ATTACHMENT 2

EXTENDED POWER UPRATE – RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION IDENTIFIED DURING AUDIT OF THE SAFETY ANALYSES CALCULATIONS

ANP-3067
Revision 1

St. Lucie Unit 1 EPU
Information to Support NRC Review of
RCS Depressurization with Pressurizer Overfill

(Cover page plus 24 pages)

Controlled Document

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Nature of Changes

Item	Page	Description and Justification
Rev. 0		
1.	All	Initial Release
Rev. 1		
1.	5	Added acronyms to Nomenclature
2.	10 and 11	Added disposition of HFP vs. HZP

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Nomenclature

AFAS	auxiliary feedwater actuation signal
AFW	auxiliary feedwater
ANP	Advanced Nuclear Power
AOO	anticipated operational occurrence
BOC	beginning-of-cycle
DNBR	departure-from-nucleate-boiling ratio
DTC	Doppler temperature coefficient
EPU	Extended Power Uprate
ESFAS	engineered safety features actuation system
FPL	Florida Power and Light
HFP	Hot Full Power
HPSI	high-pressure safety injection
HZP	Hot Zero Power
LAR	Licensing Amendment Request
LOOP	loss of offsite power
LR	Licensing Report
MFW	main feedwater
MSSVs	main steam safety valves
MTC	moderator temperature coefficient
NP	Nuclear Power
NR	narrow range
NRC	Nuclear Regulatory Commission
PORV(s)	power-operated relief valve(s)
PZR	pressurizer
RCPs	reactor coolant pumps
RCS	reactor coolant system
RPS	reactor protection system
RTP	rated thermal power
RWT	refueling water tank
SAFDLs	specified acceptable fuel design limits
SBCS	steam bypass control system
SG	steam generator
SIAS	safety injection actuation signal

Nomenclature *(Continued)*

TM/LP	thermal margin / low pressure
TS	technical specifications

1.0 Introduction

The analysis described herein provides supplementary information to support the Nuclear Regulatory Commission's (NRC's) review of the St. Lucie Unit 1 Extended Power Uprate (EPU) License Amendment Request's (LAR's) Attachment 5 Licensing Report (LR), Section 2.8.5.6.1, *Inadvertent Opening of Pressurizer Pressure Relief Valve*.

The information contained herein is specific to the St. Lucie Unit 1 EPU LAR submittal.

2.0 RCS Depressurization – Pressurizer Overfill Analysis

2.1 *Identification of Causes and Accident Description*

The Inadvertent Opening of Pressurizer Pressure Relief Valve, or Reactor Coolant System (RCS) Depressurization, event is defined, for St. Lucie Unit 1, as an accidental opening of one or both of the pressurizer power-operated relief valves (PORVs), due to a mechanical failure, spurious actuation signal, or unanticipated operator action.

The event results in a loss of RCS fluid and a fairly rapid RCS depressurization. If the moderator temperature coefficient (MTC) is positive, positive moderator density reactivity feedback caused by the depressurization leads to an increase in core power. The specified acceptable fuel design limits (SAFDLs) challenge is soon terminated, when the reactor trips on a thermal margin / low pressure (TM/LP) signal, but the RCS fluid loss and depressurization continue.

The pressurizer liquid level begins to decrease significantly after the reactor trip, and this actuates the RCS charging pumps and minimizes RCS letdown. A low-low pressurizer pressure signal subsequently actuates high-pressure safety injection (HPSI). The HPSI and charging serve to restore the pressurizer level, but if the HPSI and charging flows are not throttled or terminated, the pressurizer will begin to overfill. To prevent liquid discharge through the open PORV(s), the operators will have to close the open PORV(s) or the corresponding block valve(s) prior to the pressurizer dome becoming liquid-filled.

2.2 *Description of Analyses and Evaluations*

The purpose of this analysis was to evaluate the pressurizer overfill consequences of the RCS Depressurization event. Detailed analyses were performed using the S-RELAP5 code (Reference 1). The S-RELAP5 code was used to model the key primary and secondary system components, reactor protection system (RPS) and engineered safety features actuation system (ESFAS) trips, and core kinetics. The calculations were performed to determine the operator action time necessary for precluding liquid relief through a single accidentally opened pressurizer PORV.[a]

2.3 *Input Parameters and Assumptions*

Parameter biasing and assumptions (listed in Table 1, and discussed below) were designed to ensure conservatively high HPSI and charging flow rates, maximize initial pressurizer level, provide maximum reactivity feedback, and maximize the post-reactor-trip RCS heatup. Assumptions regarding mitigating systems and functions, along with a limiting single-failure, produce the most challenging scenario regarding pressurizer overfill.

