM)

III. METHODOLOGY

To accomplish this task the following documents were utilized:

- HFBR Final Safety Analysis Report (FSAR) Volumes I and II
- Addendum to the HFBR FSAR, 1978
- Addendum to the HFBR FSAR for 60 MW Operation, 1982
- HFBR Plant Description Manual
- HFBR Operations Procedures Manual
- HFBR Technical Specifications and References (60 MW and 40 MW Operation) February 1989
- Level I Internal Event PRA for the HFBR Volume I: Summary and Results
- Level I Internal Event PRA for the HFBR Volume II: Summary and Results

IV DETAIL

The details of the review are presented in the following two sections. The first of these sections presents the details of the review of the HFBR technical specifications. The latter section presents discussions concerning the list of systems and components required by the HFBR FSAR DBA .

IV.1 REVIEW OF THE HFBR TECHNICAL SPECIFICATIONS

The Technical Specifications define the boundaries for safe operation for the High Flux Beam Reactor. Additionally, the Technical Specifications provide the basis for the development of rules, limits and procedures contained in the HFBR Operations Procedures Manual (OPM). The HFBR FSAR and its addenda contain the safety analysis of the HFBR which sets the guidelines for the establishment of the reactor operating limits and its technical specifications.

The Technical Specifications for 40 MW and 60 MW operation for the High Flux Beam Reactor (HFBR) located at Brookhaven National Laboratory (BNL) were reviewed for conformance to the Final Safety Analysis Report and its Addenda to enhance the safety of HFBR operations. Additionally, the Operations Procedure Manual(OPM) was reviewed for any inconsistencies between the FSAR or the Technical Specifications.

To ensure safe operation, the limiting value for a parameter as allowed by Technical Specifications should be more conservative than the value of that parameter used in the accident analysis. Also, the field setpoint on the limit of the parameter should be more conservative than the Technical Specification limit. These criteria ensure that the accident analysis covers the actual plant performance, and that the field settings allow for instrument drift.

IV.1.1 Pony Motor Trip Settings (60 MW Operation)(Section 3.3.1 of HFBR Tech. Specs.)

According to the Technical Specifications, during normal operation when the pony motors (60 MW) are not coupled to the primary pumps the normal reading for the current is 2.5 amps. The scram settings on 2/2 logic are 0.5 amps (low) and 7 amps (high). However, the 60 MW Addendum to the FSAR indicates that the low current trip is at 1.0 amps. Although either trip setting will indicate an open circuit, the accident analysis value should not be higher than the Technical Specification limit.

IV.1.2 **Design Capacity of the Pony Motors (60 MW Operation)**(Section 4.3.1.2 of HFBR Tech. Specs.)

Another conflict between the 60 MW Addendum to the FSAR and the 60 MW Technical Specifications is the design capacity of the pony motor batteries. The 60 MW Addendum to the FSAR indicates a design capacity for approximately 6-2/3 hours and the 60 MW Technical Specifications indicates a design capacity of 2 hours. Although just three minutes of forced cooling by the pony motor driven primary pumps is probably adequate (60 MW), post trip, the specification of the design capacity of the batteries in the accident analysis should be less than the limit established by the Technical Specifications.

IV.1.3 **Offsite Dose Guidelines**(Section 2.1.1 & 2.2.1)

DOE Order 5480.6, Safety of Department of Energy-Owned Nuclear Reactors, Section 8a provides a reference to the application of 10 CFR Part 100 for significant impacts on dose commitments when considering reactor siting or modifications of an existing reactor. Currently, DOE Order 5480.1A, Chapter XI is still being used for DOE dose limits for uncontrolled areas, however the portions of this order which pertain to doses to the public and environmental releases is being replaced by Draft Order 5400.XX in the near future. Additionally, the portions of DOE Order 5480.1A, Chapter XI which pertain to radiation protection for workers has been replaced by DOE Order 5480.11, dated January 1, 1989. When making any modifications to the HFBR Technical Specifications this information should be considered.

IV.1.4 **Valve Type in Line P118** (Section 2.1.3)

The FSAR and the PDM indicate that there is a globe valve in line P118. However, the Technical Specifications refer to the valve as a gate valve. The Technical Specifications should be updated to reflect the proper nomenclature for systems and components.

IV.1.5 **MCHFR during a Loss of Cover Gas Pressure Accident**(Section 2.1.3)

For the loss of cover gas pressure accident the FSAR reports the MCHFR at 135 psig as 3.33, while the Technical Specifications report the MCHFR at 135 psig as 2.51. The documents should be updated to reflect the actual value of the MCHFR at 135 psig.

IV.1.6 **Poison Solution System Cadmium Quantity** (Section 3.3.6)

The terminology reported in the Technical Specifications for the poison solution concentration is not consistent with the FSAR terminology. The Technical Specifications report that the quantity of Cd in solution in the poison water tank must not be less than 1055 lbs. The FSAR reports that the poison solution tank will hold 350 gallons of solution containing 3300 lbs of $Cd(NO_3)_2 \bullet 4H_2O$ dissolved in water. Efforts should be taken to ensure that the Technical Specifications are consistent with the FSAR.

IV.1.7 **Emergency Neutron Channels** (Section 3.9)

The emergency neutron channel indicators are not an indication of absolute power and are needed only to ensure reactor shutdown in the event of a control rod malfunction in conjunction with a loss of ac power. The Technical Specifications state that the reactor shall not be operated unless 1/3 of the emergency neutron channel indicators are operable. However, to ensure the reactor is shutdown after a power outage it may be desirable to change this requirement to 2/3 emergency neutron channel indicators are operable to provide redundancy.

IV.1.8 **Removal of Experiment Thimbles** (Section 6.1.3)

Section 6.1.3, item (1) of the Technical Specifications describes the removal of in-core fast thimbles V-15 or V-16 to be replaced by experiments directly in contact with the primary coolant. What precautions are taken to prevent leakage of the primary coolant when the thimble is removed and replaced?

IV.1.9 **Accident Analyses Calculations in the FSAR**

Most of the safety related thermal - hydraulics calculations (fuel surface and center line temperatures, etc.), were based on a model "TIGR4C". It is essential that this computer model be thoroughly validated and continuously updated to include up-to-date correlations. It is not clear from the FSAR or other available literature whether such steps have been taken or not. For example, some of the correlations used to determine heat transfer coefficients [Dittus - Boelter and Jens -Lottes] may not be the most appropriate correlations for the HFBR accident analyses. During some of the analyzed accidents the mass flow rate varied considerably (1000 - 18000 GPM), the temperature difference between the wall and the bulk fluid often exceeded 100^{o} F and the operating pressure was as low as 50 psia. Under these conditions, use of the Dittus - Boelter or Jens - Lottes correlations must be quantitatively justified.

