# Pool-Type LMFBR Plant
# 1000 MWe Phase A-Extension-1 Design

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ELECTRIC POWER RESEARCH INSTITUTE

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# 1000 MWe Phase A-Extension-1 Design

## PART V: HEAT TRANSPORT SYSTEM COMPONENTS

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Interim Report, September 1978

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## LEGAL NOTICE

## PREFACE

This report describes Phase A Extension 1 work performed between February 8 and July 31, 1978 on the design of a large pool-type LMFBR power plant. The work is the result of a team effort by Bechtel Corporation and General Electric Company which was sponsored and guided by the Electric Power Research Institute (EPRI). The objective of the work was to refine certain areas of design and bring them into better focus than had been provided by Phase A work performed between April 4 and December 30, 1977.

The Phase A effort produced an initial description of the overall plant, structures and systems. During Phase A, General Electric developed the overall nuclear steam supply system (NSSS) conceptual design. It defined specific design approaches for selected NSSS components and subsystems after analyzing various design alternatives. Bechtel assumed responsibility for the intermedaite sodium piping arrangement , the access area above the reactor deck and the Balance of Plant (BOP). The resulting integrated plant design provided the necessary seismic data for both the NSSS and BOP.

The special expertise of several subcontractors was used during Phase A; Byron-Jackson provided a preliminary design of the primary sodium pump, Foster-Wheeler provided a preliminary design of the intermediate heat exchanger (IHX), and CBI Nuclear reviewed the reactor deck design and developed a construction sequence for the overall reactor assembly.

The Phase A effort by General Electric; Bechtel and the subcontractors was funded at a level of nearly 1.7 million dollars. Additionaly, General Electric contributed a company-funded effort and both General Electric and Bechtel utilized their backgrounds of prior work on pool-type LMFBRs and extensive interaction with foreign LMFBR organizations. The results of the Phase A work was published by EPRI in April 1978 in report number NP-646, "Pool-Type LMFBR Plant, 1000 MWe Phase A Design".

During Phase A Extension 1, funded at a level of approximately 1.4 million dollars, specific areas established during Phase A received further development and evaluation. These specific areas included the reactor deck, the reactor assembly, the heat transfer system components, the reactor auxiliary systems, and the instrumentation and control systems. Several subcontractors were also used during Phase A Extension 1; Foster-Wheeler designed an alternate IHX, CBI Nuclear evaluated an alternate deck support scheme and further developed the reactor assembly construction sequence, and United Nuclear Industries provided conceptual designs for removable radiation shielding in the deck.

This report of the Phase A Extension 1 work is logically divided into eight parts, which have the general title "Pool-Type LMFBR, 1000 MWe Phase A — Extension 1 Design":

| | |
|---|---|
| Part I | Executive Summary |
| Part II | Reactor Assembly — Structures |
| Part III | Reactor Assembly — Deck |
| Part IV | Reactor Assembly — Fabrication |
| Part V | Heat Transport System Components |
| Part VI | Reactor Auxiliary Systems |
| Part VII | Instrumentation and Control |
| Part VIII | Balance Of Plant |

The report is physically divided into six volumes as follows:

| | |
|---|---|
| Volume 1 | Part I |
| Volume 2 | Part II |
| Volume 3 | Part III and Part IV |
| Volume 4 | Part V |
| Volume 5 | Part VI and Part VII |
| Volume 6 | Part VIII |

A Table of Contents for all volumes is included at the end of every volume.

POOL-TYPE LMFBR PLANT

1000 MWe PHASE A - EXTENSION 1 DESIGN

Volume 4

Contents

Part V: Heat Transport System Components



A table of contents for the entire report appears at the end of each volume.

## PART V: HEAT TRANSPORT SYSTEMS COMPONENTS

### SECTION 1: INTRODUCTION AND SUMMARY

The heat transport systems carry heat from the reactor to the IHXs and from the IHXs to the steam generators. The major components in the primary heat transport system are the primary sodium pumps and IHXs, and the major components in the intermediate heat transport system are the intermediate sodium pumps and steam generators.

The sodium piping is not discussed in this section because primary sodium piping is designed as part of the reactor assembly structures and the intermediate sodium piping as part of the BOP. Also, the reactor auxiliary cooling system is treated separately as part of the auxiliary systems design task. The cold leg primary pump was designed during Phase A and no further work has been done during Phase A Extension I except for inclusion of a shutoff valve. This valve is not a fast-acting check valve and is used only to allow plant operation with a primary pump out of service.

The major design emphasis for the heat transport systems during Phase A Extension I has been in the following areas:

- Accommodation of the differential expansion between the IHX tubes and shell: in Phase A, straight tubes and a bellows on the shell were used; in Phase A Extension I bent tubes and no bellows on the shell are used in an alternate IHX design.
- Examination of the plant characteristics and limitations with only four or five of the six IHXs in service, or with only three of the four primary pumps in service.
- Identification of the major events and their number in the 40 year plant life.
- Calculation of the plant thermal transients for the above major events.
- Investigation of sodium flow patterns in the hot pool, especially mixing of hot and cold sodium after a reactor scram.

The alternate bent tube IHX design shows a slight advantage over the Phase A straight tube IHX design. Plant operation with either an IHX or primary pump out of service can be at a relatively high power level. It is estimated that the most severe thermal transients can be accommodated by components such as IHXs even when conservative assumptions about hot and cold sodium mixing phenomena are made.

PART V: HEAT TRANSPORT SYSTEM COMPONENTS

SECTION 2: INTERMEDIATE HEAT EXCHANGER DESIGN

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## INTRODUCTION

The intermediate heat exchanger (IHX) transfers energy from the radioactive primary sodium to the colder, non-radioactive intermediate sodium. The six IHX's in the 1000 MWe pool-type LMFBR plant penetrate the reactor deck structure near its outer edge as indicated in Figure 1.

A preliminary IHX concept was developed during Phase A of the 1000 MWe Pool-Type LMFBR study (Reference 1). Principal features of this concept were the straight heat transfer tubes and the bellows located below the lower tubesheet to accommodate differential thermal expansion between the average tube and the IHX shell. It also employed a diving bell or gas seal, located below the lower tubesheet, as a barrier between the hot and cold pools.

The straight tube concept was based primarily on the IHX design developed for the CRBRP with respect to tube bundle design. The Phase A IHX concept studies included basic thermal/hydraulic and structural sizing and a preliminary evaluation of shell and tubeside flow/temperature distributions.

The preliminary study showed that the straight tube concept is feasible, but also pointed out some areas where further studies were required. These areas included the shield plug region, seismic support and upper tubesheet, outer rim thickness, and gas/sodium interface control between the shrouds at the top and in the diving bell seal.

Later review of the study identified other items of concern. One of these was the ability of the bellows located in the exit region of the IHX to withstand the severe thermal transients experienced upon loss of an intermediate loop. It was suggested that the bellows should be moved to a less exposed location in the main IHX shell which would involve larger diameter bellows and deck penetration.

Another item of concern with the Phase A design was that the space near the bellows cannot be drained of intermediate sodium if the IHX is removed for maintenance. Moreover, the reduced size bellows employed tends to increase the bending movement and rotation of the lower tubesheet as a result of intermediate sodium pressure forces.

Accordingly, an alternate IHX design has been studied in this phase. Its principal features are the bent tube on a circular pitch (rather than triangular) and the built-up tube support grids similar to that used in the UK prototype fast reactor (PFR).

The scope of work for the Phase A Extension I efforts was expanded considerably over that of Phase A. In addition to establishing design requirements for the bent tube design proposed for Phase A Extension I and the thermal/hydraulic and structural sizing evaluations of the bent tube concept the work scope included several other items as follows:

1. Seismic evaluation of both the bent and straight tube designs including redesign of the grid supports to accommodate seismic loads.

2. Evaluation of loss of intermediate loop transients on the lower tubesheet region for the bent tube concept.

3. Resizing of and recosting of the straight tube concept when designed for a 1 foot smaller deck penetration and tighter tube pitch.

4. Resizing of straight tube concept assuming 2-1/4 Cr-1 Mo steel heat transfer tubes (this task was part of GE sponsored work).

5. Initial development of double bellows hot/cold pool seal and shield plug concepts.

6. Comparison of key design features of the straight and bent tube designs to aid in the selection process.

7. A study of the disassembly/assembly sequence of the shield plug and upper portions of the IHX maintenance purposes.

This report summarizes the design requirements established for the Phase A Extension I bent tube design concept. It gives the results of the major thermal/hydraulic and structural sizing calculations as well as for work scope items 1 through 7 above. Details of the seismic analysis for the straight tube design are presented in this report (see Part V, Section 3 "IHX Seismic Analysis").

A large part of the work scope was performed by the Foster Wheeler Corporation, and their report is included as Appendix VA.

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## SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A preliminary IHX concept was developed during Phase A of the 1000 MWe Pool-Type LMFBR study (Reference 1). Principal features of this concept were the straight heat transfer tubes and the bellows located below the lower tubesheet to accommodate differential thermal expansion between the average tube and the IHX shell. It also employed a diving bell or gas seal, located below the lower tube-sheet, as a barrier between the hot and cold pools.

The principal features of the alternate IHX concept studied during this phase are the bent tubes on a circular pitch (rather than triangular) and the built-up tube support grids similar to that used in the UK prototype fast reactor (PFR). The bent tube arrangement provides enough flexibility to accommodate shell to average tube differential thermal expansion and eliminates the need for a bellows for this function. It also allows tube-to-tube differential thermal expansion and the concept should therefore be more forgiving with respect to flow and temperature maldistributions, thermal transients, and tube plugging.

Both studies concentrated mostly on the main tube bundles since their integrity must be maintained over the life of the plant with minimum or no operational problems. The purpose of performing the design study on the bent tube concept was to provide a basis for comparison with the straight tube concept.

Study results to date have not revealed any significant feasibility problems with either design concept. Both concepts can be made to work when appropriate analytic and experimental work are carried out during the detailed design process to support the concept. However, the technical evaluation has shown that there are advantages and disadvantages with elements of either tube bundle design.

A qualitative technical evaluation of factors deemed important in the selection process was made. The overall conclusion of this comparative evaluation is that the bent tube concept has a definite advantage over the straight tube concept although both concepts are feasible. It is recommended that the bent tube concept be selected as the reference concept for further study during the next phase. The straight tube concept should be retained as a backup in case further studies should reveal feasibility concerns with the bent tube concept.

The technical evaluation concentrated on the tube bundle design and not on features such as the shield plug, the hot/cold pool seal, primary shutoff valve, and IRACS heat exchanger. These items are of less fundamental importance and several design options appear feasible. These options should be evaluated in more detail during later study phases.

