14.13 CONTROL ELEMENT ASSEMBLY EJECTION

14.13.1 IDENTIFICATION OF EVENT AND CAUSE

The primary function of the CEA is to control the core axial power distribution and provide instantaneous reactivity to shut down the core during controlled procedures and during abnormal and emergency conditions. The CEAs are connected to the CEA drive shafts which are enclosed in the CEDM pressure housing. The CEDM pressure housings are an extension of the reactor vessel closure head and provide a part of the reactor coolant boundary. There are a total of 61 CEDM housings (Chapter 3) on the replacement reactor vessel closure head, 57 CEAs and 4 spare CEDMs. Eight of the extension shafts that were connected to PLCEAs have been removed.

The CEAs are withdrawn, inserted, and held by the CEDMs. The CEDMs are a magnetic jack-type drive system which operate at a constant speed. A CEA is withdrawn in a programmed sequence by the CEDM lifting coil with a total drive stroke of 137". Due to the physical dimensions of the CEA extension shaft and the CEDM housing, the withdrawal of a CEA cannot breach the pressure housing.

A CEA Ejection event is defined as a rapid, uncontrolled, total withdrawal of a single or dual CEA. A dual CEA is two CEAs connected to a single CEA extension shaft. The event is postulated to occur as a result of a complete instantaneous circumferential rupture of either the CEDM pressure housing or the CEDM nozzle from the reactor vessel closure head. The pressure of the RCS causes the ejection of the extension shaft through the rupture and the movement of the CEA to a fully-withdrawn position.

The most limiting CEA Ejection event is a rapid total withdrawal of the highest worth CEA.

14.13.2 SEQUENCE OF EVENTS

A CEA Ejection event can result in an approach to the fuel SAFDLs. The action of the Variable High Power, or the TM/LP trip in conjunction with the LCOs will prevent exceeding these limits. For this event, due to the postulated breach of the CEA pressure housing, the RCS pressure boundary will also be breached and the site boundary dose guidelines will be approached.

14.13.2.1 Zero Power Case

A CEA Ejection event is initiated from HZP (10^{-9} RTP) and from within the LCOs by a rapid uncontrolled total withdrawal of a CEA within 0.10 seconds. At this point, the RCS is assumed to be breached for the purpose of determining the radiological consequences at the site boundary. The immediate reactor core response is an exponential increase in nuclear power. The delayed neutron fraction consistent with the time in cycle (BOC or EOC) is used.

At 40% (30% plus 10% uncertainty) of RTP, a VHPT is initiated. As the fuel temperature starts increasing, negative Doppler feedback partially negates the ejected CEA reactivity worth and terminates the power excursion. After the High Power Trip, RPS response and CEA holding coil delay times have elapsed, the CEAs will insert and terminate the event.

14.13.2.2 Full Power Case

A CEA Ejection event is initiated at HFP from within the LCOs by a rapid uncontrolled total withdrawal of a CEA within 0.10 seconds and the breaching of the RCS pressure boundary. The immediate reactor core response is an exponential increase in nuclear power. The delayed neutron fraction consistent with the time in cycle (BOC or EOC) is used.

At 110.33% (i.e., maximum analysis setpoint including uncertainties) of RTP, a VHPT is initiated. The negative Doppler feedback due to the increasing fuel temperature partially offsets the ejected CEA worth and terminates the power excursion. The insertion of the CEAs will terminate the event after the RPS response time and CEA holding coil delay time has elapsed.

The peak deposited energy is a function of the initial stored energy, the amount of energy generated in the fuel rod, and the amount of energy released to the coolant during the transient. The initial stored energy is a function of initial LHGR and fuel-clad gap conductivity. The energy generated in the fuel rod during the transient is a function of the ejected CEA worth and the change in the radial and axial power distribution. The amount of heat transferred out of the fuel rod is a function of the fuel-clad gap conductivity and coolant-fuel rod film coefficient. To maximize the peak deposited energy during the transient, the analysis assumes the simultaneous occurrence of the most limiting combination of these parameters.

14.13.3 CORE AND SYSTEM PERFORMANCE

14.13.3.1 Mathematical Models

The Control Rod Ejection event is analyzed to the following acceptance criteria:

1. The radial average fuel pellet enthalpy at the hot spot must be < 200 cal/g
2. A calculation was performed to ensure maximum RCS pressure is below 110% of design pressure.