Documentation on TIGR4C has been made available recently and is currently under review.

IV.1.10 **Calculation of CHF in HFBR**

Both the original FSAR and Addendum to FSAR for 60 MW Operation provided sketchy details on the calculation of CHF in HFBR. Both reports indicated that the Bernath Correlation was used to evaluate CHF in HFBR. However, in the original FSAR it was pointed out that the Bernath Correlation CHF predictions were divided by a safety factor of numerical value 1.4 to account for variations in geometrical and operating conditions between the correlation and HFBR. In this context it should be noted that the Bernath Correlation was developed for upflow of water in tubes and annuli whereas in the HFBR the water (D2O) flows downward in the rectangular channels. As mentioned earlier the factor 1.4 was presumably used to account for these differences. Independent calculations revealed that no such safety factor was used to calculate CHF in the Addendum to FSAR for 60 MW Operation. Additionally, the calculations showed that no safety factor may be necessary to account for geometry but certainly one is needed to account for the downward flow direction. Until one accurately accounts for the effect of downward flow direction on CHF, it may not be appropriate to simply use the Bernath correlation to predict CHF in the HFBR. This should not, however, restrain low power restart in view of the large margin of safety (CHFR > 4 in most cases) associated with low power operation.

IV. 1.11 **Beam Tube Surveillance**

The Advisory Committee on Nuclear Facility Safety Subcommittee on the HFBR has raised a number of questions concerning the issue of beam tube integrity. The main concern is for brittle failure in the harsh environment of radiation heating. The Technical Specifications have been revised to include Sections 3.15 and 4.15 (40 MW) and Sections 3.14 and 4.14 (60 MW) entitled "Material Surveillance Program". The material surveillance includes the sampling of control rod followers which experience a radiation field similar to that seen by the beam tubes on intervals of 75,00 MWd and is intended to satisfy this requirement. However, this is an indirect method and the indicated period between samplings is long, 5 years, at the estimated rate of 15,000 MWd operation per year. Since the integrity of the beam tubes has raised a number of questions, periodic beam tube surveillance would be included as part of the Technical Specifications. Non-destructive failure detection procedures that are based on X-rays or ultrasonics to measure beam tube thickness distributions and to detect skin cracks and pits should be evaluated for acceptable surveillance techniques. If such surveillance techniques are feasible then we recommend that they be implemented in the Technical Specifications on three-month intervals.

The survivability of the beam tube seal caps under jet impingement conditions cannot be assured by direct examination because of their remote location. The Technical Specifications have been revised to include Sections 3.18 and 4.18 (40MW) and Sections 3.17 and 4.17 (60 MW) entitled "Reactor Vessel Leakage" to attempt to satisfy this requirement. The CO_2 cavity is sampled for tritium on a weekly bases as an indication of D_2O leakage in the seal cap region. Although this is not as acceptable as physical observation it is probably the best that can be attained under the circumstance.

IV.1.12 Control Rod Settings for a Freshly Fueled Core

The full insertion of the auxiliary control rods must be assured during a fresh fuel configuration. Section 3.2.5 of the Technical Specifications specifies that the main and auxiliary control rods must be balanced with respect to one another (i.e, the distance of the main and auxiliary control rods from the core midplane is equal) unless the auxiliary rod bank is fully inserted (15 inches).

Normally with an equilibrium core, the critical position for the control rods is approximately 13.5 inches. However, for a freshly fueled core an approach to critical will need to be performed before operating at full power since the critical control rod position can not be accurately predicted for this more reactive condition. Additionally, the fresh fuel core will result in an unbalanced configuration since the main control rods will have to be inserted approximately 16 inches until fuel burnup will allow a balancing of the main and auxiliary control rods.

This situation was addressed in the auxiliary rod break accident discussed in the accident analysis section of the 1982 FSAR Addendum (Sect. 14.5.3.2). The discussion there suggested that if this situation arose then lower power limit restrictions would be implemented by administrative control. In fact, this situation did arise several times but the operation continued with the rods in a less withdrawn position, but without the promised power limitation procedures. This culminated in an Unusual Occurrence Report. The restriction on reactor power until the control rods can be balanced should be specified in the Technical Specifications.

IV.2.0

LIST OF SYSTEMS AND EQUIPMENT REQUIRED TO DETECT AND MITIGATE HFBR FSAR DESIGN BASIS ACCIDENTS

In most of the DBA analyses presented in the High Flux Beam Reactor (HFBR) Final Safety Analysis Report (FSAR), failure of a system or a group of systems cause emergency shutdown through an automatic scram. Safe and successful shutdown of the reactor after initial scram depends on satisfactory functioning of various systems and equipment that are available to mitigate DBA. The primary purpose of most of these systems is to provide adequate cooling of the reactor core after shutdown. *The original FSAR for 40 MW operation indicates that following shutdown the core is adequately cooled by natural circulation of heavy water residing in the reactor vessel. We concur with this conclusion. However, we would like to point out that due to availability of various mitigating systems that were introduced in recent modifications for 60 MW operation (pony motors, for example), reliance on natural circulation for low power restart should be treated as a last resort. If one bears this in mind, then the requirements for systems and components to mitigate DBA following steady operation at 40 MW are very similar to those corresponding to higher power levels (60 MW for example). Hence, it was decided to develop the list of required systems based on the FSAR for 60 MW operation. This list is expected to be conservative and yet practical without any modifications to the presently existing systems configuration. Additionally , the DBA analyses presented in the original FSAR for 40 MW operation were identified as obsolete in the Guide to HFBR Safety Analysis and the FSAR for 60 MW Operation provides a modified and improved DBA analyses section.*

Success criteria associated with the reactor core cooling following shutdown after steady operation at 60 MW can be given as:

1. Forced circulation of heavy water through the core (GPM $\geq$ 1000) for at least three minutes after the reactor shutdown by : (a) 1 out of 2 primary pumps or (b) 1 out of 2 pony motor driven primary pumps, or (c) 1 out of 2 shutdown pumps, and

2. Light water flow through the secondary of both the primary and shutdown heat exchangers provided by: (a) at least 1 out of 5 secondary coolant pumps, or (b) by manual opening of gravity feed line or cross connection feed line or fire hydrant feed line, or domestic water feed line.

