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Subject: **Response to Portion of NRC Request for Additional Information Letter No. 44 – Safety Analysis – RAI Numbers 4.6-23, 4.6-23S01 and 4.6-27**

Enclosure 1 contains GHNEA's response to the subject NRC RAIs transmitted via the Reference 1 letter.

If you have any questions or require additional information regarding the information provided here, please contact me.

Sincerely,

Kathy Sedney for

James C. Kinsey
Project Manager, ESBWR Licensing

D068

NRO

Reference:

1. MFN 06-255, Letter from U.S. Nuclear Regulatory Commission to David Hinds, *Request for Additional Information Letter No. 44 Related to the ESBWR Design Certification Application*, July 25, 2006

Enclosures:

1. MFN 07-253 – Response to Portion of NRC Request for Additional Information Letter No. 44 – Related to ESBWR Design Certification Application – CRD System – RAI Numbers 4.6-23, 4.6-23S01 and 4.6-27.
2. MFN 07-253 – Response to Portion of NRC Request for Additional Information Letter No. 44 – Related to ESBWR Design Certification Application – Control Rod Drop Event Frequency Evaluation

cc:	AE Cubbage	USNRC (with enclosures)
	DH Hinds	GHNEA Wilmington (with enclosures)
	BE Brown	GHNEA Wilmington (with enclosures)
	eDRF	0000-0068-5653 and 0000-0069-1155

Enclosure 1

MFN 07-253

Response to Portion of NRC Request for

Additional Information Letter No. 44

Related to ESBWR Design Certification Application

CRD System

RAI Numbers 4.6-23, 4.6-23 S01 and 4.6-27

NRC RAI 4.6-23

The Safety Evaluation for the ABWR Design Certification did not recognize the General Electric (GE) position that the control rod drop accident was beyond design basis. In response to RAI 4.6-3, differences between the ABWR fine motion control rod drive (FMCRD) and ESBWR FMCRD are discussed.

(a) Describe any enhanced features or design requirements developed for the ESBWR to minimize the probability of an excess reactivity addition event.

(b) Building upon the ABWR CRD Failure Modes and Effect Analysis (FMEA), discuss the probability and potential consequences for each scenario leading to an excess reactivity event.

GE Response

See response to RAI 4.6-23 S01 below.

NRC RAI 4.6-23 S01

From Fuels Audit 10/23 - 10/31

a. Check data and recast ABWR info as ESBWR info

b. NRC is amenable to using Japanese data if desired

GE Response

This response addresses both RAI 4.6-23 and RAI 4.6-23 S01, because the request for supplemental information has preceded transmittal of the response to RAI 4.6-23. Thus, the questions from RAI 4.6-23 have been included and answered in view of notes a. and b. above:

(a) There are no enhanced features or design requirements developed for the ESBWR. Mechanistically it is the same FMCRD as for the ABWR relative to FMEA scenarios. FMCRD design differences between ESBWR and ABWR can be seen in the response to RAI 4.6-3.

(b) Enclosure 2 "Control Rod Drop Event Frequency" provides a discussion of the probability and potential consequences of each scenario leading to an excess reactivity event. The discussion in enclosure 2 builds upon ABWR evaluations.

Affected Documents

No DCD changes will be made in response to this RAI.

NRC RAI 4.6-27

DCD Tier 2, Section 4.6.1.2 describes the CRD system functions including the "ability to position large groups of rods simultaneously." With the ability to move multiple control rods simultaneously comes the ability to inadvertently move multiple rods. This inadvertent withdrawal would introduce a more global, core-wide power transient than the traditional localized rod withdrawal error (RWE) event. Please describe the core and plant systems' response to a RWE event involving large groups of rods.

GE Response

The mitigation of spurious rod movement by one or more rods is provided by Rod Control & Information System (RC&IS) functions. A Rod Withdrawal Error (RWE) at power is protected by the Rod Worth Minimizer (RWM) and Automated Thermal Limit Monitor (ATLM) subsystems of RC&IS that terminate any spurious rod movement of one or more rods prior to operating limit violation. There are two RC&IS channels. Any disagreement between the two initiates a rod block (unless one is bypassed). Any one channel can signal rod block.

Detection of an out-of-sequence movement, based upon the Ganged Withdrawal Sequence Restriction (GWSR), when the reactor power is below the Low Power Set Point (LPSP) by either channel of the RWM, will cause an associated rod block to be enforced. If the serious failure of one channel of RWM equipment is detected with the reactor below Low Power Setpoint, with that channel not being bypassed, then a rod block is activated. The operator can bypass one channel of the RWM, but if the second channel fails, then a rod block is activated. The operator can manually bypass one channel of the RWM; however, automatic control rod movement is prevented and rod movement is only allowed in the Manual or Semi-Automatic modes.

In addition to these actions, when in the startup range, the Startup Range Neutron Monitor (SRNM) can initiate period based rod blocks and scrams that are independent of the number of rods moving out of sequence if the operator performs an inadvertent Rod Withdrawal Error or if there is a malfunction of the automated rod movement control system.

Above the Low Power Setpoint, the ATLM system monitors operating thermal limit protection function for either Minimum Critical Power Ratio (MCPR) or Maximum Linear Heat Generation rate (MLHGR). The protection algorithms block further control rod withdrawal when there is potential for either (MCPR or MLHGR) operating limit to be violated. If serious failure of one channel of ATLM equipment is detected with that channel not being bypassed, then a rod block is activated. The design of the ATLM is such that both ATLM channels must be operating normally with no bypasses for RC&IS to operate in the Automatic Mode. The operator can bypass one channel of the ATLM and if the second channel fails, then a rod block is initiated. Due to the design of the bypass function, it is physically impossible to bypass both ATLMs at the same time.

These systems are discussed in DCD Tier 2 Subsection 7.7.2.

Rod Withdrawal Error is also discussed in DCD Tier 2 Subsection 15.3.8 (Control Rod Withdrawal Error During Startup) and Subsection 15.3.9 (Control Rod Withdrawal Error During

Power Operation). As an additional resource, RAI 15.2-10 also addresses inadvertent rod movement.

Affected Documents

No DCD changes will be made in response to this RAI.

Enclosure 2

MFN 07-253

Response to Portion of NRC Request for

Additional Information Letter No. 44

Related to ESBWR Design Certification Application

CRD System

RAI Numbers 4.6-23, 4.6-23 S01 and 4.6-27

Control Rod Drop Event Frequency Evaluation

CONTROL ROD DROP EVENT FREQUENCY

1.0 Purpose: The purpose of this document is to estimate the frequency of a control rod drop event for the ESBWR plant in response to the USNRC's Request for Additional Information (RAI) generated as part of ESBWR Design Certification effort.

2.0 Background: The RAI 4.6-23 reads:

"The Safety Evaluation for the ABWR Design Certification did not recognize the General Electric (GE) position that the control rod drop accident was beyond design basis. In response to RAI 4.6-3, differences between the ABWR fine motion control rod drive (FMCRD) and ESBWR FMCRD are discussed".

(a) "Describe any enhanced features or design requirements developed for the ESBWR to minimize the probability of an excess reactivity addition event".

(b) *"Building upon the ABWR CRD Failure Modes and Effect Analysis (FMEA), discuss the probability and potential consequences for each scenario leading to an excess reactivity event".*

This document addresses the issue of control rod drop accident probability identified in part (b) of the RAI. The potential consequences of the accident are addressed in a separate document, as is the response to part (a) of the RAI.

3.0 Introduction: The control rod drop accident (CRDA) is an extremely low probability event requiring a combination of specific reactor power condition and multiple equipment failures and operator errors. In separate communication with the NRC Staff, it was agreed that GE will estimate a probability of not the classic CRDA, but a specific event in which, under some assumed conditions, the control rod can drop freely to a specified position. Thus the event being evaluated is not the classic CRDA. For instance, the CRDA can occur only under low power conditions, but this analysis will assume that the rod drop event can occur at any power level. Similarly, in case of the CRDA, the control rod has a probability of getting stuck in the core. However, this analysis will assume that the control rod gets stuck in the core with a probability of 1.0. Thus, the event for which the probability is evaluated will have a much higher probability than that of the CRDA. The NRC has not specified an acceptance criterion for the event frequency calculated in this analysis.

Strictly speaking, the analysis estimates the frequency of the event per year, but the term probability is used interchangeably, as was done by NRC in the RAI.

4.0 Events Analyzed:

The description of the FMCRD is provided in the ESBWR DCD. The events of concern are described in Attachment A and summarized below:

Event 1:

a) A combination of mechanical failures and operator error causes the control rod and the FMCRD hollow piston to be miscoupled during the drive installation and this is not detected. Alternatively, the coupling that was installed correctly during drive installation, uncouples during operation and is not detected.
b) It is then assumed that this miscoupled CR is stuck in the core.
c) The rod is then selected for withdrawal, and due to a combination of mechanical and instrumentation failure and operator error, rod block is not initiated.
d) As the rod is withdrawn, the hollow piston of the FMCRD moves to a lower position. The operators in the control room ignore the alarm that indicates the separation of the hollow piston from the drive.
e) The control rod subsequently unsticks and falls freely to the position of the FMCRD hollow piston.

Event 2:

a) In this event, the control rod and the FMCRD hollow piston stay coupled. It is then assumed that the CR is stuck in the core while still being attached to the hollow piston.
b) The rod is then selected for withdrawal, and due to a combination of mechanical and instrumentation failure and operator error, the rod block is not initiated and the ball nut moves to a lower position. The operators in the control room ignore the alarm that indicates separation.
c) The control rod subsequently unsticks and starts to drop freely.
d) There are two redundant spring-loaded latches on the hollow piston, which are designed to engage in the windows in the guide tube. Failure of one of these latches will cause the control rod to drop a distance of about 210 mm until the other latch engages in the subsequent guide tube window. The control rod and the hollow piston stay coupled through the event.

Event 3: This event starts off very similar to the Event 2 described above, until the control rod unsticks and starts to drop freely. Then both the spring-loaded latches on the hollow piston fail. This causes the control rod to drop to the ball nut position. The control rod and the hollow piston stay coupled through the event.

5.0 Analysis Method:

5.1 Fault Trees Top Events

The event is analyzed using the fault tree method. Three fault trees were developed, one for each of the events described above. The top events are as follows:

Event 1: CRDDROP: Control Rod Uncouples and Drops to the Hollow Piston Position

Event 2: CRDLATCH: While Coupled to Hollow Piston, Control Rod Drops to First Latch Position

Event 3: While Coupled to Hollow Piston. Control Rod Drops to the Ball Nut Position

5.2 Basic Events

The basic events represent the failure of mechanical and electrical components which together lead to the top event. They also include common cause failures and human errors. The fault trees have two basic events, "Control Rod Sticks in Core During Withdrawal" and "Control Rod Unsticks at a Later Time" which are assumed to occur with 100% certainty. The basic event "Control Rod Sticks in Core During Withdrawal" is assumed to have a frequency of 1.0 per year. All other events in the fault tree have a conditional probability. In many cases, the failure rate (per hour) of the basic event is multiplied by 8760 hours per year and this value is treated as a probability.

The fault trees model failure of the coupling between the drive and the control rod during drive installation and the subsequent the operator actions that detect this failure. However, there is one exception. Failure of both Class 1E separation reed switches to operate properly, (i.e. to change status from open to closed again when the ball nut is returned to normal full-out position, after first being moved to the FMCRD mechanical lower limit), can be detected by the operators performing this activity during the Zero Position adjustment that is done after the drive installation. Conservatively, no credit has been taken in this analysis for this additional manual confirmation of the separation switches operability during this initial drive installation activity.

5.3 Failure Probabilities

Failure Probabilities of basic events are discussed below.

