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THERMAL-HYDRAULIC ANALYSIS OF SCRAM AND RVACS TRANSIENTS IN
PRISM USING COMMIX-1AR: SHORT TERM RESPONSE

by

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ABSTRACT

The PRISM reactor design has been analyzed for two transients, each of which was initiated by a simultaneous loss of power to all coolant pumps and accompanied by a reactor scram. The two transients differ in the behavior assumed for the intermediate heat transport loops. The coolant flow rate in these loops decreases to, and continues under, natural circulation conditions during the SCRAM transient but ceases essentially instantaneously during the RVACS transient. The three-dimensional velocity and temperature fields during the first 20 minutes of these two transients have been calculated using the IFR variant of the COMMIX-1AR computer code. The primary system sodium flow undergoes a reasonably smooth transition from forced to natural circulation mode during both transients, although temporary flow reversal occurs in several non-heat-generating regions of the core during the RVACS transient. The most severe temperature changes in the primary system occur in the fuel assemblies and the lower upper internals structure during both transients and additionally at the intermediate heat exchanger exit during the RVACS transient. These responses are propagated to other parts of the primary system but are diminished in severity and delayed in time by the large material inventories and transport time effects. Although neither transient has reached an equilibrium condition after 20 minutes, one global trend is evident: the primary system is cooling down during the SCRAM transient and heating up during the RVACS transient. The continued cooling trend during the SCRAM transient makes it unnecessary to continue that calculation further. The RVACS transient calculation, however, needs to be continued for at least 1 to 2 days, which is the estimated time required for the power removal via the reactor vessel auxiliary cooling system to exceed the power generation in the core and, thus, establish a cooling trend.

I. INTRODUCTION

The Power Reactor Inherently Safe Module (PRISM) is a liquid-metal-cooled pool-type reactor being designed¹ by the General Electric Company (GE). An innovative safety feature of this design is provision of a path through which atmospheric air flows by natural convection over the outside of the guard vessel at all times. The flow path in this reactor vessel auxiliary cooling system (RVACS) is sized to help insure system integrity by removing post-scrum decay heat generation in a totally passive manner in the event that all active heat removal components are rendered unavailable. As the PRISM design evolves, various studies are made in order to assess the characteristics of the reactor system, both at steady state and under transient conditions. A proper analysis of the in-vessel behavior requires a coupled solution of the fluid flow and heat transfer equations in three spatial dimensions and time; both forced and natural circulation modes of fluid flow must be considered. This analysis capability is provided by the framework of the COMMIX computer codes, a version of which was used in the present analysis.

Previous reports have presented the three-dimensional velocity and temperature fields in the primary system and its immediate surroundings on a steady-state basis for (a) full-power/full-flow conditions² and (b) conditions representative of one day into a specific transient³. The present report extends these analyses into the fully transient regime. The short-term (i.e. approximately 20 minutes) responses for two protected transients, denoted SCRAM and RVACS, have been calculated. Each of the two transients is initiated from full-power/full-flow conditions by a simultaneous loss of power to all pumps accompanied by a reactor scram. The difference in the two transients is the behavior assumed in the intermediate heat transport loops, which circulate sodium from the in-vessel intermediate heat exchangers (IHX) to the ex-vessel steam generators. The SCRAM transient assumes that the sodium flow rate in the intermediate loops undergoes an orderly decrease to natural circulation conditions following the loss of power to the pumps. Under these conditions, the intermediate loops continue to remove some energy from the primary system during the transient. The RVACS transient has a more severe boundary condition imposed: the sodium flow rate in the intermediate loops rapidly decreases

to zero following loss of power to the pumps. Under these conditions, the IHX provides no capability for energy removal; the only mechanism providing cooling of the primary system is the natural circulation of air through the RVACS.

Following initiation of either transient, the decreases in the primary and intermediate coolant flow rates and the decrease in core power generation lead to transient changes in temperatures throughout the reactor system. Three important goals of the analysis are to (1) quantify the transient temperature response at key locations for use by others in assessing the potential for damage by thermal shock and stress mechanisms, (2) identify any problems associated with the transition of the flow of sodium in the primary system from a forced to a natural circulation mode, and (3) assess the ultimate coolability of the system.

The model used for this analysis is described in Section II, along with the specific boundary conditions used for the two transients. The first 20 minutes of each transient calculation has been completed; the results are presented in Section III for the SCRAM transient and in Section IV for the RVACS transient. Following these separate discussions of the transients, selected results are presented on a comparative basis in Section V. The analyses presented in this report supersede those presented in Ref. 4 and incorporate revisions to the reactor design, the structure of the COMMIX model, and the transient boundary conditions.

II. MODEL DESCRIPTION AND BOUNDARY CONDITIONS

1. Geometry

The present calculations were performed using the IFR variant of the COMMIX-1AR computer code (Ref. 5). In addition to the normal porous medium formulation of the mass, momentum, and energy conservation equations in three dimensions found in all COMMIX code versions, the 1AR version allows radiative heat transfer between surfaces of thermal structures. The IFR variant allows multiple fluids to be considered in physically separated regions, provides a transient boundary condition option which sets an inlet mass flow rate as a function of the temperature of a radiative surface, and provides several pump modeling options.

The calculations used the same 90° sector representation of the primary system and surroundings as was used for the steady-state calculations reported in Ref. 2. The major features of the geometry are illustrated in Figs. 2-1 and 2-2. The normal sodium flow pattern is up through the pump duct (cells (I-radial, J-azimuthal, K-axial)=(6,3,8-11)) to the pump outlet plenum (cells (5-7,1-5,12-13)); down through two pipes (starting in cells (7,1,11) and (7,5,11)) to the core inlet plenum (cells (1-4,1-8,2-3)); up through the assemblies (cells (1-4,1-8,4-7)) and the upper internals structure (UIS) region (cells (1-4,1-8,8-19)) to the upper portion of the hot pool (cells (1-7,1-8,17-19)); down through the intermediate heat exchanger (IHX) (cells (5-7,6-8,9-16)) to the cold pool; and up through the fixed shield region (cells (5-6,1-8,4-6)) to the pump inlet plenum (cells (5-7,1-5,7)).

The PRISM design provides an alternate path for sodium in the hot pool to return to the cold pool under some transient conditions. The actuation of this alternate path is passive: if the sodium expands sufficiently during heatup, the hot pool level rises to slots cut through the upper portion of the reactor vessel liner (RVL), allowing this sodium to enter the top of the annular space between the reactor vessel (RV) and its liner, and flow downward through this gap (cells (8-9,1-8,9-19)) to the cold pool. Overflow of sodium into and through this gap is intended to enhance energy removal via the RVACS. The design conditions for normal operation are such

that the hot pool sodium level is below the slots and the sodium level in the RVL/RV gap is lower than the level in the hot pool. The difference between these two free surface levels is a function of the pressure drops in the primary system; the two levels are essentially identical when no head is being supplied by the primary pumps. The hot pool temperature must increase by at least 70°C (125°F) during a transient in order to cause sufficient expansion of the sodium for overflow to be initiated.⁶ The COMMIX code can not model the changes in liquid level at the two free surfaces and, thus, can not be used to directly predict the onset of overflow. The present calculations were, therefore, performed assuming that (a) overflow would not occur and (b) the gap between the reactor vessel and its liner was completely filled with sodium. Assumption (a) is justified as long as the calculated increase in hot pool temperature is less than that required to initiate overflow. Justification for assumption (b) is provided by the rapid equilibration between the two liquid levels expected during the pump coastdown.

The annular gap between the reactor vessel and the guard vessel (GV) (cells (10-11,1-8,1-19)) contains Argon. The annular space between the guard vessel and the collector cylinder (CC) (cells (12-13,1-8,1-19)) is the air riser portion of the RVACS. The air downcomer (which is separated from the riser by insulation on the collector cylinder) and the inlet and exit structures are not explicitly included in the COMMIX model; however, the presence of these sections is included in formulating the boundary conditions. The heat transfer across these two annular gas regions is by a combination of radiation, convection, and conduction mechanisms.

The majority of the intermediate loop is not explicitly modeled in this analysis; however, there is a column of mesh cells (which are not shown in Figs. 2-1 and 2-2) which represents the sodium on the intermediate side of the IHX. The sodium in these cells is coupled thermally to the sodium on the primary side of the IHX using the "thermal structure" model in COMMIX. The mass flow rate and inlet temperature on the intermediate side of the IHX must be specified as boundary conditions and reflect the effects in the other portions of the intermediate loop which were not modeled in this COMMIX analysis.

Additional specifics of the model geometry, along with the parameters for the models describing heat transfer and frictional resistance, are given in Ref. 2.

2. Initial and Boundary Conditions

The initial conditions for the transient are the results calculated at full-power/full-flow steady state and are given in Ref. 2. There are six boundary conditions which must be specified for the transients: core power generation, pressure increase supplied by the primary pumps, air mass flow rate and inlet temperature for the RVACS, and sodium mass flow rate and inlet temperature on the intermediate side of the IHX. The first four of these boundary conditions are the same for both the SCRAM and the RVACS transient; the IHX intermediate side boundary conditions differ for the two transients. Boundary conditions are provided to the COMMIX-1AR code in tabular format; the code generates functional forms representing the tabular data by using a cubic spline curve fitting procedure. In some instances, data pairs were provided to the code in addition to those shown in the upcoming tables to insure final fits which were well behaved.

The power generation in the core is the sum of two components: the residual fission power induced by the delayed neutron population and the decay power from fission products. An estimate of the delayed neutron induced fission power was obtained by performing a point-kinetics calculation, using six groups of delayed neutrons, for a uniform ramp scram over 2 s from critical to an assumed shutdown eigenvalue of $k_{eff} = 0.965$. The kinetics parameters are given in Table 2-1 and correspond to oxide fuel⁷. (The use of kinetics parameters for metal fuel would alter the power induced by delayed neutrons, but, as indicated below, this component contributes little to the total integrated power during the course of the transients to be considered.) The decay power component was provided⁸ by GE, and the values used correspond to their "nominal" data. The two components of power generation* and their sum are given in Table 2-2. This

*All "extensive" numbers stated in this report (e.g. the power shown in Megawatts in Table 2-2) are for the entire reactor module, not just the 90° sector being modeled.

tabulation shows that the delayed neutron induced fission contribution is significant during the first minute following shutdown; thereafter, the decay power is the only significant contribution to the total.

The boundary condition for sodium flow in the primary system is provided by using one of the pump model options in COMMIX-1AR(IFR). Rather than developing the set of parameters needed to represent the motor/generator-driven electromagnetic pumps in PRISM in the context of the full mechanical pump model in the code, the relative pump head as a function of time was input directly. This pump head was provided⁹ by GE, as computed using their one-dimensional computer code ARIES, and is shown in Table 2-3. The initial decrease in pump head is very rapid: the supplied head is only 20% after 2 s. The decrease in head is more gradual over the next 400 s, which is the end of the data supplied by GE. Since the pump is supplying a relatively insignificant head (0.2%) at 400 s, the head was assumed to continue decreasing to zero over the next 300 s and then remain zero for the rest of the transient history in the COMMIX calculation.

The air flow rate through the RVACS is a function of the balance between buoyancy forces and dynamic pressure loss considerations along the entire flow path. A separate lumped-parameter analysis¹⁰ of this type of system has shown that the steady-state air flow rate may be stated as a function of the average reactor vessel surface temperature (or, alternately, heat flux). The reactor vessel temperature changes during a transient, and this leads to a change in the air flow rate in the RVACS. This type of boundary condition, where inlet flow rate is a function of the temperature of a radiative surface, is available in the IFR variant of the COMMIX-1AR computer code and was used for the RVACS inlet flow condition. This approach is necessary since only the air riser portion of the RVACS is included in the COMMIX model of PRISM. Using the method of Ref. 10, the relation between air flow rate and reactor vessel surface temperature has been calculated¹¹ for the PRISM model configuration, and the results are shown in Table 2-4. For actual input to the code, the flow is input as a velocity normalized with respect to steady state. The use of a correlation based on steady state analysis should be a good approximation in this case, since the reactor vessel temperature is expected to change slowly during the transients. The other boundary condition for the RVACS is the air

temperature at the inlet location in the model; this was held constant at the steady-state value (38°C or 100°F) during the transients.

The boundary conditions on the intermediate side of the IHX differ for the two transients considered in this report. Those used in the SCRAM transient were provided⁹ by GE, as calculated with their ARIES computer code, and are shown in Table 2-5. The flow represents a coastdown from forced to natural circulation conditions; the small scale fluctuations in flow after 80 s were ignored in the COMMIX analysis. The inlet temperature begins a slow decrease after the first minute. This decrease is preserved in the COMMIX analysis but is taken relative to the IHX inlet temperature needed in COMMIX to give correct primary system temperatures at full-power/full-flow steady-state conditions. (The inlet temperature needed in COMMIX is 271.7°C (521.1°F), which is somewhat lower than the 282.2°C (540.0°F) design value; the need for this downward biasing in COMMIX is due to the use of first-order differencing with rather large mesh spacings and was discussed in Ref. 2.) Both of these IHX boundary conditions were held constant after 400 s in the SCRAM transient, since that was the extent of the data provided by GE.

For the RVACS transient, the mass flow rate at the inlet to the intermediate side of the IHX was assumed to decrease, linearly, to zero over the first 2 s and remain at that zero value for the rest of the transient. A "mass continuity", rather than "specific flow", boundary condition is used for all exit flows in the COMMIX model of PRISM; thus, the mass flow rate at the exit is the mass flow rate at the inlet minus the time rate of change of the amount of mass enclosed in the system volume. The inlet and exit mass flow rates are identical at steady state, since there is no net mass change in the system. During a transient, the two mass flow rates differ due to density changes, which are a result of temperature changes. This is generally a small effect but will be noticeable in the RVACS transient: there will be a residual mass flow across the exit of the intermediate side of the IHX after 2 s as the sodium on this side continues to be heated (or cooled) by the sodium on the primary side. The inlet temperature on the intermediate side of the IHX was held constant at the steady-state value during the RVACS transient; this value has little significance since the inlet mass flow rate is rapidly decreased to zero.

Fig. 2-1. Elevation View of COMMIX Model (Azimuthal Plane J=7 is on the left and J=3 is on the right.)

Fig. 2-2. Plan View of COMMIX Model Just Below Pump Outlet Plenum (Axial Plane K=11)

TABLE 2-1. Kinetics Parameters for Oxide Fuel Core

Prompt Neutron Lifetime [s]		4.0202×10^{-7}
Effective Delayed Neutron Fraction, β_{eff}		3.3414×10^{-3}
<u>Delayed Group</u>	<u>$\lambda_i (\text{s}^{-1})$</u>	<u>β_i</u>
1	0.01298	8.0404×10^{-5}
2	0.03141	7.0847×10^{-4}
3	0.13562	6.2185×10^{-4}
4	0.34606	1.2010×10^{-3}
5	1.36880	5.5067×10^{-4}
6	3.75170	1.7897×10^{-4}

TABLE 2-2. Post-Scram Power Generation Data for Transients

Time [s]	Delayed Neutron Fission Power [% Rated]	Nominal Decay Power [% Rated]	Total Thermal Power [% Rated ^a]
0	94.19	5.810	100.0
1	12.19	5.426	17.63
3	4.39	5.061	9.45
10	2.21	4.498	6.70
30	0.962	3.875	4.84
100	0.152	3.145	3.30
200	0.0214	2.757	2.77
500 (8.3 min)		2.312	2.31
1×10^3		1.974	1.97
2×10^3 (33 min)		1.618	1.62
1×10^4 (2.8 hr)		1.997	0.997
3×10^4 (8.3 hr)		0.772	0.772
1×10^5 (1.2 day)		0.565	0.565
3×10^5		0.386	0.386
1×10^6		0.223	0.223
3×10^6		0.134	0.134
5×10^6		0.111	0.111
6.3×10^6		0.099	0.099
1.6×10^7 (185 day)		0.065	0.065

^aRated core thermal power is 425 MW (1.45×10^9 Btu/hr).