3. In case of loss of forced circulation through the core after three minutes, natural circulation of pool water in the pressure vessel enabled by automatic opening of flow reversal valves; during this phase of cooling the reactor needs to be depressurized to ensure low core temperatures as well as to enable steam condensation.

In the original design of HFBR and during the later modifications, several systems and components were incorporated to meet the criteria highlighted above. Together these systems provide various levels of depth in redundancy. A list of these systems is reproduced as Appendix-A of this report.

The scope of the present work is to identify the status and availability of each of these systems following a DBA, and to compile a list of systems and components that are required to mitigate the accident. In compiling the list, particular emphasis was given to parameter values used for automatic initiations or for manual action decisions, and equipment required to function for DBA detection and mitigation. The following sections list the major systems required for each of the design basis accidents. A condensed version of the list is presented in tabular form as Table 1.

Table 1. List of Systems/Components Required by HFBR-FSAR DBA†

	REACTOR TRIP				PRIMARY PUMPS		PONY MOTORS		SHUTDOWN PUMP		SECONDARY COOLING				RV DEPRESSURIZATION				
Initiator No.	Auto Scram	Setback	Manual Scram	Poison Water	GA101A	GA101B	GA101A	GA101B	GA102A	GA102B	No. of Pumps Required	Gravity Feed	Cross Connection	Other Systems	HCE 102	P102A,B P300A,B	Steam Condensing	D2O Makeup	Natural Circulation
IV.2.1.1	YES	–	MAN	MAN	C	C	AUTO	MAN	MAN	AUTO	◊	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.1.2	YES	–	MAN	MAN	D	D	AUTO	MAN	MAN	AUTO	◊	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.2	◊	–	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊	◊
IV.2.3	YES	–	MAN	MAN	B	B	AUTO	MAN	MAN	AUTO	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.4	–	YES	MAN	MAN	A	A	AUTO	MAN	MAN	AUTO	1 of 4	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.5	YES	–	MAN	MAN	A	A	AUTO	MAN	MAN	AUTO	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.6	YES	–	MAN	MAN	A	A	AUTO	MAN	MAN	AUTO	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.7*	YES	–	MAN	MAN	A	A	AUTO	MAN	MAN	AUTO	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.8	YES	–	MAN	MAN	D	D	AUTO	MAN	MAN	AUTO	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.9	YES	–	MAN	MAN	B	B	AUTO	MAN	MAN	AUTO	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.10*	YES	–	MAN	MAN	A	A	AUTO	MAN	MAN	AUTO	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.11*	YES	–	MAN	MAN	A	A	AUTO	MAN	MAN	AUTO	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.12	YES	–	MAN	MAN	D	A	AUTO	FAIL	MAN	AUTO	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN
IV.2.13*	YES	–	MAN	MAN	B	B	COND	COND	COND	COND	1 of 5	MAN	MAN	MAN	AUTO	MAN	MAN	MAN	MAN

◊ = Usual shutdown procedure
* = Assumed that fuel melt is local and does not affect entire system performance
† = See next page for explanation of other symbols and list of initiators

Systems required for preferred shutdown
Systems that act as first level backup
Systems failed or conditionally operational due to the initiator

Table 1. List of Systems/Components Required by HFBR-FSAR DBA (cont.)

INTIATOR #	INITIATOR
IV.2.1.1	Loss of Commercial Power. Short Duration
IV.2.1.2	Loss of Commercial Power. Prolonged Duration
IV.2.2	Error in Placement of Fuel Element During Refueling
IV.2.3	Accidental Depressurization due to Opening of HCe-102
1V.2.4	Loss of Secondary Coolant Pump
IV.2.5	Uncontrolled Rod Withdrawl
IV.2.6	Accidental Throttling of Primary Flow Control Valves
IV.2.7	Fuel Channel Blockage
IV.2.8	Loss of Power to Primary Pumps
IV.2.9	Accidental Opening of Manual Relief Valve in P-118
IV.2.10	Thimble Flooding Accident
IV.2.11	Auxiliary Rod Break Accident
IV.2.12	Seizure of Primary Pump
IV.2.13	Primary System Pipe Break

Primary Pump Status

A Operational
B Available, but conditional
C Coast Down, but breakers are closed
D Not available due to Pump Seizure or Loss of Commercial Power.

OTHER SYMBOLS

MAN Manual
AUTO Automatic
COND Conditional
FAIL Failed or Assumed fail

IV.2.1 Initiator: **Loss of Commercial Power to the Plant**

Requirement for systems and equipment to mitigate this accident depends on the duration of power loss.

IV.2.1.1 Condition: **Short Duration (< 3 Secs)**

Power outage of short duration, typically 1-2 secs, is very *frequent*. During these situation the system performance is as follows:

Reactor Trip: *Automatic scram* is initiated 0.1 sec after the power failure due to power loss to the rod drive clutches. The *manual scram* from the control room serves as the *backup* if the autoscram fails.

Primary Cooling: The primary pumps trip, and the coastdown ensues. But, the circuit breakers which are equipped with low voltage time delay circuits, remain closed which enable startup of primary pumps upon power recovery. In this case the auto shutdown pump and pony motor (60 MW) (which automatically enter the flow circulation network) provide first level redundancy. The remaining systems, including the other shut down pump and pony motor (60 MW) (which can be started from the control room) and the flow reversal valves and steam condensing equipment, provide additional redundancy.

Secondary Cooling: Immediately upon power loss, the secondary coolant pumps trip and the coastdown ensues. From the documentation provided it is not clear whether the circuit breakers remain closed or open. Therefore it is assumed that manual action from the control room is needed to restart the pumps. If all the pumps (5 out of 5) fail to restart, the operator needs to open the gravity feed line and/or the cross-connecting feed line to the primary heat exchangers.

Reactor Vessel Depressurization: If both primary and secondary pumps restart following the power recovery, it is *not required to depressurize the system*. But in case they fail, automatic depressurization valve HCe-102 opens and the reactor vessel undergoes depressurization. Failure of HCe-102 to automatically open should be compensated by manual opening of P-102, P300A or P300B.

End Result: If both primary and secondary cooling systems restart following the power recovery it is possible to *restart the reactor* and reach operating power.