- Initial Conditions – The event was initiated from rated-power-plus-uncertainty conditions, with a maximum pressurizer level, minimum pressurizer pressure, and minimum technical specifications (TS) RCS flow. Both maximum- and minimum-initial-RCS-temperature cases were analyzed.

- Reactivity Feedback – Beginning-of-cycle (BOC) moderator[b] and Doppler feedback were assumed for this event. Minimum scram worth with the most reactive rod stuck out of the core was assumed.

- Steam Generator Tube Plugging – Maximum steam generator tube plugging was assumed.

- PORV Relief – Full open-single-PORV flow rate and steam-only relief were assumed.

- Pressurizer Heaters – Both pressurizer-heaters-available and pressurizer-heaters-unavailable cases were analyzed.

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[a] According to the NRC Standard Review Plan, NUREG-0800, Section 15.6.1, an accidental depressurization of the RCS could be caused by the inadvertent opening of a pressurizer PORV, which in turn could be caused by a spurious electrical signal or by an operator error. Florida Power and Light (FPL) letter to the NRC, L-2011-448, dated October 31, 2011 (Reference 2, Attachment 1, page 10) addressed the conditions which could cause both pressurizer PORVs to open and concluded that only a spurious energization of the 63X1P-1102 relay due to a short circuit would cause both PORVs to open. This spurious relay energization, however, is not considered to be a spurious electrical signal; therefore, consistent with the requirements of NUREG-0800, it is reasonable and acceptable to assume only one stuck open PORV for this event.

[b] As a bounding assumption, moderator density feedback corresponding to the most-positive zero-power TS MTC limit was used.

- RPS and ESFAS Trips and Delays – RPS and ESFAS trip setpoints and delay times were biased to conservatively estimate the operator action time.

- Loss of Offsite Power (LOOP) – Cases assuming either LOOP at reactor trip (with the reactor coolant pumps [RCPs] beginning to coast down at that time, and the main steam safety valves [MSSVs] subsequently removing heat transferred from the primary side) or offsite power remaining available throughout the event (with the RCPs remaining in operation, and either the steam bypass control system [SBCS] [if assumed available][a] or the MSSVs providing post-trip primary-side heat removal) were analyzed.

- Main Feedwater (MFW) – MFW was terminated at reactor trip—either due to LOOP (for LOOP cases), or as a conservative assumption (for no-LOOP cases).

- HPSI and Charging – Maximum HPSI and charging flow rates, early actuation times, and a minimum refueling water tank (RWT) source temperature were assumed, to ensure the most limiting conditions for the event. No credit for automatic termination of charging, after restoration of pressurizer level, was taken.

- Letdown – No credit for automatic actuation of RCS letdown, after restoration of pressurizer level, was taken.

- Auxiliary Feedwater (AFW) – Minimum AFW flow rate, maximum actuation time, and maximum temperature were assumed.

- Single-Failure – The assumed single-failure is loss of the turbine-driven AFW pump.

The event analysis for EPU was initiated from hot full power (HFP) initial conditions. The HFP overfill analysis bounds the event from hot zero power (HZP) conditions as follows:

- The HFP analysis assumed a moderator density feedback based on the most positive Technical Specification MTC limit (+7 pcm/°F). Increased core power from moderator feedback and higher core inlet temperatures result in an earlier TM/LP trip. From HFP

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[a] For scenarios with offsite power remaining available, the following cases were analyzed: (1) maximum-capacity SBCS available, (2) minimum-capacity SBCS available, and (3) SBCS unavailable.

conditions, subsequent to reactor trip, the pressurizer pressure decreases at a faster rate due to increasing density of the fluid in the core relative to HZP. An earlier reactor trip and higher rate of depressurization after reactor scram initiates an earlier safety injection actuation signal (SIAS), an earlier initiation of the high pressure safety injection on SIAS and an earlier actuation of the charging pumps on SIAS or on pressurizer level deviation after scram all of which decrease the time to overfill.

- A bounding high initial pressurizer level assumed in the HFP case bounds the level at HZP initial conditions. A bounding high initial pressurizer level will tend to decrease the time to pressurizer overfill making the HFP case more limiting.