The following conclusions based on the Phase A and Phase A Extension I studies of two IHX concepts for the 1000 MWe LMFBR pool-type reactor are offered:

1. The study results show that both the bent and straight tube designs can meet the thermal performance requirements and the mechanical, seismic, and thermal loads imposed on them over the life of the plant with high probability of success.

2. A comparative evaluation of the concepts shows that the bent tube concept has an overall advantage over the straight tube concept mainly because of a more flexible tube configuration that is more forgiving with respect to thermal transients and flow maldistribution conditions. The former concept is also based on an actual operating concept (PFR).

3. Further work will be needed to resolve areas of concern and to perform more detailed analyses. Component features which are a part of the IHX, but which have not been studied to date (such as the shield plug and IRACS coil) need investigation.

The following recommendations are offered:

1. The bent tube concept should be adopted as the reference concept and studied further during the next study phase. The straight tube concept should be retained as a backup to the bent tube concept.

2. It is recommended that further work be performed to support the bent tube IHX concept in the following areas.

    a. Perform a transient flow and temperature distribution analysis in the lower tubesheet area.

    b. Perform a more detailed stress analysis of the lower tubesheet.

    c. Design the grid supports to provide non-uniform open areas to optimize flow distribution.

    d. Review the overall reactor system seismic response to define IHX inputs and validate the proper coupling between the IHX and the system.

e. Refine the hydraulic analysis of the inlet/outlet regions.

f. Evaluate tube vibration problems in more detail including flow induced vibration in the bend region.

3. Further design work and tradeoff studies should be performed for elements such as the shield plug, hot/cold pool seal, central duct, IRACS heat exchanger, and the primary shutoff valve. Concerning the tube bends, single versus double bend tradeoff studies should be performed in the next work phase.

# FUNCTIONAL AND DESIGN REQUIREMENTS

## 2.3.1 PLANT PROCESS DESCRIPTION

The IHX is an integral component of the energy transport system. It acts as a barrier to prevent the transport of radioactive primary sodium and fission products from the reactor containment building. There are six IHX's which receive primary sodium from the common hot pool as indicated in Figure 1. Each IHX is rated at 486 MWt.

Hot primary sodium flows through the IHX and heats the intermediate sodium and discharges to the common cold pool. The cooled primary sodium is pumped from the cold pool through the reactor core. The heated intermediate sodium is piped to the steam generator and is then pumped back to the IHX by the cold leg intermediate pump. There are six intermediate loops and steam generators.

## 2.3.2 IHX TYPE AND CONFIGURATION

### IHX Tube Bundle

The IHX is a shell and tube-type heat exchanger, vertically oriented, and is designed to meet the general design criteria of Table 1. The heat exchanger operates with the primary sodium on the tube side heating the intermediate sodium on the shell side in an essentially counterflow arrangement. The primary sodium flows down through the tubes and the intermediate sodium flows up through the shell side. The intermediate sodium is maintained at a higher pressure than the primary sodium to prevent radioactive primary sodium from leaving the reactor containment in the event of an IHX leak.

Several design features discussed separately below will be incorporated in the pool-type IHX overall layout drawing. The conceptual design of these features are the responsibility of GE.

### IRACS Auxiliary Heat Exchanger

The Intermediate Reactor Auxiliary Cooling System (IRACS) auxiliary heat exchanger will be included in the IHX. Its purpose is to transfer energy from the primary sodium to the intermediate NaK loop used for decay heat removal. The heat exchanger is of the coil type and is an integral part of the IHX component.

### Shutoff Valve

Means will be provided for preventing hot primary sodium from entering the IHX when an intermediate loop is out-of-service. The valve will be of the gas type in which the sodium level is depressed below the entrance window by gas pressure.

### Shield Plug

The IHX is designed with a removable shield plug which serves as a reactor closure at the deck level and as a biological radiation shield.

### Central Duct

The IHX has a removable central duct to channel the cold entering intermediate sodium to the bottom region of the IHX where it enters the shell side of the tube bundle. The duct also serves as the inner boundary of the annular region used to channel the hot intermediate sodium from the top portions of the IHX tube bundle to the IHX outlet nozzle.

### Fire Shield

A fire shield structure encloses the intermediate sodium inlet and outlet piping and other structures of the IHX extending above the deck level.

### Hot/Cold Pool Seal

A seal is included in the penetration between the hot and cold sodium pools that is flexible enough to compensate for radial and axial thermal expansion in the IHX and reactor assembly structures.

## 2.3.3 DIAMETER AND LENGTH LIMITATIONS

The maximum diameter of the bent tube IHX will be consistent with the 10 foot 3 inch diameter specified for the deck penetration. Clearance will be provided as necessary to insert or remove the IHX.

The maximum length of the IHX will be consistent with the overall depth of the reactor support and vessel structures at the radial location of the IHX as indicated in Figure 1.

## Design and Performance Data

The design and performance data for the IHX are given in Table 2. The following combination of design conditions must be met:

1. Primary side pressure at 10 (Primary Internal Design Pressure) psig with the intermediate side at 0 psig and a design temperature of 900°F.

2. Intermediate side pressure at 250 (Intermediate Internal Design Pressure) psig with the primary side at 0 psig and a design temperature of 900°F.

3. Primary side at 0 psig with intermediate side at 0 psia and at room temperature (leak check or drying).

## Seismic Requirements

The IHX will be designed as a seismic category I component. The seismic response spectra for the reactor deck level provided by Bechtel (Figures 4.4-22, 4.4-24, 4.4-29 and 4.4-30 in Reference 4) will be used as a basis for the analysis. The unit will be designed to withstand 5 operating basis earthquake (OBE) events and 1 safe shutdown earthquake (SSE) event. For the SSE, the IRACS coils of the IHX will remain operable and the main IHX tube bundle will retain its primary containment integrity.

## Transient Requirements

Consistent with duty cycle information described in Part V, Section 7 the IHX will be designed to withstand 556 scram transients based on a 40 year lifetime. A preliminary value of 520 scrams was used during the IHX design study; preliminary evaluation indicated that the IHX is capable of withstanding these transients. The primary sodium temperature transient that occurs as the IHX primary inlet is given in Figure 2. The primary and intermediate pumps are assumed to operate at full flow following a scram.

The IHX will be designed for approximately 20 "loss of intermediate loop transients" based on a 40 year life time. This transient assumes full primary flow and a drop in intermediate sodium flow to 12 percent in 3 minutes. The temperature transient experienced at the primary sodium exit is given in Figure 3.

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# DESIGN AND ANALYSIS

## 2.4.1
## DESIGN DESCRIPTION

Overall Design

The design layout for the bent tube IHX is shown in Figure 4 (FWEC drawing 51-3145-6-2000) developed during Phase A Extension I. The tube bundle in this design incorporates the design features that have been proposed for the IHX proposed by the British on CDFR. The overall size and configuration is consistent with the space envelope and deck penetration diameter specified for the Phase A straight tube design described in the Phase A report (Reference 1). The design description and analysis presented here is based to a great extent on the report provided by FWEC (IHX vendor) contained in Appendix VA.

The bent tube IHX is designed for operation in the vertical position within the sodium pool. It includes a removable tube bundle which is supported by a hanging support located at the top of the IHX. The two tube bends provide the flexibility required to accommodate the differential thermal expansion between the shell and tubes of this fixed tubesheet heat exchanger.

The IHX is suspended in the sodium pool within the reactor vessel. A cylindrical flow shroud or sleeve is suspended from the reactor deck and is not removable. The primary sodium flows upward in the annulus between the flow shroud and tube bundle, turns 90° to pass through flow openings in the IHX support cylinder, passes over the IRACS coil, flows downward through the tubes, and exits through the bellows seal into the cold pool. The intermediate sodium flows down through the central duct makes a 90° turn through openings in the bundle shroud, flows upward through the shell side of the tube bundle, and exits to the outlet annulus below the upper tubesheet.

The upper half of the IHX contains the shield plug and IRACS coil. The removable plug contains steel shot for radiation shielding which may be gas cooled. The IRACS bundle consists of an 8 inch pipe helical coil with the inlet and outlet connections penetrating the plug. The coils will be supported to prevent damage due to vibration and to restrain the coils against lateral seismic loads.

The bundle support has been provided with a flanged connection to bolt the IHX to the deck. The bolting will be sized to accept the lateral and vertical seismic loads plus the pressure loads. The joint will be sealed with double silicone "O" rings with a tell-tale between "O" rings which can be monitored to determine leak tightness. A metal canopy can be welded to the outside of the flange diameter to provide a back-up welded seal. The use of this seal is optional as the double "O" ring seal should be adequate. The shield plug support flange construction is similar to the main IHX support flange.

A fire shield cover has been provided at the upper end of the IHX to minimize a potential sodium fire hazard in the event of an intermediate sodium pipe break. This cover is gas tight to contain the cooling gas which circulates within the cover. The overall dimensions of the cover are consistent with the requirements provided by Bechtel (see Part VII, Section 4, "Intermediate Heat Transport System Piping Enclosure Study").

The lower half of the IHX contains the tube bundle and the seal between the hot and cold sodium pools. The seal at the bottom of the IHX is a flanged spool cylinder with a double expansion bellows. The bellows accommodates the differential thermal expansion between the reactor structures and the IHX shell. A 45° elbow is attached to the reactor structure below the IHX to direct the primary sodium flow away from the reactor vessel as it exits into the cold pool.

The complete IHX is removable and is supported from the reactor deck. Limited maintenance operations can also be performed without removing the complete IHX. This capability is described in the section on maintainability.

Tube Bundle

The upper tubesheet is fixed and supported from the hanging support. The lower tubesheet is also fixed and welded to the cylinder between the tubesheets. The thermal growth differential between the cylinder and the heat transfer tubes is accommodated by the two bends in each tube.

The tubes are 7/8 inch outer diameter and are arranged on a circumferential pitch which is 1.309 inch in the circumferential direction and averages 1.250 inch in the radial direction. The tube arrangement is shown in Figure 5 (FWEC drawing 51-3145-5-2001). The 4860 tubes are arranged in six identical 60° segments.

Each tube has a sine wave bend near the top of the bundle and an identical bend near the bottom of the bundle. These bends are similar to those proposed for the British CDFR design. The tubes are attached to the tubesheets using full penetration internal bore welds (IBW) which utilize a machined spigot on the tubesheet face as indicated in Figure 6. The tubes fit into a socket on the spigot and are welded with a rotating welding head which fits inside the tube. The welding and inspection techniques would be similar to those used on the FFTF IHX with appropriate refinements derived from the CRBRP steam generator program.