IV.2.1.2 Condition: **Prolonged Duration**

Reactor Trip: *Automatic scram* of the reactor is initiated after 0.1 secs. The manual scram from the control room serves as the backup, but this action is not required unless the auto scram mechanism fails. The poison solution dumping, once again not a requirement unless the reactor scram mechanisms fail, provides additional redundancy for reactor shutdown.

Primary Cooling: The primary pumps trip and the coast down ensues. In this case, the automatically activated *shutdown pump and pony motor (60 MW) are sufficient* to cool the reactor core. Thus, they are the only systems that are required to meet the success criteria on the primary side. The other systems that can be started from the control room (other pony motor (60 MW) and shutdown pump) serve as backup.

Secondary Cooling: The secondary pumps trip and coast down ensues. Although opening of check valve upon secondary pump failure feeds gravity driven flow to the shutdown heat exchangers, it is not clear whether that flow is adequate. Consequently, the requirement for secondary cooling is *to manually open the gravity feed and cross connection feed lines* to both the shutdown and primary heat exchangers. The fire hydrant feed and domestic water feed to the shutdown heat exchanger serve as backup.

Depressurization: Opening of primary pump circuit breakers trigger automatic opening of HCe-102 which meets the requirement. The other three manual valves, P-102 and P300 A &B, provide the backup.

Mitigating Systems: The mitigating systems are not required in this case unless the primary cooling is not sufficient. These systems, therefore, provide second level backup.

IV.2.2 Initiator: **Error in Placement of Fuel Element During Refueling**

There are no special failures or requirements associated with this class of initiators. If the error is detected during the reactor operation usual shutdown procedure can be used to shutdown the reactor and rearrange the fuel.

IV.2.3 Initiator: **Accidental Depressurization of Primary System due to Opening of HCe-102**

Reactor Trip: *Automatic Scram* of the reactor occurs when the reactor vessel pressure reaches 180 psig. Such a scram would satisfy the requirement. The *manual scram* from the control room and the *poison solution* tank both serve as *backups*.

Primary Cooling: The Primary pumps are operational only until the reactor vessel pressure falls below the low-low pressure set point (p=120 psig). At that point the breakers open and the coastdown ensues. Because the duration of primary pump operation after the reactor scram is a function of the automatic depressurization valve HCe-102 opening size, no credit can be taken for primary pumps approximately 10 secs after the reactor scram. Therefore the realistic *requirement* for primary cooling is to *automatically activate the pony motor (60 MW) and shutdown pump* which is already incorporated in the system design. In this case, the *other set of pony motor (60 MW) and shutdown pump serve as backup.*

Secondary Cooling: The accidental depressurization of the primary system has little effect on the functioning of the secondary side systems. Therefore, the *requirement* for the secondary cooling would be continual operation of 1 out of 5 secondary cooling pumps. The rest of the secondary cooling systems provide backup that can be activated manually, if need be.

Depressurization: The initiator of present interest already covers it. If depressurization below 50 psig is needed (such is the case during steam condensation) the P-102 and P-300A and P-300B valves can be opened manually.

Mitigation Systems: The requirement of mitigation systems is conditional subject to the failure of primary cooling.

IV.2.4 Initiator: **Loss of Secondary Coolant Pump**

Reactor Trip: The *reactor trip* in this class of initiators is through *automatic setback;* triggered when the heavy water inlet temperature reaches 141 ^{o}F (60.5 ^{o}C). No other reactor trip mechanism is required although both manual scram and poison dump are available as backup.

Primary Cooling: Loss of secondary coolant pump is not expected to have any significance on the primary systems performance. Therefore, the primary cooling *requirements* are in accordance with the basic *emergency shutdown procedures,* and *no special requirement* exists.

Secondary Cooling: Loss of one or two pumps can be easily compensated by manually switching on other AC pumps available in the loop. The only *requirement,* therefore, is to ensure that at least one of the available pumps is switched on immediately to avert an increase in coolant temperature. Furthermore, the secondary cooling success criteria can also be met by manually opening the gravity feed line or cross connection feed line to the primary heat exchangers. The time available for operator response is on the order of 5-10 minutes. These manual operations serve as backup if the secondary pumps cannot be restored immediately.

Reactor Vessel Depressurization: R.V. Depressurization is not necessary to mitigate the accident. After the primary cooling requirements are met and the primary pumps are shutdown, the RV undergoes depressurization through automatic opening of HCe-102.

IV.2.5 Initiator: **Uncontrolled Rod Withdrawal**

Reactor Trip: Automatic Scram when power reaches 48 MW (assuming that the reactor was originally operating at 40 MW), which meets the requirement. Additionally manual scram is available as backup and in the extreme condition manual dump of poison water can be used to ensure a sub-critical state.

Remaining Systems: The requirements for primary, secondary, R.V. Depressurization and Mitigating systems are same as those associated with basic emergency shutdown procedure.

IV.2.6 Initiator: **Accidental Throttling of Primary Flow Control Valves**

Reactor Trip: The requirement is met by *automatic scram* initiated when:

1. Primary flow falls below 16,000 GPM, or
2. Core differential pressure less than 32 Psi.

Primary Cooling: The requirement for primary cooling is automatically met by primary pumps if only one control valve (HCV 101 A or B) is throttled. But if both valves are throttled then credit cannot be taken for either primary pumps or pony motors (60 MW) beyond 12 secs. In such an extreme condition the requirement for primary cooling is met by *automatic opening of the* *shutdown pump* feed line to the core. The other shutdown pump, which needs to be started manually from the control room, acts as a backup. Furthermore, it is also possible to manually reopen the control valves to resume primary pump flow through the core.

Remaining Systems: Accidental throttling of primary flow control valves has little effect on the secondary cooling systems, reactor vessel depressurization systems or other mitigating systems. The requirement for these systems is according to the emergency shutdown procedure.

IV.2.7 Initiator: **Fuel Channel Blockage**

Reactor Trip: There is no credible way of detecting fuel channel blockage prior to partial or total failure of fuel elements adjacent to the blocked channel. The only possibility is when a instrumented fuel element is adjacent to the blocked channel. Such a possibility is remote. Therefore, the only reliable mechanism for reactor trip by *automatic scram* is through detection of *higher gamma ray activity* in the primary coolant. Consequently, the reactor trip requirement is not met until the failure of one or more fuel elements induces higher gamma activity in the primary coolant.

Remaining Systems: The primary cooling[1] , secondary cooling, R.V. depressurization and other mitigating systems are not effected by this class of initiator. Requirements for primary and secondary cooling are same as those for basic emergency shutdown procedures.