2.4 *Acceptance Criteria*

This event is classified as an anticipated operational occurrence (AOO). The acceptance criteria for this event are:

1. Pressures in the reactor coolant and main steam systems should be maintained below 110% of the design values,
2. Fuel cladding integrity should be maintained by ensuring that the minimum departure from nucleate boiling ratio (DNBR) remains above the 95/95 DNBR limit, and
3. The event should not generate a more serious plant condition without other faults occurring independently.

The principally challenged acceptance criterion for this analysis is to demonstrate that the event does not generate a more serious plant condition.[a] The analysis objective is to determine the minimum time for the pressurizer dome to become liquid-filled. A transient-termination operator action time based on this analysis result will ensure that no liquid is relieved through the accidentally opened PORV.

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[a] The challenges to the overpressure limits and SAFDLs (e.g., DNBR) are addressed in the St. Lucie Unit 1 EPU LAR's Attachment 5 LR, Section 2.8.5.6.1, *Inadvertent Opening of Pressurizer Pressure Relief Valve.*

2.5 *Results*

The sequence of events for the limiting case[a] is shown in Table 2. The system response is presented in Figure 1 to Figure 8.

The analysis showed that the minimum time from the event initiation to the pressurizer dome becoming liquid-filled is 7 minutes.[b] Thus, the operators will have no more than 7 minutes from the inadvertent opening of a pressurizer PORV to terminate the event, by closing the PORV or its block valve.

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[a] The limiting case is initiated with maximum RCS temperatures and assumes that the pressurizer heaters are unavailable and that a LOOP occurs at reactor trip—which, in turn, renders the SBCS unavailable.

[b] The pressurizer is considered to be full when the liquid fraction in the dome reaches 1.00.

Table 1 RCS Depressurization / Pressurizer Overfill: Initial Conditions and Biasing

Parameter	Value
Initial Reactor Power	3029.06 MW_t
Initial Core Inlet Temperature Range	532°F – 554°F
Initial RCS Flow Rate (total)	375,000 gpm
Initial Pressurizer Pressure	2185 psia
Initial Pressurizer Level	68.6%
Moderator Reactivity	Moderator density feedback corresponding to +7.0 pcm/°F MTC
Doppler Temperature Coefficient (DTC)	-0.80 pcm/°F
Scram Reactivity	6017.22 pcm
Steam Generator Tube Plugging	10% (both steam generators)
Open Pressurizer PORV Flow Rate (single PORV)	Sized to relieve 154,530 lb_m/hr at 2400 psia (steam only)
TM/LP Reactor Trip Setpoint	$P_{PZR} \leq 2061$ psia × A_1[a] × QR_1[b] + 15.85 psia/°F × T_{inlet} - 8950 psia, or $P_{PZR} \leq 1847$ psia
TM/LP Reactor Trip Signal-Processing Delay	0.9 s
MFW Status	Initially on auto, then terminated at reactor trip
Actuation of All Charging Pumps	At reactor trip[c]
Charging Flow Rate (total)	147 gpm
RWT Temperature	51°F
SBCS Capacity Range	24% – 58%
SBCS Secondary System Pressure Setpoint	910 psia
MSSV Setpoints	Open on pressures higher than 1030.0 psia (for Bank 1) and 1060.8 psia (for Bank 2)
Low-Low Pressurizer Pressure Safety Injection Actuation Signal (SIAS) Setpoint	1640 psia
Safety Injection Availability Delay After SIAS	0.0 s
HPSI Flow Rate	Maximum, for both HPSI pumps

[a] A_1 (of the TM/LP reactor trip function) was conservatively assumed to be 1.0 in the S-RELAP5 model.

[b] QR_1 (of the TM/LP reactor trip function) is 1.0 at power levels above 97.2% of the rated thermal power (RTP).

[c] For LOOP cases, no charging flow delay after LOOP (for emergency diesel generator startup and sequencing) was credited.

Table 1 RCS Depressurization / Pressurizer Overfill: Initial Conditions and Biasing
(Continued)

Parameter	Value
Automatic Termination of Charging and Actuation of Letdown (after pressurizer level restored)	Not credited
Low-Low Steam Generator Level Auxiliary Feedwater Actuation Signal (AFAS) Setpoint	14% narrow range (NR)
AFW Actuation Delay After AFAS	330 s[a]
AFW Flow Rate (total)	2 electric pumps × 296 gpm / pump
AFW Temperature	104°F

[a] This maximum AFW actuation delay, which includes time for emergency diesel generator startup and sequencing, was used not only for LOOP cases but also—as an additional conservatism—for no-LOOP cases.