The grid design for the tube supports is also shown in Figure 5. It is conceptually similar to the CDFR IHX design, but the members have been strengthened for the seismic requirements and additional lateral support beams or "wiggley bars" have been added. The grid support assembly consists of an internal and external ring with radial spokes between rings. The spokes are equally spaced on 30° increments and alternate between straight bars and wiggley bars to fit the tube pattern.

The grids which hold the tubes consist of press formed wedge-like members that contact the tube walls. These formed segments are spot welded to a segmental curved bar. The grid segments are positioned in an alternating pattern so that a tube at one level is displaced in the outboard direction by 0.07 inch and is then displaced in the inboard direction by an equal amount at the next higher or lower level. This arrangement results in lateral forces between the tube and the grid members which clamp the grid support to the tubes.

The grid assembly is retained at the inner rim by a C-shaped ring that is welded to the outer wall of the central strongback cylinder. The C-shaped ring has an axial clearance which permits the grid assembly to move up and down with the tubes. There is also an outer ring around the grid assembly to provide structural continuity between the inner ring, outer ring, and the radial members.

Each bundle section between tube support grids contains an inner and outer flow shroud. These shrouds are provided to control the sodium flow and to prevent channeling between the inner and outer row of tubes at the shroud walls. These shrouds are suspended from the retaining ring on the strongback and the outer rings on the grid assembly. The lower end of the shrouds will be retained circumferentially but will be free to move in the axial direction to accommodate thermal growth differentials. Expansion bellows have also been provided for the thermal growth differentials in the upper end of the intermediate sodium outlet cylinder and the double wall sodium inlet downcommer.

Lateral restraints at strategic locations between concentric cylinders prevent excessive vibration. A lateral restraint at the upper tubesheet takes the seismic forces. The seismic loads at this location will be transmitted to the shield deck and is designed to accept these loads.

Shield Plug

The shield plug occupies most of the annular space between the main IHX shell and the central downcommer in the deck penetration region. It is bolted to the main IHX support flange (See Figure 4) at the outer end and is welded to the central duct and inner shell structures on the inner perimeter. The shield plug structure as a whole serves as the primary pressure boundary in this region and as such is designed as an ASME class 1 structure.

Thermal insulation is provided at the bottom of the shield plug to limit axial heat transfer from the hot reactor cover gas. This insulation is made up of a layer of the plates at the bottom and a layer of wire mesh at the top similar to the deck insulation. Thermal insulation is also provided on the cylindrical face against the central downcommer to limit radial heat transfer from the hot exiting intermediate sodium.

The purpose of reducing heat transfer into the plug region is to avoid excessive heating of the deck penetration liner as its temperature is limited to about 150°F. This limit is dictated by stress considerations in the liner and connecting deck structures and by the presence of concrete immediately inside the liner. A gas cooling system is included in the plug to assure that the temperature limit can be met under all operating conditions. The preliminary thermal/structural analysis of the penetration region is presented in this report. (See Part III, Section 4, "Penetrations".)

The shielding material contained in the plug was initially identified as steel shot with an average of 3/8 inch diameter. The porosity of the steel shot matrix is expected to provide ample permeability for circulation of gas for cooling purposes. Steel shot has several other advantages over other shielding materials such as concrete. The shot can be removed (vacuumed out) in case repair work or inspection of the primary pressure boundary or other elements in this region is needed. In addition, steel shot has no temperature limitations as does concrete. There is, however, some concern that the shot will pack excessively as a result of thermal cycling and introduce high stresses in the plug structures that serves as the shot container. Recent work on removable shielding for the deck structure (see Part II, Section 5, "Removable Shielding") has disclosed other options which merit further investigation.

There are also regions of solid steel to limit radiation "shine" through the many direct radiation paths formed by the annular gaps. One piece of steel is located at the bottom of the radial thermal insulation section. Several steel sections are also located in the upper portions of the plug region particularly on top of the annular gaps between the many cylinders. The radiation shielding shown in Figure 4 is a result of very preliminary evaluations. Detailed analysis of radiation shielding requirements to be performed later may show the need for more steel and additional shielding in the form of boron-carbide materials in some areas.

The inlet and outlet pipes carrying NaK to and from the IRACS coil penetrate the shield plug region. The coil is hanging from the bottom of the plug and is also supported laterally to the IHX shell by an appropriate arrangement. Further design work of this support arrangement will be performed during later study. phases.

There are three major gaps or annuli that communicate with the reactor cover gas and potential for sodium frost formation exist. Vapor traps are therefore needed in these gaps to limit sodium vapor diffusion. Dip-type sodium vapor seals are indicated in Figure 4 at this time. Alternate trap designs will have to be evaluated during future study phases.

Mechanical Design Comparison

The mechanical design of the bent tube IHX concept developed during Phase A Extension I differ in several respects from the straight tube concept developed during Phase A. The major characteristics of the two concepts are tabulated in Table 3 and sketches of the concepts are given in Figure 7. From the sketches it is seen that the overall lengths are approximately the same and both will fit into the 10 foot and 3 inch deck penetration. The major difference between the two is in the tube bundle design and tube support arrangement.

The Phase A concept employs straight tubes supported by drilled plates. The tubes are welded to the tubesheets by front face fillet welds as indicated in Figure 8 and explosively expanded into the tubesheet hole. The tube features of the straight tube concept is similar to that of the CRBRP IHX. Differential thermal expansion between the average tube and shell is taken by an expansion bellows located in the primary exit plenum of the IHX as indicated schematically in Figure 7. Tube-to-tube differential thermal expansion that may arise from flow maldistribution or tube plugging must be accommodated by elastic deformation of the tubes. Rigid support plates at appropriate elevations are provided to avoid tube buckling under these conditions.

In the bent tube design thermal expansion between the average tube and the shell is taken by the two bends in the tubes. Tube-to-tube differential thermal expansion is also accommodated by the bends which makes this concept more forgiving with respect to flow and temperature maldistributions. Tube plugging will also be easier to accommodate. Rigid tube support to avoid tube buckling is not required although the built-up grid support must be capable of taking lateral seismic loads.

Other major differences between the concepts include the sealing arrangements between the hot and cold pool and the IRACS auxiliary heat exchanger design. In the bent tube concept a double bellows seal is used instead of the diving bell gas-type seal selected for the straight tube concept. Both of these seals appear feasible. The U-tube IRACS heat exchanger in the Phase A concept was replaced by the coil type design in the Phase A Extension I concept because of the higher availability expected for the latter in which there are no tube-to-tube-sheet welds.

## Maintenance Considerations

Major maintenance operations of the tube bundle such as tube plugging and replacement of the hot/cold pool seal bellows will normally require removal of the complete IHX from the reactor. Such maintenance will be performed after cleaning and at least local decontamination in separate facilities provided for this purpose. This is a major operation which has been evaluated to some extent in Reference 4. It will require a large shielding cask which is also used for pump maintenance operations and a replacement plug. This replacement plug would require IRACS auxiliary heat exchanger, and a valve for shutting off primary sodium flow, as well as the necessary shielding if operation of the reactor is to be resumed resumed on N-1 loops.

Since IHX removal is a major operation, attempts have been made in the mechanical design to provide for certain maintenance capabilities that do not require removal of the complete IHX.

## Major IHX Subassemblies

Figure 9 shows the four major subassemblies in the bent tube IHX. Subassembly 1 is the central duct. It is removed from the IHX by cutting the intermediate sodium inlet and outlet pipes and by making one cut (cut A-A in Figure

9) where it attaches to the shield plug. This cutting operation appears feasible, but will require temporary shielding and bagging. Some special equipment may also be required.

Subassembly 2 is the flanged cover on the shield plug (See Figures 4 and 9). Its removal requires cutting the gas cooling and IRACS lines and unbolting of the flange. It can be lifted up along with the gas flow distribution shroud. The steel shot contained in the plug can be removed to the extent necessary.

Subassembly 3 consists of the shield plug and the IRACS coil suspended from it. Removal of it requires cutting the inner IHX shell just below the expansion bellows (cut B-B in Figure 9). After unbolting the flanged support, this assembly can be lifted out into the shield cask and maintenance operations performed as necessary.

The fourth subassembly is the main IHX tube bundle and the main shell or hanging support. In-place maintenance operations on this subassembly appears feasible in principle. Access to the upper tubesheet for remote inspection and maintenance is provided by depressing the sodium level by pressurization using the gas valve control system.

Tube Inspection and Plugging

Review of the HEDL Report HEDL-TME-75-29 entitled "In-service Examination of IHX Tubing with Eddy Current NDT Equipment" indicated that it is entirely feasible to design remote tube probing equipment but that no eddy current examination method was found to avoid the signal from residual sodium on the inside surface of the tube.

It appears that the IHX bundle must be removed from the sodium pool and be decontaminated before the tube inspection can be performed. Further study and development is required before a tube inspection procedure can be recommended.

FWEC has developed a tube plugging mechanism for straight tubes that can be remotely activated. This mechanism can be passed through (from top tubesheet to bottom tubesheet) a pre-selected tube, make a 90° turn and engage the tube that is to be plugged in the lower tubesheet. The device places an explosive tube plug in the tube and the handling device is retracted after deformation. The products from the explosive plug are contained within the plug. Plugging of the tube in the upper tubesheet can be performed in the same manner except that the linkage device is not required.

Further development is required to determine if the FWEC tube plugging mechanism can be modified to pass through a bent tube and to determine the feasibility of using an explosive tube plug in a sodium environment. A method of locating a leaking tube or weld also needs to be developed.

### 2.4.2 THERMAL/HYDRAULIC ANALYSIS

Thermal Sizing of Bent Tube Concept

The thermal design and performance requirements for the bent tube IHX are shown in Table 2. The bent tube pool IHX design utilizes 7/8 inch outer diameter stainless steel tubing with a circumferential pitch of 1.3096 inches and an average radial pitch of 1.2504 inches. The 10 foot 3 inch diameter deck penetration limitation can accommodate an IHX with a total of 4860 tubes.

A summary of thermal sizing of the bent tube IHX is shown in Table 4. The total tube length including the bends is 25.09 feet. The distance between tubesheet faces is 24.45 feet. The overall thermal design margin is about 18 percent.

Primary Side Pressure Drop

The pressure drop on the primary (tube) side is limited by the difference in levels between the hot and cold pools which is specified to be 2 psi equivalent. A summary of tube side pressure drop of the bent tube pool IHX design is given in Table 5. The total pressure loss on the primary side from nozzle to nozzle is estimated to be 3.2 psi which is above the specified 2 psi.* It is noted that a large fraction of the pressure drop is in the exit passage (1.0 psi). The total pressure drop could be reduced to 2.3 psi if the duct diameter were increased to twice its present diameter of 42 inches I.D.