5.3.1 "OPERRORCOUPLING": Operator installs the control rod with a coupling error.

During installation of the control rod, the operator makes an error that results in improper coupling between the control rod and the hollow piston. Subsequently, this error has the potential of being detected and corrected during a "Pull Test" and an "Overtravel Test".

This probability is based on NUREG/CR-4772, "Accident Sequence Evaluation Program Human Reliability Analysis Procedure", Reference 7.2. In this reference, Table 5-2,

Note 2, (page 5-6), recommends a basic human error probability of 0.03 for pre-accident tasks. No credit is given for any recovery from this initial error, but separately, credit is taken for the "Pull Test" and "Overtravel Test". These two tests are done at a different time and by different crew and at different locations, and therefore no dependency is assumed among these operator actions. Similarly, there is no dependence between this error and the other operator errors modeled, namely, OPERROR3 and OPERROR4.

5.3.2 "COUPLING": Control rod and hollow piston coupling fails during operation.

The control rod can only be uncoupled from the FMCRD by relative rotation, which is not possible during operation. The control rod cannot rotate, because it is always constrained between four fuel assemblies and the hollow piston has rollers that operate in a track within the FMCRD. Only structural failure would permit or result in control rod-to-FMCRD uncoupling.

The failure rate is estimated based on the FMCRD operating experience in Europe and Japan. In Europe, there are two FMCRD designs, one by KWU and the other by Asea-Atom. The KWU FMCRD resembles the ESBWR design more closely. Per the operating experience recorded in Reference 7.4, the drive-years of experience in the KWU plants is as follows:

Plant Name	Drive-years of Experience Through 1989
Lingen	361
Wurgassen	1,097
Brunsbuettel	883
Philippsburg	867
Isar	1,102
Krummel	815
Grundermingen B	687
Grundermingen C	583
Total	6,395 Drive-years

While there has been no coupling failures have occurred in these plants to date, there is no reference that documents this. Similarly, there are no coupling failures in the 20 plant-years of operation in Japan, representing 4200 drive-years of operation. While this is not documented in any specific reference, GE will be able to document it if needed. Thus the combined experience base of KWU plant experience until 1989 and the Japanese ABWR experience till 2006 gives zero coupling failures in 6,395

+ 4200 = 10,595 drive-years. Assuming a Chi-squared distribution, at 50% confidence, the failure rate is 1.386/(2*10,595) = 6.5E-5 failures per drive-year. This is converted to an annual failure probability of 6.5 E-5.

A fraction of the control rods are tested during operation per plant's technical specifications. These tests would reveal this type of failure in the drives tested. However, no credit was taken for these tests.

5.3.3 "SPRING": Weighing table spring fails in compressed condition.

Springs are passive devices that generally have a low failure rate. Reference 6.3, IEEE Standard 500-1984, page 1299, provides a failure rate data for Heavy Springs under the category of Energy Absorption Equipment. The recommended failure rate is 0.6E-6 per hour. The yearly failure rate is treated as the conditional probability of failure during a year. The value is (0.6E-6)*(8760) = 0.0053.

5.3.4 "SPRINGLATCHA and SPRINGLATCHB": Hollow Piston Spring-loaded Latch A (B) Fails to Open

The spring-loaded latch operates like a spring that is in compression. Therefore, the failure rate and probability is assumed to be same as that for the Spring above. The failure probability is 0.0053.

5.3.5 "CCFSPRINGLATCH": Common Cause Failure of Both Hollow Piston Spring-loaded Latches.

The CCF is estimated by multiplying the single latch failure probability by a beta factor of 0.1. The failure probability = (0.0053)*(0.1 Beta Factor) = 0.00053.

5.3.6 "OVERTRAVELREEDSW": Failure of over travel reed switch

Overtravel reed switch is normally in open position, and closes when it detects the motion of the magnet located in the hollow piston.
Failure rate of reed switch is assumed to be similar to that of a temperature switch. Reference 7.1, EPRI's ALWR Utilities Requirement Document, PRA Key Assumptions and Groundrules, page A.A-25 provides a failure rate of 3.6E-7 per hour for the Temperature Switch failing to operate on demand. The failure probability is obtained by multiplying this failure rate by 8760. The failure probability is obtained as (3.6E-7)*8760 = 0.0032. The same reference identifies a failure probability of 1.0E-4 per demand. For this analysis, the higher value of 0.0032 failures per demand is used.

5.3.7 "SEPREEDSWAOPEN" and "SEPREEDSWBOPEN": Separation reed switch A (B) fails in open position

The separation switches are reed switches, which are designed to detect the separation of control rod and hollow piston. The separation reed switches are normally closed and they are designed to open on demand. These get tested during refueling outages. Failure rate of reed switch is assumed to be similar to that of a temperature switch, except that since the reed switch is normally closed, the failure rate for spurious operation is used. Based on Reference 7.1, EPRI URD, the failure rate for temperature switch to operate spuriously is 3.8E-6 per hour. Spurious opening of these reed switches will be indicated in the control room. It is judged that a spurious opening will be detected within a eight-hour shift. The probability of a spurious initiation during eight hours is calculated to be (3.8E-6)*8 =3.0E-5. This value of 3.0E-5 per demand is used as the failure probability for this basic event.

5.3.8 "SEPREEDSWACLOSED" and "SEPREEDSWBCLOSED": Separation reed switch A (B) fails in closed position

The separation reed switches are normally closed and they are designed to open on demand. The failure probability of reed switches to fail in the closed position is estimated based on the failure rate of a temperature switch to operate on demand. This value was estimated in 5.3.5 above for the overtravel reed switch. The failure probability is 0.0032 per demand.

5.3.9 "CCFREEDSWOPEN": CCF of Both Separation Switches in Open Position

The separation reed switches are normally closed and they are designed to open on demand. This common cause failure probability of separation reed switches is estimated by multiplying the random failure probability by a beta factor of 0.05 for spurious operation. This conservative beta factor is based on values recommended in page A.A-29 in EPRI URD KAG, Reference 7.1. The failure probability then is 3.0E-5*0.05 = 1.5E-6

5.3.10 "CCFREEDSWCLOSED": CCF of Both Separation reed Switches in Closed Position

The common cause failure probability of separation reed switches is estimated by multiplying the random failure probability by a beta factor of 0.1 . This conservative beta factor is based on values recommended in page A.A-29 in EPRI URD KAG, Reference 7.1. The failure probability then is 0.0032*0.1=0.00032 or 3.2E-4.

5.3.11 "LAMP1", and "LAMP2": Failure of Overtravel Indication in Control Room, and Failure of Separation Indicator in Control Room.

Control room indicator failure probability is estimated based on a failure rate of 0.6E-6 per hour per page 42 of Reference 7.3, IEEE 500-1984. The failure probability per year = (0.6E-6 per hour)*(8760 hours) = 0.0053

5.3.12 "OPERROR1": Miscoupling Undetected by Pull Test.
This probability is based on NUREG/CR-4772, "Accident Sequence Evaluation Program Human Reliability Analysis Procedure", Reference 7.2. In this reference, Table 5-2, Note 2, (page 5-6), recommends a basic human error probability of 0.03 for pre-accident tasks. The procedure requires adjustment of this number to account for special conditions. There is nothing associated with the Pull Test that would warrant an adjustment to this number. Based on note 4 and 6 of the Table 5-2 in the reference, a recovery factor of 0.1 is applied for checking. The resulting value is 0.03*0.1 = 0.003 for OPERROR1.

There is no other operator error that has any dependency with this operator action. The Pull Test is done locally whereas the Overtravel test is done in the control room.

5.3.13 "OPERROR2": Operator Fails to Notice Overtravel Indication in Control room.
This operator action is done in the control room and is part of the overtravel test. The control room indication is provided by the RC&IS logic that sends the status of the overtravel reed switch. The value of 0.003 developed for OPERROR1 is judged to be applicable for this operator action also.

A dependency is assumed between this operator action and OPERROR5, "Operator Fails to Notice Separation Indication in Control Room During Overtravel Test" and this is factored in calculating that operator error probability.

5.3.14 "OPERROR3": Operator Fails to Notice Separation Indication in Control Room During Overtravel Test.

This basic event involves operator failing to notice separation indication and alarm in the control room during the overtravel test. The control room indication is provided by the Class 1E separation reed switches. This operator action is similar to OPERROR2 and has a dependency with it. OPERROR2 also involves failing to notice separation during an overtravel test, except that the control room indication is provided by an overtravel reed switch. Because of the dependency, OPERROR3 is assigned a value of 0.1 based on engineering judgment.

5.3.15 "OPERROR4": Operator Fails to Notice Alarm in Control Room.
This basic event involves operator failing to notice separation indication and alarm in the control room. It is judged that there will not be other signals coincident with this signal competing for operator's attention. Also, the operator response to this alarm is judged to be skill-based, and committed to memory by the operator. Accordingly, a human error

probability of 0.001 is assigned based on item 10 of Table 5, page 8-14, of Reference 7.2.

This operator action is separated in time from other operator actions associated with the Pull Test or the Overtravel test, and therefore has no dependency with the other operator actions modeled in the analysis.

5.3.16 "RCISLOGIC": RC&IS Logic Fails to Provide Signal and Indication in Control Room.

RC&IS provides a number of functions relating to this event. During the overtravel test it provides the indication in the control room of the overtravel reed switch and the Class 1E separation switch status. During that test, it also provides indication of separation, as detected by the separation reed switches, in the control room. During plant operation, it detects the change in status of the separation reed switch, (which detects separation between the control rod and the hollow piston, or the hollow piston and the drive), and initiates a rod block. It also provides indication of the separation in the control room. In addition RC&IS provides information to the operator about the status of position of each of the control rods. It is expected that any logic failure in the RC&IS will be detected within a 8-hour shift, as the system provides information needed for the operator. A failure of one of the channels of the system initiates a rod block and failure of both channels disables the whole system, which also will prevent any rod motion. Therefore, the RC&IS logic failure that can fail this function is a unique common cause failure which does not initiate a rod block, but disables the specific function of interest, such as not provide status of the overtravel or separation reed switch.

Common Cause Failure probability of RC&IS failure
= (5.0E-6/hour)*(8 hours)*(0.1 beta) = 4.0E-6

where:

the logic failure per channel is estimated to be 5.0E-6/hour, based on Reference 7.1, EPRI ALWR URD KAG, page A.A-24, for item Logic Card.

8 hours represents the time during which any failure can be detected and repaired, based on engineering judgment

0.1 is the common cause failure beta factor that models the failure of the redundant channel during this eight-hour period.

As noted earlier, the failure of both channels of the RC&IS would disable the whole system preventing plant operation. Based on engineering judgment, a CCF that uniquely disables specific functions but not the whole system is taken to be one percent of the above value, which is equal to 4.0E-8.

5.3.17 "ALARMLOGIC": Plant alarm system logic fails to provide signal and indication in control room.

The plant alarm system logic is independent of the RC&IS and it provides alarm to the operator if there is a separation in the FMCRD. The failure probability is calculated by multiplying a logic card failure rate by 8760 and a beta common cause factor of 0.1 account for both channels . The failure probability = (5.0E-6)*(8760)*(0.1) = 4.4E-3. This estimate is conservative as the failure of one channel of the logic is expected to be repaired as soon as it is detected.

5.3.18 "SEPARATIONALARM": Control Room Separation Alarm Fails.

This alarm failure rate is taken from Reference 7.3, IEEE Standard 500-1984, page 52. The rate for failing to operate on demand, for Annunciator Modules, (Buzzers), is 0.87 E-6 per hour. The failure probability is determined by multiplying this rate by 8760 hours. The failure probability = (0.87 E-6)*(8760) = 0.0076.