Table 2 RCS Depressurization / Pressurizer Overfill: Sequence of Events

Event	Time (s)
Event initiation – single pressurizer PORV inadvertently opens	0.0
Pressurizer pressure reaches TM/LP setpoint	60.2
TM/LP signal actuates reactor trip, offsite power is assumed to be lost, MFW is lost, RCPs begin to coast down, turbine trips, and all RCS charging is assumed to begin	61.1
Lowest steam generator (SG) level reaches AFAS setpoint	66.1
MSSVs first open	66.5
Pressurizer pressure reaches SIAS setpoint	107.2
HPSI begins	110.1
AFW flow to SG-1 and SG-2 begins	396.1
Pressurizer dome becomes liquid-filled	444.7

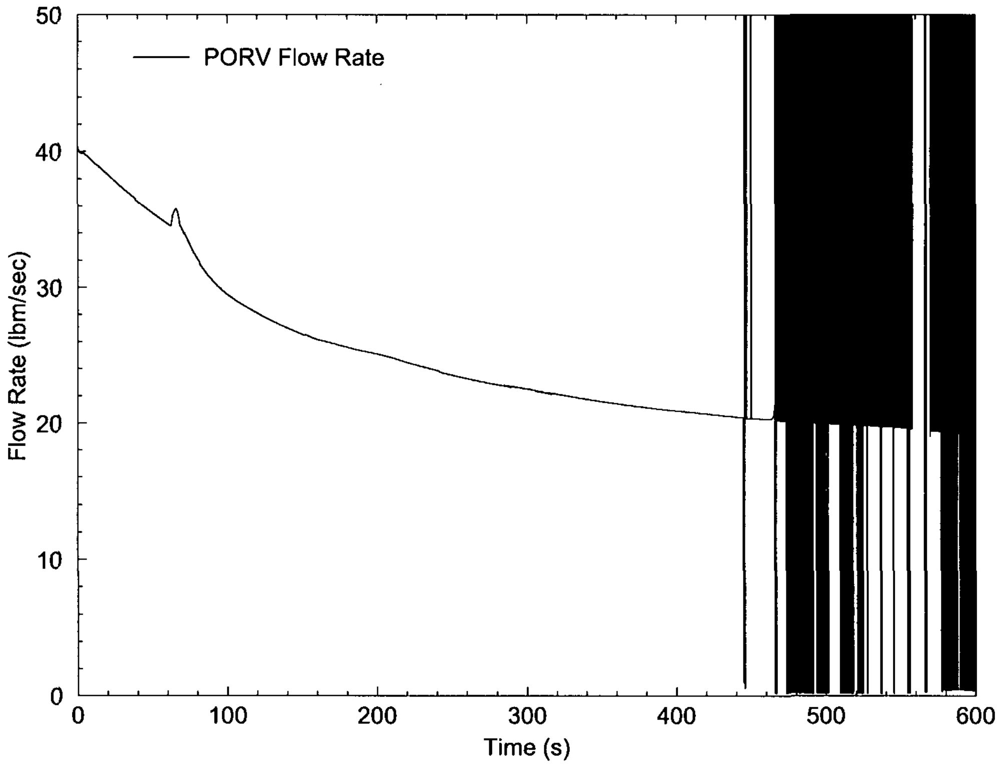

Figure 1 RCS Depressurization / Pressurizer Overfill – Pressurizer PORV Flow Rate