The estimated pressure drops for the straight tube design are also given in Table 5 for comparison. It is noted that both the tube and the exit passage pressure drops are lower than for the bent tube design. The tube pressure drop is higher because of the combined effect of the smaller tubes and the bends used in the bent tube design. The exit passage drop is greater because of the smaller diameter specified for this section to accommodate the hot/cold pool seal bellows. The straight tube design employed a diving bell-type seal in this region which did not require an exit-passage diameter reduction.

*This value was increased to 2.5 psi at the end of the Phase A Extension I Study.

The higher-than-specified pressure drop for the bent tube design will have to be addressed during later study phases. The primary pressure drop limit can be increased to the 2.5 psi as originally specified in Phase A. A more detailed structural evaluation of the bellows seal may show that its diameter can be sufficiently increased to satisfy overall pressure drop limitations for the IHX. Use of a diving bell seal instead of the bellows seal in the bent tube design also appears feasible and will be investigated.

Shell Side Pressure Drop

The total shell side pressure drop from the inlet nozzle to the outlet nozzle is calculated to be 13.1 psi. The flow distribution in the tube bundle is essentially axial except at the inlet and exit bundle regions. The pressure drop through the support grids used in the bent tube design (with about 70 percent perforation) is seen from Table 6 to be small compared to that in the tube support plates of the straight tube design. This factor,as well as the primarily axial flow pattern in the bent tube design,reduces the tube bundle pressure drop to an insignificant fraction of that experienced in the straight tube. The total pressure drop is seen from Table 6 to be only about half of that found for the straight tube design.

Flow and Temperature Distributions

The shell-side flow distribution in the lower entrance region was analyzed using the COMMIX computer code. Only the lower two grid spans of the tube bundle were modeled. The analysis of the full fow rate conditions indicates a flow maldistribution of about $\pm$17 percent after the first grid. This is reduced to $\pm$4 percent after crossing the second tube support grid which implies that the assumption of uniform axial flow in the central portions of the tube bundle is quite good. At 12 percent shell side mass flow rate, essentially the same degree of flow maldistribution is found in the bundle inlet region. Further details of the flow distribution analysis are given in Appendix VA.

There is a fundamental difference between the bent and straight tube designs regarding shell-side flow distribution. The bent tube design has low pressure drop grid supports and essentially axial flow. The straight tube design,on the other hand, has high pressure drops in the tube support plates and a larger degree of cross-flow mixing in the tube bundle. This is necessary to assure good flow and temperature distributions in the straight tube design which is needed to avoid tube buckling problems. The bent tubes have built-in flexibility and do not require nearly as good flow and temperature distributions to operate satisfactorily. Improvements in the flow and temperature distributions in the bent tube design will require increased tube support grid pressure drop by reduced perforation or by baffling. Since such improvements would increase the crossflow and the concern regarding tube vibration, the impact on tube vibration will be evaluated and verified before incorporating design changes.

The temperature distribution of the IHX tube bundle was also investigated using an axisymmetric, thermal performance code. Uniform axial flow distribution was assumed from the first to the last tube support grid on the shell side. Primary side flow was assumed to be equally distributed among all tubes. Figure 10 shows the radial temperature distribution across the tube bundle at three different axial locations under full load conditions.

The temperature difference between the outermost tube and the innermost tube location is about 73°F in the inlet region. This is due to the cross flow effect in this region. The temperature near the outer radius is higher. This radial temperature difference is seen to decrease for higher elevations in the tube bundle. In the exit region, the hotter shell side sodium near the outer radius will flow towards the inner radius and mix with the colder sodium making the radial temperature difference negligible.

Radial temperature differences in the tube bundle becomes worse under the intermediate loop loss transient when the intermediate sodium flow drops to 12 percent and the primary flow is maintained at 100 percent of full flow. Thermal analysis results indicate that heat transfer takes place mainly in the first span in the intermediate inlet region. Sodium temperature reaches equilibrium with the primary sodium 850°F after the first two lower spans. The radial temperature distribution at the lower tubesheet area where the radial temperature difference is greatest is shown in Figure 4. More detailed results are given in Appendix VA

Reduced Diameter IHX

The IHX deck penetration diameter influences to a certain extent the size of the reactor vessel and should therefore be made as small as practical. The IHX studies so far have assumed a penetration diameter of 10 feet and 3 inches. The feasibility of reducing the penetration by as much as 1 foot was investigated for the straight tube concept.

The results show that the tube pitch has to be reduced from 1.4 inches to 1.28 inches and the tube length increases from 25.125 feet to 26.08 feet for a 1 foot reduction in penetration diameter. This design will result in an acceptable primary side pressure drop. It appears, however, that the shell side pressure drop will be excessive and tube vibration may become more of a problem because of the higher cross flow velocities. Further investigations of these items will be needed to confirm the feasibility of this option.

Flow Induced Vibration

The tubes are exposed to cross flow at the bundle entrance and exit regions and also at the upper and lower bend regions. Flow velocities are highest near the entrance and exit windows because these are located on the inner perimeter of the tube bundle. Sodium cross flow can give rise to vortex shedding and flow-induced vibrations of the tubes. The natural frequencies of the tubes were calculated using the ANSYS computer program for two assumed boundary conditions. The computed tube frequencies were compared to the vortex shedding frequencies at the entrance/exit regions and the bend region.

The lowest mode natural frequencies were found to be below or only slightly higher than the vortex shedding frequencies. It is good engineering practice to assure that the natural frequencies of the tubes should be 50 percent higher than the vortex shedding frequencies. This criterion is not met under the worst case assumptions. Under these conditions it is concluded that the tube vibration amplitude must be demonstrated to be small by test. It is therefore recommended that a flow test be performed to qualify the tubes.

Seismic Analysis

Seismic analysis of the bent tube and straight tube designs were performed using ANSYS computer models with the Bechtel supplied (Reference 4) seismic response spectra as input. The results are reported in Section V-3 which follows this section, in Reference 2, and in Appendix VA. A summary of the results are presented here.

Results of the bent tube design seismic analysis assuming seismic supports at the top flange and bottom (lower tubesheet) indicated unacceptable loads at the inner shroud. Two alternate approaches were explored to reduce the loads in the inner shroud to acceptable levels. The first approach involved the use of an intermediate seismic support at the upper tubesheet elevation whereas the second approach involved increasing the inner shroud thickness. Both approaches reduced the seismic loads to acceptable levels, but the reduction was more significant when the inner shroud thickness was increased.

Seismic analysis of the straight tube design assumed three different types of intermediate seismic support in addition to top flange support. The first case assumed seismic support at the upper tubesheet with the loads transmitted to the flow shroud. The flow shroud was connected to the bottom of the deck in this case. A second case considered that the load carrying flow shroud was supported at the top of the deck structure. The third case assumed no intermediate support either at the upper, or lower tubesheets.

The results showed that stresses and deflections are acceptable for the first two cases assuming support at the upper tubesheet. However, the loads in the main IHX shell are unacceptable for buckling if support is provided only at the top flange as was assumed in the third case. In all cases, high loads and deflections were experienced at the top of the central duct structure. Additional spacers or thickening of the materials should alleviate this problem.

Further refinements in the analytic modeling will be required at a later time. These preliminary analyses indicate that both designs are acceptable for seismic loadings with minor modifications. There appears to be no significant differences between the two designs except that somewhat more attention has to be paid to the tube support arrangement (grid) used in the bent tube design. A separate analysis and sizing of the grid for lateral seismic loads is presented in Appendix VA.

Thermal/Structural Analysis

A qualitative comparative evaluation of thermal transients indicates that the upset transient "Loss of One IHTS Loop without Scram" is the most severe for the large pool IHX. This transient was identified early in the work to provide a conservative basis for FWEC to proceed. More recent studies (Part V, Section 7, "Duty Cycle") show that the magnitude and rate of this transient is significantly reduced by reducing the primary sodium flow after scram. The effect of this reduction will be evaluated in later work. This controlling upset transient causes a significant upshock at the lower tubesheet, while the upper tubesheet is unaffected. This upshock causes a monotonic increase in primary sodium temperature at the lower tubesheet due to a sudden reduction in intermediate sodium flow (to 12 percent of full flow) in about 2 minutes. The temperature near the outside of the tubesheet monotonically increases to a higher value than does the temperature near the center of the tubesheet due to the reduced intermediate fluid cross flow. The primary outlet temperature variation in the radial direction is about 150°F, and the intermediate fluid temperature radial variation across the tubesheet diameter is about 300°F

(See Figure 11). This quasi-steady state condition was evaluated using an ANSYS computer model as described in Appendix VA.

A maximum linearized surface stress range of 53,499 psi was found at the inner crotch region of the tubesheet (see Figures 12 and 13 in Appendix VA). This stress is predominately caused by the thermal discontinuity between the thin head and the tubesheet. The maximum peak surface stress is 60,094 psi occurring at the top of the tubesheet ID.

These stresses exceed Code Case 1592 limits using elastic analysis methods. Re-evaluation of these stresses with the reduced transient input is required and, if necessary, inelastic analysis will be performed to show structural adequacy of the lower tubesheet junctions. The controlling parameter in the inelastic analysis is expected to be fatigue damage. Creep damage and accumulated strain (ratchetting) will not be critical. FWEC experience with the CRBRP-IHX lower tubesheet region indicates that this lower tubesheet has a high probability of success in meeting the Code limits.

The thermal stress results indicated the possibility of eliminating the double head design at the lower tubesheet region. The purpose of the inner hemi-head is to shield the lower tubesheet hemi-head and crotch region from high temperature gradients. Assuming that there are no additional transients which can cause stress reversal, it is judged that a high probability of success exists in satisfying the Code allowables, with the inner hemi-head removed.

Cost Comparison

The straight tube and bent tube heat exchangers have different concepts for the roof plug, auxiliary cooling coils, and sodium hot/cold pool seal. However, it is possible to use either of the alternate concepts in any combination with either the straight tube or bent tube designs. Therefore, the cost differentials between straight and bent tube are confined to comparisons of specific design features within the tube bundle. It is assumed that all other costs would be comparable.

Costs of the tube bundle consist of the five major cost categoreis: (1) tubing, (2) tube bending, (3) tubesheet machining, (4) tube support structures, and (5) assembly. Differential cost estimates for the straight and bent tube designs for these cost categories were prepared and are summarized in Table 7 (see Appendix VA for explanations).

Table 7

Differential Cost Summary Per IHX -
Bent Tube Versus Straight Tube Concepts

| Cost Category | | Differential Cost $ (Relative to Straight Tube) |
|---|---|---|
| Tubing | | -33,785 |
| Tube Bending | | +280,000 |
| Tubesheet Machining | | +216,722 |
| Tube Support Structures | | -144,722 |
| Assembly | | +115,000 |
| | Total | +432,643 |

It is assumed that the balance of the material and labor costs will be the same for both designs. Therefore, the total cost increase for the bent tube design is 432,643 or \$0.89 per $kW_t$. This represents a 4.3 percent increase from the straight tube design. The cost increase will be partly offset by reduced intermediate sodium pumping costs.