TABLE 2-3. Primary Pump Pressure Increase vs.
Time for Transients

Time [s]	Pump Head [% Initial ^a]
0	100.0
2	21.2
4	18.3
6	16.3
8	14.6
10	13.2
20	8.7
40	5.0
60	3.3
100	1.8
150	1.1
200	0.70
300	0.36
400	0.20
>700	0.0 ^b

^aInitial pump head is 0.744 MPa (108 lb_f/in²) at full flow.

^bAssumed.

TABLE 2-4. RVACS Air Mass Flow Rate vs.
Reactor Vessel Temperature

Reactor Vessel Average Temperature		Air Mass Flow Rate	
[°C]	([°F])	[kg/s]	([lb _m /s])
165	(329)	10.1	(22.4)
230	(446)	12.8	(28.2)
318	(604)	16.1	(35.5)
346	(655)	-- steady state --	17.1 (37.7)
435	(815)	20.3	(44.7)
522	(972)	23.3	(51.3)
662	(1224)	27.6	(61.0)
808	(1486)	31.7	(69.8)
1061	(1942)	37.6	(82.8)

TABLE 2-5. IHX Intermediate Side Boundary
Conditions for the SCRAM Transient

Time [s]	Mass Flow Rate [% Rated ^a]	Inlet Temperature Change	
		[°C]	([°F])
0	100.0	0.0	(0.0)
2	92.4		
4	71.0		
6	57.3		
8	47.9		
10	41.1		
12	35.8		
16	28.4		
20	23.3		
24	19.6		
30	15.7		
40	11.4		
50	8.66		
60	6.89 * ^c	0.0	(0.0)
80	5.10	-0.2 *	(-0.4)
100	5.09 *	-0.9 *	(-1.6)
150	5.18 *	-3.2	(-5.8)
200	5.24 *	-7.2 *	(-13.0)
250	5.26 *	-10.7	(-19.3)
300	5.23 *	-12.0 *	(-21.6)
342	5.16 *	-12.4	(-22.3)
400	4.99 *	-10.6	(-19.1)
>400 ^b	5.10	-10.6	(-19.1)

^aRated mass flow rate is 2.28 Mg/s (18.1×10^6 lb_m/hr) for the total of all intermediate loops.

^bTabulated values provided by GE for 400 s; values were held constant in COMMIX after that time.

^cEntries flagged with an asterisk (*) were not input to COMMIX; the code interpolates between adjacent input values using a cubic-spline curve fitting technique.

III. RESULTS CALCULATED FOR THE SCRAM TRANSIENT

The COMMIX-1AR computer code has been used to calculate the first 18 minutes of this transient. The results presentation is divided into four subsections: key global results; propagation of temperature changes around the primary system; development of and changes in thermal gradients; and a final summary section. The figures in this section show temperatures in units of degrees Celsius [$^{\circ}\text{C}$]; an alternate set of figures using units of degrees Fahrenheit [$^{\circ}\text{F}$] is included as Appendix A.

1. Key Global Quantities

Selected quantities of general interest are presented in this section. A reference guide to the spatial locations at which results will be shown is provided in Fig. 3-1.

The flow through the primary pump is shown in Fig. 3-2. The quantity shown for flow in this and other figures is actually the velocity normalized to the steady-state value; this quantity is representative of the relative mass flow but does not include the effect of coolant density changes during the transient. The initial decrease in flow is quite rapid, reaching 50% flow in only 1.5 s. The flow decrease then becomes more gradual, reaching 10% flow in 125 s. The long term flow value of ~4% is in a natural convection mode, as driven by the thermal gradients in the system, since there is no head supplied by the pump after 700 s.

The power and flow in the driver (DR) fuel assemblies are shown in Fig. 3-3. The power shown here is that transferred to the fluid. As shown in Table 3-1, this value exceeds the power generated in the fuel during the first minute of the transient; this difference represents a cooling of the fuel and release of energy stored in the fuel at steady state. After the first minute, the situation is in quasi-equilibrium since the power transferred to the sodium closely matches the power generated in the fuel. This table serves as a reminder of the dynamics involved in cooling the core during a transient. The coolant flow through the driver fuel assemblies shown in Fig. 3-3 follows the flow coastdown shown for the primary pump in Fig. 3-2. The expanded time scale used in Fig. 3-3a shows that the relative

power-to-flow ratio is less than 1 except for the first 5 s. As shown in Fig. 3-4a, this condition leads to an initial peak in coolant temperature during the first 5 s; this peak is small, being only 34°C (61°F). Also shown in Fig. 3-4 is the fuel temperature at the fuel centerline; the rapid decrease in fuel temperature is indicative of the power imbalance shown in Table 3-1. (Recall that this calculation is for an oxide fuel core; the fuel temperature and initial stored energy for a metal fuel core would be smaller than the oxide fuel numbers due to the high thermal conductivity of metal fuel.) At longer times, the temperature difference between the fuel and coolant remains relatively constant (but gradually decreasing), as shown in Fig. 3-4b. This is a graphical representation of the quasi-equilibrium situation mentioned above. The inlet and exit coolant temperatures are shown in Fig. 3-5. The exit temperature initially increases over the first 5 s, decreases over the next 55 s, and then increases slowly over the next 750 s. This behavior is consistent with the power-to-flow ratio information shown in Fig. 3-3, which increases over the first 2 s, decreases over the next 50 s, slowly increases over the next 550 s (but remains less than one), and then slowly decreases after 600 s. The final decreasing behavior in the exit coolant temperature is augmented by the decrease in inlet coolant temperature. The behavior of the inlet temperature and the relation between inlet and exit temperature will be discussed further in Sec. III.2.

The key results for the radial blanket (RB) fuel assemblies are shown in Figs. 3-6 through 3-8. The results for power, flow, and temperatures are similar to those shown in Figs. 3-3 through 3-5 for the driver fuel assemblies. The temperatures in the radial blanket are smaller than those in the driver (except for the inlet temperature, which is essentially the same in the two regions).

The flows and temperatures for the removable radial shield (RRS) assemblies and the core bypass (BYP) region are shown in Figs. 3-9 through 3-11. The mass flow through these regions follows the transient behavior shown for the pump in Fig. 3-2. Although these two regions do not contain heat generating solids, they do exchange energy across the assembly walls with the radial blanket fuel assemblies and across the support cylinder to the fixed shield (FS) region. This heat transfer mode is responsible for the changes in exit temperature shown in Figs. 3-10 and 3-11.

Results for the intermediate side of the IHX are shown in Figs. 3-12 and 3-13. The flow and the inlet temperature are just the graphical presentations of the boundary conditions shown in Table 2-5. The exit temperature in Fig. 3-13 shows a small initial decrease and increase during the 80 s flow coastdown. Following this, the exit temperature is continually decreasing. When these temperatures are combined with the mass flow changes, the rate at which energy is removed from the primary system via the IHX is found to be decreasing during the transient; the energy removal rate is shown in Table 3-1.

The air flow rate in the RVACS is shown in Fig. 3-12. This flow only decreases slightly (2%) during the 18 minutes of the transient. Since this flow is an increasing function of the reactor vessel temperature (cf. Table 2-4), this figure indicates a decreasing average reactor vessel temperature; the decrease is small, being only 8 °C (14 °F) during the 18 minutes of the transient. As shown in Fig. 3-14, the exit temperature of the air is essentially constant during the transient. Combining the flow and temperature information from Figs. 3-12 and 3-14, the rate at which energy is removed via the RVACS is constant during the transient. As shown in Table 3-1, energy removal via the RVACS is small when compared with removal via the IHX for this transient.

2. Propagation of Temperature Response

The discussion in this section moves around the primary system in a complete loop, starting at the core inlet, comparing the temperature at one location with that at the next key location downstream. This will illustrate the time delays associated with transport effects and the mitigation of response by the large sodium inventory in a pool reactor concept. The spatial locations of the key points plotted are identified on Fig. 3-15; each point appears on two successive figures and a uniform temperature scale is utilized to aid in the comparisons.

The coolant temperatures in the driver fuel assemblies are shown in Fig. 3-16 at the inlet (axial plane K=3) and in the cell adjacent to the heat generating fuel (K=5). The inlet temperature is relatively constant but a definite decrease is shown in the long term; the response of the inlet temperature is explained at the end of this section. The section adjacent

to the fuel shows an initial increase during the first 5 s as the power-to-flow ratio increases; as the power-to-flow ratio decreases over the next 45 s, the coolant temperature decreases. (This early behavior is more visible in Figs. 3-3a and 3-4a.) Over the next 650 s, the power-to-flow ratio increases again but remains less than 1, so the coolant temperature rises slowly to a value lower than its initial value. The decrease in this coolant temperature after 700 s is primarily due to the decrease in assembly inlet temperature rather than changes in power-to-flow ratio (which is decreasing).

As shown in Fig. 3-17, the response at the assembly exit ($K=7$) is of the same magnitude as that at the mid-core location; the only difference is a time shift, indicative of the time required for fluid to move from one location to another. The response at the bottom-center of the UIS is identical to that at the driver fuel assembly exit, as shown in Fig. 3-18; these two locations are for adjacent computational cells, so the time delay for transport is minimal. The bottom of the UIS, therefore, experiences a temperature transient which differs little from that felt in the assemblies. The initial peak in temperature at the bottom-center of the UIS ($K=8$) is not felt at the mid-height-center of the UIS ($K=14$) as shown in Fig. 3-19a. The middle does respond to the larger decrease, but not until 30 s into the transient. In the longer term, the response in the middle lags the response at the bottom as shown in Fig. 3-19b. The slow response at the mid-UIS location (which is Point 5 or cell (1,5,14)) is explained, in part, by remembering that most core exit flow is diverted to the refueling slot (azimuthal node $J=1$) and the UIS periphery (radial node $I=4$) rather than traveling directly through the center of the UIS. The transient response is minimized further at the top of the hot pool (HP) ($K=19$), as shown in Fig. 3-20. Although this upper elevation does not experience the rather sharp decrease in temperature felt at lower elevations, the upper region is undergoing a slow cooling transient.

In contrast to the behavior at the top of the hot pool, the inlet to the IHX does experience the temperature transient, as shown in Fig. 3-21. The IHX inlet is more in the direct flow path than is the top of the hot pool, and the response more closely resembles that at the middle of the UIS. The initial response is delayed by ~35 s and the magnitude is smaller than at the mid-UIS location.

Fig. 3-22 shows the temperature response at each end of the IHX. Initially, the primary flow is decreasing faster than the intermediate flow; this leads to a relative overcooling of the primary system and a decrease in IHX exit temperature during the first 15-20 s. Between 20 and 340 s, the relative intermediate flow is smaller than the primary flow; this results in the primary system being undercooled and the exit temperature begins to rise. The rise is terminated at 150 s as the effect of the decreasing inlet temperature is propagated to the exit.

The transient temperature change at the IHX exit is substantially mitigated by the mass of sodium in the cold pool (CP). As shown in Fig. 3-23, the inlet to the fixed shield region sees only a very small temperature transient. The extrema are also delayed in time relative to their occurrences at the IHX exit. Further mitigation of the transient response is noted at the exit of the fixed shield region, as shown in Fig. 3-24. The large structural mass in this region plays a role in the mitigation. There is also some regenerative heating in this region by conduction of heat from the core bypass zone (radial node I=4) through the support cylinder. Little further mitigation occurs between the exit of the fixed shields and the pump or the core inlet plenum, as shown in Figs. 3-25 and 3-26; these figures do indicate a continued time delay in the occurrence of extrema. The long term decrease in IHX exit temperature is eventually propagated downstream to the fixed shield, pump, and core inlet plenum regions. These results, thus, indicate that the cold pool regions are undergoing a cooling transient in the long term.

3. Temperature Gradients

The temperature distribution in the primary system at full-power/full-flow steady-state conditions is characterized by a uniform cold pool, a uniform upper hot pool, and a radial distribution in the lower hot pool that diminishes with increasing elevation. This section describes how some of these characteristics change during the course of the transient. The spatial locations to be shown in transient plots are identified in Fig. 3-27.

The radial temperature gradient at the bottom of the UIS is shown in Fig. 3-28. The response in the center (CTR) follows the driver fuel assembly exit. The response at the edge (EDG) is due to a combination of exit flow from the core bypass region and lateral flow diversion from other core assembly exits from the center to the edge, as induced by the lower baffle/support plate of the UIS. Although there is some time shifting at the edge due to the lateral flow diversion and mixing processes, the bottom of the UIS experiences a radial temperature gradient which is generally decreasing during the transient. The response at mid-height of the UIS (K=14) is shown in Fig. 3-29. There is no radial temperature gradient at this elevation at steady state and only a slight gradient develops during the transient. This gradient is likely due to the fact that most of the flow is diverted to the periphery of the UIS by the baffle plates, so the edge responds faster to changes than does the center.

The radial gradients at the top of the hot pool are shown in Figs. 3-30 and 3-31, which correspond, respectively, to the pump side (J=1) and the IHX side (J=7) of the configuration. The expanded temperature scales on these figures show that only a small radial gradient develops (less than 8 °C or 13 °F) and that the pump and IHX sides of the configuration are behaving similarly.

The axial temperature gradient in the center of the hot pool is shown in Fig. 3-32. The bottom of this region (K=8) is initially 13 °C (23 °F) hotter than the top (K=19). The bottom experiences the rapid transient response of the exit flow from the assemblies, but this is not felt at the top. After the first 10 s of the transient, the bottom is always cooler than the top; the difference is 33 °C (59 °F) after 18 minutes of the transient. The axial temperature gradients in the top 2 m (7 ft) of the hot pool are shown in Figs. 3-33 and 3-34, which correspond, respectively, to the pump and IHX sides of the configuration. As seen before in the radial gradient, the two sides of the configuration respond similarly and the top level of the pool (K=19) responds very slowly to temperature changes. There is no axial temperature gradient across this space at steady state; the gradient reaches a maximum of ~60 °C (110 °F) in 4 minutes and has decreased to ~35 °C (60 °F) after 18 minutes of transient.

The temperature responses shown for the hot pool in Figs. 3-28 through 3-34 would appear to provide justification for assuming that there would be no overflow of sodium from the top of the hot pool into the gap between the reactor vessel and its liner. Although the temperature in the lower portion of the pool initially increases, the increase is small, is not sustained, and will not cause sufficient expansion of the hot pool sodium; thereafter, the hot pool is actually being cooled rather than heated.

The axial temperature gradient in the upper part of the cold pool is shown in Fig. 3-35. The solid curve is the temperature at the exit of the IHX; the chain-dot curve is the temperature 3.4 m (11 ft) below the IHX exit in the annulus between the fixed shield and the reactor vessel. The lower elevation follows the same trends as the upper elevation, but the response is delayed in time and the magnitude is smaller. As shown in Fig. 3-36, the pump side of the cold pool at this mid-height elevation generally follows the IHX side of the configuration, but experiences the transient changes of the IHX exit temperature in a much diminished manner. This diminished response on the pump side is a rather straightforward result, given the arrangement of piping which connects the pump outlet plenum to the core inlet plenum. The results in Fig. 3-36 illustrate that there is only a small azimuthal temperature gradient at mid-height in the cold pool. The temperature gradient in the lower part of the cold pool is shown in Fig. 3-37. The solid curve is for the mid-height elevation and shows the average response for the pump and IHX sides of the configuration. The chain-dot curve is for a location at the bottom center of the cold pool. This latter location is below the core inlet plenum and is relatively isolated from the various transient responses in the rest of the system. All of the cold pool temperatures shown in Figs. 3-35 through 3-37 exhibit a cooling trend and general lack of significant temperature gradients in the long term.