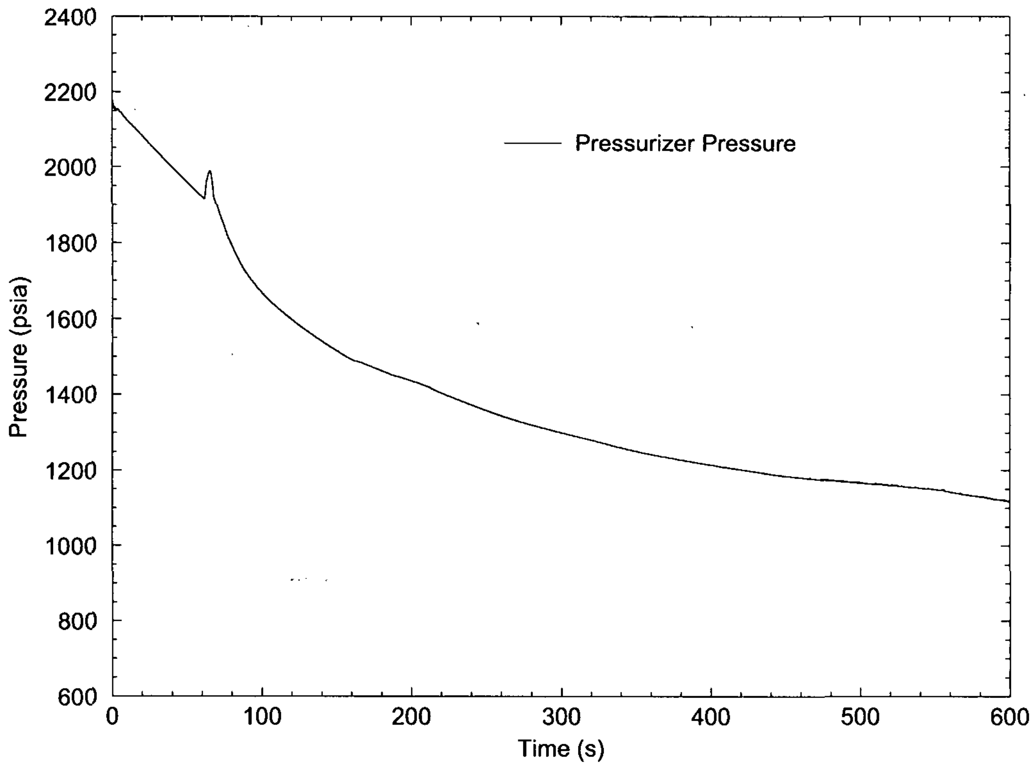

Figure 2 RCS Depressurization / Pressurizer Overfill – Pressurizer Pressure

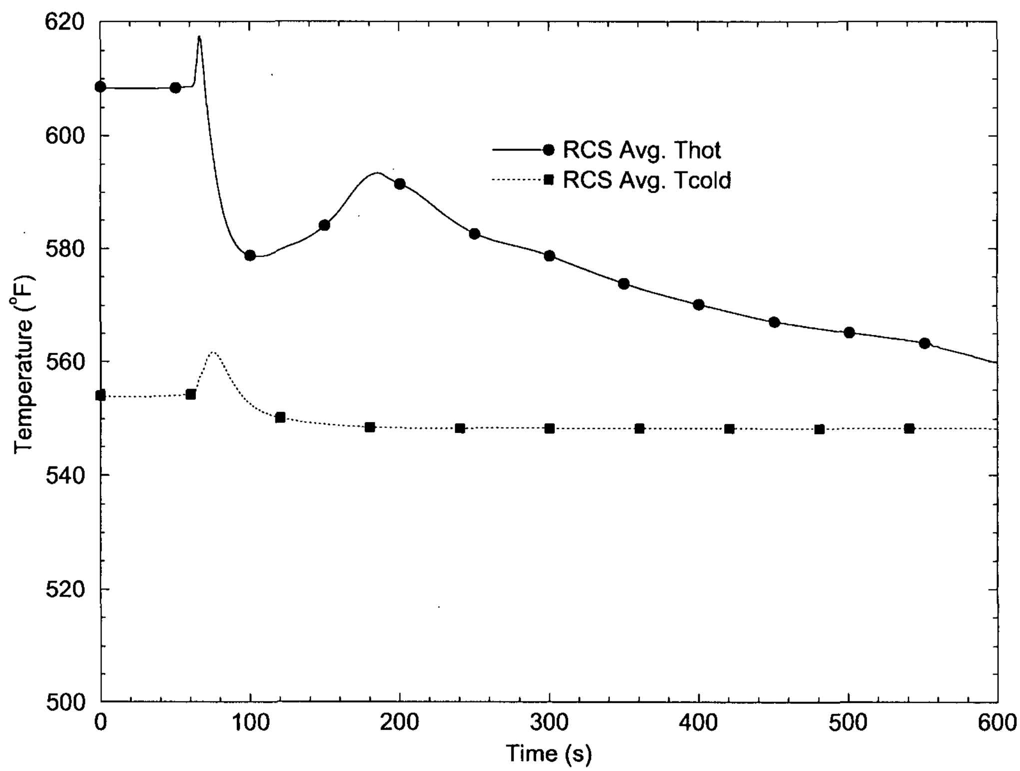

Figure 3 RCS Depressurization / Pressurizer Overfill – RCS Coolant Temperatures

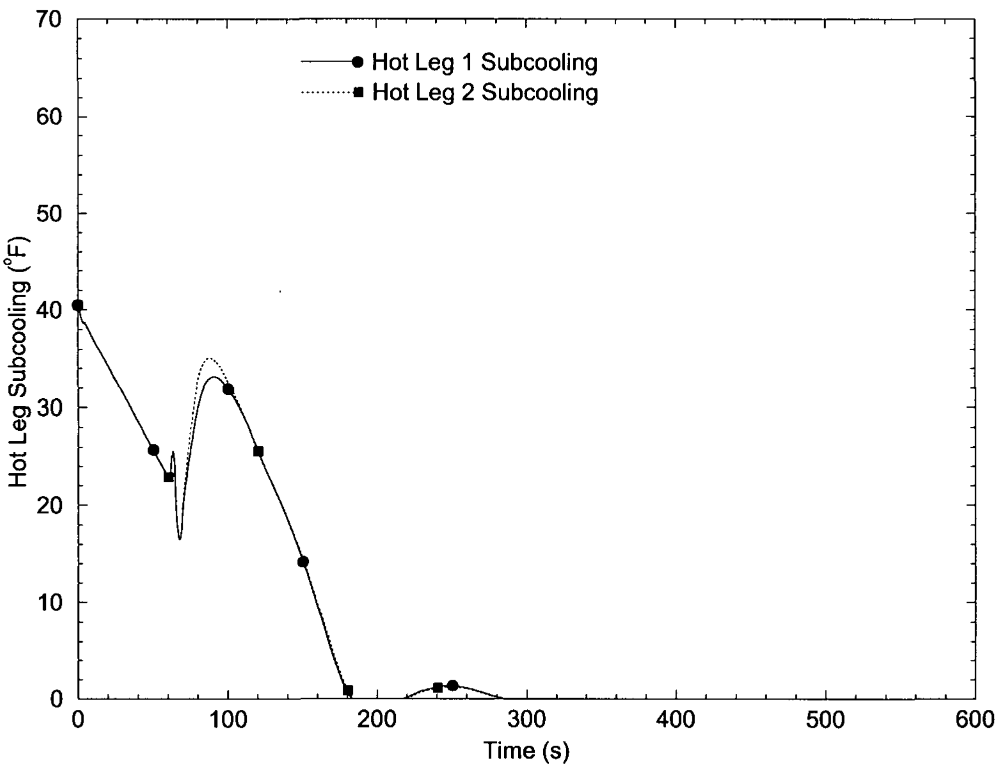