## V-2.5

## DISCUSSION

The purpose of performing the design study on the bent tube concept based primarily on PFR operating experience and CDFR design experience was to provide a basis for comparison with the straight tube concept based primarily on CRBRP IHX design experience. Both studies concentrated mostly on the main tube bundles since their integrity must be maintained over the life of the plant with minimum or no operational problems. There is more flexibility in the design of other elements of the IHX such as the shield plug, the hot/cold seal, central duct, primary sodium shutoff valve, and the IRACS heat exchanger. One design or the other can be adopted with either tube bundle concept.

In reporting the results of these studies, attempts were made firstly to present the bent tube concept study results and secondly to compare the attributes of important design features as well as cost of the two concepts. This comparison will be the basis for selecting a reference concept for further studies in later phases.

Study results to date have not revealed any significant feasibility problems with either design concept. The general feeling is that both concepts can be made to work when appropriate analytic and experimental work are carried out during the detailed design process to support the concept. However, the technical evaluation has shown that there are advantages and disadvantages with elements of either tube bundle design.

A qualitative technical evaluation of the factors deemed important in the concept selection process is presented in the tabulation below.

COMPARISON OF CONCEPTS

| | | Bent Tube Concept | Straight Tube Concept |
|---|---|---|---|
| 1. | Costs | - | - |
| 2. | Margin for Transients Plus Flow Maldistribution | ++ | |
| 3. | Shell Bellows | ++ | |
| 4. | Tube $\Delta P$ | | + |
| 5. | Shell $\Delta P$ | + | |
| 6. | Seismic | | (+?) |
| 7. | Tubesheet Crevices | + | |
| 8. | Weld Inspection | + | |
| 9. | Tube Supports (Crevices, Complexity) | | + |
| 10. | Tube Inspection* | | + |
| 11. | Tube Plugging* | | + |
| 12. | Experience | ++ | |

Legend:

- \- = Standoff
- \+ = Nominal Advantage
- ++ = Significant Advantage
- * If possible and if required.

A general discussion and reasoning for the particular weight given to each factor follows.

The capital cost of each concept listed as the first item is regarded as a stand-off although the cost evaluation presented earlier indicated a slight advantage for the straight tube concept principally because of a simpler weld and tube configuration. This slight cost advantage, however, is not significant and will be offset by increased intermediate sodium pumping costs for the higher shell-side pressure drops required to assure good flow and temperature distributions in the straight tube concept.

The second item in the tabulation concerns margin for thermal transients and flow and temperature maldistributions. Here the bent tube concept is judged to have a significant advantage relative to the straight tube concept. The principal reason for this is that the bent tubes are more flexible and can withstand greater tube-to-tube temperature differences during transients and a greater degree of flow maldistribution is acceptable without exceeding allowable stress limits. The straight tube design is much more sensitive to these effects and an element of uncertainty exist in establishing a design that will eliminate such concerns.

Item number three concerns the large diameter expansion bellows employed in the straight tube concept to accommodate the average tube-to-shell temperature difference. The tube bends serve this function in the bent tube design and its elimination is considered a significant advantage for the bent tube design in the pool concept, where diameter is at a premium. Preliminary evaluation of the bellows design has shown that such a bellows is feasible. There is, however, an element of uncertainty with respect to life and maintenance requirements for the large size bellows.

The fourth and fifth items concern tube-side and shell-side pressure drops. The straight tube concept is judged to have a nominal advantage over the bent tube concept because of the higher pressure drop caused by the tube bends. The bent tube concept, however, has the lowest shell-side pressure drop.

Item number six concerns the ability of the concepts to withstand seismic loadings. Although the preliminary evaluations show that both concepts are feasible, a slight advantage is assigned to the straight tube concept because of its stiffer tube support arrangement. The drilled tube support plates are inherently better when subjected to lateral seismic loads as compared to the built-up grid supports used in the bent tube concept. The structural evaluations of the grid supports, however, showed that an adequate design is feasible.

Tubesheet crevices, listed as item 7 in the tabulation, do not occur in the bent tube concept as it presently exist and this concept is therefore considered to have a nominal advantage over the straight tube concept where a front face fillet weld is used. However, there are differences of opinion as to the importance of this feature since the straight tube is explosively expanded into the tubesheet resulting in a virtually leak proof and highly bonded joint in itself. It is noted that a front face fillet weld like the one used in the straight tube concept can be used in the bent tube concept, but the internal bore weld used in the bent tube concept cannot be used in the straight tube concept.

Item number 8 concerns weld inspection. Again the internal bore weld used in the bent tube concept has an advantage as it can be x-rayed 100 percent whereas the front face fillet weld cannot. Other less reliable means such as dye penetrant and helium sniffing techniques must be adapted.

The tube support method is listed as item number 9. The drilled tube support plate used in the straight tube concept is considered superior to the grid type supports because it is simpler and has fewer crevices. The grid supports are made of virtually thousands of parts welded together in such a way that crevices are formed. The relatively large contact area with the tubes are also potential crevices where corrosion may start following component cleaning or where sodium/water reaction products may lodge. It is believed that this uncertainty can be resolved by an improved design supported by tests as necessary.

In-place tube inspection and plugging listed as items 10 and 11 is considered to be easier in the straight tube concept because there are no tube bends to obstruct the movement of inspection or tube plugging devices inside the tubes. The straight tube concept is assigned nominal advantages for these items although further development may show that these operations are also feasible in bent tube concept. There is also a question if these operations are required and if indeed they can be performed in a pool reactor in either concept.

The last item listed in the tabulation concerns operating experience. Here it is concluded that the bent tube concept has a significant advantage because of the PFR operating experience. Equivalent operating experience is not available for the straight tube concept except for the French Phenix reactor in which the primary sodium is on the shell side rather than on the tube side.

The overall conclusion of this comparative evaluation is that the bent tube concept has a definite advantage over the straight tube concept although both concepts are feasible. It is recommended that the bent tube concept be selected as a reference concept for further study during the next phase. The straight tube concept should be retained as a backup in case further studies should reveal feasibility concerns with the bent tube concept.

The technical evaluation has concentrated on the tube bundle design and not on features such as the shield plug, the hot/cold pool seal, primary shutoff valve, and IRACS heat exchanger. These items are of less fundamental importance and several design options appear feasible. These options should be evaluated in more detail during later study phases.

Table 1

GENERAL DESIGN REQUIREMENTS

| | |
|---|---|
| Number of IHX's in Plant | 6 |
| Design Life (years) | 40 |
| Material of Construction | 304 SS* |
| Tube Configuration | Sine Waves |
| Primary Flow Location | Tube Side |
| Normal Operating Range (percent of full load) | 60-100 |
| Primary Sodium Shutoff Valve Type | Gas |
| Tube Thermal Expansion Prov. | Bends in Tubes |
| Hot/Cold Pool Seal Type | Double Bellows |
| Decay Heat Removal | IRACS Coil |
| Central Duct | Removable (Cut 2 Welds) For Maintenance |
| Shield Plug and IRACS Coil | Removable (After Removing Central Duct) For Maintenance |

*Preferred material. Vendor may recommend alternates if considered necessary to meet the design requirements.

Table 2

DESIGN AND PERFORMANCE DATA

- Design Temperatures:

  Primary. . . . . . . . . . . . . . . . . . . . . . . .900°F
  Intermediate. . . . . . . . . . . . . . . . . . . . . 835°F

- Operating Temperatures:

  Primary Inlet. . . . . . . . . . . . . . . . . . . . .875°F
  Primary Outlet. . . . . . . . . . . . . . . . . . . . 594°F

  Intermediate Inlet. . . . . . . . . . . . . . . . . . 550°F
  Intermediate Outlet. . . . . . . . . . . . . . . . . .815°F

  Auxiliary Inlet. . . . . . . . . . . . . . . . . . . .580°F
  Auxiliary Outlet. . . . . . . . . . . . . . . . . . . 845°F

- Design Pressure:

  Primary Side. . . . . . . . . . . . . . . . . . . . . 10 psig
  Intermediate Side. . . . . . . . . . . . . . . . . . .250 psig

- Unit Thermal Rating:

  Primary IHX. . . . . . . . . . . . . . . . . . . . . .486 MWt
  Auxiliary IHX. . . . . . . . . . . . . . . . . . . . .3 MWt

- Unit Flow Rate:

  Primary Na. . . . . . . . . . . . . . . . . . . . 19.25 x $10^6$ lbs/Hr.
  Intermediate Na. . . . . . . . . . . . . . . . . .20.29 x $10^6$

- Pressure Drop:

  Tube Side. . . . . . . . . . . . . . . . . . . . . . .2.0 psi*
  Shell Side. . . . . . . . . . . . . . . . . . . . . . 30 psi

*It was decided to increase this value to 2.5 psi at the end of Phase A Extension I.

Table 3

DESIGN CONCEPT COMPARISON

| | Phase A | Phase A Extension |
|---|---|---|
| IHX Size | 6 Per Loop<br>486 MWt Per IHX | 6 Per Loop<br>486 MWt Per IHX |
| Tubes | 4420-1" O.D. x .045 Min. Wall x 25'-1-1/2" Lg. | 4860-7/8" O.D. x .040" Min. Wall x 24'-5 3/8" |
| Tube Configuration | Straight | Double Sine Wave |
| Heat Transfer Surface Area | 20,052 $ft^2$ | 27,204 $ft^2$ |
| Upper Tubesheet | Fixed | Fixed |
| Lower Tubesheet | Floating | Fixed |
| Bundle Size | 42" Inner Tube Limit<br>106.75" Outer Tube Limit | 42.56" Inner Tube Limit<br>107.54" Outer Tube Limit |
| Tube Pitch | 1.40" Triangular Pitch | 1.250" Raidal Pitch<br>1.309 Circumferential Pitch |
| Tube Support | Perforated Disc (Tube Slides through Support Plate Holes) | Grid Type (Tube Clamped to Grid) |
| Penetration Opening Size For IHX | 10' - 3" | 10' - 3" |