The average fuel pellet enthalpy limit is imposed by Reference 12. To preserve a coolable geometry and avoid molten fuel-to-coolant interaction, the modified criterion from peak radial average fuel enthalpy is 200 cal/g.

The peak RCS pressure for the analysis of record is that performed to support Reference 2.

The control rod ejection analysis is broken into three components: (1) fuel enthalpy calculation, (2) S-RELAP5 transient simulation, and (3) XCOBRA-IIIC DNB calculation and FCM calculation.

Fuel enthalpy is calculated using the methodology described in Reference 11. The fuel enthalpy calculation is based upon cycle-specific parameters, calculated at four state points; HFP-BOC, HFP-EOC, HZP-BOC, and HZP-EOC. The burnup dependence of cycle-specific parameters (ejected rod worth, post-ejected F_q, Doppler reactivity, and delayed neutron fraction) is bounded by evaluating at BOC and EOC only. The use of cycle-specific parameters instead of bounding data requires calculations to be performed each reload.

The PDIL contains a breakpoint which allows rod banks to be partially inserted at HZP conditions. A partially inserted rod bank may lead to an ejected worth and power peak that does not bound the ejected worth and power peak produced by rods that are fully inserted. Therefore, the HZP peak average radial fuel enthalpy is calculated based upon a modified PDIL (modified in analytical space) that assumes CEA Bank 3 to be fully inserted at HZP (Reference 12).

The S-RELAP5 hot-spot model is used to calculate the fuel centerline temperature, consistent with the methodology in Reference 10. In addition, S-RELAP5 is used to determine the conditions for subsequent DNBR calculations.

The XCOBRA-IIIC fuel assembly thermal-hydraulic code is used to calculate the flow and enthalpy distribution for the entire core and the DNB performance for the DNB limiting assembly. The limiting assembly DNBR calculations were performed using an approved DNB correlation at the statepoints HZP-BOC, HZP-EOC, HFP-BOC, and HFP-EOC. Both of these computer codes are described in Section 14.1.4.1.

The RCS pressure used in the DNBR calculations is held constant at the initial core exit pressure. For the HFP cases, a design axial power shape was assumed that bounds the LCO and LSSS ASI limits.

14.13.3.2 <u>Input Parameters and Initial Conditions</u>

The input parameters and initial conditions used in the analysis are listed in Table 14.13-1. Those parameters which are unique to the analysis are discussed below.

Analyses were performed using either BOC or EOC physics parameters. Although there is a burnup dependence associated with the delayed neutron fraction (smaller with exposure, prompts higher ejected worth) and Doppler coefficient (more negative with exposure, prompts more negative reactivity feedback), the calculations at the extremes of the burnup window adequately covers the variability in key physics parameters. The maximum positive BOC MTC was used for the BOC case, consistent with the power level analyzed. The EOC MTC, calculated at EOC HZP conditions, is used for the EOC HFP and HZP cases.

Hot zero power and HFP BOC and EOC analyses were performed. Conservative (i.e., bounding) post-ejection peaking and ejected worth were used to determine deposited energy values.

The analyses assumed the CEA is ejected in 0.10 seconds. The HFP analysis assumes the CEA is ejected from the transient insertion limit. The ejected worth is increased in analysis to ensure that the power excursion is arrested by Doppler reactivity feedback, followed by a reactor trip signal, within 5 seconds of when the power excursion begins.

The full power case assumes the core is initially operating at 2754 MWt while the zero power ejection assumes an initial power level of 2.8 W. A VHPT is conservatively assumed to initiate at 110.33% of 2737 MWt for the full power case and 40% (30% + 10% uncertainty) of 2737 MWt for the zero power case to terminate the event. The plant protection system setpoints were adjusted to account for uncertainty and time delay. The initiation of scram was delayed to account for holding coil decay.

The RCPs were assumed to be running and no loss of offsite power is assumed, consistent with the current licensing basis. Pressurizer spray and PORVs were assumed to be available but pressurizer heaters were assumed unavailable.

14.13.3.3 <u>Results</u>

Table 14.13-2 contains the results for the zero power and HFP CEA Ejection events. Figures 14.13-1 and 14.13-2 present the core power response for the full power and zero power cases for the analysis. The results show the calculated hot spot centerline fuel temperature remains below the fuel melting point (corrected for Gadolinia content and burnup).

Fuel damage assumptions used in the dose analysis are conservative and are described below.