Figure 4 RCS Depressurization / Pressurizer Overfill – RCS Subcooling

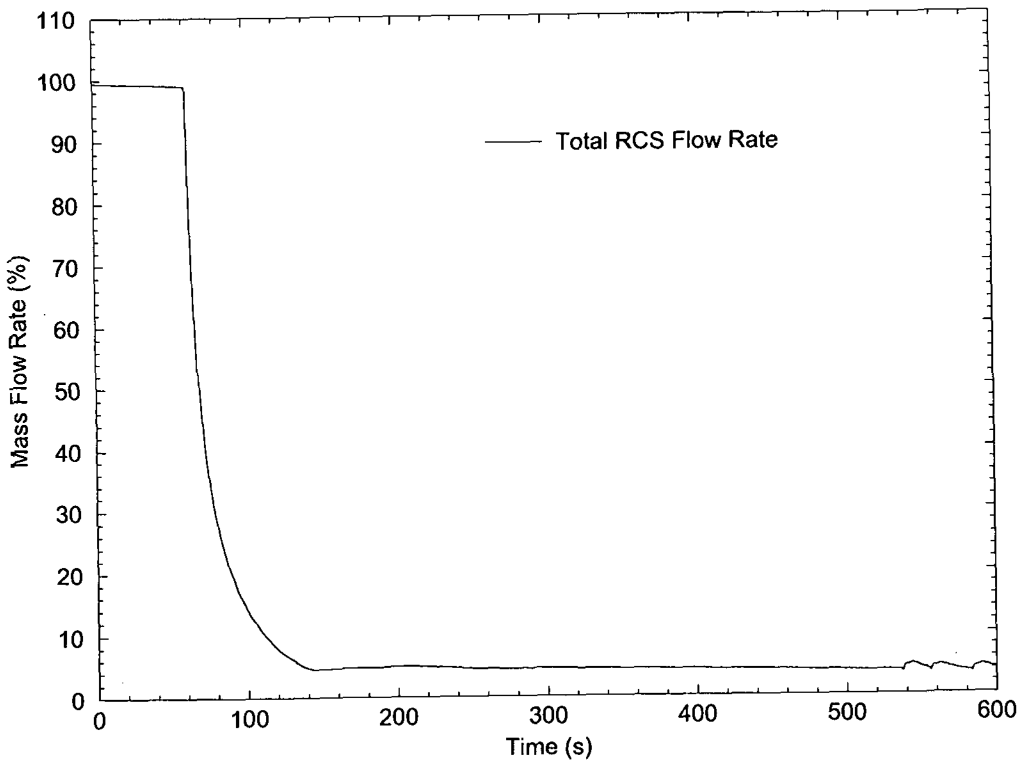

Figure 5 RCS Depressurization / Pressurizer Overfill – Total RCS Flow Rate

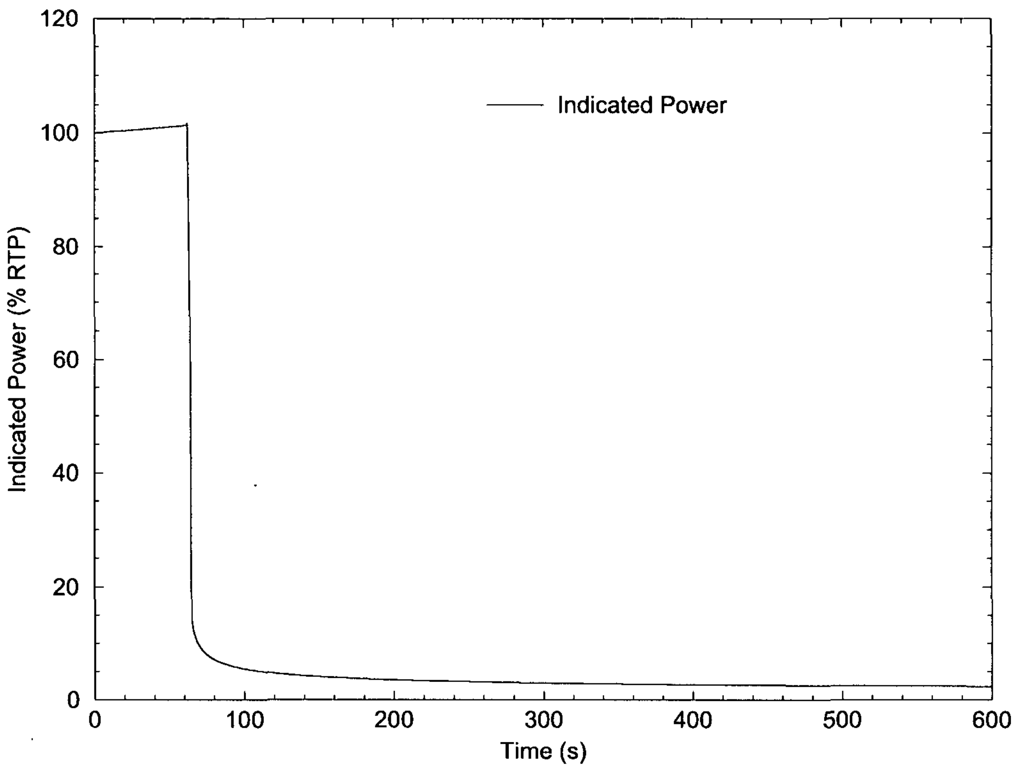

Figure 6 RCS Depressurization / Pressurizer Overfill – Indicated Reactor Power