Table 4

THERMAL SIZING OF 486 MWt BENT TUBE IHX

| | |
|---|---|
| Number of Tubes | 4680 |
| Tube OD (Inches) | 7/8 |
| Tube Wall Thickness (Inches) | 0.0394 (1MM) $\pm$15 Percent |
| Tube Pitch (Inches) | |
| Circumferential | 1.3096 |
| Average Radial | 1.2504 |
| <u>Tube Length</u> | <u>Feet</u> |
| Basic Sizing | 21.22 |
| Shell-Side Flow-Bypass Effect (1 Percent of Full Flow) | 0.59 |
| Uncertainties in Heat Transfer Coefficients and Wall Conductivity (90 Percent Confidence Level) | 1.38 |
| Partially Inactive Support Plates | 0.70 |
| Partially Inactive Bundle Inlet/Outlet Region | 1.20 |
| Required Tube Length | 25.09 |

Design Margin = 18 Percent

Table 5

PRIMARY SIDE PRESSURE DROPS (psi)

| | | Bent Tube Design | Straight Tube Design |
|---|---|---|---|
| Hot Pool to Inside Top Plenum | | 0.322 | .322 |
| Through Auxiliary Coils | | 0.033 | .033 |
| Tubes (Frictions, 2 Bends, Inlet Exit) | | 1.863 | 1.262 |
| | SUBTOTAL | 2.218 | 1.618 |
| Exit Passage | | 1.0 | .15 |
| | TOTAL | 3.218 | 1.767 |

Table 6

SHELL SIDE PRESSURE DROP (PSI)

| | Bent Tube Design | Straight Tube Design |
|---|---|---|
| Inlet Downcommer | 2.109 | 2.088 |
| 90° Turn to Tube Bundle | 0.963 | .963 |
| Tube Bundle (Inc. Inlet Pref.) | 1.950 | 16.490 |
| 90° Turn from Tube Bundle | 2.609 | 2.609 |
| Outlet Annulus | 5.431 | 5.431 |
| TOTAL | 13.062 | 27.581 |

## REFERENCES


1. Pool-Type LMFBR Plant, 1000 MWe Phase A Design, EPRI NP-646, Volume 1, April, 1978.

3. Pool-Type LMFBR Plant, 1000 MWe Phase A Design, EPRI NP-646, Volume 7, April, 1978.

4. Pool-Type LMFBR Plant, 1000 MWe Phase A Design, EPRI NP-646, Volume 6, Part V-5, April, 1978.

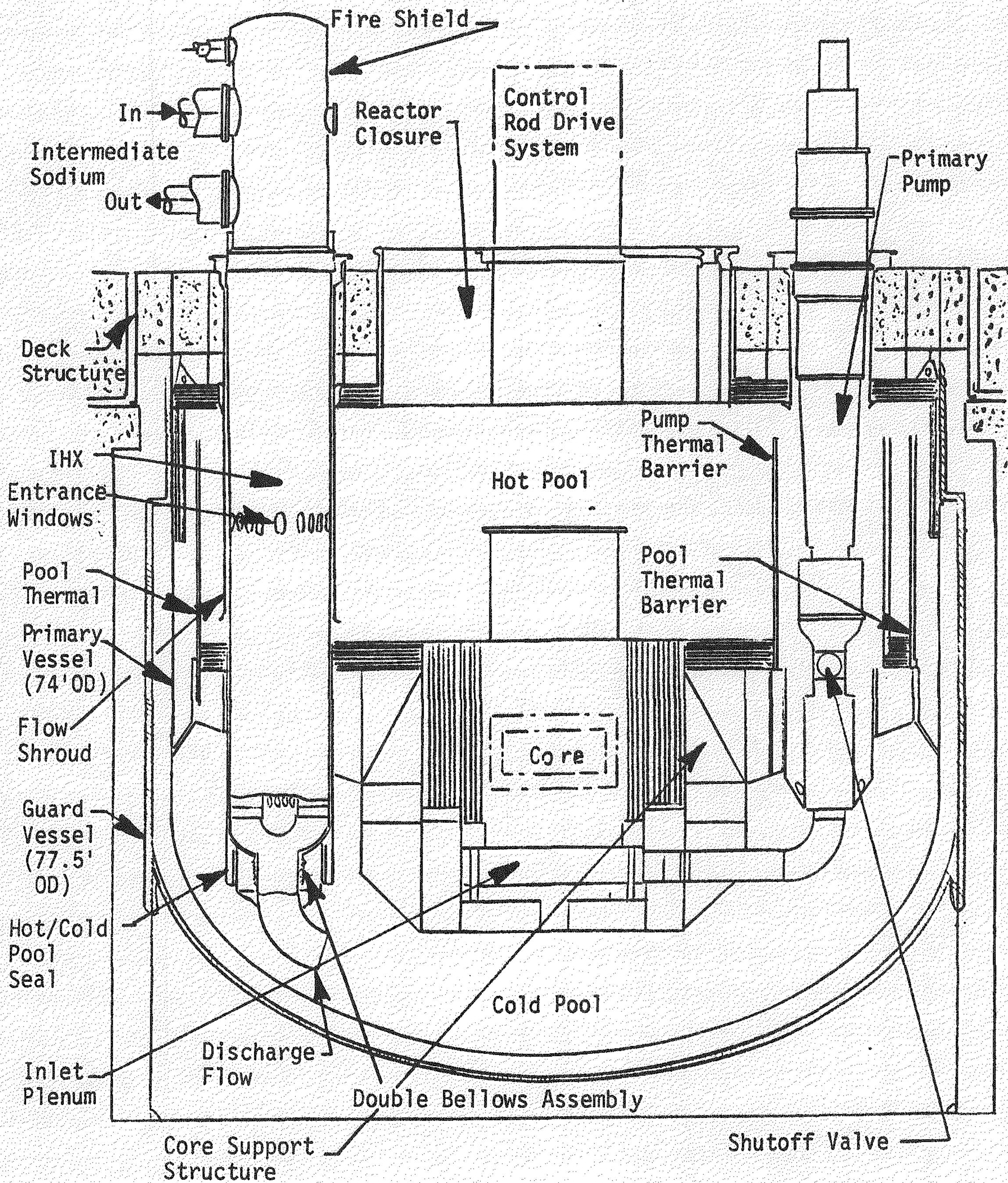


Figure 1 Reactor Assembly

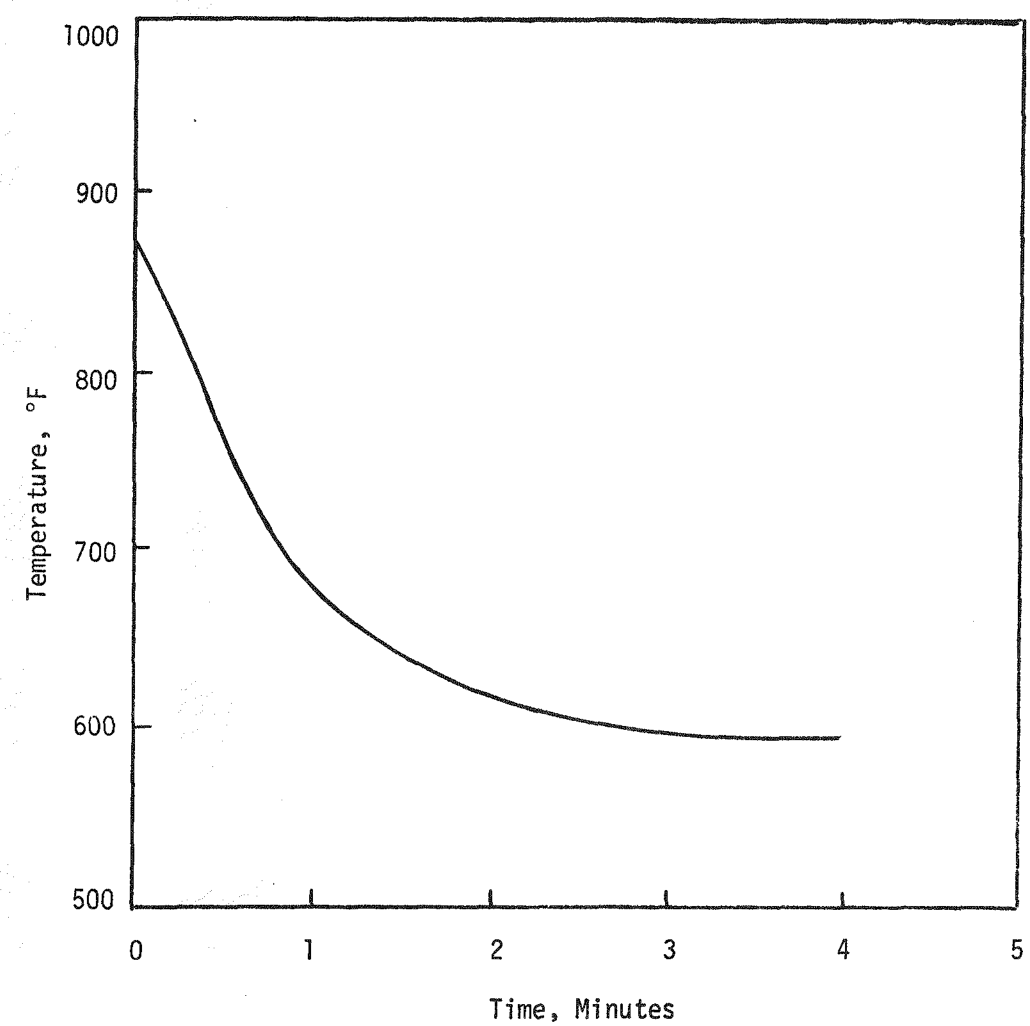


Figure 2 Reactor Scram From 100 Percent Power (Primary And Intermediate Pumps At Full-IHX Primary Inlet Flow)