An overall picture of the primary system axial temperature gradient is shown in Fig. 3-38, which compares the top center of the hot pool with the bottom center of the cold pool. Both of these points respond relatively slowly to the temperature transients in the system. This overall axial gradient is generally showing a decrease during the transient. The long term results (> 700 s) indicate a general cooling trend for the entire system.

The radial temperature differences between the several material regions at the top of the reactor vessel are shown in Figs. 3-39 through 3-41. The sodium assumed to be between the reactor vessel and its liner is seen to follow the sodium at the edge of the hot pool in cooling during the transient in Fig. 3-39. The Argon between the reactor vessel and the guard vessel cools at a slower rate than the sodium, as shown in Fig. 3-40. The air in the RVACS riser remains essentially unchanged in temperature, as shown in Fig. 3-41. The temperature gradients across the tops of these three structures do not change significantly from their initial conditions.

4. Summary

The preceding subsections have presented the results of the SCRAM transient out to 18 minutes. The velocity and temperature distributions at this time are shown in Figs. 3-42 and 3-43. The velocities show a pattern similar to that existing at full-power/full-flow steady state but with a smaller magnitude corresponding to ~4% flow. The temperature distribution shows development of an axial gradient in the upper portion of the hot pool and to a lesser extent in the cold pool. These two figures represent only a snapshot at one point in the history of the transient; the system has not reached a new steady state and these distributions are, thus, continuing to change.

Although the system has not come to equilibrium, there is no need to continue the present calculation. Based on the power balance shown in Table 3-1, the power being removed by the IHX and RVACS always exceeds the power being generated in the fuel. The system is, therefore, always cooling down in a global sense. There are, however, localized temperature increases and other rapid changes; the largest of these appears to be in the core and IHX exit regions; these extrema are mitigated in the rest of the system by the large sodium inventory and the structural masses. These transient behaviors may be useful to others in evaluating the consequences of thermal shocks. As long as the present boundary conditions can be maintained, this transient appears to go smoothly from forced convection to natural convection and coolability would appear to be demonstrated.

K J = 5,3

Fig. 3-1. Guide to spatial locations (A through M) used in Figures 3-2 through 3-14

PRISM: SCRAM TRANSIENT: PUMP

Fig. 3-2. Coolant flow rate in primary pump (M) during SCRAM transient

PRISM: SCRAM TRANSIENT: DR: POWER TO FLUID & FLOW

Fig. 3-3a. Power to fluid (B) and coolant flow rate (A) in driver fuel assembly during SCRAM transient

PRISM: SCRAM TRANSIENT: DR: POWER TO FLUID & FLOW

Fig. 3-3b. Power to fluid (B) and coolant flow rate (A) in driver fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR-MID: FUEL-CL & NA

Fig. 3-4a. Fuel centerline and adjacent coolant temperatures in driver fuel assembly (B) during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR-MID: FUEL-CL & NA

Fig. 3-4b. Fuel centerline and adjacent coolant temperatures in driver fuel assembly (B) during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR: EXIT & INLET

Fig. 3-5. Exit (C) and inlet (A) coolant temperatures for driver fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: RB: POWER TO FLUID & FLOW

Fig. 3-6a. Power to fluid (E) and coolant flow rate (D) in radial blanket fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: RB: POWER TO FLUID & FLOW

Fig. 3-6b. Power to fluid (E) and coolant flow rate (D) in radial blanket fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: RB-MID: FUEL-CL & NA

Fig. 3-7a. Fuel centerline and adjacent coolant temperatures in radial blanket fuel assembly (E) during SCRAM transient.

PRISM: SCRAM TRANSIENT: RB-MID: FUEL-CL & NA

Fig. 3-7b. Fuel centerline and adjacent coolant temperatures in radial blanket fuel assembly (E) during SCRAM transient.

PRISM: SCRAM TRANSIENT: RB: EXIT & INLET

Fig. 3-8. Exit (F) and inlet (D) coolant temperatures for radial blanket fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: INLET: RRS & BYP

Fig. 3-9. Coolant flow rate in removable radial shield assembly (G) and core bypass region (I) during SCRAM transient.

PRISM: SCRAM TRANSIENT: RRS: EXIT & INLET

Fig. 3-10. Exit (H) and inlet (G) coolant temperatures for removable radial shield assemblies during SCRAM transient.

PRISM: SCRAM TRANSIENT: BYP: EXIT & INLET

Fig. 3-11. Exit (J) and inlet (I) coolant temperatures for core bypass region during SCRAM transient.

PRISM: SCRAM TRANSIENT: INLET: RVACS & IHX(INT)

Fig. 3-12. Coolant flow rate through RVACS (K) and intermediate loop side of IHX during SCRAM transient.

PRISM: SCRAM TRANSIENT: IHX(INT): EXIT & INLET

Fig. 3-13. Exit and inlet coolant temperatures for intermediate loop side of IHX during SCRAM transient.

Fig. 3-14. Exit (L) and inlet (K) coolant temperatures for RVACS during SCRAM transient.

Fig. 3-15. Guide to spatial locations (1 through 12) used in Figures 3-16 through 3-26.

PRISM: SCRAM TRANSIENT: DR: MID & INLET

Fig. 3-16. Coolant temperatures at mid-elevation (2) and inlet (1) for driver fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR: EXIT & MID

Fig. 3-17. Coolant temperatures at exit (3) and mid-elevation (2) for driver fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: UIS-BOT-CTR & DR-EXIT

Fig. 3-18. Coolant temperatures at bottom center of UIS (4) and exit of driver fuel assembly (3) during SCRAM transient.

PRISM: SCRAM TRANSIENT: UIS: MID-CTR & BOT-CTR

Fig. 3-19a. Coolant temperatures at mid-elevation (5) and bottom (4) in radial center of UIS during SCRAM transient

PRISM: SCRAM TRANSIENT: UIS: MID-CTR & BOT-CTR

Fig. 3-19b. Coolant temperatures at mid-elevation (5) and bottom (4) in radial center of UIS during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP-TOP-CTR & UIS-MID-CTR

Fig. 3-20. Coolant temperatures at top of hot pool (6) and mid-elevation of UIS (5) in radial center of primary system during SCRAM transient.

PRISM: SCRAM TRANSIENT: IHX(PRI)-INLET & HP-TOP-CTR

Fig. 3-21. Coolant temperatures at IHX primary side inlet (Avg. 7 and 8) and top center of hot pool (6) during SCRAM transient.

PRISM: SCRAM TRANSIENT: IHX(PRI): INLET & EXIT

Fig. 3-22. Coolant temperatures at inlet (Avg. 7 and 8) and exit (9) of IHX primary side during SCRAM transient.

Fig. 3-23. Coolant temperatures at fixed shield inlet (10) and IHX primary side exit (9) during SCRAM transient.

PRISM: SCRAM TRANSIENT: FS: EXIT & INLET

Fig. 3-24. Coolant temperatures at exit (11) and inlet (10) of fixed shield region during SCRAM transient.

PRISM: SCRAM TRANSIENT: PUMP & FS-EXIT

Fig. 3-25. Coolant temperatures in primary pump duct (12) and at exit of fixed shield region (11) during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR-INLET & PUMP

Fig. 3-26. Coolant temperatures at driver fuel assembly inlet (1) and in primary pump duct (12) during SCRAM transient.

$J = 7, 3$

$J = 5, 1$

Fig. 3-27. Guide to spatial locations (a through q) used in Figs. 3-28 through 3-41.

PRISM: SCRAM TRANSIENT: UIS-BOT: CTR & EDG

Fig. 3-28a. Coolant temperatures at bottom of UIS at radial center (d) and edge (e) during SCRAM transient.

PRISM: SCRAM TRANSIENT: UIS-BOT: CTR & EDG

Fig. 3-28b. Coolant temperatures at bottom of UIS at radial center (d) and edge (e) during SCRAM transient.

PRISM: SCRAM TRANSIENT: UIS-MID: CTR & EDG

Fig. 3-29. Coolant temperatures at mid-elevation of UIS at radial center (g) and edge (h) during SCRAM transient.

Fig. 3-30. Coolant temperatures at top of hot pool at radial center (k) and edge on pump side (1) during SCRAM transient.

Fig. 3-31. Coolant temperatures at top of hot pool at radial center (k) and edge on IHX side (n) during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP-CTR: TOP & BOT

Fig. 3-32. Coolant temperatures in radial center of hot pool at top (k) and bottom (d) during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP(PUMP): K=19 & 17

Fig. 3-33. Coolant temperatures at edge of upper hot pool on pump side at top of pool (1) and horizontal baffle (i) during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP(IHX): K=19 & 17

Fig. 3-34. Coolant temperatures at edge of upper hot pool on IHX side at top of pool (n) and IHX inlet (j) during SCRAM transient.

PRISM: SCRAM TRANSIENT: IHX(PRI)-EXIT & CP-MID-EDG(IHX)

Fig. 3-35. Coolant temperatures at edge of upper cold pool on IHX side at IHX exit (f) and mid-elevation in pool (c) during SCRAM transient.

Fig. 3-36. Coolant temperatures at edge of cold pool at mid-elevation on pump side (b) and IHX side (c) during SCRAM transient.

Fig. 3-37. Coolant temperatures in cold pool at mid-elevation edge (Avg. b and c) and bottom center (a) during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP-TOP-CTR & CP-BOT-CTR

Fig. 3-38. Coolant temperatures in radial center at top of hot pool (k) and bottom of cold pool (a) during SCRAM transient.

PRISM: SCRAM TRANSIENT: TOP: HP-EDG & OVFLW

Fig. 3-39. Coolant temperatures at top of system at edge of hot pool (m) and in gap between reactor vessel and its liner (o) during SCRAM transient.

PRISM: SCRAM TRANSIENT: TOP: OVFLW & ARGON

Fig. 3-40. Coolant temperatures at top of system in gaps between reactor vessel and its liner (o) and reactor and guard vessels (p) during SCRAM transient.

PRISM: SCRAM TRANSIENT: TOP: ARGON & AIR

Fig. 3-41. Coolant temperatures at top of system in gaps between reactor and guard vessels (p) and guard vessel and collector cylinder (q) during SCRAM transient.

Fig. 3-42. Coolant velocity distribution in primary system after 1072 s of SCRAM transient.

40	40	42	44	46	48	50	52	53	55	56	58	61	62	63	65	67	69	71	73	74
41	42	43	47	52	54	54	56	58	61	64	64	67	68	69	71	74	76	78	80	82
301	316	300	300	299	297	296	306	274	272	284	297	310	326	346	358	358	356	418	429	
302	315	301	309	312	312	291	290	276	272	284	287	310	326	346	358	358	395	420	428	
302	315	301	306	312	315	297	304	277	272	284	297	310	326	346	358	358	394	420	427	
302	315	317	318	333	338	338	389	390	390	391	391	391	391	391	391	391	392	394	421	427
302	315	316	320	373	375	375	392	390	391	391	391	391	391	391	391	391	392	394	420	428
303	315	316	319	382	383	383	392	390	391	391	391	391	391	391	391	391	392	395	419	428
304	315	316	317	395	395	395	395	392	391	391	391	391	391	391	391	391	392	395	420	428
305	316	316	318	395	395	395	395	392	391	391	391	391	391	391	391	391	392	395	420	429
304	316	317	319	382	383	383	393	392	391	391	391	391	391	391	391	391	392	394	420	429
304	316	317	320	373	375	375	393	391	391	391	391	391	391	391	391	391	392	394	421	427
303	316	317	319	353	356	359	380	390	391	391	391	391	391	391	391	391	391	394	421	427
303	316	303	307	311	313	314	323	323	324	324	317	316	317	316	317	316	391	394	421	427
303	316	304	308	310	312	314	314	314	314	315	315	315	315	315	315	315	391	394	421	427
303	316	304	304	305	306	315	322	323	323	324	317	316	317	316	317	316	391	394	421	427
40	42	43	47	52	54	54	56	58	61	64	64	67	68	69	71	74	76	78	80	82
41	42	43	47	52	54	54	56	58	61	64	64	67	68	69	71	74	76	78	80	82
40	41	42	44	48	50	50	52	53	55	56	58	61	62	63	65	67	69	71	73	74
41	42	43	47	52	54	54	56	58	61	64	64	67	68	69	71	74	76	78	80	82
40	41	42	44	48	50	50	52	53	55	56	58	61	62	63	65	67	69	71	73	74

J = 7,3

Fig. 3-43. Coolant temperature [°C] distribution in configuration after 1072 s of SCRAM transient.

TABLE 3-1. SCRAM Transient Power Balance

Time [s]	Source (DR + RB)		Loss		
	Generate in Fuel [MW]	Transfer to Fluid [MW]	IHX [MW]	RVACS [MW]	IHX + RVACS [MW]
0	425	425	-424	-0.71	-425
1	75	310	-404	-0.71	-404
2	47	249	-366	-0.71	-367
5	34	162	-239	-0.71	-239
10	29	88	-163	-0.71	-164
30	21	29	- 78	-0.71	- 79
60	15	17	- 38	-0.71	- 39
120	13.8	13.5	- 24.1	-0.71	- 24.9
300	10.8	10.5	- 20.7	-0.71	- 21.4
600	9.2	9.1	- 17.3	-0.70	- 18.0
908	8.5	8.5	- 16.1	-0.70	- 16.8
1058	8.3	8.4	- 16.0	-0.70	- 16.7

IV. RESULTS CALCULATED FOR THE RVACS TRANSIENT

The COMMIX-1AR computer code has been used to calculate the first 20 minutes of this transient. The results presentation is divided into four subsections: key global results; propagation of temperature changes around the primary system; development of and changes in thermal gradients; and a final summary section. The figures in this section present temperatures in units of degrees Celsius [$^{\circ}\text{C}$]; an alternate set of figures using units of degrees Fahrenheit [$^{\circ}\text{F}$] is included as Appendix B.

1. Key Global Quantities

Selected quantities of general interest are presented in this section. A reference guide to the spatial locations at which results will be shown is provided in Fig. 4-1.

The flow through the primary pump is shown in Fig. 4-2. The quantity shown for flow in this and other figures is actually the velocity normalized to the steady-state value; this quantity is representative of the relative mass flow but does not include the effect of coolant density changes during the transient. The initial decrease in flow is quite rapid, reaching 50% flow in only 1.5 s. The flow decrease then becomes more gradual, reaching 10% flow in 115 s. Following total loss of pump driving head at 700 s, the primary sodium flow rate of ~2% is in a natural convection mode. The thermal gradients driving this natural convection flow are continuing to develop after 700 s, as indicated by the slowly increasing flow shown in Fig. 4-2 after this time.