14.13.4 DOSE ANALYSIS

The CEA Ejection event dose analysis conforms to the regulatory requirements of 10 CFR 50.67 and Reference 9 using AST methodology. The doses resulting from a postulated CEA Ejection event would be a composite of doses resulting from portions of the release going out via the Containment and portions via the secondary system. If regulatory compliance to dose limits can be demonstrated for each of the scenarios, the dose consequences of a scenario that is a combination of the two will be encompassed by the more restrictive of the two analyzed scenarios. The fuel melting temperature criterion used for release of large fractions of fission gases will correspond to the initiation of melting. If the temperature is insufficient to cause incipient fuel melt but is sufficient to cause clad damage, then the gas gap activity of the affected fuel pins is assumed to be released instantaneously and uniformly into the primary system. For this AST analysis, the worst-case historical fraction for incipient centerline melting of 8% including clad failure is assumed. However, based on a 1987 SER (Reference 6), Calvert Cliffs accepted a 10% fuel damage fraction. Since 8% of the fuel is assumed to melt with clad failure, an additional 2% of the fuel is assumed to experience clad failure with no fuel melt releasing the gas gap contents. Note that since only the highest power fuel pins are assumed to be damaged, the releases are increased by the pin power peaking factor of 1.7.

For the 30-day containment release path scenario, the failed/melted fuel activity resulting from a postulated CEA Ejection event (consisting of 100% of the noble gases, 25% of the iodines, 30% of the alkali metals, 5% of the tellurium metals, 2% of the bariums and strontiums, 0.25% of the noble metals, 0.05% of the cerium group, and 0.02% of the lanthanides contained in the fuel which is estimated to reach initiation of melting and 10% of the noble gases, 10% of the iodines, and 24% of the alkali metals which are contained in the gas gaps of the fuel which experience clad failure) is released into the primary system, which is then released in its entirety into the Containment via the ruptured control rod drive mechanism housing. The released activity is instantaneously and uniformly mixed in the free volume of the Containment and is then released at the containment Technical Specification leak rate into the environment. Cleanup via aerosol natural deposition using the 10^{th} percentile Powers aerosol decontamination model, and containment filtration using two 20,000 ± 2,000 cfm recirculation filtration units at 90% inorganic and 30% organic iodine efficiency with manual initiation at 20 minutes post-accident is credited. The analysis was performed using the RADTRAD computer code.

For the 8-hour secondary release path scenario, the failed/melted fuel activity, resulting from a postulated CEA Ejection event (consisting of 100% of the noble gases, 50% of the iodines, 30% of the alkali metals, 5% of the tellurium metals, 2% of the bariums and strontiums, 0.25% of the noble metals, 0.05% of the cerium group, and 0.02% of the lanthanides contained in the fuel which is estimated to reach initiation of melting, and 10% of the noble gases, 10% of the iodines, and 24% of the alkali metals which are contained in the gas gaps of the fuel which experience clad failure) is released into the primary system, which is then transmitted into the secondary system via the Technical Specification SG tube leakage. The condenser is assumed to be unavailable due to loss-of-offsite power. Environmental releases occur from both SGs via the ADVs and MSSVs. The SG tubes remain covered for the duration of the event; therefore the gap iodines have a partition coefficient of 100 in the SGs. A conservative flashing fraction is assumed (10% for the first 15 minutes and 1% thereafter); however, no credit for scrubbing in the SG is assumed. The steam release from the SG for the first 1800 seconds was taken directly from a CESEC calculation. The steam release from 1800 seconds to 8 hours is based on a simple energy balance methodology; that is, the steam released from 1800 seconds to 8 hours is based on the amount of steam required to remove the residual heat from the primary and secondary systems, the decay heat generated in the core, and the reactor coolant pump heat. The steam release rates are divided by a partition coefficient of 100 per Reference 9 and entered into the RADTRAD computer code.

The activity released to the environment is transported to the site boundary and to the Control Room via appropriate atmospheric dispersion coefficients. A constant Control Room inleakage of 3500 cfm was assumed in this analysis. Control Room filtration is credited based on a nominal flow of 10,000 $\pm$ 1,000 cfm per train. A charcoal filter efficiency of 90% is credited for elemental and organic iodine, while a high efficiency particulate air (HEPA) efficiency of 99% is credited for particulate iodine. The Control Room and site boundary doses are calculated based on the appropriate breathing rates and occupancy factors and on References 7 and 8 dose conversion factors. Additional inputs are included in Table 14.13-3.