IV.2.8 Initiator: **Loss of Power to Primary Pumps**

Reactor Trip: This requirement is met by automatic scram triggered by:

1. Primary pump current below the lower set point (35 amp), or
2. Primary flow rate is below the lower set point (16, 000 GPM), or
3. Core differential pressure less than 32 psi.

---

[1]Note: It is assumed that fuel melt is local and its effect on the primary systems /components performance is minimal. In reality, however, the overheating may cause fuel element bowing and complete fuel channel blockage that prevents natural circulation in the later stages. Because the analysis of melt propagation is complicated and the probability of occurrence of such an event is very low, it is assumed that the melt is local.

Primary cooling: In this class of accidents, the primary pumps can not be given any credit beyond coastdown; i.e., it can not be assumed that operator actions would recover the primary pumps immediately. The primary cooling *requirement* is satisfied by flow from the *pony motor (60 MW)* and the *shutdown pump* which come on-line automatically. The other set of pony motor (60 MW) and shutdown pump that requires manual initiation provide a backup. Second level of redundancy is provided by the steam condensing equipment that is categorized as part of the mitigating systems.

Remaining Systems: The remaining systems, including secondary cooling systems and RV depressurization systems, are not effected by the initiator under discussion. These systems are to be controlled in accordance with the basic emergency shutdown procedure.

IV.2.9 Initiator: **Accidental Opening of Manual Relief Valve in Line P-118.**

Reactor Trip: This requirement is met by *automatic scram* action triggered by low reactor vessel pressure (RV pressure $\leq$ 180 psig).

Primary Cooling: The primary pumps are operational until the RV pressure falls below 120 psig. Thereafter, the primary pumps coast down. During the period of their operation, the primary pumps provide enough flow to meet the success criteria. But the duration of their operation is subjected to the size of the relief valve opening. Hence credit cannot be taken for primary pumps beyond a minute after shutdown. After the primary pumps coastdown, the automatically initiated pony motor (60 MW) and the shutdown pump meet the cooling requirements. The other set of pony motor (60 MW) and shutdown pump which are available on manual initiation from the control room, are the backup.

Remaining System: Status quo as per emergency shutdown procedures.

IV.2.10 Initiator: **Thimble Flooding Accident**

Reactor Trip: The reactor is tripped by automatic scram triggered when the reactor power reaches 48 MW. The manual scram and poison solution dumping serve as first and second level backup, respectively.

Remaining Systems: The primary and secondary cooling systems and the rest of the mitigating systems are not affected by this class of initiators. So the requirements for various systems during shutdown are consistent with the basic emergency procedures. One exception, however, is that the initiator is associated with probable fuel cladding failure (60 MW) (very small probability), due to simultaneous occurrence of rapid depressurization and overheating of the cladding, in spite of proper functioning of the mitigating systems.

IV.2.11 Initiator: **Auxiliary Rod Break Accident**

Reactor Trip: The reactor is tripped by automatic scram initiated when the reactor power reaches 48 MW. The manual scram and poison solution dumping provide first and second level redundancy.

Remaining Systems: Very similar to the previous case.

IV.2.12 Initiator: **Seizure of Primary Pump**

Reactor Trip: This requirement is fulfilled by automatic scram initiated when:

1. The Primary pump current exceeds the higher set point (150 amp), or
2. The flow rate falls below 16000 GPM, or
3. The core differential pressure falls below 32 psi.

Primary Cooling System: Although only one primary pump is available and pumping, the core flow rate is adequate to remove decay heat from the core. This operation of available primary pump for at least 3 minutes after shutdown meets the primary cooling requirement. The shutdown pumps (automatic and/or manual) and the manually initiated pony motor (60 MW) (automatically initiated pony motor (60 MW) was assumed to be driving the seized primary pump) serve as backups.

Remaining Systems: The remaining systems that include secondary cooling systems, reactor vessel depressurization systems and the mitigating systems are not affected by this initiator. Therefore, their performance requirements are in accordance with the basic shutdown procedures.

IV.2.13 Initiator: **Primary System Pipe Break**

The break is conservatively assumed to be a large LOCA that is capable of draining the core below the elevation of the outlet within 3 mins.

Reactor Trip: Automatic reactor trip is activated by:

1. Low liquid level (< 209" hot D_2O), and/or
2. Low the pressure (< 180 psig).

The manual scram can also be initiated if the leak is detected prior to automatic scram. In such a case isolation of the break is possible. The poison solution dumping provides the backup.

Primary Cooling: The primary pumps are operational until the low-low liquid level logic is tripped and there after both primary pumps and shutdown pump are shutoff. The pony motor (60 MW) or the primary pump coast down provide forced circulation through the core until the outlet of the vessel is uncovered. Obviously, time taken to reach the point of outlet uncovery depends on the break size and other systems performance. As pointed out earlier, it is assumed that the uncovery occurs within the initial 3 mins. In such a case, the core is cooled by natural circulation of residing heavy water in the reactor vessel. As pointed out at the start of this section, for power levels below 40 MW natural circulation together with steam condensing is sufficient to adequately cool the reactor core. However, it should be pointed out that to avert core damage operator intervention is necessary.

Secondary Cooling: The secondary cooling systems are not affected by this class of initiators. Hence the secondary cooling systems performance requirements are exactly same as those corresponding to the basic emergency shutdown procedures.

Reactor Vessel Depressurization: The low-low level logic trip automatically opens the depressurization valve HCe 102 and siphon break valve HCe-101C to depressurize the reactor vessel. From the reactor safety view point, faster depressurization would minimize the leakage rate and provides longer duration of forced circulation. In view of this, for initiators of this class it is advisable to depressurize the reactor vessel through manual opening of P-102 and P-300A and P-300B in addition to HCe-102. Such procedures were already outlined in Operating Procedures Manual (OPM). For this purpose it is advisable to make P-102 and P300 A & B remotely operable from the control room.

Mitigating Systems: Once the liquid level falls below the outlet, forced circulation through the core is not available. Thereafter, the core is cooled by natural circulation and steam condensing mechanisms. The secondary flow through shutdown and primary heat exchangers should continue to condense and recirculate the steam. In its absences it may be advisable to dump poison solution to makeup for loss of coolant by evaporation.

IV.3.0

REVIEW OF THE OPERATIONS PROCEDURES MANUAL

The HFBR OPM was reviewed against the FSAR and its Addenda and the Technical Specifications to ensure consistency among the documents. Additionally, the procedures in the OPM were reviewed to determine if they were easily understandable and executable.