The power and flow in the driver (DR) fuel assemblies are shown in Fig. 4-3. The power shown here is that transferred to the fluid. As shown in Table 4-1, this value exceeds the power generated in the fuel during the first minute of the transient; this difference represents a cooling of the fuel and release of energy stored in the fuel at steady state. After the first minute, the situation is in quasi-equilibrium since the power transferred to the sodium closely matches the power generated in the fuel. This table serves as a reminder of the dynamics involved in cooling the core during a transient. The coolant flow through the driver fuel assemblies shown in Fig. 4-3 follows the flow coastdown shown for the primary pump in Fig. 4-2. The expanded time

scale used in Fig. 4-3a shows that the relative power-to-flow ratio is less than 1 except for the first 5 s. As shown in Fig. 4-4a, this condition leads to an initial peak in coolant temperature during the first 5 s; this peak is small, being only 34 °C (61 °F). Also shown in Fig. 4-4 is the fuel temperature at the fuel centerline; the rapid decrease in fuel temperature is indicative of the power imbalance shown in Table 4-1. (Recall that this calculation is for an oxide fuel core; the fuel temperature and initial stored energy for a metal fuel core would be smaller than the oxide fuel numbers due to the high thermal conductivity of metal fuel.) At longer times, the temperature difference between the fuel and coolant remains relatively constant (but gradually decreasing), as shown in Fig. 4-4b. This is a graphical representation of the quasi-equilibrium situation mentioned above. The inlet and exit coolant temperatures are shown in Fig. 4-5. The exit temperature initially increases over the first 5 s, decreases over the next 55 s, and then increases slowly over the remainder of the transient. The first minute of this response is consistent with the power-to-flow ratio behavior (cf. Fig. 4-3a) which increases during the first 2 s, decreases over the next 55 s, and then begins increasing again. The increase in exit temperature after the first minute is due to the combined effects of an inlet temperature increase of ~25°C (45°F) over 600 s and the power-to-flow ratio which continues to increase until 700 s. This last peak in power-to-flow ratio is initially reflected as a peak in the temperature of the coolant adjacent to the heat generating fuel (cf. Fig. 4-4b); thermal transport and inertia effects delay the response at the exit (cf. Fig. 4-5). The behavior of the inlet temperature and the relation between inlet and exit temperature will be discussed further in Sec. IV.2.

The key results for the radial blanket (RB) fuel assemblies are shown in Figs. 4-6 through 4-8. The results for power, flow, and temperatures are generally similar to those shown in Figs. 4-3 through 4-5 for the driver fuel assemblies. The temperatures in the radial blanket are generally smaller than those in the driver (except for the inlet temperature, which is essentially the same in the two regions). An exception to this similarity in behavior is the behavior of the coolant flow rate which decreases to a smaller relative value in the radial blanket fuel assemblies than in the driver fuel assemblies (cf. Fig. 4-6b vs. 4-3b). This flow rate decrease causes the power-to-flow ratio in the radial blanket fuel assemblies to exceed 1.0 after 400 s. The

near stagnation of flow in these assemblies does not lead to excessively high temperatures during this part of the transient.

The flows and temperatures for the removable radial shield (RRS) assemblies and the core bypass (BYP) region are shown in Figs. 4-9 through 4-11. The mass flow through these regions follows the transient behavior shown for the pump in Fig. 4-2 for the first 400 s. After this time the coolant flow rates in the removable radial shield assemblies and the core bypass region continue to decrease but at a rate which is faster than in the pump region. Flow reversal occurs at 510 s in the core bypass region and at 630 s in the removable radial shield assemblies. The reversal is short term (180 s) in the removable radial shield assemblies but persists in the core bypass region for the rest of the history shown in Fig. 4-9. The occurrence of flow reversal indicates a temporary decrease in the driving pressure across these two regions. This does not appear to have severe consequences, since neither region contains heat generating solids. Both regions do exchange energy with adjacent regions. This energy exchange results in the temperature at the exit of the removable radial shield assemblies following that at the exit of the radial blanket fuel assemblies (cf. Fig. 4-10 vs. 4-8). Similarly the exchange of energy with the removable radial shield assemblies and the fixed shield region affects the temperature at the top of the core bypass region, as shown in Fig. 4-11; the change in slope of the exit temperature curve at 510 s is due to reversal of flow in this region. The inlet temperature for the removable radial shield assemblies and the core bypass region follow those shown previously for the two fuel assembly regions.

The inlet flow rate for the intermediate side of the IHX is shown in Fig. 4-12. This is just the graphical presentation of the boundary condition described in Sec. II.2, which is a rapid decrease of flow to zero during the first 2 s. The inlet and exit temperatures will not be shown since they have little significance under this zero-flow condition. As indicated in Sec. II.2, there is a certain amount of residual mass flow across the exit of the intermediate side of the IHX following cessation of flow at the inlet. This is due to the expansion (or contraction) of the sodium contained within the intermediate side of the IHX as it is heated (or cooled) by the primary side. There is an energy flow associated with this residual mass flow, and this is shown in Table 4-1. Although the values may seem significant with

respect to the core power generation or the power removed by the RVACS, the rate has no significant effect with regard to cooling (or heating) of the primary system; instead, it is energy flow associated with a non-zero net mass flow on the intermediate side of the IHX.

The air flow rate in the RVACS is shown in Fig. 4-13. This flow increases slightly (6%) during the first 10 minutes of the transient. Since this flow is an increasing function of the reactor vessel temperature (cf. Table 2-4), this figure indicates an increasing average reactor vessel temperature; the increase is moderate, being 28°C (51°F) during this time. The increase in reactor vessel temperature is a result of increasing temperatures in the primary side of the IHX and in the cold pool, since these regions are coupled thermally to the reactor vessel. As shown in Fig. 4-14, the exit temperature of the air is essentially constant during the transient. Combining the flow and temperature information from Figs. 4-13 and 4-14, the rate at which energy is removed via the RVACS is approximately constant during the transient. As shown in Table 4-1, the RVACS, which is essentially the only energy removal path during this transient, is removing energy at a rate which is small when compared with the generation rate during the first 20 minutes of this transient.

2. Propagation of Temperature Response

The discussion in this section moves around the primary system in a complete loop, starting at the core inlet, comparing the temperature at one location with that at the next key location downstream. This will illustrate the time delays associated with transport effects and the mitigation of response by the large sodium inventory in a pool reactor concept. The spatial locations of the key points plotted are identified on Fig. 4-15; each point appears on two successive figures and a uniform temperature scale is utilized to aid in the comparisons.

The coolant temperatures in the driver fuel assemblies are shown in Fig. 4-16 at the inlet (axial plane K=3) and in the cell adjacent to the heat generating fuel (K=5). The inlet temperature is relatively constant during the first 75 s but then increases by ~25°C (45°F) during the next 425 s and shows a continued slow increase in the long term; the response of the inlet

temperature is explained at the end of this section. The section adjacent to the fuel shows an initial increase during the first 5 s as the power-to-flow ratio increases; as the power-to-flow ratio decreases over the next 55 s, the coolant temperature decreases. (This early behavior is more visible in Figs. 4-3a and 4-4a.) Over the next 750 s, the mid-elevation temperature increases substantially due to the combined increases in power-to-flow ratio and inlet temperature; the decrease after 800 s is due to a decrease in power-to-flow ratio, which peaked at ~700 s.

As shown in Fig. 4-17, the response at the assembly exit ($K=7$) is somewhat diminished in magnitude and delayed in time relative to the response at the mid-core location; this response is a result of fluid mixing and transport time effects. The response at the bottom-center of the UIS is identical to that at the driver fuel assembly exit, as shown in Fig. 4-18; these two locations are for adjacent computational cells, so the time delay for transport is minimal. The bottom of the UIS, therefore, experiences a temperature transient which is only slightly less severe than that experienced within the assemblies. The initial peak in temperature at the bottom-center of the UIS ($K=8$) is not felt at the mid-height-center of the UIS ($K=14$) as shown in Fig. 4-19a. The middle does respond to the larger decrease, but not until 30 s into the transient. In the longer term, the response in the middle lags the response at the bottom as shown in Fig. 4-19b. The slow response at the mid-UIS location (which is Point 5 or cell (1,5,14)) is explained, in part, by remembering that most core exit flow is diverted to the refueling slot (azimuthal node $J=1$) and the UIS periphery (radial node $I=4$) rather than traveling directly through the center of the UIS. The transient response is minimized further at the top of the hot pool (HP) ($K=19$), as shown in Fig. 4-20. Although this upper elevation does not experience the rather sharp decrease in temperature felt at lower elevations, the upper region is undergoing a slow cooling transient during most of the history shown here. After 18 minutes, the temperature at the top of the hot pool stops decreasing and begins increasing, finally responding to the heating trend which has been occurring at the bottom of the hot pool since 3 minutes into the transient.

In contrast to the behavior at the top of the hot pool, the inlet to the IHX does experience the temperature transient, as shown in Fig. 4-21. The IHX inlet is more in the direct flow path than is the top of the hot pool, and the

response more closely resembles that at the middle of the UIS. The initial response is delayed by ~35 s and the magnitude is smaller than at the mid-UIS location. Between 800 and 1200 s, the IHX inlet temperature is within 5°C (9°F) of the mid-center UIS temperature.

Figure 4-22 shows the temperature response at each end of the IHX. The initial (first 100 s) increase in the IHX exit temperature is indicative of the rapid total loss of energy removal capability on the intermediate side. The later response at the exit is following that at the inlet, with a time delay for transient effects and showing some degree of energy exchange through the IHX casing with the rest of the primary system.

The transient temperature change at the IHX exit is substantially mitigated by the mass of sodium in the cold pool (CP). As shown in Fig. 4-23, the inlet to the fixed shield region sees only a small (25°C or 45°F) temperature increase. The maximum temperature is also delayed in time relative to its occurrence at the IHX exit. Little further mitigation of the magnitude of the transient response is noted at the fixed shield exit, in the pump duct, or in the core inlet plenum, as shown in Figs. 4-24 through 4-26. There is a distinct time delay in the response at successive downstream locations. The majority of the temperature increase in these regions occurs between 50 and 500 s in the transient; however, these temperatures continue to increase at a slow rate in the long term.

3. Temperature Gradients

The temperature distribution in the primary system at full-power/full-flow steady-state conditions is characterized by a uniform cold pool, a uniform upper hot pool, and a radial distribution in the lower hot pool that diminishes with increasing elevation. This section describes how some of these characteristics change during the course of the transient. The spatial locations to be shown in transient plots are identified in Fig. 4-27.

The radial temperature gradient at the bottom of the UIS is shown in Fig. 4-28. The response in the center (CTR) follows the driver fuel assembly exit for the entire history. The initial response at the edge (EDG) is due to a combination of exit flow from the core bypass region and lateral flow

diversion from other core assembly exits from the center to the edge, as induced by the lower baffle/support plate of the UIS. The initial response at the edge lags that in the center, resulting in the edge being somewhat hotter than the center from 8 to 125 s. After approximately 450 s, the response at the edge is altered by reversal of flow in the removable radial shield assemblies and the core bypass region. This results in a long term radial temperature gradient which is approximately twice the steady-state value. The response at mid-height of the UIS ($K=14$) is shown in Fig. 4-29. There is no radial temperature gradient at this elevation at steady state and only a slight gradient develops during the transient. This gradient is likely due to the fact that most of the flow is diverted to the periphery of the UIS by the baffle plates, so the edge responds faster to changes than does the center.

The radial gradients at the top of the hot pool are shown in Figs. 4-30 and 4-31, which correspond, respectively, to the pump side ($J=1$) and the IHX side ($J=7$) of the configuration. The expanded temperature scales on these figures show that only a small radial gradient develops (less than 8°C or 13°F) and that the pump and IHX sides of the configuration are behaving similarly.

The axial temperature gradient in the center of the hot pool is shown in Fig. 4-32. The bottom of this region ($K=8$) is initially 13°C (23°F) hotter than the top ($K=19$). The bottom experiences the rapid transient response of the exit flow from the assemblies, but this is not felt at the top. Between 10 and 800 s, the bottom is cooler than the top by as much as 110°C (200°F). After 18 to 20 minutes, the bottom is approximately 30°C (55°F) hotter than the top and the directions of further temperature changes at the two elevations appears to have reversed. The axial temperature gradients in the top 2 m (7 ft) of the hot pool are shown in Figs. 4-33 and 4-34, which correspond, respectively, to the pump and IHX sides of the configuration. As seen before in the radial gradient, the two sides of the configuration respond similarly and the top level of the pool ($K=19$) responds very slowly to temperature changes. There is no axial temperature gradient across this space at steady state; the gradient reaches a maximum of $\sim 55^{\circ}\text{C}$ (100°F) in 5 minutes and has decreased to $\sim 10^{\circ}\text{C}$ (20°F) after 20 minutes of transient.

The temperature responses shown for the hot pool in Figs. 4-28 through 4-34 would appear to provide justification for assuming that there would be no

overflow of sodium from the top of the hot pool into the gap between the reactor vessel and its liner. Although the temperature in the lower portion of the pool initially increases, the increase is small, is not sustained, and will not cause sufficient expansion of the hot pool sodium; thereafter, the combination of slow increases and decreases in temperature would appear to result in a hot pool temperature which is cooler than the initial temperature during this 20 minute transient history.

The axial temperature gradient in the upper part of the cold pool is shown in Fig. 4-35. The solid curve is the temperature at the exit of the IHX; the chain-dot curve is the temperature 3.4 m (11 ft) below the IHX exit in the annulus between the fixed shield and the reactor vessel. The lower elevation follows the same trends as the upper elevation, but the response is delayed in time and the magnitude is smaller. A relatively constant temperature difference ($\sim 35^{\circ}\text{C}$ or 60°F) between these two elevations is present after approximately 10 minutes. As shown in Fig. 4-36, the pump side of the cold pool at this mid-height elevation closely follows the IHX side of the configuration. The slight delay in response on the pump side is a rather straightforward result, given the arrangement of piping which connects the pump outlet plenum to the core inlet plenum. The results in Fig. 4-36 illustrate that there is essentially no azimuthal temperature gradient at mid-height in the cold pool. The temperature gradient in the lower part of the cold pool is shown in Fig. 4-37. The solid curve is for the mid-height elevation and shows the average response for the pump and IHX sides of the configuration. The chain-dot curve is for a location at the bottom center of the cold pool. This latter location is below the core inlet plenum and is relatively isolated from the various transient responses in the rest of the system; this region is showing a gradual increase in temperature in response to the increases experienced at the higher elevations in the cold pool. The results in Fig. 4-37 also indicate the potential for a temperature gradient to be established in the lower cold pool. Based on the results shown in Figs. 4-35 through 4-37, the cold pool is at a temperature higher than its initial condition during this transient and an axial temperature gradient has developed. These results do not establish that a heating trend necessarily continues beyond 20 minutes, since the time derivatives of the temperatures are so small (although, they are positive).

An overall picture of the primary system axial temperature gradient is shown in Fig. 4-38, which compares the top center of the hot pool with the bottom center of the cold pool. Both of these points respond relatively slowly to the temperature transients in the system. This overall axial gradient is generally showing a decrease during the transient. The upper elevation is showing a cooling trend for the first 18 minutes, followed by a heating trend. The lower elevation shows a continued heating trend during the 20 minute history.

The radial temperature differences between the several material regions at the top of the reactor vessel are shown in Figs. 4-39 through 4-41. The sodium assumed to be between the reactor vessel and its liner is seen to follow the sodium at the edge of the hot pool in cooling during the transient in Fig. 4-39. The Argon between the reactor vessel and the guard vessel cools at a slower rate than the sodium, as shown in Fig. 4-40. The air in the RVACS riser remains essentially unchanged in temperature, as shown in Fig. 4-41. The temperature gradients across the tops of these three structures do not change significantly from their initial conditions.

4. Summary

The preceding subsections have presented the results of the RVACS transient out to 20 minutes. The velocity and temperature distributions at this time are shown in Figs. 4-42 and 4-43. Important differences in the velocity distribution after 20 minutes with respect to its initial condition include: (a) the smaller overall magnitude corresponding to ~2% flow; (b) a circulation pattern on the periphery of the UIS (cells (4,1-8,8-19)), which is upward on the hotter IHX side (azimuthal cells J = 6-8) and downward on the cooler pump side (J = 1-5); (c) the small magnitude reverse flow in the core bypass region (cells (4,1-8,3-7)); and (d) a reverse flow in the inner portion of the fixed shield region (cells (5,1-8,3-6)). The temperature distribution shows development of an axial gradient in the cold pool and to a lesser extent in the upper portion of the hot pool. These two figures represent only a snapshot at one point in the history of the transient; the system has not reached a new steady state and these distributions are, thus, continuing to change.