5.4 It is judged that the failure of the permanent magnets that actuate the reed switches is very unlikely and is not modeled in the analysis.

5.5 Mutually Exclusive Events

The following events cannot occur at the same time and cutsets involving these combination of basic events will be deleted from the quantification.

SEPREEDSWAOPEN*SEPREEDSWACLOSED
SEPREEDSWBOPEN*SEPREEDSWBCLOSED
CCFREEDSWOPEN*CCFREEDSWCLOSED
CCFREEDSWOPEN*SEPREEDSWACLOSED
CCFREEDSWOPEN*SEPREEDSWBCLOSED

CCFREEDSWOPEN*SEPREEDSWACLOSED
*SEPREEDSWBCLOSED
CCFREEDSWCLOSED*SEPREEDSWAOPEN
CCFREEDSWCLOSED*SEPREEDSWBOPEN
CCFREEDSWCLOSED*SEPREEDSWAOPEN* SEPREEDSWBOPEN

6.0 Results:

The fault tree models were quantified using a standard fault tree computer code that model Boolean logic. The results are as follows:

Event 1: CRDDROP: Control Rod Uncouples and Drops to the Hollow Piston Position

The event frequency is estimated to be 3.7E-7 per reactor-year.

Event 2: CRDLATCH: While Coupled to Hollow Piston, Control Rod Drops to First Latch Position

The event frequency is estimated to be 6.0E-5 per reactor-year.

Event 3: While Coupled to Hollow Piston. Control Rod Drops to the Ball Nut Position

The event frequency is estimated to be 3.1E-6 per reactor-year

The analysis is extremely conservative as the control rod is assumed to stick in the core with a probability of 1.0 and unlike the CRDA design basis accident, this event can occur at any reactor power level while the plant is operating normally at or close to full power (so for the remainder of this specific analysis, it is assumed the reactor is operating at full power when any of the events described above occurs). Therefore, these results should not be compared against the CRDA accident frequency criterion because the CRDA could only occur while the reactor power is in very low reactor power conditions with the reactor initially at or near critical conditions during a startup or shutdown transition, which occurs only a very small percentage of time during a normal plant operating cycle).

It is also judged that a better documentation of the FMCRD operating experience will provide a lower failure rate for some of the basic events and thus yield a lower estimate of the frequency.

7.0 References:

7.1 "Advanced Light Water Reactor Utility Requirements Document. Volume III, ALWR Passive Plant, Chapter 1, Appendix A, PRA Key Assumptions and Groundrules", EPRI, May 1997

7.2 NUREG/CR-4772, "Accident Sequence Evaluation Program Human Reliability Analysis Procedure", US NRC, February 1987

7.3 IEEE Standard 500-1984, "IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear Power Generating Stations".

7.4 "Provenness of the Advanced Boiling Water Reactor (ABWR) Based on Experience, Development, and Testing", August, 1995, GE Nuclear Energy

ATTACHMENT A

CONTROL ROD DROP SCENARIO FOR THE ESBWR FMCRD

Control Rod Drop Scenario for the ESBWR FMCRD

Purpose

This document defines the failure paths for the ESBWR fine motion control rod drive (FMCRD) that lead to a control rod drop condition. The sequences of events in these failure paths provide the basis for calculating the probability of a control rod drop for each path. This calculation is being performed for input into the response to NRC RAI (Request for Additional Information) 4.6-23 related to the ESBWR Design Certification application (Reference 1).

The scope of the probability calculation is limited to an evaluation of the mechanical design capabilities of the ESBWR FMCRD to detect and prevent a control rod drop given the assumption that a control rod sticks in the core during withdrawal. Considerations of plant operating conditions and consequences of rod drop are outside its scope.

Control Rod Drop Scenarios

Table 1 provides the control rod drop scenario for the case where the control rod (CR) and FMCRD hollow piston (HP) are not properly coupled. Each of the five steps in the table has to occur to result in a rod drop event.

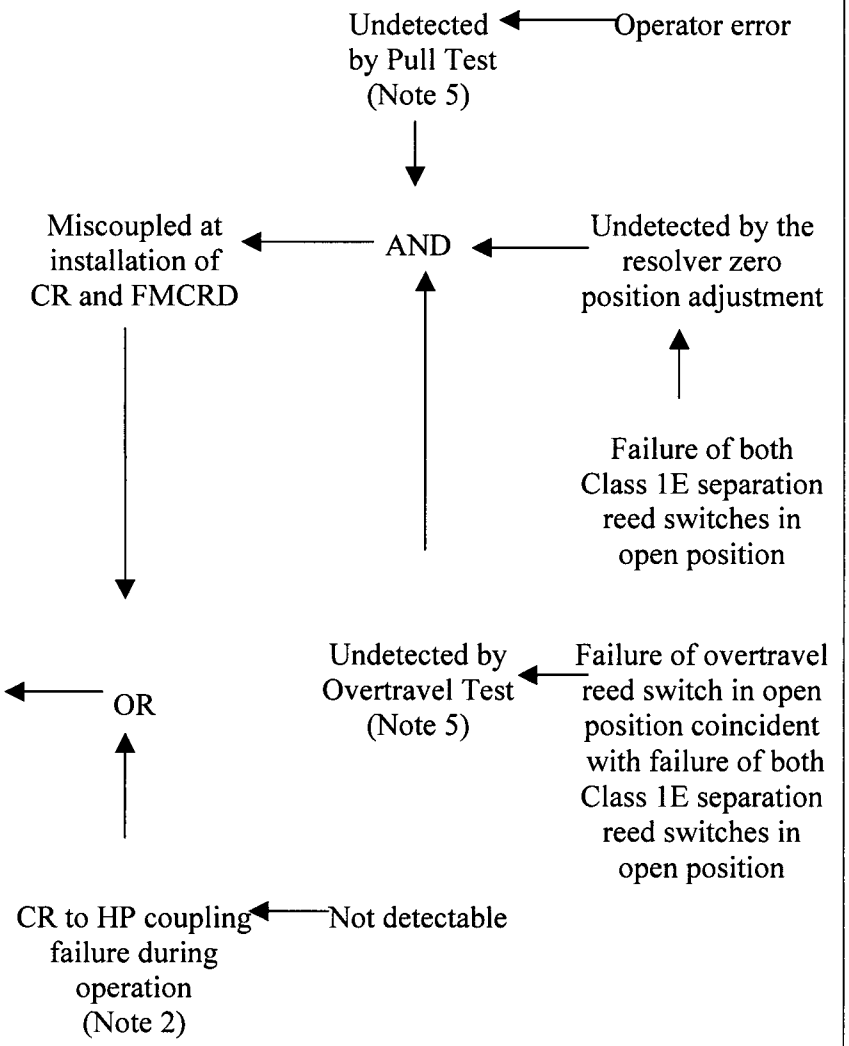
Table 2 provides the control rod drop scenario for the case where the CR and HP are properly coupled together. Table 2 describes two scenarios: 1) The failure of one of the two latches on the hollow piston, which coupled with other failures can result in a control rod drop to the first latch position, and 2) The failure of both latches, which coupled with other failures, can result in a larger drop, up to the ball nut position.

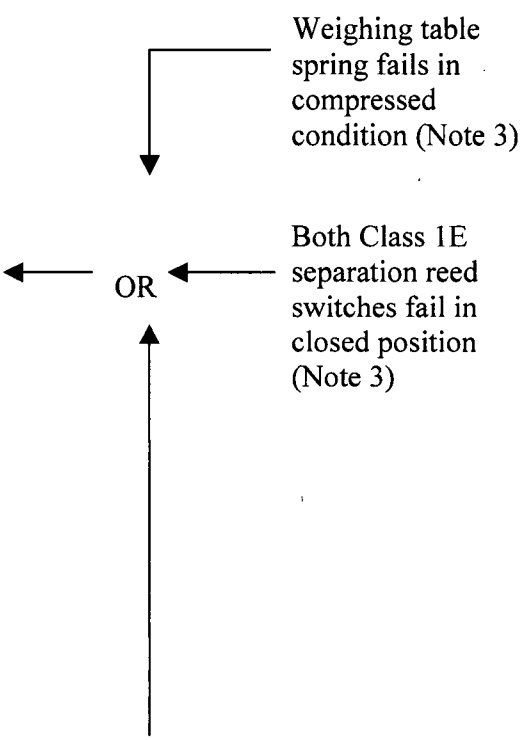
The probability calculation focuses on the capability of the FMCRD to prevent a control rod drop after a stuck CR condition is encountered. For this reason, the probability of the CR sticking in the core and the probability of subsequently unsticking after separation from the FMCRD are both considered to be equal to 1.

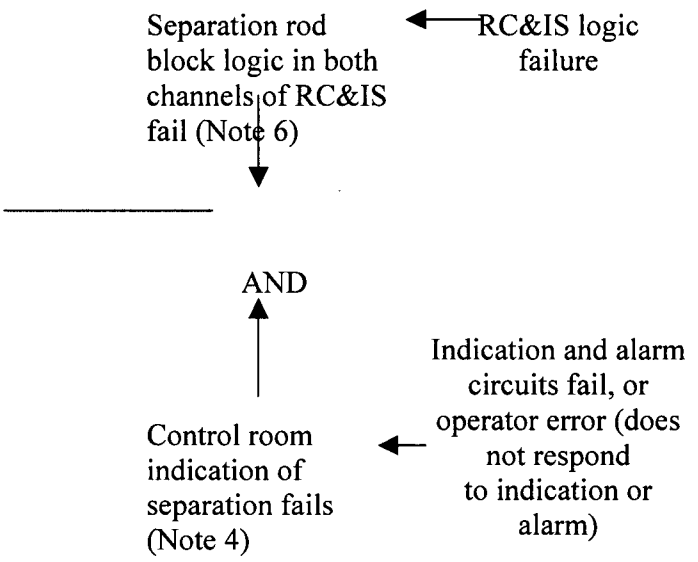
References

1. Letter from Martha C. Barillas (NRC) to David H. Hinds (GE), Request for Additional Information Letter No. 44 Related to ESBWR Design Certification Application, dated July 25, 2006 (MFN 06-255 received July 31, 2006).

Table 1 Control Rod Drop Scenario 1 – Control Rod and FMCRD Hollow Piston are Miscoupled

Event Sequence	Failure Scenario for Event
1. CR and HP not coupled (Note 1)	
2. CR sticks in core during withdrawal	High friction between the CR and fuel channels

Event Sequence	Failure Scenario for Event
3. The operator selects the stuck control rod for withdrawal. CR to HP separation is not detected by the FMCRD and RC&IS and rod block is not initiated. The hollow piston moves down by gravity.	

Event Sequence	Failure Scenario for Event
	
4. CR unsticks subsequently.	Release of friction between the CR and fuel channels
5. Control rod drops to the FMCRD hollow piston position	

SEE NOTES FOR TABLE 1 AND 2

Table 2 Control Rod Drop Scenario 2 – Control Rod and FMCRD Hollow Piston are Coupled

Event Sequence	Failure Scenario for Event
1. CR sticks in core during withdrawal	← High friction between the CR and fuel channels
2. HP separation is not detected by the FMCRD and RC&IS. Revise as corrected in Table 1.	↓ Weighing table spring fails in compressed condition (Note 3) ← OR ← Both Class 1E separation reed switches fail in closed position (Note 3) ↑ Separation rod block logic in both channels of RC&IS fail (Note 6) ← RC&IS logic failure ↓ AND ↑ Control room indication of separation fails (Note 4) ← Indication and alarm circuits fail, or operator error (does not respond to indication or alarm)
3. CR unsticks subsequently.	← Release of friction between the CR and fuel channels
4a. One HP latch fails to engage (Note 7)	← Mechanical failure

Event Sequence	Failure Scenario for Event
5a. CR coupled to the HP drops to the first latch position where the second spring-loaded latch engages into the window in the guide tube.	← Release of friction between the CR and fuel channels
OR	
4b. Both HP latches fail to engage. (Note 7)	← Mechanical failure
5b. CR coupled to the HP drops to the FMCRD ball nut position	← Release of friction between the CR and fuel channels

SEE NOTES FOR TABLES 1 AND 2

Notes for Tables 1 and 2

1. A bayonet coupling between the control rod and FMCRD is provided. The coupling spud at the top end of the hollow piston engages and locks into a mating socket at the base of the control rod. The coupling requires a 45-degree rotation for engaging or disengaging. Once locked, the drive and control rod form an integral unit that must be manually unlocked by specific procedures before the components can be separated. The FMCRD flange lines up with the control rod drive housing flange only in the coupled position. Once bolted to the housing, any movement of the FMCRD mechanism is prevented.