The EAB, LPZ, and Control Room doses for the design-basis CEA Ejection event are detailed in the following table. Note that all values are below the regulatory limits.

Results	EAB Rem	LPZ Rem	Control Room Rem
8 hour Secondary Pathway	0.32798	0.088148	4.76271
30 day Containment Pathway	0.8513	0.2190	2.0281
Regulatory Limits	6.3000	6.3000	5.0000

The most limiting case is a CEA ejection from HFP at BOC conditions. The sequence of events for this condition is presented in Table 14.13-2. Figures 14.13-1 and 14.13-2 present core power as a function of time for this condition.

The S-RELAP5 plant simulation results from the analysis of the CEA Ejection event were used a input to DNBR calculations. The plant simulations were adjusted to account for power, temperature, pressure, and flow measurement uncertainties in the minimum DNBR calculations. The MDNBR was above the NRC-approved DNB correlation upper 95/95 limit plus a 2% mixed core penalty. In addition, adequate FCM margin exists. The total average fuel pellet deposited enthalpy was determined to be less than 200 cal/g using the Reference 11 methodology.

14.13.5 CONCLUSION

The analysis of the CEA Ejection event demonstrates that operating within the LCOs and in conjunction with the LSSS will limit fuel clad failure to less than 10%, will prevent exceeding the RCS Pressure Upset Limit, and will therefore limit the radiological site boundary dose to well within the criteria in 10 CFR 50.67 guidelines.

The analysis of this event explicitly included the effects of extended burnup and since the resultant site boundary doses are within 10 CFR 50.67 limits, it is concluded that the consequences of the CEA Ejection event are acceptable.

The most limiting case is a CEA Ejection from HFP at BOC conditions. The sequence of events for this condition is presented in Table 14.13-2. Figures 14.13-1 and 14.13-2 present the core power as a function of time for this condition.

The S-RELAP5 plant simulation results from the analysis of the CEA Ejection event were used as input to DNBR calculations. The plant simulations were adjusted to account for power, temperature, pressure and flow measurement uncertainties in the minimum DNBR calculations. The MDNBR was above the NRC-approved DNB correlation upper 95/95 limit plus a 2% mixed core penalty. In addition, adequate FCM margin exists. The total average fuel pellet deposited enthalpy was determined to be less than 200 cal/g using the Reference 11 methodology.

14.13.6 REFERENCES

1. CENPD-190A, "CEA Ejection, CE Method of Control Element Ejection," January 1976

2. Letter from Mr. Alexander N. Chereskin (NRC) to Mr. Bryan C. Hanson (Exelon), dated December 30, 2015, Calvert Cliffs Nuclear Power Plant, Unit Nos. 1 and 2 – Issuance of Amendment RE: Revision to Pressurizer Safety Valve Technical Specifications

3. Deleted

4. Deleted

5. Deleted

6. Letter from NRC to BGE, “Revised Safety Evaluation Supporting Amendment No. 108 to Facility Operating License No. DPR-69,” June 30, 1987

7. Federal Guidance Report (FGR) 11, “Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion,” September 1988

8. Federal Guidance Report (FGR) 12, “External Exposure to Radionuclides in Air, Water, and Soil,” September 1993

9. Regulatory Guide 1.183, “Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors,” July 2000

10. EMF-2310(P)(A), Revision 1, “SRP Chapter 15 Non-LOCA Methodology for Pressurized Water Reactors,” May 2004

11. XN-NF-78-44(A), “Generic Analysis of the Control Rod Ejection Transient for PWRs”

12. Letter from Mr. D. V. Pickett (NRC) to Mr. G. H. Gellrich (CCNPP), dated February 18, 2011, Calvert Cliffs Nuclear Power Plant, Unit Nos. 1 and 2 - Amendment Re: Transition from Westinghouse Nuclear Fuel to AREVA Nuclear Fuel (TAC Nos. ME2831 and ME2832)