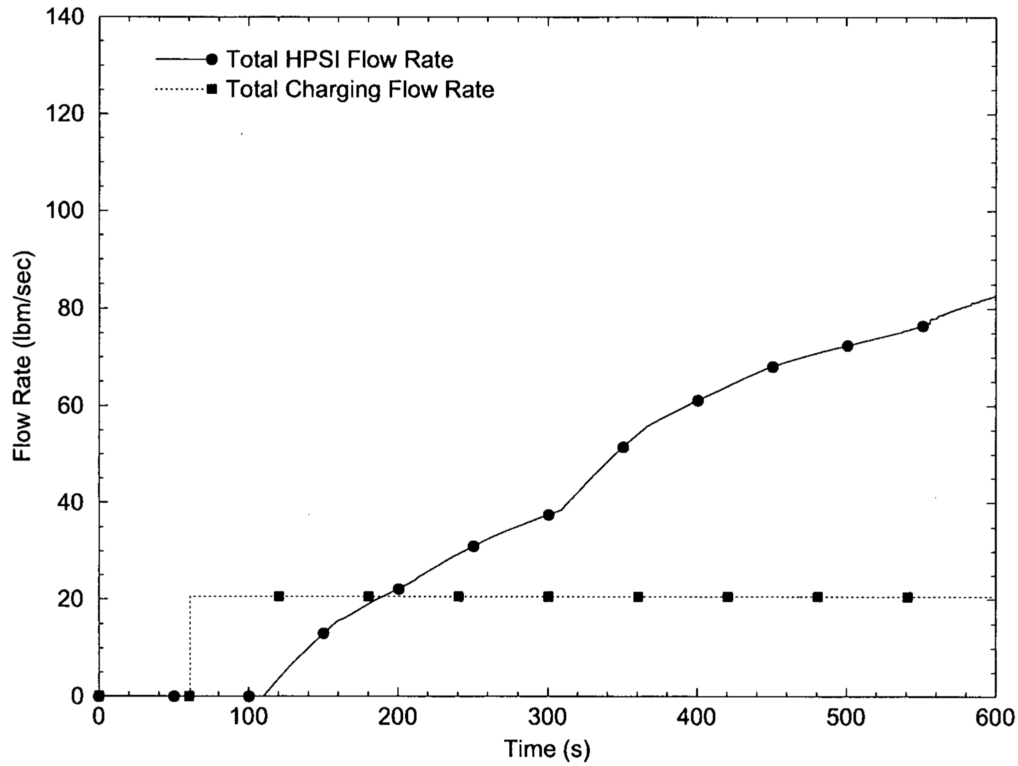

Figure 7 RCS Depressurization / Pressurizer Overfill – Total HPSI and Charging Flow Rates

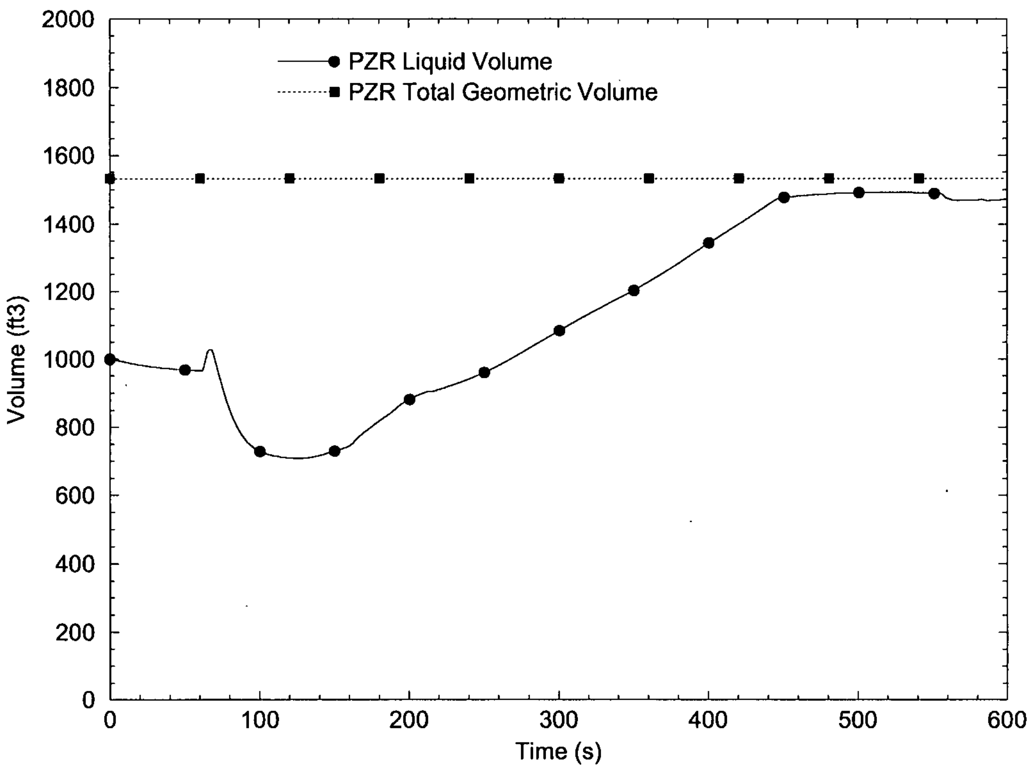

Figure 8 RCS Depressurization / Pressurizer Overfill – Pressurizer Liquid Volume

3.0 References

1. EMF-2310(P)(A) Revision 1, *SRP Chapter 15 Non-LOCA Methodology for Pressurized Water Reactors*, Framatome ANP, May 2004.

2. L-2011-448, *Response to NRC Reactor Systems Branch and Nuclear Performance Branch Request for Additional Information Regarding Extended Power Uprate License Amendment Reguest*, FPL letter to NRC, dated October 31, 2011.