Based on the power balance shown in Table 4-1, the power being generated in the fuel always exceeds the power being removed via the RVACS (which is the only means of cooling the primary system after 2 s). The system is, thus, always heating up in a global sense during the first 20 minutes of this transient. Superimposed on this global heating are localized temperature increases and other rapid changes; the largest of these appears to be in the core and IHX exit regions; these extrema are mitigated in the rest of the system by the large sodium inventory and the structural masses. These transient behaviors may be useful to others in evaluating the consequences of thermal shocks. Flow reversals occurred in the removable radial shield assemblies and the core bypass region during the transition from forced to natural circulation flow in the primary system; these reversals do not appear to be a cause for concern. The continued global heating of the system should eventually lead to an increased energy removal rate via the RVACS. A one-dimensional analysis estimates⁶ that the power removal via the RVACS will not exceed the power generation in the fuel until 30 hours into the transient. The present history calculated using COMMIX is much too short to address this long term behavior and, thus, the calculation needs to be continued.

Fig. 4-1. Guide to spatial locations (A through M) used in Figures 4-2 through 4-14.

PRISM: RVACS TRANSIENT: PUMP

Fig. 4-2. Coolant flow rate in primary pump (M) during RVACS transient

PRISM: RVACS TRANSIENT: DR: POWER TO FLUID & FLOW

Fig. 4-3a. Power to fluid (B) and coolant flow rate (A) in driver fuel assembly during RVACS transient

PRISM: RVACS TRANSIENT: DR: POWER TO FLUID & FLOW

Fig. 4-3b. Power to fluid (B) and coolant flow rate (A) in driver fuel assembly during RVACS transient.

PRISM: RVACS TRANSIENT: DR-MID: FUEL-CL & NA

Fig. 4-4a. Fuel centerline and adjacent coolant temperatures in driver fuel assembly (B) during RVACS transient.

PRISM: RVACS TRANSIENT: DR-MID: FUEL-CL & NA

Fig. 4-4b. Fuel centerline and adjacent coolant temperatures in driver fuel assembly (B) during RVACS transient.

PRISM: RVACS TRANSIENT: DR: EXIT & INLET

Fig. 4-5. Exit (C) and inlet (A) coolant temperatures for driver fuel assembly during RVACS transient.

PRISM: RVACS TRANSIENT: RB: POWER TO FLUID & FLOW

Fig. 4-6a. Power to fluid (E) and coolant flow rate (D) in radial blanket fuel assembly during RVACS transient.

PRISM: RVACS TRANSIENT: RB: POWER TO FLUID & FLOW

Fig. 4-6b. Power to fluid (E) and coolant flow rate (D) in radial blanket fuel assembly during RVACS transient.

PRISM: RVACS TRANSIENT: RB-MID: FUEL-CL & NA

Fig. 4-7a. Fuel centerline and adjacent coolant temperatures in radial blanket fuel assembly (E) during RVACS transient.

PRISM: RVACS TRANSIENT: RB-MID: FUEL-CL & NA

Fig. 4-7b. Fuel centerline and adjacent coolant temperatures in radial blanket fuel assembly (E) during RVACS transient.

PRISM: RVACS TRANSIENT: RB: EXIT & INLET

Fig. 4-8. Exit (F) and inlet (D) coolant temperatures for radial blanket fuel assembly during RVACS transient.

PRISM: RVACS TRANSIENT: INLET: RRS & BYP

Fig. 4-9. Coolant flow rate in removable radial shield assembly (G) and core bypass region (I) during RVACS transient.

PRISM: RVACS TRANSIENT: RRS: EXIT & INLET

Fig. 4-10. Exit (H) and inlet (G) coolant temperatures for removable radial shield assemblies during RVACS transient.

Fig. 4-11. Exit (J) and inlet (I) coolant temperatures for core bypass region during RVACS transient.

PRISM: RVACS TRANSIENT: IHX(INT) INLET

Fig. 4-12. Coolant flow rate through intermediate loop side of IHX during RVACS transient.

PRISM: RVACS TRANSIENT: INLET: RVACS & IHX(INT)

Fig. 4-13. Coolant flow rate through RVACS (K) and intermediate loop side of IHX during RVACS transient.

PRISM: RVACS TRANSIENT: RVACS(AIR): EXIT & INLET

Fig. 4-14. Exit (L) and inlet (K) coolant temperatures for RVACS during RVACS transient.

Fig. 4-15. Guide to spatial locations (1 through 12) used in Figures 4-16 through 4-26.

PRISM: RVACS TRANSIENT: DR: MID & INLET

Fig. 4-16. Coolant temperatures at mid-elevation (2) and inlet (1) for driver fuel assembly during RVACS transient.

Fig. 4-17. Coolant temperatures at exit (3) and mid-elevation (2) for driver fuel assembly during RVACS transient.

Fig. 4-18. Coolant temperatures at bottom center of UIS (4) and exit of driver fuel assembly (3) during RVACS transient.

Fig. 4-19a. Coolant temperatures at mid-elevation (5) and bottom (4) in radial center of UIS during RVACS transient

PRISM: RVACS TRANSIENT: UIS: MID-CTR & BOT-CTR

Fig. 4-19b. Coolant temperatures at mid-elevation (5) and bottom (4) in radial center of UIS during RVACS transient.

PRISM: RVACS TRANSIENT: HP-TOP-CTR & UIS-MID-CTR

Fig. 4-20. Coolant temperatures at top of hot pool (6) and mid-elevation of UIS (5) in radial center of primary system during RVACS transient.

PRISM: RVACS TRANSIENT: IHX(PRI)-INLET & HP-TOP-CTR

Fig. 4-21. Coolant temperatures at IHX primary side inlet (Avg. 7 and 8) and top center of hot pool (6) during RVACS transient.

PRISM: RVACS TRANSIENT: IHX(PRI): INLET & EXIT

Fig. 4-22. Coolant temperatures at inlet (Avg. 7 and 8) and exit (9) of IHX primary side during RVACS transient.

Fig. 4-23. Coolant temperatures at fixed shield inlet (10) and IHX primary side exit (9) during RVACS transient.

PRISM: RVACS TRANSIENT: FS: EXIT & INLET

Fig. 4-24. Coolant temperatures at exit (11) and inlet (10) of fixed shield region during RVACS transient.

Fig. 4-25. Coolant temperatures in primary pump duct (12) and at exit of fixed shield region (11) during RVACS transient.

PRISM: RVACS TRANSIENT: DR-INLET & PUMP

Fig. 4-26. Coolant temperatures at driver fuel assembly inlet (1) and in primary pump duct (12) during RVACS transient.

$J = 7, 3$

$J = 5, 1$

Fig. 4-27. Guide to spatial locations (a through q) used in Figs. 4-28 through 4-41.

PRISM: RVACS TRANSIENT: UIS-BOT: CTR & EDG

Fig. 4-28a. Coolant temperatures at bottom of UIS at radial center (d) and edge (e) during RVACS transient.

PRISM: RVACS TRANSIENT: UIS-BOT: CTR & EDG

Fig. 4-28b. Coolant temperatures at bottom of UIS at radial center (d) and edge (e) during RVACS transient.

PRISM: RVACS TRANSIENT: UIS-MID: CTR & EDG

Fig. 4-29. Coolant temperatures at mid-elevation of UIS at radial center (g) and edge (h) during RVACS transient.

Fig. 4-30. Coolant temperatures at top of hot pool at radial center (k) and edge on pump side (l) during RVACS transient.

PRISM: RVACS TRANSIENT: HP-TOP: CTR & EDG(IHX)

Fig. 4-31. Coolant temperatures at top of hot pool at radial center (k) and edge on IHX side (n) during RVACS transient.

PRISM: RVACS TRANSIENT: HP-CTR: TOP & BOT

Fig. 4-32. Coolant temperatures in radial center of hot pool at top (k) and bottom (d) during RVACS transient.

PRISM: RVACS TRANSIENT: HP(PUMP): K=19 & 17

Fig. 4-33. Coolant temperatures at edge of upper hot pool on pump side at top of pool (1) and horizontal baffle (i) during RVACS transient.

PRISM: RVACS TRANSIENT: HP(IHX): K=19 & 17

Fig. 4-34. Coolant temperatures at edge of upper hot pool on IHX side at top of pool (n) and IHX inlet (j) during RVACS transient.

PRISM: RVACS TRANSIENT: IHX(PRI)-EXIT & CP-MID-EDG(IHX)

Fig. 4-35. Coolant temperatures at edge of upper cold pool on IHX side at IHX exit (f) and mid-elevation in pool (c) during RVACS transient.

PRISM: RVACS TRANSIENT: CP-MID-EDG: PUMP & IHX

Fig. 4-36. Coolant temperatures at edge of cold pool at mid-elevation on pump side (b) and IHX side (c) during RVACS transient.

PRISM: RVACS TRANSIENT: CP: MID-EDG & BOT-CTR

Fig. 4-37. Coolant temperatures in cold pool at mid-elevation edge (Avg. b and c) and bottom center (a) during RVACS transient.

PRISM: RVACS TRANSIENT: HP-TOP-CTR & CP-BOT-CTR

Fig. 4-38. Coolant temperatures in radial center at top of hot pool (k) and bottom of cold pool (a) during RVACS transient.

PRISM: RVACS TRANSIENT: TOP: HP--EDG & OVFLW

Fig. 4-39. Coolant temperatures at top of system at edge of hot pool (m) and in gap between reactor vessel and its liner (o) during RVACS transient.

PRISM: RVACS TRANSIENT: TOP: OVFLW & ARGON

Fig. 4-40. Coolant temperatures at top of system in gaps between reactor vessel and its liner (o) and reactor and guard vessels (p) during RVACS transient.

PRISM: RVACS TRANSIENT: TOP: ARGON & AIR

Fig. 4-41. Coolant temperatures at top of system in gaps between reactor and guard vessels (p) and guard vessel and collector cylinder (q) during RVACS transient.

Fig. 4-42. Coolant velocity distribution in primary system after 1200 s of RVACS transient.

40	40	41	44	48	49	51	53	55	57	60	61	62	64	66	68	70	71	73
41	42	43	47	52	54	56	58	61	64	66	68	69	71	73	75	77	79	81
337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337
338	350	353	360	363	369	378	391	395	397	401	405	406	410	413	417	420	423	427
338	350	350	348	347	348	377	394	394	397	401	405	406	410	413	417	420	423	428
338	350	346	343	344	347	378	391	394	397	401	406	408	410	413	417	421	423	424
338	349	349	334	355	358	376	434	427	424	422	422	421	422	422	422	422	422	422
336	349	349	337	415	406	401	443	417	416	418	419	419	420	420	420	421	422	424
337	349	348	340	438	425	416	448	419	416	417	418	419	420	421	419	421	422	426
338	349	349	346	464	461	454	454	432	417	417	418	420	420	421	421	421	421	423
337	349	350	347	465	481	454	453	430	419	422	419	422	422	423	423	422	422	423
336	350	350	341	436	426	415	435	416	416	418	419	420	421	422	422	421	422	422
335	350	350	338	418	406	399	416	416	417	419	420	420	420	420	421	421	422	424
334	350	350	335	354	355	363	416	417	418	419	418	420	420	420	421	421	422	428
340	351	345	344	345	347	348	347	348	348	349	349	351	349	351	349	351	349	351
340	352	348	348	348	348	348	348	348	347	347	347	347	347	347	347	347	347	347
338	352	355	359	365	367	350	348	348	348	351	348	352	386	394	400	419	423	427
344	355	344	348	348	348	348	348	348	348	348	348	348	348	348	348	348	348	348
41	42	43	47	52	54	56	58	61	64	66	68	69	71	73	75	77	79	81
40	40	41	44	48	49	51	53	55	57	60	61	62	64	66	68	70	71	73

J = 7,3

Fig. 4-43. Coolant temperature [°C] distribution in configuration after 1200 s of RVACS transient.

TABLE 4-1. RVACS Transient Power Balance

Time [s]	Source (DR + RB)		Loss	
	Generate in Fuel [MW]	Transfer to Fluid [MW]	IHX ^a [MW]	RVACS [MW]
0	425	425	-424	-0.71
1	75	310	-228	-0.71
2	47	246	- 22	-0.71
5	34	162	- 15	-0.71
10	29	88	- 9.4	-0.71
30	21	29	- 1.6	-0.71
60	15	17	+ 0.1	-0.71
120	13.8	13.2	+ 0.7	-0.71
300	10.8	10.1	+ 0.2	-0.72
600	9.2	8.6	~0	-0.73
898	8.5	8.4	~0	-0.73
1200	8.1	8.1	~0	-0.73

^aLoss via IHX after 2 s is due to residual mass flow at exit and is not a factor in removing energy from the primary system.

V. COMPARISON OF RESULTS FOR THE SCRAM AND RVACS TRANSIENTS

Selected results for the SCRAM and RVACS transients are presented on a comparative basis in this section; both similarities and differences are discussed. Figure 5-1 provides a guide to the spatial locations at which results will be compared; the responses at all of these locations were shown previously in Secs. III and IV for the individual transients. The figures in this section present temperatures in units of degrees Celsius [$^{\circ}\text{C}$]; an alternate set of figures using units of degrees Fahrenheit [$^{\circ}\text{F}$] is included as Appendix C.

The relative flow rate through the pump is shown in Fig. 5-2. This flow rate is representative of the total mass flow rate in the primary system. Since both transients have the same pump head decay supplied as a boundary condition, any differences in flow rate must be due to other dynamic effects. The initial (<100 s) flow coastdown is nearly identical for the two transients; the later history shows a flow rate for the SCRAM transient which is approximately twice the value in the RVACS transient. Recalling that the head supplied by the pump is only 2% at 100 s and 0 after 700 s, the higher flow rate in the SCRAM transient is likely to be due to the strong thermal gradient associated with continued energy removal through the IHX. This energy removal path is not available in the RVACS transient; the thermal gradient induced in the primary system by air flow through the reactor vessel auxiliary cooling system is continuing to develop in this transient. At the end of the histories shown, the primary system mass flow rate is slowly increasing in both transients. Associated with the lower flow rate in the RVACS transient were temporary flow reversals in the removable radial shield assemblies and the core bypass region.

The rapid loss of IHX energy removal capability during the RVACS transient is also responsible for it being characterized by an increasing temperature in the pump region, as shown in Fig. 5-3. Later in the histories, this temperature is indicative of global cooling in the SCRAM transient and global heating in the RVACS transient.

The temperature of the coolant adjacent to the heat generating fuel in the driver fuel assemblies is shown in Fig. 5-4. The initial (<50 s) behavior

is the same for both transients; the differing IHX behaviors are not transmitted to the core region in this short time. For this early time during both transients, the coolant temperature initially increases by 35°C (60°F) in 2 s, which is a rate of change of 17°C/s (30°F/s), and then decreases by 160°C (280°F) in 55 s, which is a rate of change of -3°C/s (-5°F/s). This initial response is followed by an increase during the mid-term portion of both transients; the magnitude and rate of increase are higher during the RVACS transient (115°C (210°F) and 0.15°C/s (0.27°F/s)) than during the SCRAM transient (45°C (80°F) and 0.07°C/s (0.12°F/s)). A primary contributor to this difference in the mid-term response is the lower mass flow rate during the RVACS transient; this is augmented at longer times by the higher inlet temperature (similar to the pump temperature in Fig. 5-3) during the RVACS transient.