IV.3.1 Time Requirement of Certain Procedures

Throughout the OPM certain actions are called for by procedure. For example, the opening of the steam vent valves or the tripping of a motor. If these actions require movement outside of the control room and a significant period of time to accomplish this should be pointed out in the procedures.

IV.3.2 NIAS and FVCA Alarms

As a reminder to the operators the difference between the Nuclear Incident Alarm System (NIAS) and the Fuel Vault Criticality Alarm (FVCA). should be pointed out in the OPM.

IV.3.3 Consistency of Scram Settings

OPM chapter 2.1, Table 2.1-1 entitled Setback, Seismic Alarm, Depressurization, and Low-Low Action Settings Table presents some scram levels which conflict with those reported in the HFBR FSAR as follows:

1. The scram setting for high primary coolant gamma activity is reported in the HFBR FSAR Update for 60 MW Operation as 100% of full scale; while in Table 2.1-1 the scram setting is reported as 75±5% of scale.

2. The pony motor (60 MW) normally run at 2.5 amps when uncoupled to the primary pumps. The scram setting reported in the HFBR FSAR for pony motor (60 MW) current is 1.0 amp (low) and 7.0 amp (high). However, Table 2.1-1 reports the scram setting as 1±.5 amp (low) and 6±.5 (high).

3. The primary pump motor scram settings are 150 A (high) and 35 A (low) as reported in the HFBR FSAR. However, in Table 2.1-1 the scram settings are indicated as 140±10 A (high) and 70±5 A (low).

Scram and trip settings should agree among all of the documents. Table 2.1-1 from OPM chapter 2.1 should be reviewed for inconsistencies against the FSAR and the Technical Specifications.

3.4 Net Time to Steam Generation

OPM chapter 3.4, section 14.4 states that during a reactor vessel leak, depending upon the reactor level and the reactor power history, boiling may begin within 12 minutes. This item is currently being reviewed and a first estimate indicates that the 12 minutes to boiling may need to be revised.

V. CONCLUSIONS

The Technical Specifications are well written and the items commented on should not delay the low power restart. However, a number of items were identified which should be resolved to maintain consistency between the Technical Specifications, the FSAR and the OPM. The relevant FSAR analytical bases are incorporated into the Technical Specifications. Additionally, the OPM is well written and easy to understand for the operators and does not require further modification before restart.

In some of the accidents analyzed (Fuel Channel Blockage (40 or 60 MW), for example), there is a probability (<1E-3) that the hottest portion of the fuel element reaches CHF in spite of proper mitigating action by the automated systems. As a consequence of these accidents, it is possible that part of the fuel will melt. But, the melting is expected to be local and probably will have no effect on the system integrity. The fission products would be released in a controlled manner and the dose consequences will be within the guideline values for uncontrolled areas. Consequently, this does not pose a problem for HFBR low power restart.

The review also indicates that in most of DBAs analyzed in the HFBR-FSAR the systems and components required to mitigate the accident are automated. Systems that are controlled manually from the control room provide the first and second level redundancy. One exception is the Large LOCA (large primary system pipe break) where operator intervention is a necessity. In this accident operator may have to depressurize the reactor and vent steam through the steam vent valves (P-300 A and B). The only modification suggested pertains to steam vent valves P-300 A&B. It is recommended that for low power restart (40 MW) steam vent valves P-300 A&B be modified for remote manual operation and for 60 MW operation they be modified to be fully automated in the event of a vessel or beam tube break. However, it is important to note that in spite of full automation of valves P-300 A&B at 60 MW, the control room and operations level may be inaccessible during accidents for any manual mitigating actions (poison solution addition) due to the high radiation levels; therefore core damage may result. Additionally, although the pony motors are not required for low power restart they should be included as another level of forced cooling redundancy. With exception to these recommendations, the presently available systems structure is adequate for low power restart of HFBR.

APPENDIX A

SYSTEM	FUNCTION	OPERATIONAL STATUS	SAFETY STATUS	DIRECT INTERFACES	REQUIRED DIRECT INTERFACES	REFERENCES & COMMENTS
1. Primary Coolant	Coolant for fuel assemblies and control rod blades.	Operating	Front line	2. Secondary Coolant 3. Cover gas 4. Reactor Shutdown Cooling System 5. Natural Circulation 6. Poison Solution 7. Primary Coolant Purification 9. Instrumentation 11. AC Electrical Distribution 15. Pony Motors 17. Depressurizing System 19. D2O Experimental Facilities Cooler 20. DA Drain and D2O Transfer and Storage System 21. Helium Supply 23. Compressed Air 25. Low-low Level Trip 26. Helium Circulation System 29. Reactor Scram System 30. Reactor Setback System 31. Fuel Cladding Failure Safety System 32. DC Electrical Distribution	2. Secondary Coolant 3. Cover gas 4. Reactor Shutdown Cooling System 5. Natural Circulation 11. AC Electrical Distribution 15. Pony Motors 17. Depressurizing System 21. Helium Supply 29. Reactor Scram System 30. Reactor Setback System 31. Fuel Cladding Failure Safety System 32. DC Electrical Distribution	Siphon break line and valve considered part of primary coolant system.
2. Secondary Coolant	Coolant for primary D2O cooler, D2O shutdown cooler, thermal shield, biological shield, experimental facility	Operating	Front line	1. Primary Coolant 3. Cover gas 4. Reactor Shutdown Cooling System 5. Natural Circulation 6. Poison Solution 8. Thermal Shield Cooling 9. Instrumentation 11. AC Electrical Distribution 12. Biological Shield Cooling 15. Pony Motors 19. D2O Experimental Facilities Cooler 28. Deionized Water System 32. DC Electrical Distribution 33. Domestic Water Supply	1. Primary Coolant 4. Reactor Shutdown Cooling System	