2. The control rod can only be uncoupled from the FMCRD by relative rotation, which is not possible during operation. The control rod cannot rotate, because it is always constrained between four fuel assemblies and the hollow piston has rollers that operate in a track within the FMCRD. Only structural failure would permit or result in control rod-to-FMCRD uncoupling.

3. Two redundant and separate Class 1E reed switches are provided to detect the separation of the hollow piston from the ball nut. The two reed switches are physically separated from one another with their cabling run through separate conduits. The separation switches are classified as Class 1E, because their function detects a detached control rod and causes a rod block, thereby preventing a rod drop accident.

   The principle of operation of the control rod separation mechanism is illustrated in Figure 1. During normal operation, the weight of the control rod and hollow piston resting on the ball-nut causes the spindle assembly to compress a spring on which the lower half of the splined coupling between the drive shaft and spindle assembly rests (the lower half of the splined coupling is also known as the "weighing table"). When the hollow piston separates from the ball-nut, or when the control rod separates from the hollow piston, the spring is unloaded and pushes the weighing table and spindle assembly upward. This action causes a magnet in the weighing table to actuate the Class 1E separation reed switches located in a position probe outside the lower housing. See note 8 for additional details on the reed switch operation.

4. An automatic rod block is provided in the RC&IS. Each channel of the RC&IS monitors the current status of both of the Class 1E separation reed switches. Under normal RC&IS operating conditions, if either separation reed switch indicates control rod separation, then detection of this abnormal condition by either of the normally operating RC&IS channels will initiate a rod withdrawal block for a selected control rod for which this condition has been detected. If one RC&IS channel is failed or bypassed, the operating RC&IS channel will initiate a rod withdrawal block for a selected control rod. Control rods can be withdrawn only if they are in the selected status. If both channels of the RC&IS fail, normal control rod movement capability is lost (including withdrawal movements). Additionally, an I&C system that is separate from, and independent of the RC&IS logic, uses the input from the separation reed

switches to provide a Class 1E indication and non-Class 1E alarm in the control room to alert the operator of a separation.

5. Coupling integrity is verified by pull test of the control rod from above upon initial coupling at installation and after FMCRD maintenance operations in which the control rod and drive have been mechanically uncoupled and then restored to the coupled condition in preparation for normal FMCRD operation. It is also verified by an "overtravel" test in which the ball-nut is driven down beyond the normal "full-out" position to the overtravel position (i.e., the coupling check position). If the control rod and hollow piston are properly coupled, the control rod will backseat in the control rod guide tube as the ball-nut moves downward. After the weighing spring has raised the spindle to the limit of its travel, further rotation of the spindle in the withdraw direction will drive the ball-nut down away from the piston (assuming the coupling is engaged). Erroneous downward movement of the piston is detected by a reed position switch at the overtravel position, indicating uncoupling of the hollow piston from the control rod. (Note, this overtravel reed position switch is different from the Class 1E separation reed switches). The Class 1E separation reed switches do not actuate (i.e. these switches do not change to the open switch status) in this test condition if the hollow piston and control rod are uncoupled (but both of these switches will actuate if the hollow piston and control rod are coupled). It takes a combination of the failure of the overtravel reed position switch in the open position and the failure of the both Class 1E separation switches in the open position to result in the miscoupling to go undetected during an overtravel test. However, if the two Class 1E separation switches failed in this manner, plant start-up is not possible. Therefore, it is extremely unlikely that the plant would operate with a miscoupled drive. There are two channels of RC&IS logic that detect activation of the overtravel reed position switch. Any one channel is sufficient to provide indication in the control room of the overtravel switch status indication. Both channels have to fail for the failure of the indication. However, failure of both channels is an unacceptable failure for the RC&IS operation and the all the system indication turn into a magenta color indicating a system problem. Therefore, a very rare common cause failure, which just disables the indication, but not the rest of the system, would be required to cause the current overtravel reed switch position to go undetected. The current status of the Class 1E separation reed switches for each FMCRD is also indicated in the control room by information provided by the two RC&IS channels (i.e. separation status for any individual FMCRD is indicated if either of the two separation reed switch inputs to that RC&IS channel is active). As in the case of the overtravel switch position indication, a very rare common cause failure, which just disables the indication, but not the rest of the system would be required to cause the current status of the Class 1E separation reed switches to go undetected. See note 8 for additional details on the reed switch operation.

6. If both RC&IS channels have failed there would normally be no capability to perform normal control rod withdrawal movement because of related automatic abnormal condition detection capability inherent in the RC&IS dual channel equipment and associated rod block logic and abnormal condition control logic. For example, with neither RC&IS dual channel equipment placed in the bypass status, a detected failure

of one channel of RC&IS logic will prevent continued normal movement from occurring (because both RC&IS channels must not have a critical failure detection condition and both must provide normal movement command signals to the local inverter controller logic and rod block logic associated with movement of an individual control rod to accomplish normal movement functions). Similarly, if one channel of the RC&IS dual channel equipment is bypassed (e.g. because the operator has taken this action after detection of failure in the equipment of one RC&IS channel in order to allow continued capability to perform normal rod movements with remaining operable RC&IS channel), then detection of occurrence of subsequent failure of the unbypassed channel also prevents further normal rod movements. Consequently, there is very high probability that if both RC&IS channels have failed, there would not be the possibility of performing rod withdrawal movements that could lead to control rod to hollow piston separation occurrence while both channels of RC&IS are failed.

However, for conservatism, it is assumed there is a extremely low probability common mode RC&IS logic failure that causes ONLY the separation rod block logic functionality to not perform as specified, even though one or both channels of RC&IS have successfully received signals that the separation condition has been detected (i.e. it is assumed there is no automatic abnormal condition detection of this very unlikely type of logic failure scenario). For this logic failure scenario for both RC&IS channels, it is assumed that normal rod withdrawal movement capability is still possible. However, as shown in Table 1 and Table 2, the operator would also have to ignore the independent separation condition detection indication provided by safety related equipment and the related non-class 1E separation detection alarm circuitry (or this separate monitoring and alarm circuitry from RC&IS would also have to fail), for the potential for a normal rod withdrawal movement to be completed with both RC&IS channels failed. This is one possible failure scenario that could result in a control rod drop situation with the separation rod block logic of both channels of RC&IS being in a failed condition.

7. Two redundant, spring-loaded latches on the hollow piston open to engage in windows in the guide tube within the FMCRD to catch the hollow piston if separation from the ball-nut were to occur. These latches open to support the hollow piston (and control rod) following scram until the ball nut is run up to provide the normal support for the hollow piston (and control rod).

8. The status of the overtravel reed switch and the Class 1E Separation reed switches during the overtravel test and during plant operation are given in the following four tables.

TABLE A: OVERTRAVEL TEST – STATUS OF OVERTRAVEL REED SWITCH				
COUPLING AND PLANT STATUS	**OVERTRAVEL REED SWITCH (Ball Nut At Full-Out Position)**		**OVERTRAVEL REED SWITCH (Ball Nut At Overtravel Position)**	
		Explanation		Explanation
Hollow Piston Coupled To Control Rod Plant is getting ready for operation after maintenance. (Normal Condition)	Open	HP at normal full-out. Therefore, magnet attached to HP is not close to overtravel reed switch.	Open	HP does not move downward after CR backseats in RPV during withdrawal of ball nut to the overtravel position. Therefore, magnet attached to HP does not move downward enough to get close enough to close the overtravel reed switch.
Hollow Piston Decoupled from the Control Rod. Plant is getting ready for operation after maintenance. (Abnormal Condition)	Open	HP at normal full-out. Therefore, magnet attached to HP is not close to overtravel reed switch.	Closed	HP, which is decoupled from the CR, continues to move downward during withdrawal of the ball nut to the overtravel position. Therefore, magnet attached to HP does move downward enough to close the overtravel reed switch.

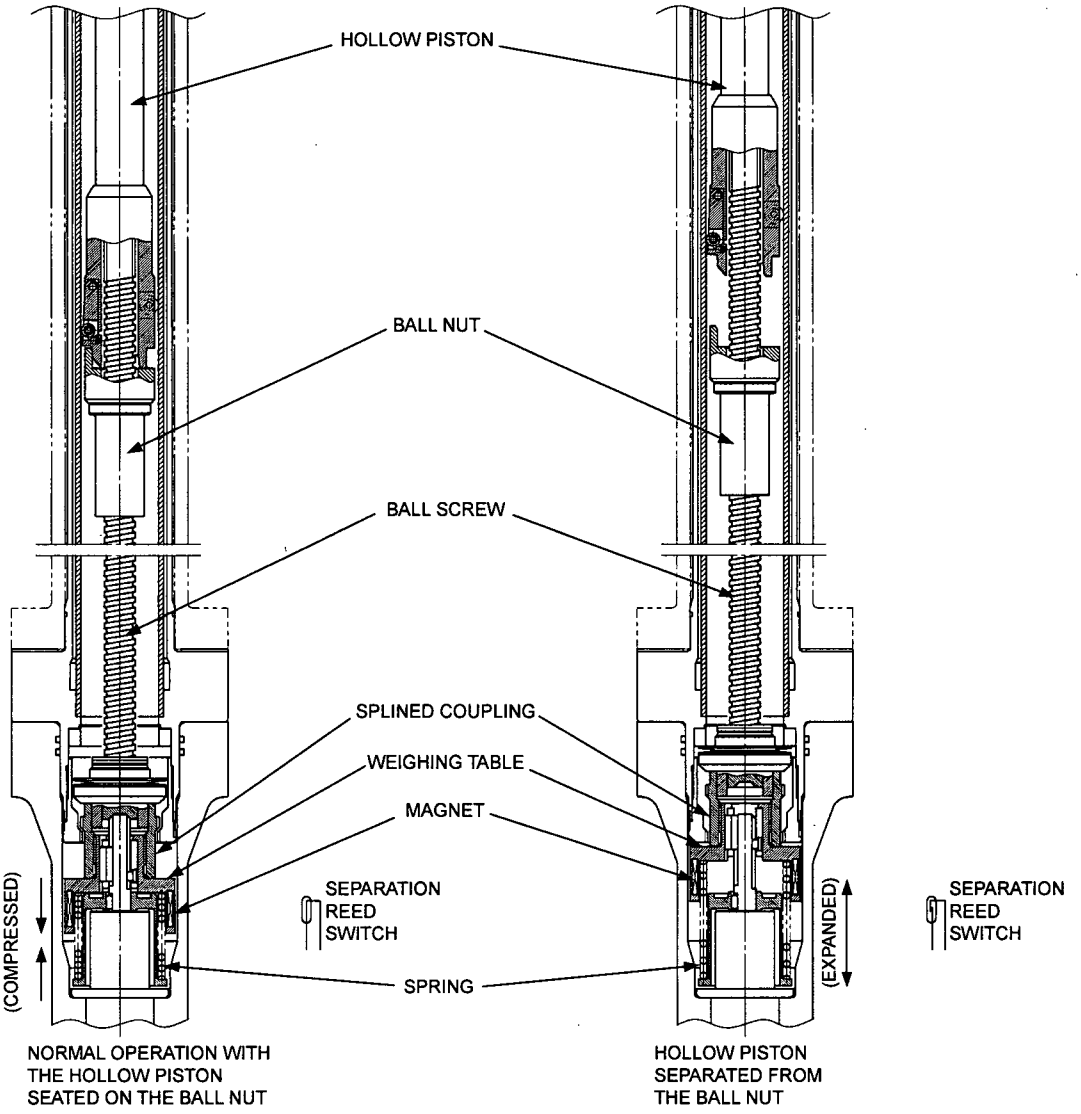
TABLE B: OVERTRAVEL TEST – STATUS OF SEPARATION REED SWITCH				
COUPLING STATUS	**SEPARATION REED SWITCH (Ball Nut at Full-Out Position)**		**SEPARATION REED SWITCH (Ball Nut At Overtravel Position)**	
		Explanation		Explanation
Hollow Piston Coupled To Control Rod. Plant is getting ready for operation after maintenance. (Normal Condition)	Closed	Weight of the CR and HP keeps the table spring compressed.	Open	The CR and HP movement downward is prevented after the Control Rod backseats. The table spring expands sufficiently as the CR and HP weight is lifted off the table springs during withdrawal of the ball nut to the overtravel position such that the separation reed switches status changes to open.
Hollow Piston Decoupled from the Control Rod. Plant is getting ready for operation after maintenance. (Abnormal Condition)	Closed	Weight of the CR and HP keeps the table spring compressed.	Closed	When the HP is decoupled from the CR, the CR socket is lifted up relative to the HP compared to its normal condition. Because this additional lift plus the gap between the socket and the control rod guide tube is greater than the overtravel distance, the CR will not backseat at the overtravel position. In this condition the CR and HP weight keeps the spring compressed such that the separation switches remain closed.