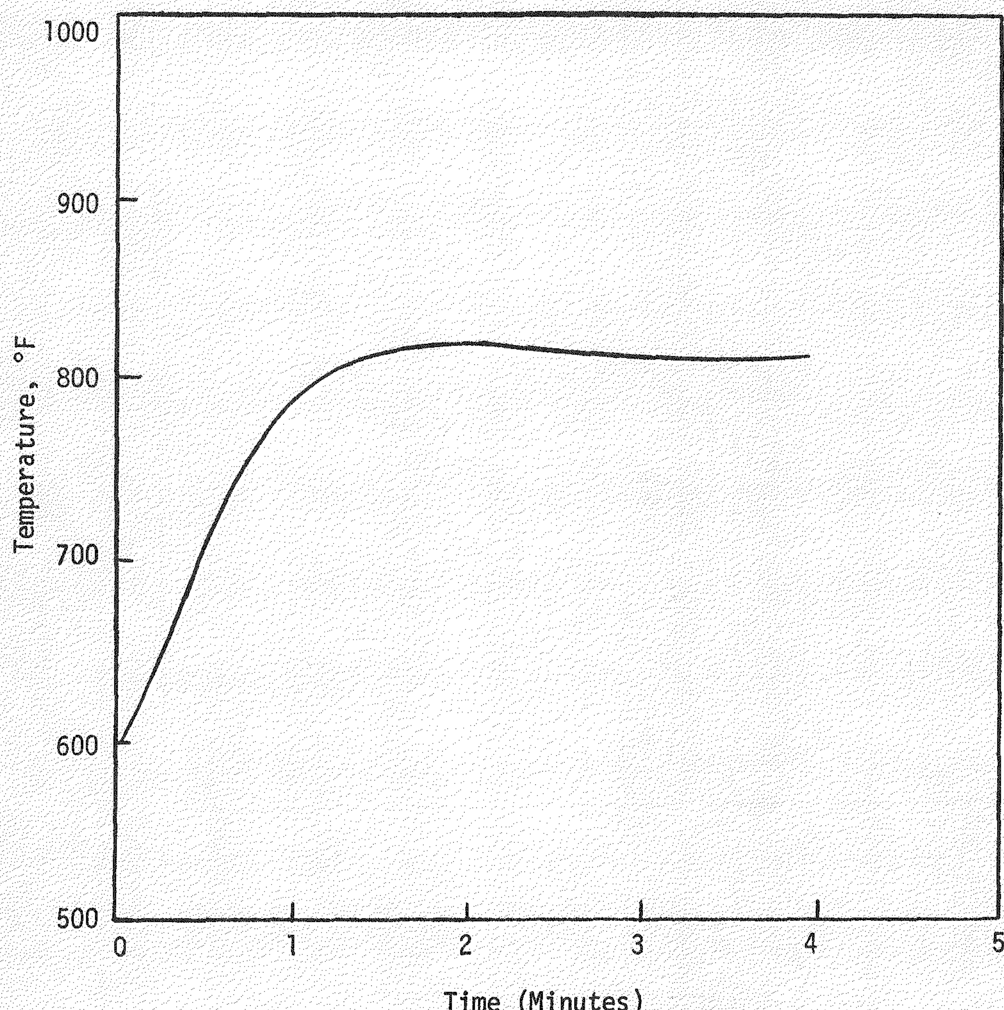


Figure 3 Intermediate Pump Trip - IHX Primary Outlet (No Scram)