SYSTEM	FUNCTION	OPERATIONAL STATUS	SAFETY STATUS	DIRECT INTERFACES	REQUIRED DIRECT INTERFACES	REFERENCES & COMMENTS
3. Helium Cover Gas	Maintains 200 psig surge volume pressure, provides inert and compressible volume to absorb liquid surges, & removes radiolytic and corrosion gases	Operating	Support	1. Primary Coolant 4. Reactor Shutdown Cooling System 5. Natural Circulation 6. Poison Solution 9. Instrumentation 11. AC Electrical Distribution 17. Depressurizing System 21. Helium Supply System 22. Nuclear Safety System 23. Compressed Air System 25. Low-low level Trip 26. Helium Circulation System	1. Primary Coolant 5. Natural Circulation 17. Depressurizing System 21. Helium Supply System. 26. Helium Circulation System	
4. Reactor Shutdown Cooling System	Removal of decay heat	1/2 pumps oper.	Front line	1. Primary Coolant 2. Secondary Coolant 3. Cover Gas 5. Natural Circulation 11. AC Electrical Distribution 17. Depressurizing System 22. Nuclear Safety System 25. Low-low level Trip 32. DC Electrical Distribution	1. Primary Coolant 2. Secondary Coolant 11. AC Electrical Distribution 25. Low-low level Trip 32. DC Electrical Distribution	
5. Natural Circulation	Removes decay heat in the event of loss of forced flow.	Standby	Front line	1. Primary Coolant 2. Secondary Coolant 3. Helium Cover Gas 4. Reactor Shutdown Cooling System 9. Instrumentation 17. Depressurizing System 20. DA Drain and D2O Transfer and Storage System 25. Low-low Level Trip	1. Primary Coolant 17. Depressurizing System 25. Low-low Level Trip	

SYSTEM	FUNCTION	OPERATIONAL STATUS	SAFETY STATUS	DIRECT INTERFACES	REQUIRED DIRECT INTERFACES	REFERENCES & COMMENTS
6. Poison Solution	Insures adequate shutdown in the event of light water flooding (cadmium nitrate solution) and serves as a backup to the control rod	Standby	Frontline	1. Primary Coolant 2. Secondary Coolant 3. Helium Cover Gas 5. Natural Circulation 9. Instrumentation 17. Depressurizing System 21. Helium Supply System 33. Domestic Water Supply	1. Primary Coolant 33. Domestic Water Supply	
7. Primary Coolant Purification	Purifier of D2O	Operating	None	1. Primary Coolant 6. Poison Solution 9. Instrumentation 11. AC Electrical Distribution 20. DA Drain and D2O Transfer and Storage System	1. Primary Coolant 11. AC Electrical Distribution 20. DA Drain and D2O Transfer and Storage System	
8. Thermal Shield Cooling	Removes heat generated by radiation adsorption	Operating	None	2. Secondary Coolant 9. Instrumentation 11. AC Electrical Distribution 28. Deionized Water System 33. Domestic Water Supply	2. Secondary Coolant 11. AC Electrical Distribution 28. Deionized Water System	
9. Instrumentation	Measures nuclear and non-nuclear parameters	Operating	Support	1. Primary Coolant 2. Secondary Coolant 3. Cover gas 4. Reactor Shutdown Cooling System 5. Natural Circulation 6. Poison Solution 7. Primary Coolant Purification 11. AC Electrical Distribution 14. Reactor Building Containment 15. Pony Motors 17. Depressurizing System 19. D2O Experimental Facilities Cooler	11. AC Electrical Distribution	

SYSTEM	FUNCTION	OPERATIONAL STATUS	SAFETY STATUS	DIRECT INTERFACES	REQUIRED DIRECT INTERFACES	REFERENCES & COMMENTS
				20. DA Drain and D2O Transfer and Storage System 21. Helium Supply 23. Compressed Air System 25. Low-low Level Trip 26. Helium Circulation System 28. Deionized Water System 8. Thermal Shield Cooling 10. Control Rod System 12. Biological Shield Cooling 18. Nuclear Incident Accident Alarm 22. Nuclear Safety System 32. DC Electrical Distribution	32. DC Electrical Distribution	
10. Control Rod Drive	Moves main and auxiliary control rods	Operating	Front line	6. Poison Solution 9. Instrumentation 11. AC Electrical Distribution 18. Nuclear Incident Accident Alarm 22. Nuclear Safety System	9. Instrumentation 11. AC Electrical Distribution 18. Nuclear Incident Accident Alarm 22. Nuclear Safety System	
11. AC Electrical Distribution	Provides AC motive power to prime movers and Instr. and control components	Operating	Support	1. Primary Coolant 2. Secondary Coolant 4. Reactor Shutdown Cooling System 7. Primary Coolant Purification 8. Thermal Shield Cooling 9. Instrumentation 10. Control Rod System 12. Biological Shield Cooling 13. Offsite Power 14. Reactor Building Containment 15. Pony Motors 16. Battery Sources 17. Depressurizing System 18. Nuclear Incident Accident Alarm 19. D2O Experimental Facilities Cooler 20. DA Drain and D2O Transfer and Storage System	13. Offsite Power 16. Battery Sources	

SYSTEM	FUNCTION	OPERATIONAL STATUS	SAFETY STATUS	DIRECT INTERFACES	REQUIRED DIRECT INTERFACES	REFERENCES & COMMENTS
				21. Helium Supply 22. Nuclear Safety System 23. Compressed Air System 24. Emergency Generator 25. Low-low Level Trip 26. Helium Circulation System 28. Deionized Water System 32. DC Electrical Distribution 33. Domestic Water Supply	24. Emergency Generator 32. DC Electrical Distribution	
12. Biological Shield Cooling	Removes heat from the biological shield and also provides the cooling for the Experimental Facility outside of the thermal shield.	Operating	None	2. Secondary Coolant 11. AC Electrical Distribution 28. Deionized Water 33. Domestic Water Supply	2. Secondary Coolant 11. AC Electrical Distribution 28. Deionized Water	
13. Offsite Power	Provides power to the BNL transformer building to power the HFBR systems.	Operating	Support	11. AC Electrical Distribution	11. AC Electrical Distribution	
14. Reactor Containment	Retains the radioactive release of any conceiveable reactor accident.	Operating	Front line	9. Instrumentation 11. AC Electrical Distribution 17. Depressurizing Valve 18. Nuclear Incident Accident Alarm 23. Compressed Air System 33. Domestic Water Supply	18. Nuclear Incident Accident Alarm	
15. Pony Motors	Provides safe transistion to flow reversal cooling. Connected to main pumps. Required for increase to 60 MW	1/2 Operating	Front line	1. Primary Coolant 2. Secondary Coolant 3. Cover gas 4. Reactor Shutdown Cooling System 5. Natural Circulation 9. Instrumentation 11. AC Electrical Distribution 25. Low-low level Trip 32. DC Electrical Distribution	1. Primary Coolant 32. DC Electrical Distribution	