The differences in mid-driver behaviors are propagated to the bottom of the UIS, as shown in Fig. 5-5. There is little mitigation in the magnitude of the response at the downstream location. There is a delay in the response at the bottom of the UIS relative to the behavior within the driver fuel assemblies; this delay is due to transport time and heat capacity effects. The rate of change of temperature at the bottom of the UIS is similar to that found within the driver fuel assemblies during the first 100 s but somewhat smaller at later times.

The top of the hot pool experiences a similar degree of cooling during both transients, as shown in Fig. 5-6. The rate of cooling is rather uniform and rather small, averaging -0.04°C/s (-0.08°F/s), relative to changes at the bottom of the UIS. This results in a temperature decrease of 45°C (80°F) at the top of the hot pool during the first 20 minutes of both transients. This region is relatively isolated from the main flow path but is slowly responding to the change in temperatures at lower elevations in the hot pool, which have generally been cooler than their initial value during both transients.

The temperatures at the primary-side inlet to the IHX are very similar during these two transients, as shown in Fig. 5-7. The similarity in the response for the two transients indicates that a number of minutes elapse before the effects of losing IHX energy removal capability during the RVACS transient can be propagated completely around the primary system. There is no temperature response at this location during the first 35 s of either

transient. Over the next 300 to 400 s, the temperature decreases by $\sim 75^{\circ}\text{C}$ (135°F), at a maximum rate of change of -0.6°C/s (-1.0°F/s). This decrease is in response to the decrease in fuel assembly coolant temperature which occurred during the first 55 s of the transients (cf. Fig. 5-4). At later times, the IHX inlet temperature is increasing during both transients; the magnitude and average rate of this increase are larger during the RVACS transient (25°C (45°F) and 0.03°C/s (0.05°F/s)) than during the SCRAM transient (5°C (10°F) and 0.008°C/s (0.015°F/s)). The response at the IHX inlet follows that found in the fuel assemblies, but the magnitude and rate of change are diminished and the response is delayed in time. The large coolant inventory associated with a pool-type reactor design is a significant contributor in this mitigation and delay. The longer term responses are following, but lagging, the differences in core exit temperature behavior.

The differences in IHX energy removal capability are clearly evident in the IHX primary-side exit temperature comparison shown in Fig. 5-8. As this energy removal capability is rapidly lost during the RVACS transient, the exit temperature increases rapidly by 120°C (220°F) over 105 s, which is an average rate of change of 1.2°C/s (2.1°F/s). During the SCRAM transient, the intermediate loop continually provides some degree of energy removal capability; the exit temperature initially decreases by 20°C (40°F) in 20 s, which is a rate of change of -1°C/s (-2°F/s); the exit temperature then increases by 50°C (90°F) in 110 s, which is a rate of 0.4°C/s (0.8°F/s). After the first 2 minutes, the exit temperature is showing a cooling trend during both transients; the magnitude and average rate of the temperature decrease are larger during the SCRAM transient (-75°C (-130°F) and -0.08°C/s (-0.15°F/s)) than during the RVACS transient (-50°C (-90°F) and -0.05°C/s (-0.09°F/s)).

The differences in IHX exit temperature response lead to different temperature responses in the cold pool during these two transients, as illustrated in Fig. 5-9. The temperature shown in this figure is for a relatively isolated location below the core inlet plenum; this region responds slowly to changes occurring in the rest of the system. The temperature response in this region is generally following the response at the IHX exit but is significantly delayed in time; therefore, the rate of change of temperature at the bottom of the cold pool is much smaller than that at the IHX exit. The temperature in this region is, however,

indicative of the system heating which is occurring during the RVACS transient and the system cooling which is occurring during the SCRAM transient.

The relative air flow rate in the reactor vessel auxiliary cooling system is shown in Fig. 5-10 for the two transients. Recall that this flow rate increases with increasing reactor vessel temperature. There is a slow mid-term heating of the vessel during the RVACS transient, leading to a 6% increase in air flow rate. This heating is associated with the rapid total loss of capability for the intermediate side of the IHX to remove energy from the primary side; this loss of cooling capability leads to increases in temperature for the sodium on the primary side of the IHX and in the cold pool; this temperature increase is transmitted to the reactor vessel, since it is thermally coupled to the sodium. The air flow rate experiences little change during the SCRAM transient until ~500 s, after which the air flow rate decreases in response to the decreasing reactor vessel temperature.

Selected results after 18 minutes of these two transients are compared with initial values in Table 5-1. The heat rate balance shows that the IHX is removing about twice the power being generated in the core after 18 minutes of the SCRAM transient; the system is clearly in a cooldown mode. In contrast, only ~10% of the core power generation is being removed from the primary system after 18 minutes of the RVACS transient; the IHX is providing essentially no cooling and the system has not heated sufficiently to promote increased power removal via the natural circulation of air through the reactor vessel auxiliary cooling system. The system is, thus, continuing to be heated after 18 minutes of the RVACS transient, and the transient is far from being considered terminated. The various temperatures tabulated indicate that the sodium has been cooled by 5 to 90°C (10 to 160°F) after 18 minutes of the SCRAM transient; the RVACS transient results indicate cooling of the hot pool by ~50°C (90°F) but heating of the cold pool by 15 to 75°C (30 to 130°F).

Fig. 5-1. Guide to spatial locations used in Figs. 5-2 through 5-10

PRISM: RVACS VS. SCRAM TRANS.: PUMP

Fig. 5-2. Coolant flow rate in primary pump (12) during RVACS and SCRAM transients

Fig. 5-3. Coolant temperature in primary pump (12) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: DR-MID

Fig. 5-4. Coolant temperature adjacent to fuel in driver fuel assembly (2) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: UIS-BOT-CTR

Fig. 5-5. Coolant temperature at bottom center of UIS (4) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: HP-TOP-CTR

Fig. 5-6. Coolant temperature at top of hot pool (6) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: IHX(PRI)-INLET

Fig. 5-7. Coolant temperature at IHX primary side inlet (7) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: IHX(PRI)-EXIT

Fig. 5-8. Coolant temperature at IHX primary side exit (9) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: CP-BOT-CTR

Fig. 5-9. Coolant temperature at bottom of cold pool (a) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: RVACS(AIR)

Fig. 5-10. Coolant flow rate in RVACS (K) during RVACS and SCRAM transients

TABLE 5-1. SCRAM vs. RVACS Transient Results

	Steady State	Transient	
		SCRAM	RVACS
Time [s]	0	1058	1048
Heat Rate Balance [MW]:			
Generate - core	425.00	8.31	8.32
Remove - IHX	-424.09	-15.96	-0.05
Remove - RVACS	-0.71	-0.70	-0.73
Mass Flow Rate [kg/s]:			
Primary	2250	90	49
Intermediate	2280	116	~0
RVACS	17.1	16.8	18.0
Primary System Temperature [°C]:			
DR - inlet	321	316	348
DR - middle:			
Fuel - ctr	1303	409	483
Coolant	482	396	469
DR - exit	482	395	452
UIS - mid,ctr	469	391	414
Hot Pool - top,ctr	469	428	422
IHX - inlet	469	396	416
IHX - exit	321	276	394
Cold Pool - bot,ctr	321	304	336
Pump	321	315	347
RVACS Temperature [°C]:			
RV - avg	347	339	374
GV - avg	232	231	235
CC - avg	153	153	153
Air - inlet	38.0	38.0	38.0
Air - exit	77.7	78.0	77.0

VI. SUMMARY

A three-dimensional thermal-hydraulic analysis has been performed for two protected transients in PRISM. Both transients were initiated by the simultaneous loss of power to all pumps and accompanied by a reactor scram. The two transients differed in the behavior assumed in the intermediate heat transport loops. During the SCRAM transient, the intermediate loop flow rate was assumed to decrease to natural circulation conditions (~5% flow); this provided a significant degree of continued energy removal from the primary system. During the RVACS transient, the intermediate loop flow was assumed to stop completely (essentially instantaneously); the only means of cooling the primary system was the natural circulation of air through the reactor vessel auxiliary cooling system.

The first 20 minutes of each transient has been calculated using the IFR variant of the COMMIX-1AR computer code. Each of these transients required about 30 hours of computer time.

The responses in the core and in the hot pool during the first few minutes of the RVACS transient were similar to the responses calculated during the SCRAM transient, being relatively unaffected by the differences in intermediate loop behaviors. The differences in intermediate loop behaviors were initially reflected as differences in cold pool temperatures; these differences in cold pool behaviors induced later differences in temperature response in the rest of the primary system. The largest rates of temperature change occurred during the first two minutes of both transients. The largest rate of change was 17°C/s (30°F/s), corresponding to the increase in driver assembly coolant temperature during the first 2 s. The largest change was a decrease of 160°C (280°F) at a rate of -3°C/s (-5°F/s) for this same location in the driver fuel assemblies. These two initial responses were felt, without mitigation, at the bottom of the UIS. The response at the inlet to the IHX, however, was mitigated by the large sodium inventory, large structural mass, and transport time effects in the hot pool; the initial peak in the fuel assemblies was not felt at the IHX inlet and the later decrease was reduced to 75°C (135°F) at a rate of -0.6°C/s (-1.0°F/s). The exit of the IHX experienced an early temperature

increase of 120°C (220°F) at a rate of 1.2°C/s (2.1°F/s) during the RVACS transient; this location experienced an initial decrease of 20°C (40°F) at a rate of -1°C/s (-2°F/s) followed by an increase of 50°C (90°F) at a rate of 0.4°C/s (0.8°F/s) during the SCRAM transient. The response of the cold pool to these changes at the IHX exit was mitigated by the large material inventories. The rates of temperature changes at later times were lower than those experienced earlier in the transients.

The sodium flow in the primary system appeared to undergo a smooth transition from forced to natural (~4% flow) circulation mode during the SCRAM transient. A lower natural circulation flow rate (~2%) was established during the RVACS transient; temporary flow reversals occurred in several non-heat-generating regions near the core, but these reversals did not appear to induce adverse consequences.

Although the system has not reached equilibrium after 20 minutes of either transient, a trend was evident based on the power balance. During the SCRAM transient, the power removed from the primary system by the IHX always exceeded the power generated in the core; the system was, thus, always cooling down in a global sense. This trend will continue as long as the assumed intermediate loop behavior can be maintained; therefore, there is little need to continue the SCRAM transient calculation for a longer time than that shown in this report. The reverse of this trend was found during the RVACS transient, where the only means of cooling the primary system was the reactor vessel auxiliary cooling system. The power removed from the primary system by the reactor vessel auxiliary cooling system was less than 10% of the core power generation during the 20 minute transient history; the primary system was, thus, continually heating up in a global sense during the RVACS transient. Although the continued heatup of the primary system induces a higher power removal via the reactor vessel auxiliary cooling system, this increase is occurring slowly and is not expected to exceed the core power generation (which is continuing to decrease) until 1 to 2 days into the RVACS transient. The calculation of the RVACS transient, thus, needs to be continued for a significantly longer history in order to assess the ultimate coolability of the system.

VII. REFERENCES

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APPENDIX A: SCRAM Transient Results in Alternate Units

In Section III of the main text, figures showing temperatures were prepared using units of degrees Celsius [$^{\circ}\text{C}$]. As an aid to comparing these results with others, an alternate set of figures using units of degrees Fahrenheit [$^{\circ}\text{F}$] has been prepared and included as this Appendix. The figure numbering follows that used in the main text (e.g. Fig. A-4a of this appendix presents the same information as Fig. 3-4a of the main text) and is, thus, not contiguous, since only those figures showing temperatures are duplicated.

PRISM: SCRAM TRANSIENT: DR-MID: FUEL-CL & NA

Fig. A-4a. Fuel centerline and adjacent coolant temperatures in driver fuel assembly (B) during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR-MID: FUEL-CL & NA

Fig. A-4b. Fuel centerline and adjacent coolant temperatures in driver fuel assembly (B) during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR: EXIT & INLET

Fig. A-5. Exit (C) and inlet (A) coolant temperatures for driver fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: RB-MID: FUEL-CL & NA

Fig. A-7a. Fuel centerline and adjacent coolant temperatures in radial blanket fuel assembly (E) during SCRAM transient.

PRISM: SCRAM TRANSIENT: RB-MID: FUEL-CL & NA

Fig. A-7b. Fuel centerline and adjacent coolant temperatures in radial blanket fuel assembly (E) during SCRAM transient.

PRISM: SCRAM TRANSIENT: RB: EXIT & INLET

Fig. A-8. Exit (F) and inlet (D) coolant temperatures for radial blanket fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: RRS: EXIT & INLET

Fig. A-10. Exit (H) and inlet (G) coolant temperatures for removable radial shield assemblies during SCRAM transient.

PRISM: SCRAM TRANSIENT: BYP: EXIT & INLET

Fig. A-11. Exit (J) and inlet (I) coolant temperatures for core bypass region during SCRAM transient.

PRISM: SCRAM TRANSIENT: IHX(INT): EXIT & INLET

Fig. A-13. Exit and inlet coolant temperatures for intermediate loop side of IHX during SCRAM transient.

PRISM: SCRAM TRANSIENT: RVACS(AIR): EXIT & INLET

Fig. A-14. Exit (L) and inlet (K) coolant temperatures for RVACS during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR: MID & INLET

Fig. A-16. Coolant temperatures at mid-elevation (2) and inlet (1) for driver fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR: EXIT & MID

Fig. A-17. Coolant temperatures at exit (3) and mid-elevation (2) for driver fuel assembly during SCRAM transient.

PRISM: SCRAM TRANSIENT: UIS-BOT-CTR & DR-EXIT

Fig. A-18. Coolant temperatures at bottom center of UIS (4) and exit of driver fuel assembly (3) during SCRAM transient.

PRISM: SCRAM TRANSIENT: UIS: MID-CTR & BOT-CTR

Fig. A-19a. Coolant temperatures at mid-elevation (5) and bottom (4) in radial center of UIS during SCRAM transient

Fig. A-19b. Coolant temperatures at mid-elevation (5) and bottom (4) in radial center of UIS during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP-TOP-CTR & UIS-MID-CTR

Fig. A-20. Coolant temperatures at top of hot pool (6) and mid-elevation of UIS (5) in radial center of primary system during SCRAM transient.

PRISM: SCRAM TRANSIENT: IHX(PRI)-INLET & HP-TOP-CTR

Fig. A-21. Coolant temperatures at IHX primary side inlet (Avg. 7 and 8) and top center of hot pool (6) during SCRAM transient.

PRISM: SCRAM TRANSIENT: IHX(PRI): INLET & EXIT

Fig. A-22. Coolant temperatures at inlet (Avg. 7 and 8) and exit (9) of IHX primary side during SCRAM transient.

PRISM: SCRAM TRANSIENT: FS-INLET & IHX(PRI)-EXIT

Fig. A-23. Coolant temperatures at fixed shield inlet (10) and IHX primary side exit (9) during SCRAM transient.

PRISM: SCRAM TRANSIENT: FS: EXIT & INLET

Fig. A-24. Coolant temperatures at exit (11) and inlet (10) of fixed shield region during SCRAM transient.

Fig. A-25. Coolant temperatures in primary pump duct (12) and at exit of fixed shield region (11) during SCRAM transient.

PRISM: SCRAM TRANSIENT: DR-INLET & PUMP

Fig. A-26. Coolant temperatures at driver fuel assembly inlet (1) and in primary pump duct (12) during SCRAM transient.

PRISM: SCRAM TRANSIENT: UIS-BOT: CTR & EDG

Fig. A-28a. Coolant temperatures at bottom of UIS at radial center (d) and edge (e) during SCRAM transient.

PRISM: SCRAM TRANSIENT: UIS-BOT: CTR & EDG

Fig. A-28b. Coolant temperatures at bottom of UIS at radial center (d) and edge (e) during SCRAM transient.