TABLE 14.13-1

INITIAL CONDITIONS AND INPUT PARAMETERS FOR THE CEA EJECTION EVENT

PARAMETER	UNITS	VALUE
FULL POWER		
Core Power Level	MWt	2754
Core Inlet Temperature	°F	548
RCS Pressure	psia	2250
Vessel Flow Rate	gpm	370,000
Effective MTC (Density vs Reactivity)	pcm/°F	+1.5 (BOC) -10.36 (EOC)
Doppler Reactivity Coefficient	pcm/°F	-0.9 (BOC) -1.1 (EOC)
Ejected CEA Worth	pcm	350 (BOC) 150 (EOC)
Delayed Neutron Fraction	---	0.006469 (BOC) 0.005227 (EOC)
Post-Ejection F_q	---	2.875 (BOC) 2.7175 (EOC)
CEA Bank Worth at Trip	pcm	-5420
CEA Drop Time	sec	3.10
ZERO POWER		
Core Power Level	W	2.8
Core Inlet Temperature	°F	532
RCS Pressure	psia	2250
Vessel Flow Rate	gpm	370,000
Effective MTC (Density vs Reactivity)	pcm/°F	+7.0 (BOC) -10.36 (EOC)
Doppler Reactivity vs. Fuel Temperature	---	Nominal for time in life, reduced by uncertainty, and biased 10% less negative
Ejected CEA Worth	pcm	660 (BOC) 530 (EOC)
Delayed Neutron Fraction	---	0.006469 (BOC) 0.005227 (EOC)
Post-Ejection F_q	---	6.884 (BOC)\ 9.260 (EOC)
CEA Bank Worth at Trip	pcm	-3500
CEA Drop Time	sec	3.10

TABLE 14.13-2

CEA EJECTION EVENT RESULTS

FULL POWER	**BOC CONDITIONS**	
Time (sec)	**EVENT**	**VALUE**
0.0	Beginning of reactivity insertion	---
0.023	High Power scram setpoint reached	110.33%
0.10	Ejected CEA Fully Withdrawn	---
0.14	Maximum Nuclear Power	~ 210%
0.923	CEA Insertion Begins	---
1.865	Minimum DNBR	> MDNBR Limit
1.9	Maximum Core Heat Flux	3518 MWt
3.25	Maximum Fuel Centerline Temperature	4398.2 °F

ZERO POWER	**BOC CONDITIONS**	
Time (sec)	**EVENT**	**VALUE**
0.0	Beginning of reactivity insertion	---
0.10	Ejected CEA Fully Withdrawn	---
1.099	High Power scram setpoint reached	40.0%
1.275	Maximum Nuclear Power	~ 160%
2.199	CEA Insertion Begins	---
3.70	Minimum DNBR	> MDNBR Limit
3.725	Maximum Core Heat Flux	1495.1 MWt
4.9	Maximum Fuel Centerline Temperature	4309.6 °F

TABLE 14.13-3

ASSUMPTIONS FOR RADIOLOGICAL CONSEQUENCES OF THE CEA EJECTION EVENT

(1) Iodine releases from the SGs to the environment are assumed to be 97% elemental and 3% organic. Iodine released from the failed fuel is assumed to be 95% particulate, 4.85% elemental, and 0.15% organic.

(2) The maximum allowable containment leakage rate L_a contained in the Containment Leakage Rate Testing Program of Technical Specification 5.5.16 is 0.16 percent per day at P_a. Per Reference 9, the Containment should be assumed to leak at the leak rate incorporated in the Technical Specifications for the first 24 hours, and at 50% of this leak rate for the remaining duration of the accident.

(3) The breathing rate and Control Room occupancy factors are per Reference 9.

- Breathing rate:
  - 3.5E-4 m^3/s for 0-8 hours
  - 1.8E-4 m^3/s for 8-24 hours
  - 2.3E-4 m^3/s for 24-720 hours
- Occupancy factors:
  - 1.0 for 0-24 hours
  - 0.6 for 24-96 hours
  - 0.4 for 96-720 hours

(4) The ADV to site boundary 2-hour, atmospheric dispersion coefficient is 1.44E-4 sec/m^3.

(5) The Containment to site boundary 2-hour, atmospheric dispersion coefficient is 1.30E-4 sec/m^3.

(6) The atmospheric dispersion coefficients from the ADV to the Control Room are:

- 3.83E-3 sec/m^3 for 0-2 hours
- 3.25E-3 sec/m^3 for 2-8 hours
- 1.32E-3 sec/m^3 for 8-24 hours
- 9.92E-4 sec/m^3 for 24-96 hours
- 7.92E-4 sec/m^3 for 96-720 hours

(7) The atmospheric dispersion coefficients from the Containment to the Control Room are:

- 1.11E-3 sec/m^3 for 0-2 hours
- 7.29E-4 sec/m^3 for 2-8 hours
- 3.19E-4 sec/m^3 for 8-24 hours
- 2.36E-4 sec/m^3 for 24-96 hours
- 1.98E-4 sec/m^3 for 96-720 hours