TABLE C: NORMAL POWER OPERATION – STATUS OF SEPARATION REED SWITCHES WHEN COUPLING FAILS		
COUPLING/PLANT STATUS	**SEPARATION REED SWITCH**	
		Explanation
Hollow Piston Coupled To Control Rod, and Control Rod is not stuck in the core. Plant is at operating full power. (Normal Condition)	Closed	Weight of the CR and HP keeps the table spring compressed, which keeps the separation reed switches closed.
Hollow Piston Decoupled from the Control Rod, and Control Rod is not stuck in the core. Plant is at operating full power. (Abnormal Condition)	Closed	When the CR is withdrawn, the CR and HP will continue to rest on the ball nut. Weight of the CR and HP keeps the table spring compressed, which keeps the separation reed switches closed. (Note, this is not the condition being analyzed in this study)
Hollow Piston Decoupled from the Control Rod, and Control Rod stuck in the core. Plant is at operating full power. (Abnormal Condition)	Open	When the CR is withdrawn, the CR is stuck in the core, and only the HP will continue to rest completely on the ball nut as the ball nut moves down during withdrawal movement of the ball nut. As the ball nut moves downward from the position where the CR is stuck, the springs continue to expand until the ball nut has moved down far enough such that there is no CR weight supported by the springs, and the springs stop expanding, with only the full HP weight remaining on the ball nut at this time (and for any further withdrawal movement of the ball nut). This partial spring expansion is sufficient to cause the table magnets movement away from the separation switches enough to cause the separation switches to change to open status. The

		reed switches open and provide indication/alarm in the control room, as well as initiate a withdrawal rod block (when the RPS Reactor Mode Switch is in STARTUP or RUN mode).

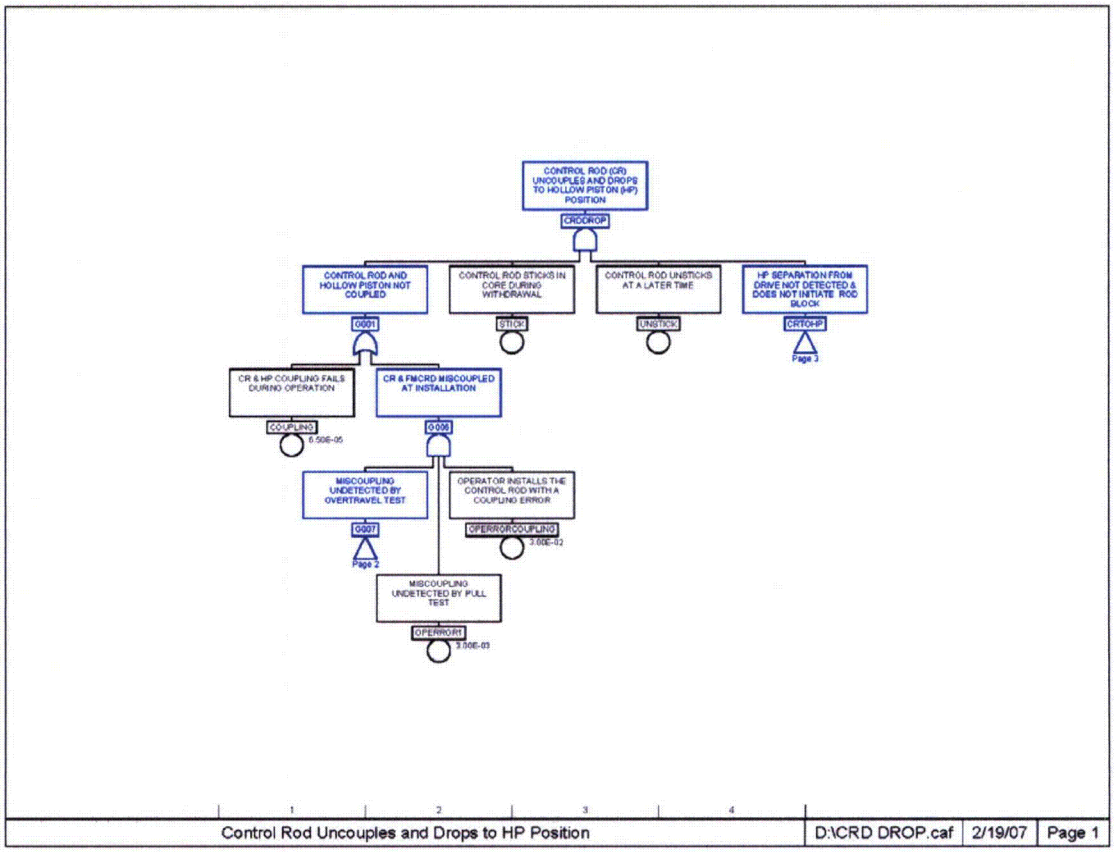
TABLE D: NORMAL POWER OPERATION – STATUS OF SEPARATION REED SWITCHES WHEN CONTROL ROD STAYS COUPLED BUT IS STUCK IN THE CORE		
COUPLING/PLANT STATUS	**SEPARATION REED SWITCH**	
		Explanation
Hollow Piston Coupled To Control Rod, and Control Rod is stuck in the core. Plant is at operating full power. CR is withdrawn. (Abnormal Condition)	Open	As the ball nut moves downward from the position where the CR is stuck, the springs begin to expand as both the weight of the CR and HP on the springs reduces (because neither the CR or HP move downward any further after becoming stuck). During the spring expansion, at some point the expansion is sufficient to cause the table magnet movement away from the separation switches enough to cause the separation switches to change to open status (and the separation reed switches remain open if the ball nut continues to move downward and the springs would expand fully for sufficient downward movement; but, the separation withdrawal rod block function normally limits the further downward movement of the ball nut). Change of either separation switch status to open initiates the rod withdrawal block logic (RPS Reactor mode switch in STARUP or RUN) and control room indication and alarm.

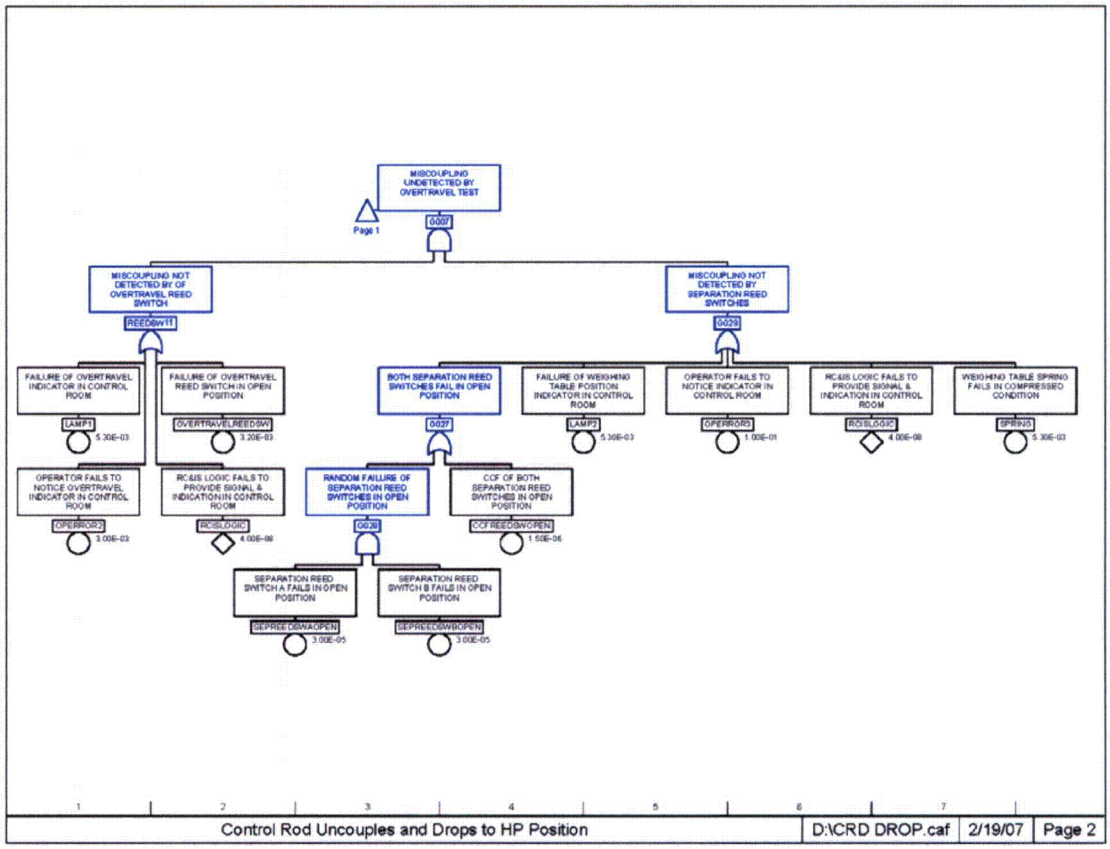
Figure 1 Control Rod Separation Detection



ATTACHMENT B

FAULT TREE FOR TOP GATE CRDDROP: CONTROL ROD UNCOUPLES AND DROPS TO HOLLOW PISTON POSITION


CONTROL ROD (CR) UNCOUPLES AND DROPS TO HOLLOW PISTON (HP) POSITION
CRDDROP
CONTROL ROD AND HOLLOW PISTON NOT COUPLED
CONTROL ROD STICKS IN CORE DURING WITHDRAWAL
CONTROL ROD UNSTICKS AT A LATER TIME
HP SEPARATION FROM DRIVE NOT DETECTED & DOES NOT INITIATE ROD BLOCK
G001
STICK
UNSTICK
CRTO-HP
Page 3
CR & HP COUPLING FAILS DURING OPERATION
CR & FMCRD MISCOUPLED AT INSTALLATION
COUPLING
6.50E-05
G006
MISCOUPLING UNDETECTED BY OVERTRAVEL TEST
OPERATOR INSTALLS THE CONTROL ROD WITH A COUPLING ERROR
G007
Page 2
OPERRORCOUPLING
3.00E-02
MISCOUPLING UNDETECTED BY PULL TEST
OPERRORT
3.00E-03
1
2
3
4
Control Rod Uncouples and Drops to HP Position
D:\CRD DROP.caf
2/19/07
Page 1