PRISM: SCRAM TRANSIENT: UIS-MID: CTR & EDG

Fig. A-29. Coolant temperatures at mid-elevation of UIS at radial center (g) and edge (h) during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP-TOP: CTR & EDG(PUMP)

Fig. A-30. Coolant temperatures at top of hot pool at radial center (k) and edge on pump side (1) during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP-TOP: CTR & EDG(IHX)

Fig. A-31. Coolant temperatures at top of hot pool at radial center (k) and edge on IHX side (n) during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP-CTR: TOP & BOT

Fig. A-32. Coolant temperatures in radial center of hot pool at top (k) and bottom (d) during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP(PUMP): K=19 & 17

Fig. A-33. Coolant temperatures at edge of upper hot pool on pump side at top of pool (1) and horizontal baffle (i) during SCRAM transient.

PRISM: SCRAM TRANSIENT: HP(IHX): K=19 & 17

Fig. A-34. Coolant temperatures at edge of upper hot pool on IHX side at top of pool (n) and IHX inlet (j) during SCRAM transient.

Fig. A-35. Coolant temperatures at edge of upper cold pool on IHX side at IHX exit (f) and mid-elevation in pool (c) during SCRAM transient.

Fig. A-36. Coolant temperatures at edge of cold pool at mid-elevation on pump side (b) and IHX side (c) during SCRAM transient.

Fig. A-37. Coolant temperatures in cold pool at mid-elevation edge (Avg. b and c) and bottom center (a) during SCRAM transient.

Fig. A-38. Coolant temperatures in radial center at top of hot pool (k) and bottom of cold pool (a) during SCRAM transient.

PRISM: SCRAM TRANSIENT: TOP: HP-EDG & OVFLW

Fig. A-39. Coolant temperatures at top of system at edge of hot pool (m) and in gap between reactor vessel and its liner (o) during SCRAM transient.

PRISM: SCRAM TRANSIENT: TOP: OVFLW & ARGON

Fig. A-40. Coolant temperatures at top of system in gaps between reactor vessel and its liner (o) and reactor and guard vessels (p) during SCRAM transient.

PRISM: SCRAM TRANSIENT: TOP: ARGON & AIR

Fig. A-41. Coolant temperatures at top of system in gaps between reactor and guard vessels (p) and guard vessel and collector cylinder (q) during SCRAM transient.

104	105	107	112	119	122	126	128	132	137	142	143	145	149	152	156	159	163	166
105	107	110	115	120	125	133	137	142	147	152	154	156	160	164	168	172	175	179
176	179	180	183	187	190	193	196	199	202	205	208	211	214	217	220	223	226	229
232	235	238	241	244	247	250	253	256	259	262	265	268	271	274	277	280	283	286
289	292	295	298	301	304	307	310	313	316	319	322	325	328	331	334	337	340	343
346	349	352	355	358	361	364	367	370	373	376	379	382	385	388	391	394	397	400
403	406	409	412	415	418	421	424	427	430	433	436	439	442	445	448	451	454	457
460	463	466	469	472	475	478	481	484	487	490	493	496	499	502	505	508	511	514
517	520	523	526	529	532	535	538	541	544	547	550	553	556	559	562	565	568	571
574	577	580	583	586	589	592	595	598	601	604	607	610	613	616	619	622	625	628
631	634	637	640	643	646	649	652	655	658	661	664	667	670	673	676	679	682	685
688	691	694	697	700	703	706	709	712	715	718	721	724	727	730	733	736	739	742
745	748	751	754	757	760	763	766	769	772	775	778	781	784	787	790	793	796	799
802	805	808	811	814	817	820	823	826	829	832	835	838	841	844	847	850	853	856
859	862	865	868	871	874	877	880	883	886	889	892	895	898	901	904	907	910	913
916	919	922	925	928	931	934	937	940	943	946	949	952	955	958	961	964	967	970
973	976	979	982	985	988	991	994	997	1000	1003	1006	1009	1012	1015	1018	1021	1024	1027
1030	1033	1036	1039	1042	1045	1048	1051	1054	1057	1060	1063	1066	1069	1072	1075	1078	1081	1084
1087	1090	1093	1096	1099	1102	1105	1108	1111	1114	1117	1120	1123	1126	1129	1132	1135	1138	1141
1144	1147	1150	1153	1156	1159	1162	1165	1168	1171	1174	1177	1180	1183	1186	1189	1192	1195	1198
1201	1204	1207	1210	1213	1216	1219	1222	1225	1228	1231	1234	1237	1240	1243	1246	1249	1252	1255
1258	1261	1264	1267	1270	1273	1276	1279	1282	1285	1288	1291	1294	1297	1300	1303	1306	1309	1312
1315	1318	1321	1324	1327	1330	1333	1336	1339	1342	1345	1348	1351	1354	1357	1360	1363	1366	1369
1372	1375	1378	1381	1384	1387	1390	1393	1396	1399	1402	1405	1408	1411	1414	1417	1420	1423	1426
1429	1432	1435	1438	1441	1444	1447	1450	1453	1456	1459	1462	1465	1468	1471	1474	1477	1480	1483
1486	1489	1492	1495	1498	1501	1504	1507	1510	1513	1516	1519	1522	1525	1528	1531	1534	1537	1540
1543	1546	1549	1552	1555	1558	1561	1564	1567	1570	1573	1576	1579	1582	1585	1588	1591	1594	1597
1600	1603	1606	1609	1612	1615	1618	1621	1624	1627	1630	1633	1636	1639	1642	1645	1648	1651	1654
1657	1660	1663	1666	1669	1672	1675	1678	1681	1684	1687	1690	1693	1696	1699	1702	1705	1708	1711
1714	1717	1720	1723	1726	1729	1732	1735	1738	1741	1744	1747	1750	1753	1756	1759	1762	1765	1768
1771	1774	1777	1780	1783	1786	1789	1792	1795	1798	1801	1804	1807	1810	1813	1816	1819	1822	1825
1828	1831	1834	1837	1840	1843	1846	1849	1852	1855	1858	1861	1864	1867	1870	1873	1876	1879	1882
1885	1888	1891	1894	1897	1900	1903	1906	1909	1912	1915	1918	1921	1924	1927	1930	1933	1936	1939
1942	1945	1948	1951	1954	1957	1960	1963	1966	1969	1972	1975	1978	1981	1984	1987	1990	1993	1996
1999	2002	2005	2008	2011	2014	2017	2020	2023	2026	2029	2032	2035	2038	2041	2044	2047	2050	2053
2056	2059	2062	2065	2068	2071	2074	2077	2080	2083	2086	2089	2092	2095	2098	2101	2104	2107	2110
2113	2116	2119	2122	2125	2128	2131	2134	2137	2140	2143	2146	2149	2152	2155	2158	2161	2164	2167
2170	2173	2176	2179	2182	2185	2188	2191	2194	2197	2200	2203	2206	2209	2212	2215	2218	2221	2224
2227	2230	2233	2236	2239	2242	2245	2248	2251	2254	2257	2260	2263	2266	2269	2272	2275	2278	2281
2284	2287	2290	2293	2296	2299	2302	2305	2308	2311	2314	2317	2320	2323	2326	2329	2332	2335	2338
2341	2344	2347	2350	2353	2356	2359	2362	2365	2368	2371	2374	2377	2380	2383	2386	2389	2392	2395
2398	2401	2404	2407	2410	2413	2416	2419	2422	2425	2428	2431	2434	2437	2440	2443	2446	2449	2452
2455	2458	2461	2464	2467	2470	2473	2476	2479	2482	2485	2488	2491	2494	2497	2500	2503	2506	2509
2512	2515	2518	2521	2524	2527	2530	2533	2536	2539	2542	2545	2548	2551	2554	2557	2560	2563	2566
2569	2572	2575	2578	2581	2584	2587	2590	2593	2596	2599	2602	2605	2608	2611	2614	2617	2620	2623
2626	2629	2632	2635	2638	2641	2644	2647	2650	2653	2656	2659	2662	2665	2668	2671	2674	2677	2680
2683	2686	2689	2692	2695	2698	2701	2704	2707	2710	2713	2716	2719	2722	2725	2728	2731	2734	2737
2740	2743	2746	2749	2752	2755	2758	2761	2764	2767	2770	2773	2776	2779	2782	2785	2788	2791	2794
2797	2800	2803	2806	2809	2812	2815	2818	2821	2824	2827	2830	2833	2836	2839	2842	2845	2848	2851
2854	2857	2860	2863	2866	2869	2872	2875	2878	2881	2884	2887	2890	2893	2896	2899	2902	2905	2908
2911	2914	2917	2920	2923	2926	2929	2932	2935	2938	2941	2944	2947	2950	2953	2956	2959	2962	2965
2968	2971	2974	2977	2980	2983	2986	2989	2992	2995	2998	3001	3004	3007	3010	3013	3016	3019	3022
3025	3028	3031	3034	3037	3040	3043	3046	3049	3052	3055	3058	3061	3064	3067	3070	3073	3076	3079
3082	3085	3088	3091	3094	3097	3100	3103	3106	3109	3112	3115	3118	3121	3124	3127	3130	3133	3136
3139	3142	3145	3148	3151	3154	3157	3160	3163	3166	3169	3172	3175	3178	3181	3184	3187	3190	3193
3196	3199	3202	3205	3208	3211	3214	3217	3220	3223	3226	3229	3232	3235	3238	3241	3244	3247	3250
3253	3256	3259	3262	3265	3268	3271	3274	3277	3280	3283	3286	3289	3292	3295	3298	3301	3304	3307
3310	3313	3316	3319	3322	3325	3328	3331	3334	3337	3340	3343	3346	3349	3352	3355	3358	3361	3364
3367	3370	3373	3376	3379	3382	3385	3388	3391	3394	3397	3400	3403	3406	3409	3412	3415	3418	3421
3424	3427	3430	3433	3436	3439	3442	3445	3448	3451	3454	3457	3460	3463	3466	3469	3472	3475	3478
3481	3484	3487	3490	3493	3496	3499	3502	3505	3508	3511	3514	3517	3520	3523	3526	3529	3532	3535
3538	3541	3544	3547	3550	3553	3556	3559	3562	3565	3568	3571	3574	3577	3580	3583	3586	3589	3592
3595	3598	3601	3604	3607	3610	3613	3616	3619	3622	3625	3628	3631	3634	3637	3640	3643	3646	3649
3652	3655	3658	3661	3664	3667	3670	3673	3676	3679	3682	3685	3688	3691	3694	3697	3700	3703	3706
3709	3712	3715	3718	3721	3724	3727	3730	3733	3736	3739	3742	3745	3748	3751	3754	3757	3760	3763
3766	3769	3772	3775	3778	3781	3784	3787	3790	3793	3796	3799	3802	3805	3808	3811	3814	3817	3820
3823	3826	3829	3832	3835	3838	3841	3844	3847	3850	3853	3856	3859	3862	3865	3868	3871	3874	3877
3880	3883	3886	3889	3892	3895	3898	3901	3904	3907	3910	3913	3916	3919	3922	3925	3928	3931	3934
3937	3940	3943	3946	3949	3952	3955	3958	3961	3964	3967	3970	3973	3976	3979	3982	3985	3988	3991
3994	3997	4000	4003	4006	4009	4012	4015	4018	4021	4024	4027	4030	4033	4036	4039	4042	4045	4048
4051	4054	4057	4060	4063	4066	4069	4072	4075	4078	4081	4084	4087	4090	4093	4096	4099	4102	4105
4108	4111	4114	4117	4120	4123	4126	4129	4132	4135	4138	4141	4144	4147	4150	4153	4156	4159	4162
4165	4168	4171	4174	4177	4180	4183	4186	4189	4192	4								

$$\bar{J} = 7,3$$

Fig. A-43. Coolant temperature [°F] distribution in configuration after 1072 s of SCRAM transient.

TABLE A-1. SCRAM Transient Power Balance

Time [s]	Source (DR + RB)		Loss		
	Generate in Fuel [10 ⁶ Btu/hr]	Transfer to Fluid [10 ⁶ Btu/hr]	IHX [10 ⁶ Btu/hr]	BVACS [10 ⁶ Btu/hr]	IHX + BVACS [10 ⁶ Btu/hr]
0	1451	1451	-1448	-2.41	-1451
1	256	1058	-1379	-2.41	-1381
2	160	850	-1250	-2.41	-1253
5	116	553	- 816	-2.41	- 818
10	99	300	- 557	-2.41	- 560
30	72	99	- 266	-2.41	- 269
60	51	58	- 130	-2.41	- 133
120	47	46	- 82	-2.41	- 85
300	37	36	- 71	-2.41	- 73
600	31	31	- 59	-2.40	- 61
908	29	29	- 55	-2.39	- 57
1058	28	29	- 55	-2.38	- 57

APPENDIX B: RVACS Transient Results in Alternate Units

In Section IV of the main text, figures showing temperatures were prepared using units of degrees Celsius [$^{\circ}\text{C}$]. As an aid to comparing these results with others, an alternate set of figures using units of degrees Fahrenheit [$^{\circ}\text{F}$] has been prepared and included as this Appendix. The figure numbering follows that used in the main text (e.g. Fig. B-4a of this appendix presents the same information as Fig. 4-4a of the main text) and is, thus, not contiguous, since only those figures showing temperatures are duplicated.

PRISM: RVACS TRANSIENT: DR-MID: FUEL-CL & NA

Fig. B-4a. Fuel centerline and adjacent coolant temperatures in driver fuel assembly (B) during RVACS transient.

PRISM: RVACS TRANSIENT: DR-MID: FUEL-CL & NA

Fig. B-4b. Fuel centerline and adjacent coolant temperatures in driver fuel assembly (B) during RVACS transient.

PRISM: RVACS TRANSIENT: DR: EXIT & INLET

Fig. B-5. Exit (C) and inlet (A) coolant temperatures for driver fuel assembly during RVACS transient.

PRISM: RVACS TRANSIENT: RB-MID: FUEL-CL & NA

Fig. B-7a. Fuel centerline and adjacent coolant temperatures in radial blanket fuel assembly (E) during RVACS transient.

PRISM: RVACS TRANSIENT: RB-MID: FUEL-CL & NA

Fig. B-7b. Fuel centerline and adjacent coolant temperatures in radial blanket fuel assembly (E) during RVACS transient.

PRISM: RVACS TRANSIENT: RB: EXIT & INLET

Fig. B-8. Exit (F) and inlet (D) coolant temperatures for radial blanket fuel assembly during RVACS transient.

PRISM: RVACS TRANSIENT: RRS: EXIT & INLET

Fig. B-10. Exit (H) and inlet (G) coolant temperatures for removable radial shield assemblies during RVACS transient.

PRISM: RVACS TRANSIENT: BYP: EXIT & INLET

Fig. B-11. Exit (J) and inlet (I) coolant temperatures for core bypass region during RVACS transient.

PRISM: RVACS TRANSIENT: RVACS(AIR): EXIT & INLET

Fig. B-14. Exit (L) and inlet (K) coolant temperatures for RVACS during RVACS transient.

PRISM: RVACS TRANSIENT: DR: MID & INLET

Fig. B-16. Coolant temperatures at mid-elevation (2) and inlet (1) for driver fuel assembly during RVACS transient.

PRISM: RVACS TRANSIENT: DR: EXIT & MID

Fig. B-17. Coolant temperatures at exit (3) and mid-elevation (2) for driver fuel assembly during RVACS transient.

PRISM: RVACS TRANSIENT: UIS-BOT-CTR & DR-EXIT

Fig. B-18. Coolant temperatures at bottom center of UIS (4) and exit of driver fuel assembly (3) during RVACS transient.