SYSTEM	FUNCTION	OPERATIONAL STATUS	SAFETY STATUS	DIRECT INTERFACES	REQUIRED DIRECT INTERFACES	REFERENCES & COMMENTS
16. Battery System	Provides backup power in the event of the loss of the AC electrical distribution system.	Standby	Front line	32. DC Electrical Distribution 11. AC Electrical Distribution	32. DC Electrical Distribution 11. AC Electrical Distribution	
17. Depressurizing System	Depressurizes the reactor surge volume if main and shutdown pumps are stopped. Also provides overpressure protection through safety vent valves.	Standby	Front line	1. Primary Coolant 2. Secondary Coolant 3. Cover gas 4. Reactor Shutdown Cooling System 5. Natural Circulation 6. Poison Solution 9. Instrumentation 21. Helium Supply System 23. Compressed Air System 25. Low - low level trip 26. Helium Circulation System 32. DC Electrical Distribution	5. Natural Circulation 23. Compressed Air System 25. Low - low level trip	23. Required to not depressurize, but not required to depressurize. Only needed when using main pumps on AC at shutdown.
18. Nuclear Incident Accident Alarm	Monitors the radiation level in the containment building.	Operating	Front line	3. Helium Cover Gas 9. Instrumentation 11. AC Electrical Distribution 14. Reactor Building Containment 17. Depressurizing System 32. DC Electrical Distribution	14. Reactor Building Containment 32. DC Electrical Distribution	
19. D2O Experimental Facility Cooler	Removes heat generated in the fast and thermal irradiation thimbles	Operating	None	1. Primary Coolant 2. Secondary Coolant 7. Primary Coolant Purification 9. Instrumentation 11. AC Electrical Distribution 20. DA Drain and D2O transfer and storage system	1. Primary Coolant 2. Secondary Coolant 11. AC Electrical Distribution	

SYSTEM	FUNCTION	OPERATIONAL STATUS	SAFETY STATUS	DIRECT INTERFACES	REQUIRED DIRECT INTERFACES	REFERENCES & COMMENTS
20. DA Drain and D2O Transfer and Storage System	Fills the various process systems and replaces any lost D2O, collects D2O drained from components (tank FA-101) stores a supply of D2O in tank FA-102 for emergency primary makeup	Operating	Support	1. Primary Coolant 4. Reactor Shutdown Cooling System 7. Primary Coolant Purification 9. Instrumentation 11. AC Electrical Distribution 19. Shutdown HX 24. Helium Supply System	1. Primary Coolant 24. Helium Supply System	1. Required for makeup following breach in primary system.
21. Helium Supply System	Provides high & low pressure helium for various processes	Operating	Support	1. Primary Coolant 3. Cover Gas 5. Natural Circulation 6. Poison Solution 11. AC Electrical Distribution	1. Primary Coolant	1. Required to open siphon break valve.
22. Nuclear Safety System	Provides automatic scram or setback signals to the control rod drive system. See Table 4 and Table 5.	Operating	Front line	11. AC Electrical Distribution 9. Instrumentation	11. AC Electrical Distribution 9. Instrumentation	
23. Compressed Air System	Provides compressed air to the reactor building and the pumphouse	Operating	Support	3. Helium Cover Gas 9. Instrumentation 11. AC Electrical Distribution 17. Depressurizing System 33. Domestic Water Supply	11. AC Electrical Distribution	
24. Emergency Power Generator	Propane powered generator; backup to the AC electrical distribution system	Standby	Support	9. Instrumentation 11. AC Electrical Distribution 27. Propane Supply 33. Domestic Water Supply	11. AC Electrical Distribution 27. Propane Supply	
25. Low - low level trip	Trips all pumps, opens the flow reversal valves, the depressurizing valve, and the siphon break valve.	Standby	Front line	1. Primary Coolant 5. Natural Circulation 9. Instrumentation 11. AC Electrical Distribution 17. Depressurizing Valve 23. Compressed Air System	5. Natural Circulation 9. Instrumentation 11. AC Electrical Distribution 17. Depressurizing Valve	

SYSTEM	FUNCTION	OPERATIONAL STATUS	SAFETY STATUS	DIRECT INTERFACES	REQUIRED DIRECT INTERFACES	REFERENCES & COMMENTS
26. Helium Circulation System	Circulates helium from the surge volume through the recombiner and back to the surge volume	Operating	None	1. Primary Coolant 3. Helium Cover Gas 21. Helium Supply System	1. Primary Coolant 21. Helium Supply System	
27. Propane Supply	Provides a propane supply to to the emergency generator.	Standby	Front line	24. Emergency power Generator	24. Emergency power Generator	
28. Deionized Water system	Provides coolant for the biological and thermal shield cooling systems	Operating	None	2. Secondary Coolant 8. Thermal Shield Cooling 9. Instrumentation 11. AC Electrical Distribution 12. Biological Shield Cooling 33. Domestic Water Supply	2. Secondary Coolant 11. AC Electrical Distribution	
29. Reactor Scram System	Protects the reactor from out of limit conditions by scram signals as outlined in Table 4.	Operating	Front line	9. Instrumentation 11. AC Electrical Distribution	9. Instrumentation 11. AC Electrical Distribution	
30. Reactor Setback System	Protects the reactor from out of limit conditions by setback signals as outlined in Table 5.	Operating	Front line	9. Instrumentation 11. AC Electrical Distribution	9. Instrumentation 11. AC Electrical Distribution	
31. Fuel Cladding Failure Safety System	Provides a scram signal when breaches in the fuel cladding are detected	Operating	Front line	1. Primary Coolant 9. Instrumentation 11. AC Electrical Distribution	9. Instrumentation 11. AC Electrical Distribution	
32. DC Electrical Distribution	Provides DC motive power to prime movers and Instr. and control components	Standby	Front line	11. AC Electrical Distribution 16. Battery System 24. Emergency Generator	11. AC Electrical Distribution 16. Battery System 24. Emergency Generator	
33. Domestic Water Supply	Light water supply for many HFBR systems including secondary water system makeup, air compressor cooling and emergency generator cooling.	Operating	Support	2. Secondary Coolant 6. Poison Solution 8. Thermal Shield Cooling 11. AC Electrical Distribution 12. Biological Shield Cooling 14. Reactor Containment 23. Compressed Air System 24. Emergency Power Generator 28. Deionized Water System	6. Poison Solution 24. Emergency Power Generator	