MISCOUPLING UNDETECTED BY OVERTRAVEL TEST
0007
Page 1
MISCOUPLING NOT DETECTED BY OF OVERTRAVEL REED SWITCH
REEDSWT1
MISCOUPLING NOT DETECTED BY SEPARATION REED SWITCHES
0029
FAILURE OF OVERTRAVEL INDICATOR IN CONTROL ROOM
LAMP1
5.30E-03
FAILURE OF OVERTRAVEL REED SWITCH IN OPEN POSITION
OVERTRAVELREEDSW
3.20E-03
BOTH SEPARATION REED SWITCHES FAIL IN OPEN POSITION
0027
FAILURE OF WEIGHING TABLE POSITION INDICATOR IN CONTROL ROOM
LAMP2
5.30E-03
OPERATOR FAILS TO NOTICE INDICATOR IN CONTROL ROOM
OPERROR5
1.00E-01
RC&IS LOGIC FAILS TO PROVIDE SIGNAL & INDICATION IN CONTROL ROOM
RCSLOGIC
4.00E-08
WEIGHING TABLE SPRING FAILS IN COMPRESSED CONDITION
SPRN5
5.30E-03
OPERATOR FAILS TO NOTICE OVERTRAVEL INDICATOR IN CONTROL ROOM
OPERROR3
3.00E-03
RC&IS LOGIC FAILS TO PROVIDE SIGNAL & INDICATION IN CONTROL ROOM
RCSLOGIC
4.00E-08
RANDOM FAILURE OF SEPARATION REED SWITCHES IN OPEN POSITION
0028
CCF OF BOTH SEPARATION REED SWITCHES IN OPEN POSITION
CCFREEDSWOPEN
1.50E-06
SEPARATION REED SWITCH A FAILS IN OPEN POSITION
SEPREEDSWAOPEN
3.00E-05
SEPARATION REED SWITCH B FAILS IN OPEN POSITION
SEPREEDSWBOPEN
3.00E-05
1
2
3
4
5
6
7
Control Rod Uncouples and Drops to HP Position
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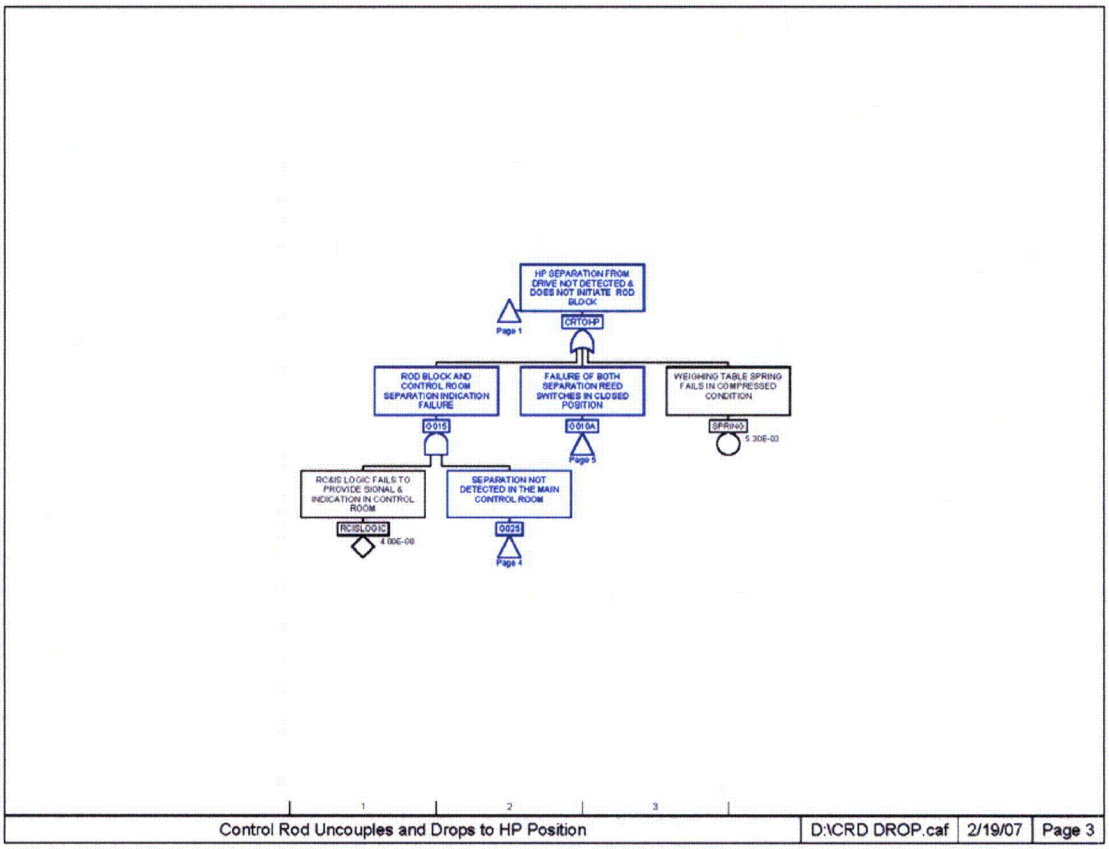
2/19/07
Page 2


HP SEPARATION FROM DRIVE NOT DETECTED & DOES NOT INITIATE ROD BLOCK
CRTOHP
Page 1
ROD BLOCK AND CONTROL ROOM SEPARATION INDICATION FAILURE
FAILURE OF BOTH SEPARATION REED SWITCHES IN CLOSED POSITION
WEIGHING TABLE SPRING FAILS IN COMPRESSED CONDITION
G015
G010A
Page 5
SPRING
5.30E-03
RC&IS LOGIC FAILS TO PROVIDE SIGNAL & INDICATION IN CONTROL ROOM
SEPARATION NOT DETECTED IN THE MAIN CONTROL ROOM
RC&ILOGIC
4.00E-00
G023
Page 4
1
2
3
Control Rod Uncouples and Drops to HP Position
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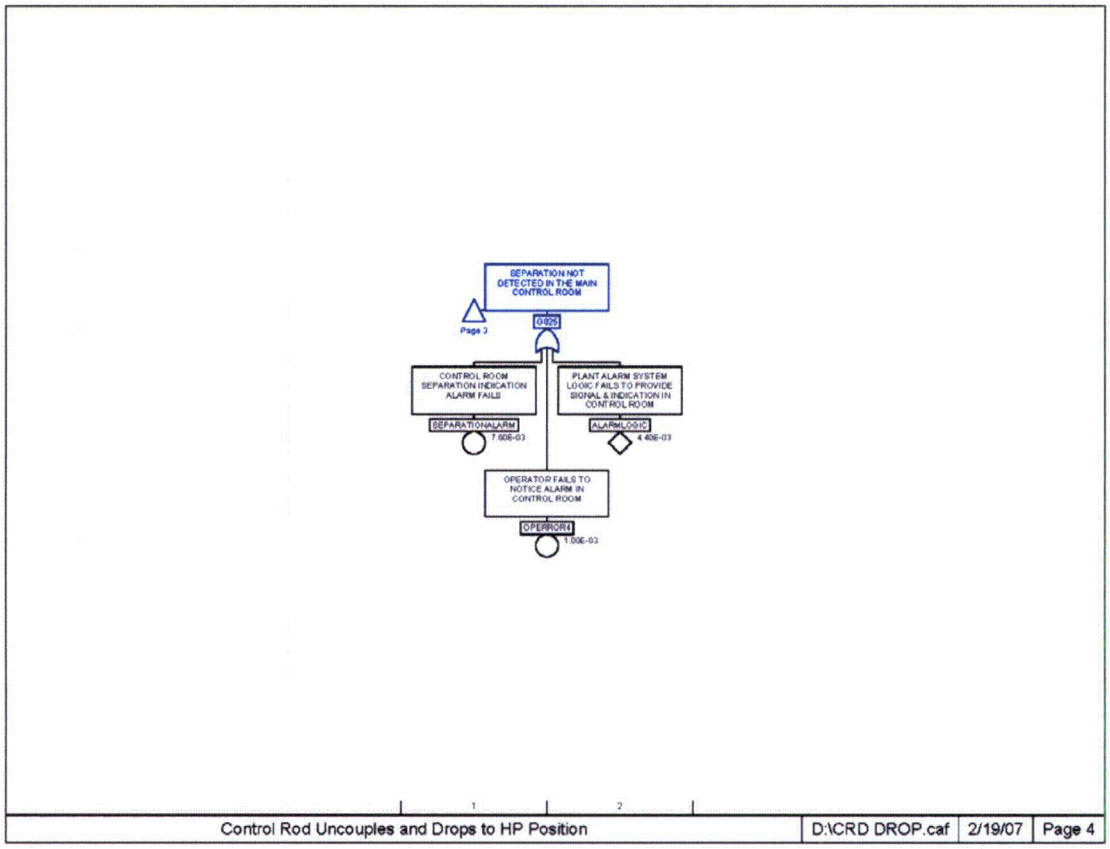
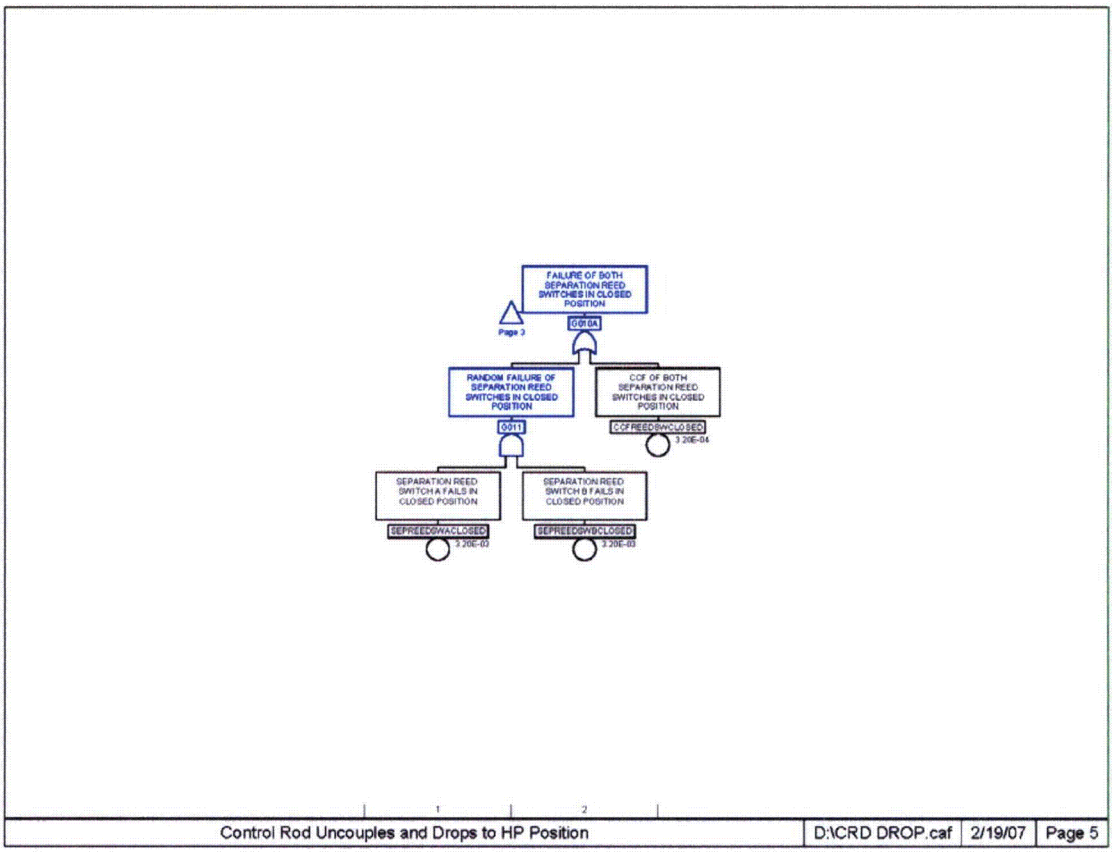
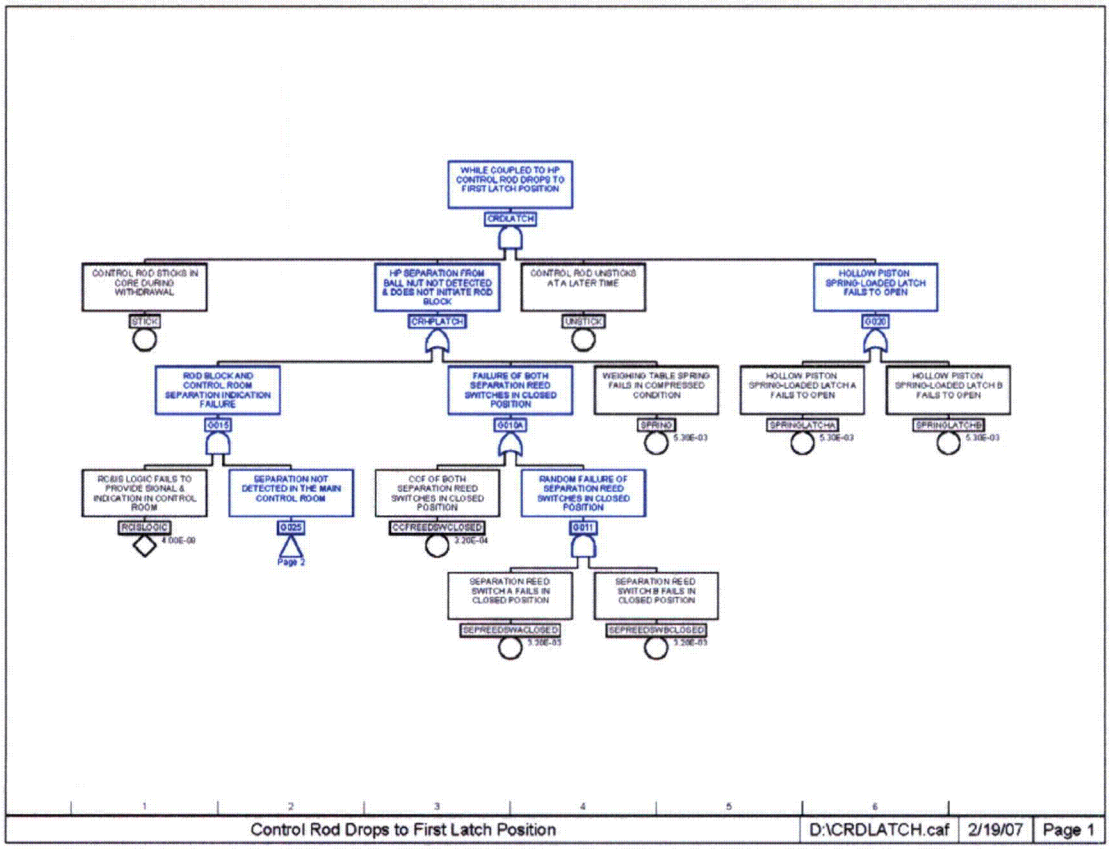
2/19/07
Page 3