PRISM: RVACS TRANSIENT: UIS: MID-CTR & BOT-CTR

Fig. B-19a. Coolant temperatures at mid-elevation (5) and bottom (4) in radial center of UIS during RVACS transient

PRISM: RVACS TRANSIENT: UIS: MID-CTR & BOT-CTR

Fig. B-19b. Coolant temperatures at mid-elevation (5) and bottom (4) in radial center of UIS during RVACS transient.

Fig. B-20. Coolant temperatures at top of hot pool (6) and mid-elevation of UIS (5) in radial center of primary system during RVACS transient.

PRISM: RVACS TRANSIENT: IHX(PRI)-INLET & HP-TOP-CTR

Fig. B-21. Coolant temperatures at IHX primary side inlet (Avg. 7 and 8) and top center of hot pool (6) during RVACS transient.

Fig. B-22. Coolant temperatures at inlet (Avg. 7 and 8) and exit (9) of IHX primary side during RVACS transient.

PRISM: RVACS TRANSIENT: FS-INLET & IHX(PRI)-EXIT

Fig. B-23. Coolant temperatures at fixed shield inlet (10) and IHX primary side exit (9) during RVACS transient.

PRISM: RVACS TRANSIENT: FS: EXIT & INLET

Fig. B-24. Coolant temperatures at exit (11) and inlet (10) of fixed shield region during RVACS transient.

PRISM: RVACS TRANSIENT: PUMP & FS-EXIT

Fig. B-25. Coolant temperatures in primary pump duct (12) and at exit of fixed shield region (11) during RVACS transient.

PRISM: RVACS TRANSIENT: DR-INLET & PUMP

Fig. B-26. Coolant temperatures at driver fuel assembly inlet (1) and in primary pump duct (12) during RVACS transient.

PRISM: RVACS TRANSIENT: UIS-BOT: CTR & EDG

Fig. B-28a. Coolant temperatures at bottom of UIS at radial center (d) and edge (e) during RVACS transient.

PRISM: RVACS TRANSIENT: UIS-BOT: CTR & EDG

Fig. B-28b. Coolant temperatures at bottom of UIS at radial center (d) and edge (e) during RVACS transient.

PRISM: RVACS TRANSIENT: UIS-MID: CTR & EDG

Fig. B-29. Coolant temperatures at mid-elevation of UIS at radial center (g) and edge (h) during RVACS transient.

PRISM: RVACS TRANSIENT: HP-TOP: CTR & EDG(PUMP)

Fig. B-30. Coolant temperatures at top of hot pool at radial center (k) and edge on pump side (l) during RVACS transient.

PRISM: RVACS TRANSIENT: HP-TOP: CTR & EDG(IHX)

Fig. B-31. Coolant temperatures at top of hot pool at radial center (k) and edge on IHX side (n) during RVACS transient.

PRISM: RVACS TRANSIENT: HP-CTR: TOP & BOT

Fig. B-32. Coolant temperatures in radial center of hot pool at top (k) and bottom (d) during RVACS transient.

PRISM: RVACS TRANSIENT: HP(PUMP): K=19 & 17

Fig. B-33. Coolant temperatures at edge of upper hot pool on pump side at top of pool (1) and horizontal baffle (i) during RVACS transient.

PRISM: RVACS TRANSIENT: HP(IHX): K=19 & 17

Fig. B-34. Coolant temperatures at edge of upper hot pool on IHX side at top of pool (n) and IHX inlet (j) during RVACS transient.

PRISM: RVACS TRANSIENT: IHX(PRI)-EXIT & CP-MID-EDG(IHX)

Fig. B-35. Coolant temperatures at edge of upper cold pool on IHX side at IHX exit (f) and mid-elevation in pool (c) during RVACS transient.

PRISM: RVACS TRANSIENT: CP-MID-EDG: PUMP & IHX

Fig. B-36. Coolant temperatures at edge of cold pool at mid-elevation on pump side (b) and IHX side (c) during RVACS transient.

PRISM: RVACS TRANSIENT: CP: MID-EDG & BOT-CTR

Fig. B-37. Coolant temperatures in cold pool at mid-elevation edge (Avg. b and c) and bottom center (a) during RVACS transient.

PRISM: RVACS TRANSIENT: HP-TOP-CTR & CP-BOT-CTR

Fig. B-38. Coolant temperatures in radial center at top of hot pool (k) and bottom of cold pool (a) during RVACS transient.

PRISM: RVACS TRANSIENT: TOP: HP-EDG & OVFLW

Fig. B-39. Coolant temperatures at top of system at edge of hot pool (m) and in gap between reactor vessel and its liner (o) during RVACS transient.

PRISM: RVACS TRANSIENT: TOP: OVFLW & ARGON

Fig. B-40. Coolant temperatures at top of system in gaps between reactor vessel and its liner (o) and reactor and guard vessels (p) during RVACS transient.

PRISM: RVACS TRANSIENT: TOP: ARGON & AIR

Fig. B-41. Coolant temperatures at top of system in gaps between reactor and guard vessels (p) and guard vessel and collector cylinder (q) during RVACS transient.

104	105	107	111	119	121	127	131	135	140	142	143	147	151	154	157	161	164
105	107	110	116	128	129	133	136	140	142	143	147	151	154	157	161	164	178
106	108	112	120	130	134	138	142	146	148	150	152	154	156	158	160	162	165
107	110	114	122	132	136	140	144	148	150	152	154	156	158	160	162	164	167
108	112	116	124	134	138	142	146	150	152	154	156	158	160	162	164	166	169
109	114	118	126	136	140	144	148	152	154	156	158	160	162	164	166	168	171
110	116	120	128	138	142	146	150	154	156	158	160	162	164	166	168	170	173
111	118	122	130	140	144	148	152	156	158	160	162	164	166	168	170	172	175
112	120	124	132	142	146	150	154	158	160	162	164	166	168	170	172	174	177
113	122	126	134	144	148	152	156	160	162	164	166	168	170	172	174	176	179
114	124	128	136	146	150	154	158	162	164	166	168	170	172	174	176	178	181
115	126	130	138	148	152	156	160	164	166	168	170	172	174	176	178	180	183
116	128	132	140	150	154	158	162	166	168	170	172	174	176	178	180	182	185
117	130	134	142	152	156	160	164	168	170	172	174	176	178	180	182	184	187
118	132	136	144	154	158	162	166	170	172	174	176	178	180	182	184	186	189
119	134	138	146	156	160	164	168	172	174	176	178	180	182	184	186	188	191
120	136	140	148	158	162	166	170	174	176	178	180	182	184	186	188	190	193
121	138	142	150	160	164	168	172	176	178	180	182	184	186	188	190	192	195
122	140	144	152	162	166	170	174	178	180	182	184	186	188	190	192	194	197
123	142	146	154	164	168	172	176	180	182	184	186	188	190	192	194	196	199
124	144	148	156	166	170	174	178	182	184	186	188	190	192	194	196	198	201
125	146	150	158	168	172	176	180	184	186	188	190	192	194	196	198	200	203
126	148	152	160	170	174	178	182	186	188	190	192	194	196	198	200	202	205
127	150	154	162	172	176	180	184	188	190	192	194	196	198	200	202	204	207
128	152	156	164	174	178	182	186	190	192	194	196	198	200	202	204	206	209
129	154	158	166	176	180	184	188	192	194	196	198	200	202	204	206	208	211
130	156	160	168	178	182	186	190	194	196	198	200	202	204	206	208	210	213
131	158	162	170	180	184	188	192	196	198	200	202	204	206	208	210	212	215
132	160	164	172	182	186	190	194	198	200	202	204	206	208	210	212	214	217
133	162	166	174	184	188	192	196	200	202	204	206	208	210	212	214	216	219
134	164	168	176	186	190	194	198	202	204	206	208	210	212	214	216	218	221
135	166	170	178	188	192	196	200	204	206	208	210	212	214	216	218	220	223
136	168	172	180	190	194	198	202	206	208	210	212	214	216	218	220	222	225
137	170	174	182	192	196	200	204	208	210	212	214	216	218	220	222	224	227
138	172	176	184	194	198	202	206	210	212	214	216	218	220	222	224	226	229
139	174	178	186	196	200	204	208	212	214	216	218	220	222	224	226	228	231
140	176	180	188	198	202	206	210	214	216	218	220	222	224	226	228	230	233
141	178	182	190	200	204	208	212	216	218	220	222	224	226	228	230	232	235
142	180	184	192	202	206	210	214	218	220	222	224	226	228	230	232	234	237
143	182	186	194	204	208	212	216	220	222	224	226	228	230	232	234	236	239
144	184	188	196	206	210	214	218	222	224	226	228	230	232	234	236	238	241
145	186	190	198	208	212	216	220	224	226	228	230	232	234	236	238	240	243
146	188	192	200	210	214	218	222	226	228	230	232	234	236	238	240	242	245
147	190	194	202	212	216	220	224	228	230	232	234	236	238	240	242	244	247
148	192	196	204	214	218	222	226	230	232	234	236	238	240	242	244	246	249
149	194	198	206	216	220	224	228	232	234	236	238	240	242	244	246	248	251
150	196	200	208	218	222	226	230	234	236	238	240	242	244	246	248	250	253
151	198	202	210	220	224	228	232	236	238	240	242	244	246	248	250	252	255
152	200	204	212	222	226	230	234	238	240	242	244	246	248	250	252	254	257
153	202	206	214	224	228	232	236	240	242	244	246	248	250	252	254	256	259
154	204	208	216	226	230	234	238	242	244	246	248	250	252	254	256	258	261
155	206	210	218	228	232	236	240	244	246	248	250	252	254	256	258	260	263
156	208	212	220	230	234	238	242	246	248	250	252	254	256	258	260	262	265
157	210	214	222	232	236	240	244	248	250	252	254	256	258	260	262	264	267
158	212	216	224	234	238	242	246	250	252	254	256	258	260	262	264	266	269
159	214	218	226	236	240	244	248	252	254	256	258	260	262	264	266	268	271
160	216	220	228	238	242	246	250	254	256	258	260	262	264	266	268	270	273
161	218	222	230	240	244	248	252	256	258	260	262	264	266	268	270	272	275
162	220	224	232	242	246	250	254	258	260	262	264	266	268	270	272	274	277
163	222	226	234	244	248	252	256	260	262	264	266	268	270	272	274	276	279
164	224	228	236	246	250	254	258	262	264	266	268	270	272	274	276	278	281
165	226	230	238	248	252	256	260	264	266	268	270	272	274	276	278	280	283
166	228	232	240	250	254	258	262	266	268	270	272	274	276	278	280	282	285
167	230	234	242	252	256	260	264	268	270	272	274	276	278	280	282	284	287
168	232	236	244	254	258	262	266	270	272	274	276	278	280	282	284	286	289
169	234	238	246	256	260	264	268	272	274	276	278	280	282	284	286	288	291
170	236	240	248	258	262	266	270	274	276	278	280	282	284	286	288	290	293
171	238	242	250	260	264	268	272	276	278	280	282	284	286	288	290	292	295
172	240	244	252	262	266	270	274	278	280	282	284	286	288	290	292	294	297
173	242	246	254	264	268	272	276	280	282	284	286	288	290	292	294	296	299
174	244	248	256	266	270	274	278	282	284	286	288	290	292	294	296	298	301
175	246	250	258	268	272	276	280	284	286	288	290	292	294	296	298	300	303
176	248	252	260	270	274	278	282	286	288	290	292	294	296	298	300	302	305
177	250	254	262	272	276	280	284	288	290	292	294	296	298	300	302	304	307
178	252	256	264	274	278	282	286	290	292	294	296	298	300	302	304	306	309
179	254	258	266	276	280	284	288	292	294	296	298	300	302	304	306	308	311
180	256	260	268	278	282	286	290	294	296	298	300	302	304	306	308	310	313
181	258	262	270	280	284	288	292	296	298	300	302	304	306	308	310	312	315
182	260	264	272	282	286	290	294	298	300	302	304	306	308	310	312	314	317
183	262	266	274	284	288	292	296	300	302	304	306	308	310	312	314	316	319
184	264	268	276	286	290	294	298	302	304	306	308	310	312	314	316	318	321
185	266	270	278	288	292	296	300	304	306	308	310	312	314	316	318	320	323
186	268	272	280	290	294	298	302	306	308	310	312	31					

TABLE B-1. RVACS Transient Power Balance

Time [s]	Source (DR + RB)		Loss	
	Generate in Fuel [10 ⁶ Btu/hr]	Transfer to Fluid [10 ⁶ Btu/hr]	IHX ^a [10 ⁶ Btu/hr]	RVACS [10 ⁶ Btu/hr]
0	1451	1451	-1448	-2.41
1	256	1048	- 778	-2.41
2	160	840	- 75	-2.41
5	116	553	- 51	-2.41
10	99	300	- 32	-2.41
30	72	99	- 5.6	-2.41
60	51	58	+ 0.5	-2.41
120	47	45	+ 2.3	-2.41
300	37	34	+ 0.6	-2.45
600	31	29	-0	-2.49
898	29	29	- 0.1	-2.49
1200	28	28	- 0.2	-2.50

^aLoss via IHX after 2 s is due to residual mass flow at exit and is not a factor in removing energy from the primary system.

APPENDIX C: Comparison of SCRAM and RVACS Transients
in Alternate Units

In Section V of the main text, figures showing temperatures were prepared using units of degrees Celsius [$^{\circ}\text{C}$]. As an aid to comparing these results with others, an alternate set of figures using units of degrees Fahrenheit [$^{\circ}\text{F}$] has been prepared and included as this Appendix. The figure numbering follows that used in the main text (e.g. Fig. C-3 of this appendix presents the same information as Fig. 5-3 of the main text) and is, thus, not contiguous, since only those figures showing temperatures are duplicated.

PRISM: RVACS VS. SCRAM TRANS.: PUMP

Fig. C-3. Coolant temperature in primary pump (12) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: DR-MID

Fig. C-4. Coolant temperature adjacent to fuel in driver fuel assembly (2) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: UIS-BOT-CTR

Fig. C-5. Coolant temperature at bottom center of UIS (4) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: HP-TOP-CTR

Fig. C-6. Coolant temperature at top of hot pool (6) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: IHX(PRI)-INLET

Fig. C-7. Coolant temperature at IHX primary side inlet (7) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: IHX(PRI)-EXIT

Fig. C-8. Coolant temperature at IHX primary side exit (9) during RVACS and SCRAM transients

PRISM: RVACS VS. SCRAM TRANS.: CP-BOT-CTR

Fig. C-9. Coolant temperature at bottom of cold pool (a) during RVACS and SCRAM transients

TABLE C-1. SCRAM vs. RVACS Transient Results

	Steady State	Transient	
		SCRAM	RVACS
Time [s]	0	1058	1048
Heat Rate Balance [10^6 Btu/hr]:			
Generate - core	1451.01	28.37	28.41
Remove - IHX	-1447.90	-54.49	-0.16
Remove - RVACS	-2.41	-2.39	-2.49
Mass Flow Rate [lb_m/s]:			
Primary	4960	198	108
Intermediate	5027	256	~0
RVACS	37.7	37.0	39.7
Primary System Temperature [°F]:			
DR - inlet	610	601	658
DR - middle:			
Fuel - ctr	2377	768	901
Coolant	900	745	876
DR - exit	900	743	846
UIS - mid,ctr	875	736	777
Hot Pool - top,ctr	875	802	792
IHX - inlet	875	745	781
IHX - exit	610	529	741
Cold Pool - bot,ctr	610	579	637
Pump	610	599	657
RVACS Temperature [°F]:			
RV - avg	657	642	705
GV - avg	450	448	455
CC - avg	307	307	307
Air - inlet	100	100	100
Air - exit	171.9	172.4	170.6