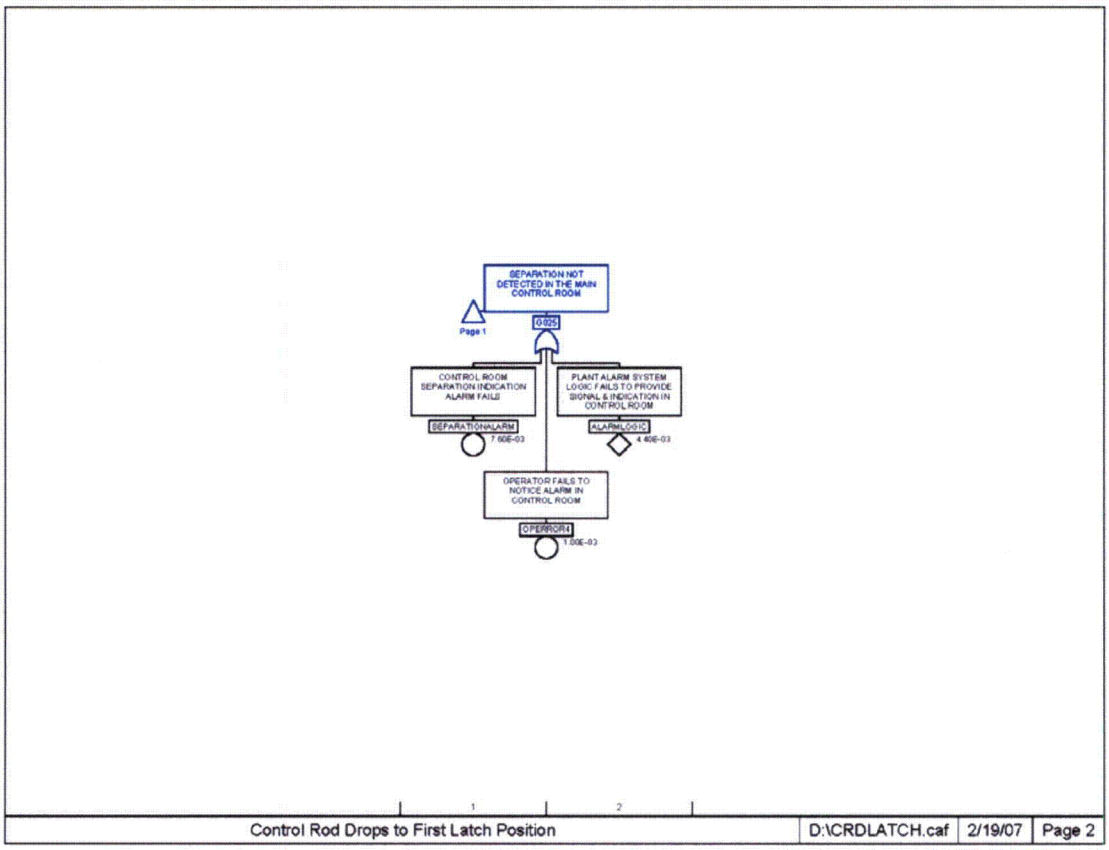

SEPARATION NOT DETECTED IN THE MAIN CONTROL ROOM
G025
Page 3
CONTROL ROOM SEPARATION INDICATION ALARM FAILS
SEPARATIONALARM
7.60E-03
PLANT ALARM SYSTEM LOGIC FAILS TO PROVIDE SIGNAL & INDICATION IN CONTROL ROOM
ALARMLOGIC
4.40E-03
OPERATOR FAILS TO NOTICE ALARM IN CONTROL ROOM
OPERROR4
1.00E-02
1
2
Control Rod Uncouples and Drops to HP Position
D:\CRD DROP.caf
2/19/07
Page 4


FAILURE OF BOTH SEPARATION REED SWITCHES IN CLOSED POSITION
G 01 0A
Page 3
RANDOM FAILURE OF SEPARATION REED SWITCHES IN CLOSED POSITION
G011
CCF OF BOTH SEPARATION REED SWITCHES IN CLOSED POSITION
CCFREEDSWCLOSED
3.20E-04
SEPARATION REED SWITCH A FAILS IN CLOSED POSITION
SEPREEDSWACLOSED
3.20E-03
SEPARATION REED SWITCH B FAILS IN CLOSED POSITION
SEPREEDSWBCLOSED
3.20E-03
1
2
Control Rod Uncouples and Drops to HP Position
D:\CRD DROP.caf
2/19/07
Page 5

ATTACHMENT C

FAULT TREE FOR TOP GATE CRDLATCH: WHILE COUPLED TO HOLLOW PISTON CONTROL ROD DROPS TO FIRST LATCH POSITION


WHILE COUPLED TO HP CONTROL ROD DROPS TO FIRST LATCH POSITION
CRDLATCH
CONTROL ROD STICKS IN CORE DURING WITHDRAWAL
STICK
HP SEPARATION FROM BALL NUT NOT DETECTED & DOES NOT INITIATE ROD BLOCK
CRHPLATCH
CONTROL ROD UNSTICKS AT A LATER TIME
UNSTICK
HOLLOW PISTON SPRING-LOADED LATCH FAILS TO OPEN
G020
ROD BLOCK AND CONTROL ROOM SEPARATION INDICATION FAILURE
G015
FAILURE OF BOTH SEPARATION REED SWITCHES IN CLOSED POSITION
G010A
WEIGHING TABLE SPRING FAILS IN COMPRESSED CONDITION
SPRING
5.30E-03
HOLLOW PISTON SPRING-LOADED LATCH A FAILS TO OPEN
SPRINGLATCHA
5.30E-03
HOLLOW PISTON SPRING-LOADED LATCH B FAILS TO OPEN
SPRINGLATCHB
5.30E-03
RC&IS LOGIC FAILS TO PROVIDE SIGNAL & INDICATION IN CONTROL ROOM
RCSILOGIC
4.80E-09
SEPARATION NOT DETECTED IN THE MAIN CONTROL ROOM
G025
Page 2
CCF OF BOTH SEPARATION REED SWITCHES IN CLOSED POSITION
CCFREEDSWCLOSED
2.20E-04
RANDOM FAILURE OF SEPARATION REED SWITCHES IN CLOSED POSITION
G011
SEPARATION REED SWITCH A FAILS IN CLOSED POSITION
SEPREEDSWACLOSED
5.30E-03
SEPARATION REED SWITCH B FAILS IN CLOSED POSITION
SEPREEDSWBCLOSED
5.30E-03
1
2
3
4
5
6
Control Rod Drops to First Latch Position
D:\CRDLATCH.caf
2/19/07
Page 1


SEPARATION NOT DETECTED IN THE MAIN CONTROL ROOM
G-025
Page 1
CONTROL ROOM SEPARATION INDICATION ALARM FAILS
SEPARATIONALARM
7.60E-03
PLANT ALARM SYSTEM LOGIC FAILS TO PROVIDE SIGNAL & INDICATION IN CONTROL ROOM
ALARMLOGIC
4.40E-03
OPERATOR FAILS TO NOTICE ALARM IN CONTROL ROOM
OPERROR1
1.00E-02
1
2
Control Rod Drops to First Latch Position
D:\CRDLATCH.caf
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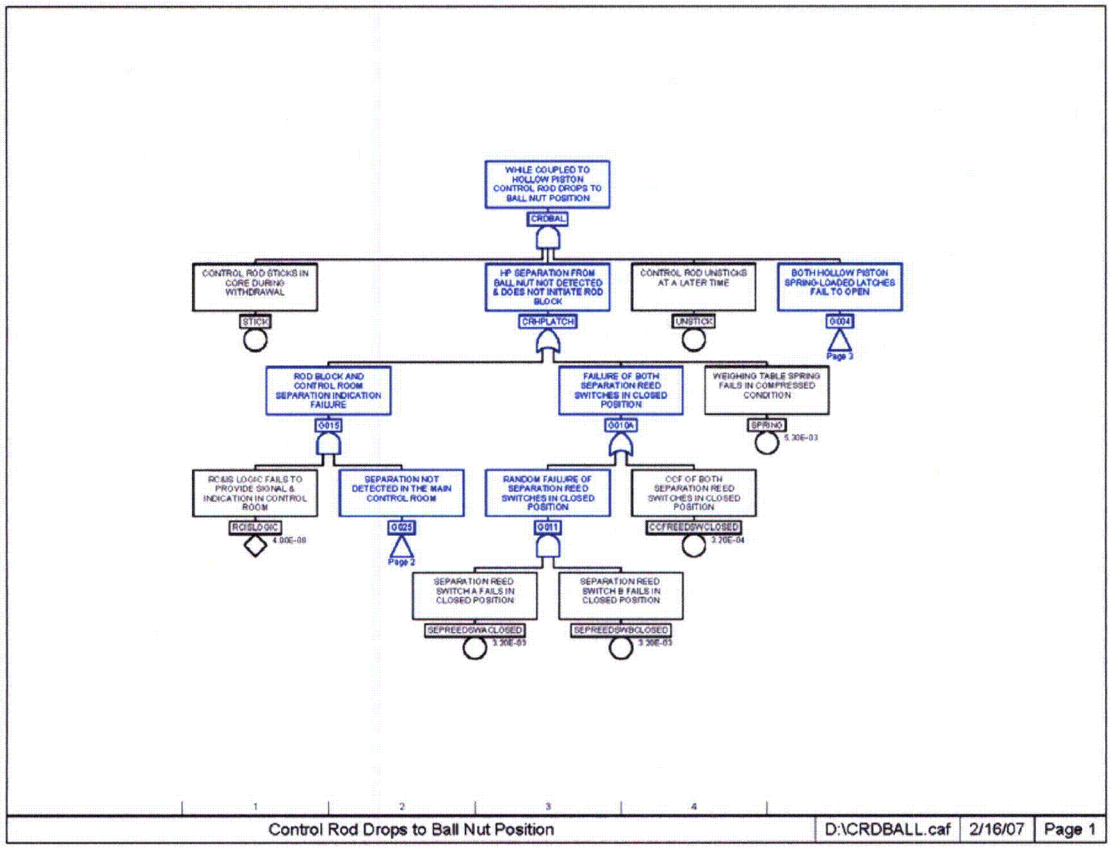
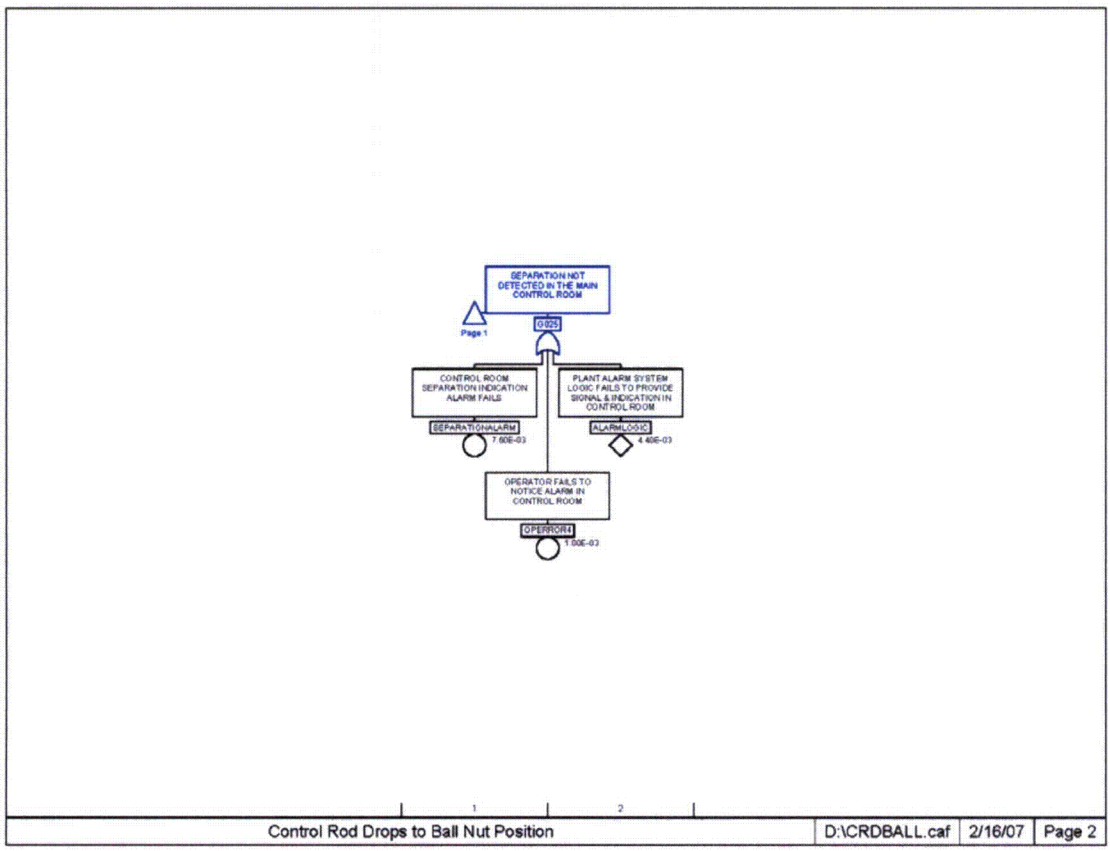
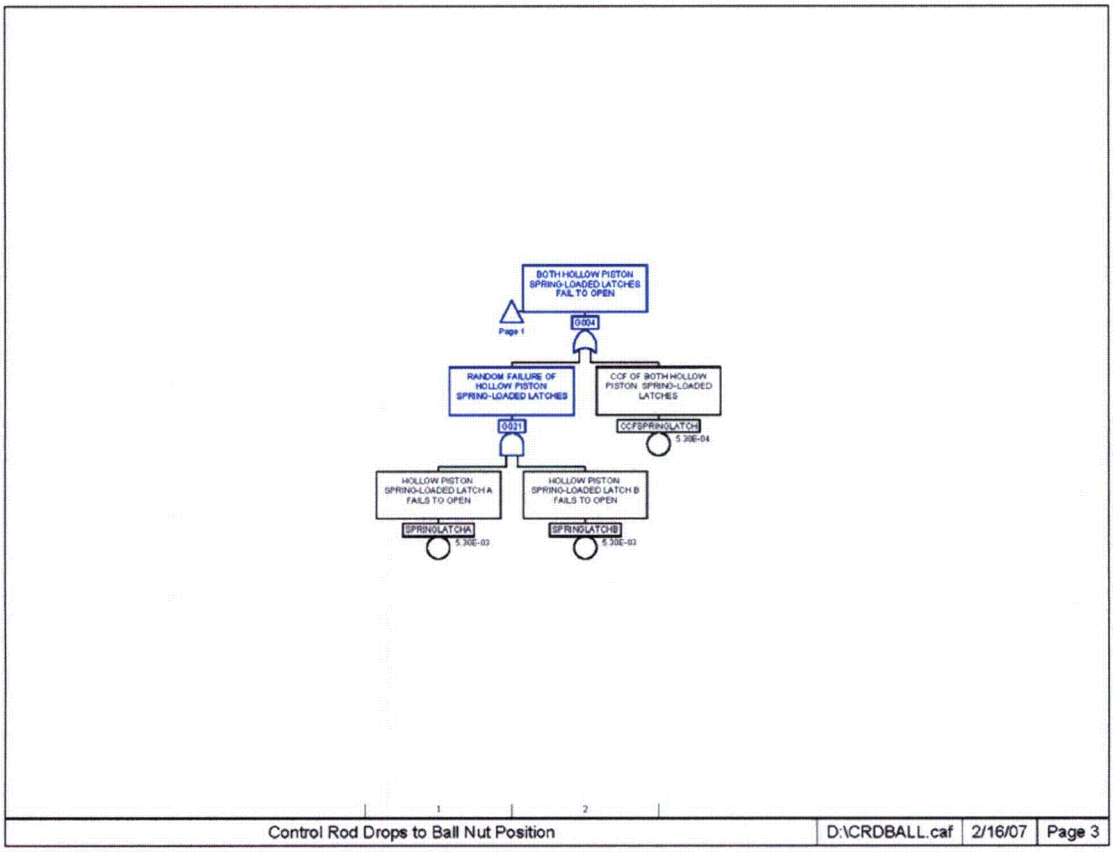
Page 2

ATTACHMENT D

FAULT TREE FOR TOP GATE CRDBALL: WHILE COUPLED TO HOLLOW PISTON CONTROL ROD DROPS TO BALL NUT POSITION


WHILE COUPLED TO HOLLOW PISTON CONTROL ROD DROPS TO BALL NUT POSITION
CRDBAL
CONTROL ROD STICKS IN CORE DURING WITHDRAWAL
STICK
HP SEPARATION FROM BALL NUT NOT DETECTED & DOES NOT INITIATE ROD BLOCK
CRHPLATCH
CONTROL ROD UNSTICKS AT A LATER TIME
UNSTICK
BOTH HOLLOW PISTON SPRING-LOADED LATCHES FAIL TO OPEN
0004
Page 3
ROD BLOCK AND CONTROL ROOM SEPARATION INDICATION FAILURE
0015
FAILURE OF BOTH SEPARATION REED SWITCHES IN CLOSED POSITION
0010A
WEIGHING TABLE SPRING FAILS IN COMPRESSED CONDITION
SPRING
5.30E-03
RCIS LOGIC FAILS TO PROVIDE SIGNAL & INDICATION IN CONTROL ROOM
RCISLOGIC
4.00E-06
SEPARATION NOT DETECTED IN THE MAIN CONTROL ROOM
0025
Page 2
RANDOM FAILURE OF SEPARATION REED SWITCHES IN CLOSED POSITION
0011
CCF OF BOTH SEPARATION REED SWITCHES IN CLOSED POSITION
CCFREEDSWCLOSED
3.20E-04
SEPARATION REED SWITCH A FAILS IN CLOSED POSITION
SEPREEDSWACLOSED
3.30E-03
SEPARATION REED SWITCH B FAILS IN CLOSED POSITION
SEPREEDSWBCLOSED
3.20E-03
1
2
3
4
Control Rod Drops to Ball Nut Position
D:\CRDBALL.caf
2/16/07
Page 1


SEPARATION NOT DETECTED IN THE MAIN CONTROL ROOM
Page 1
G-025
CONTROL ROOM SEPARATION INDICATION ALARM FAILS
PLANT ALARM SYSTEM LOGIC FAILS TO PROVIDE SIGNAL & INDICATION IN CONTROL ROOM
SEPARATIONALARM
7.60E-03
ALARMLOGIC
4.40E-03
OPERATOR FAILS TO NOTICE ALARM IN CONTROL ROOM
OPERROR4
1.00E-03
1
2
Control Rod Drops to Ball Nut Position
D:\CRDBALL.caf
2/16/07
Page 2


BOTH HOLLOW PISTON SPRING-LOADED LATCHES FAIL TO OPEN
Page 1
0004
RANDOM FAILURE OF HOLLOW PISTON SPRING-LOADED LATCHES
CCF OF BOTH HOLLOW PISTON SPRING-LOADED LATCHES
0021
CCFSPRINGLATCH
5.30E-04
HOLLOW PISTON SPRING-LOADED LATCH A FAILS TO OPEN
HOLLOW PISTON SPRING-LOADED LATCH B FAILS TO OPEN
SPRINGLATCHA
5.30E-03
SPRINGLATCHB
5.30E-03
1
2
Control Rod Drops to Ball Nut Position
D:\CRDBALL.caf
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