Figure 4 Bent Tube IHX Concept

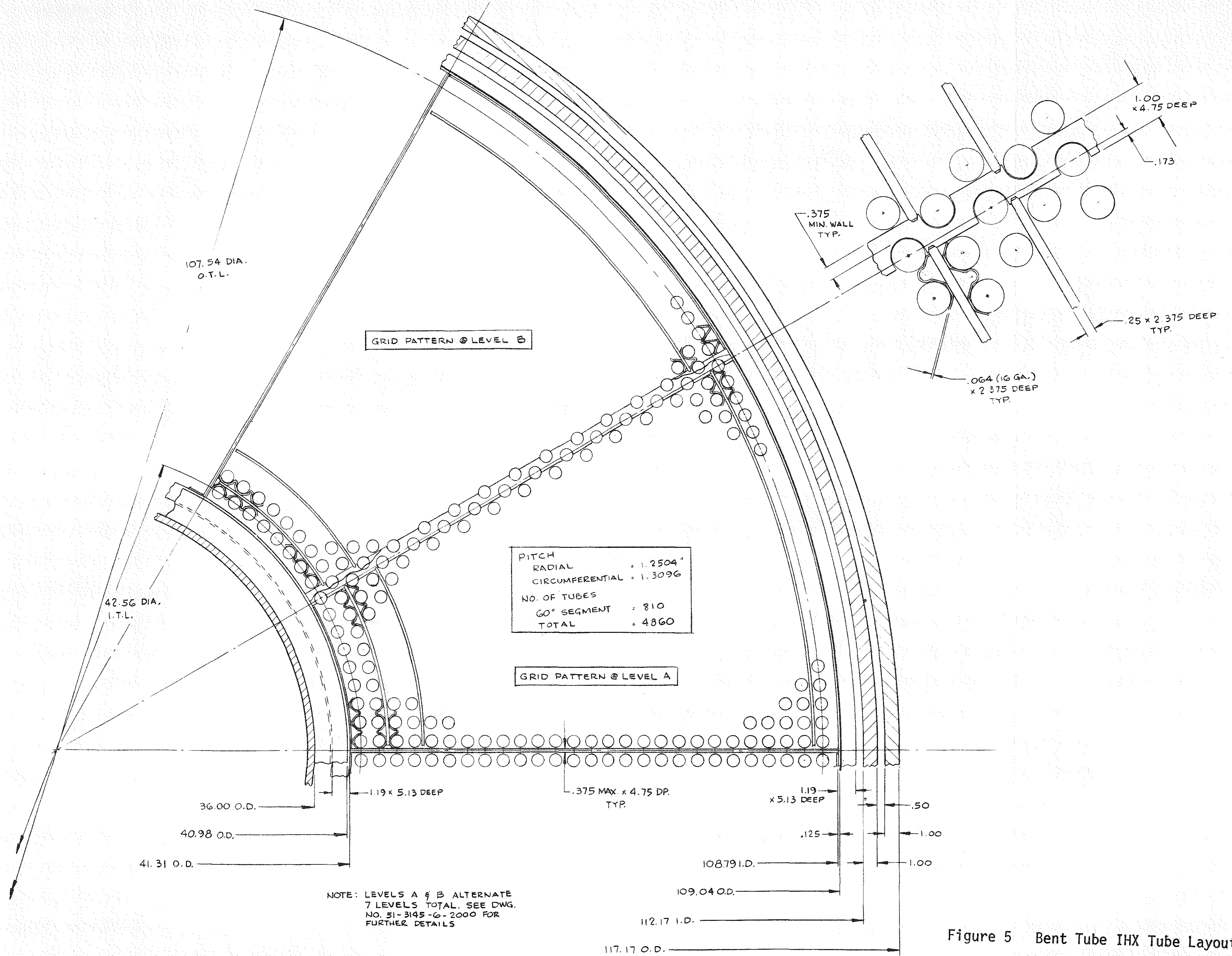


Figure 5 Bent Tube IHX Tube Layout And Support

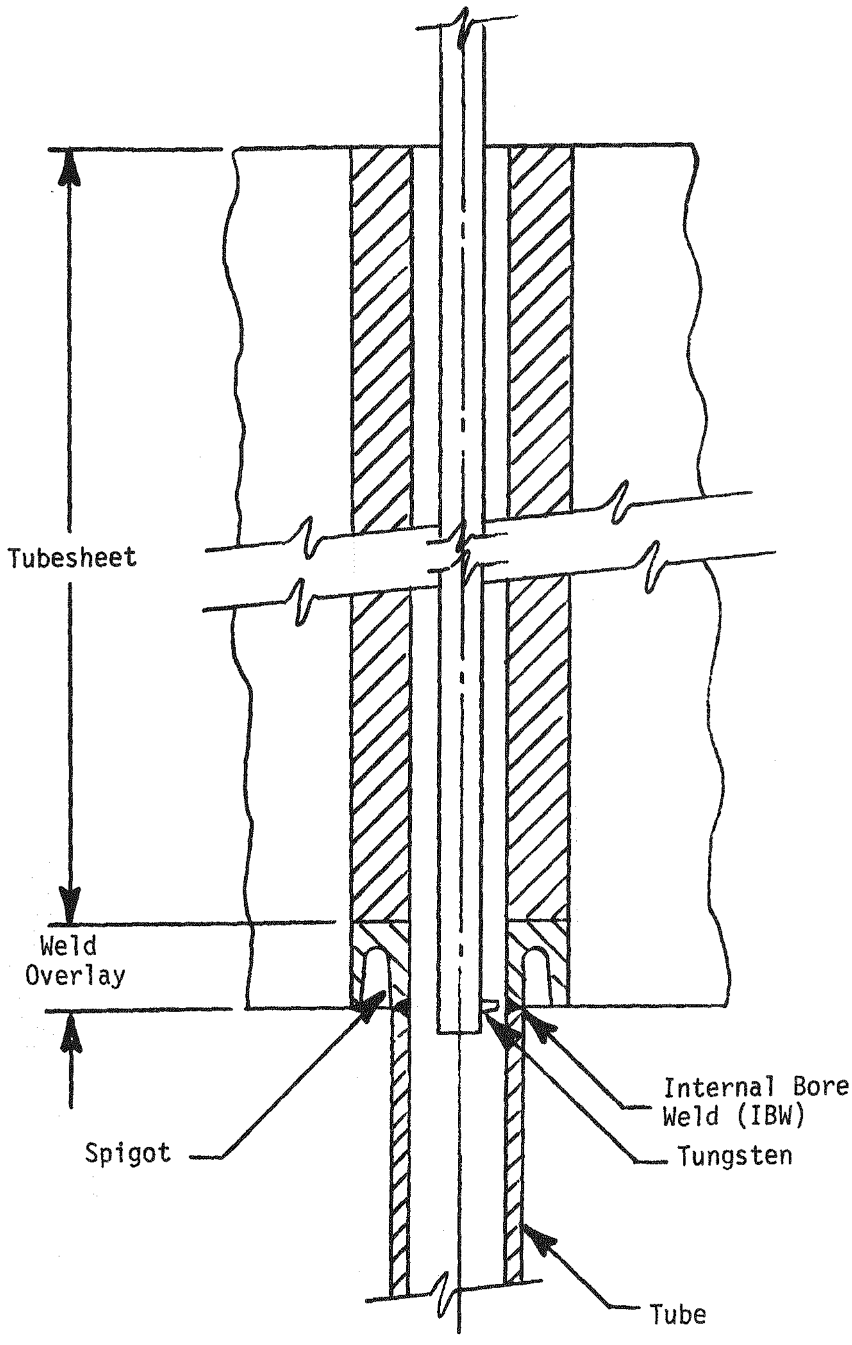


Figure 6 Internal Bore Weld Configuration

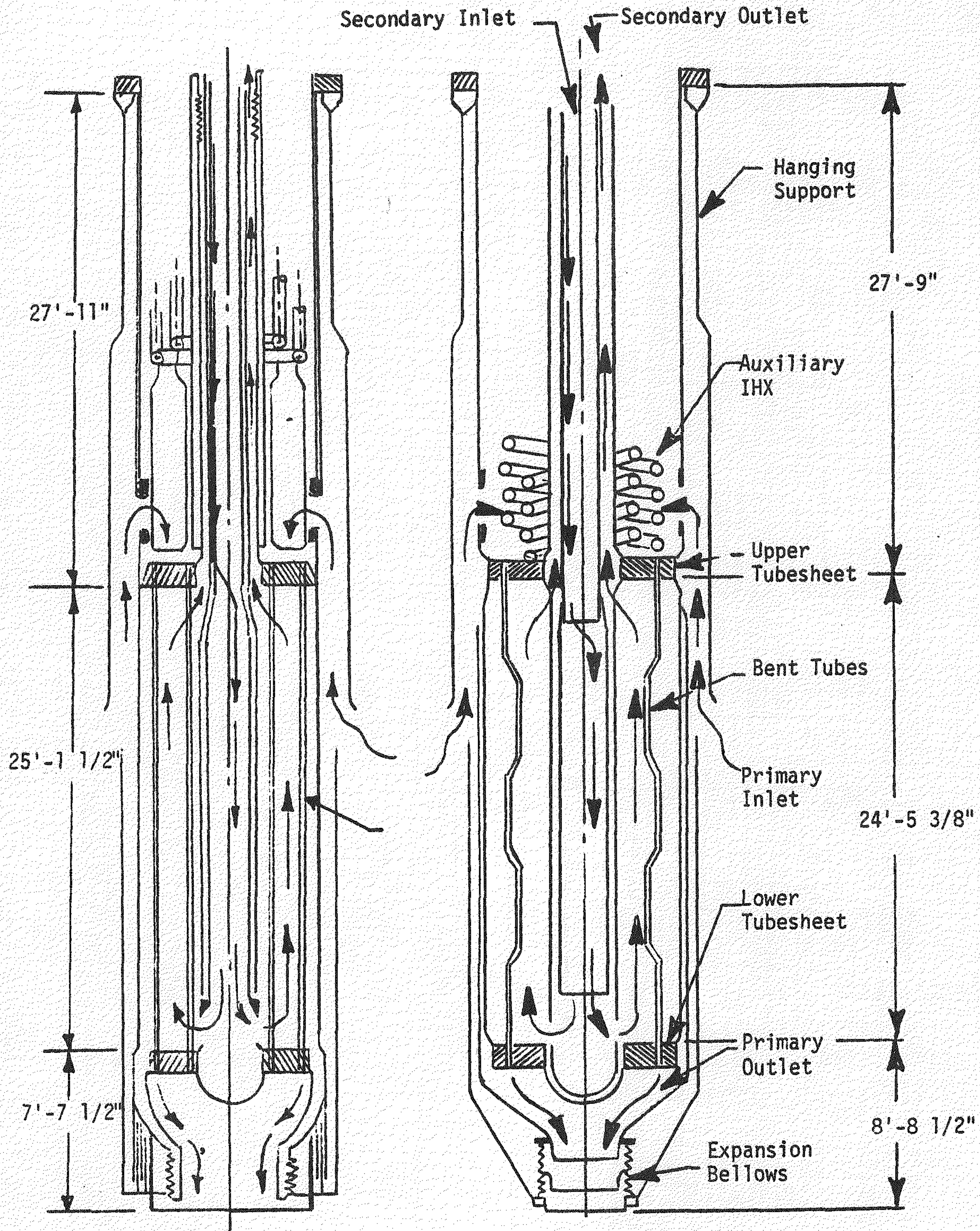


Figure 7 Comparison Of IHX Design Features

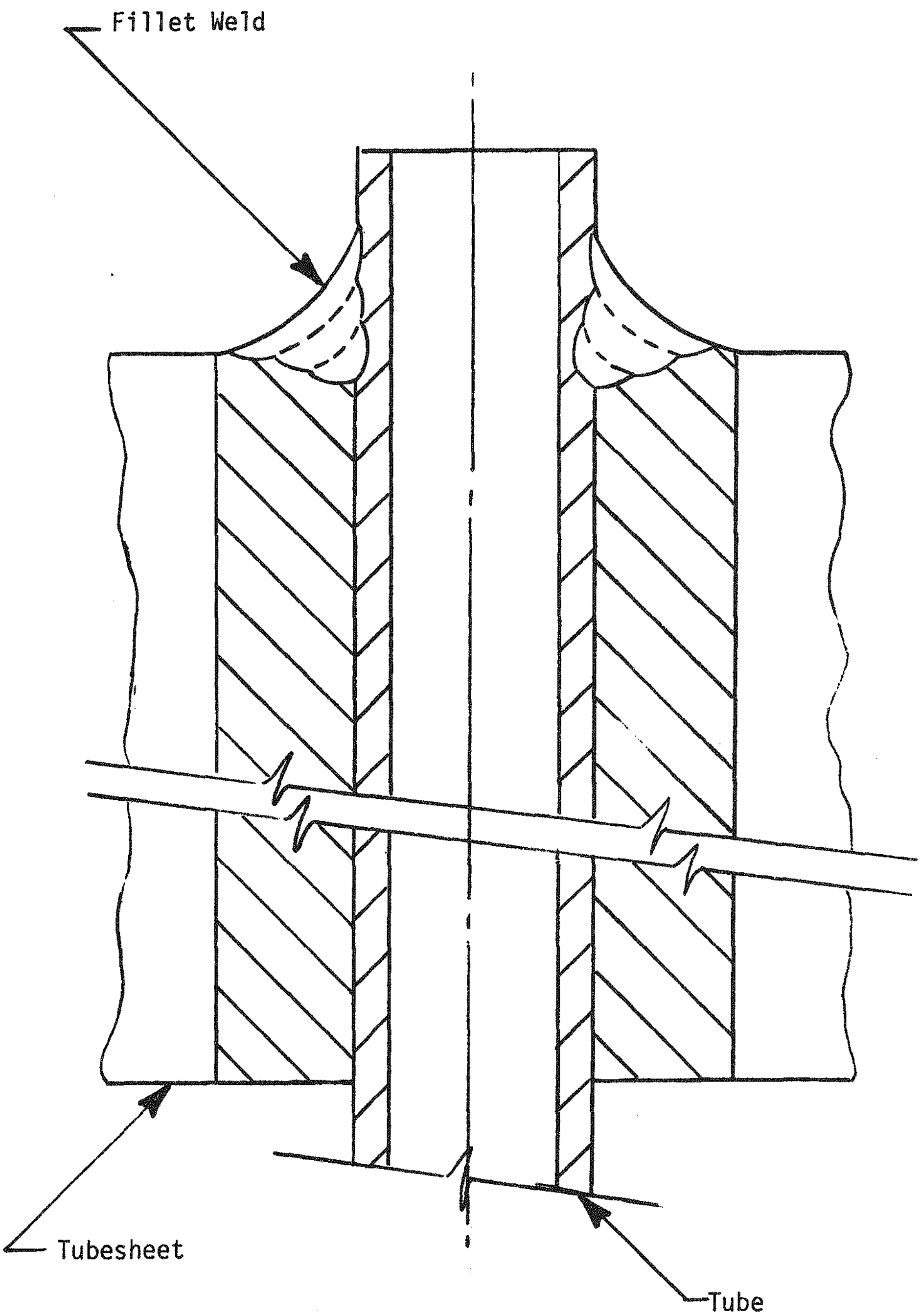


Figure 8 Front Face Weld Configuration

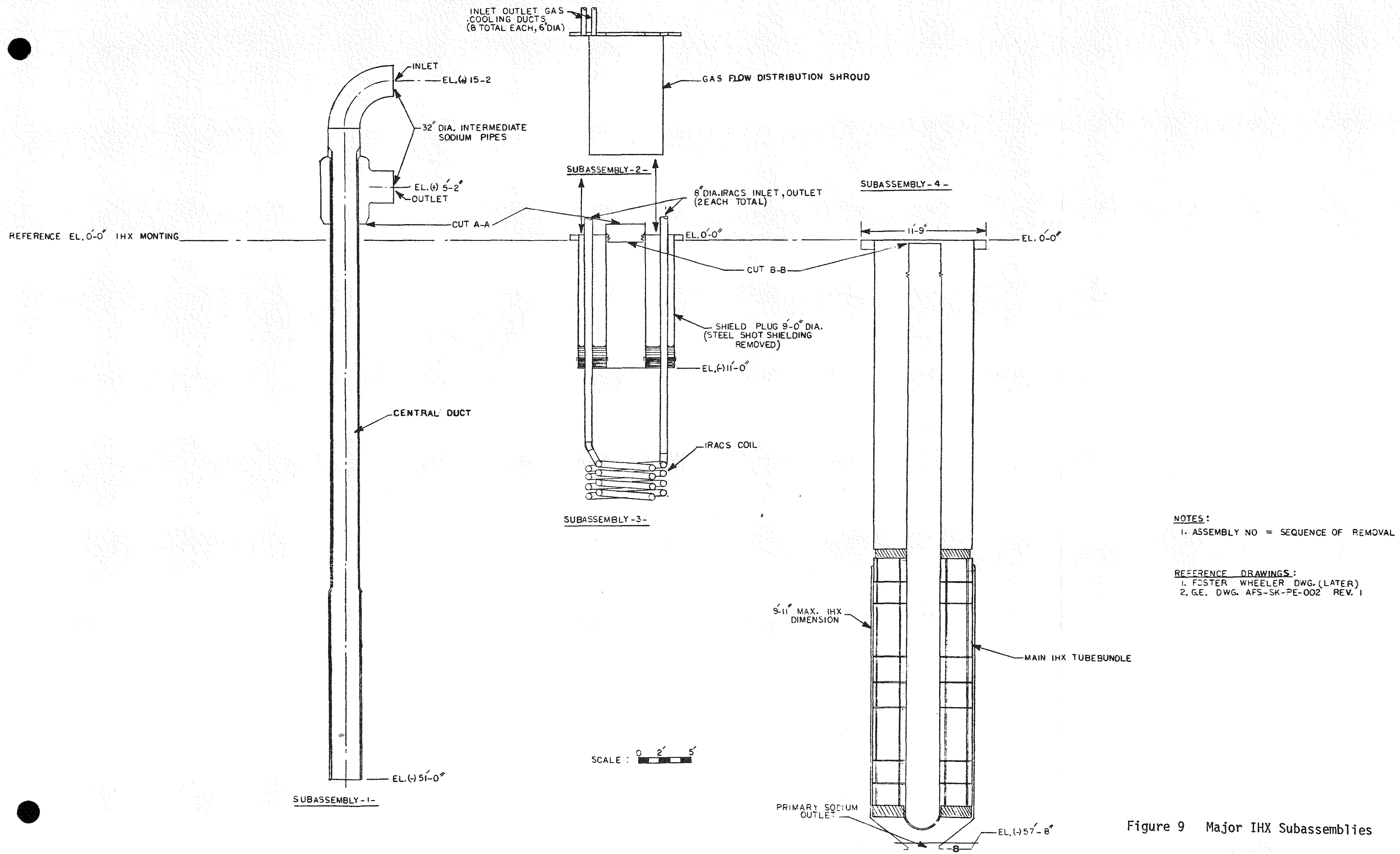


Figure 9 Major IHX Subassemblies

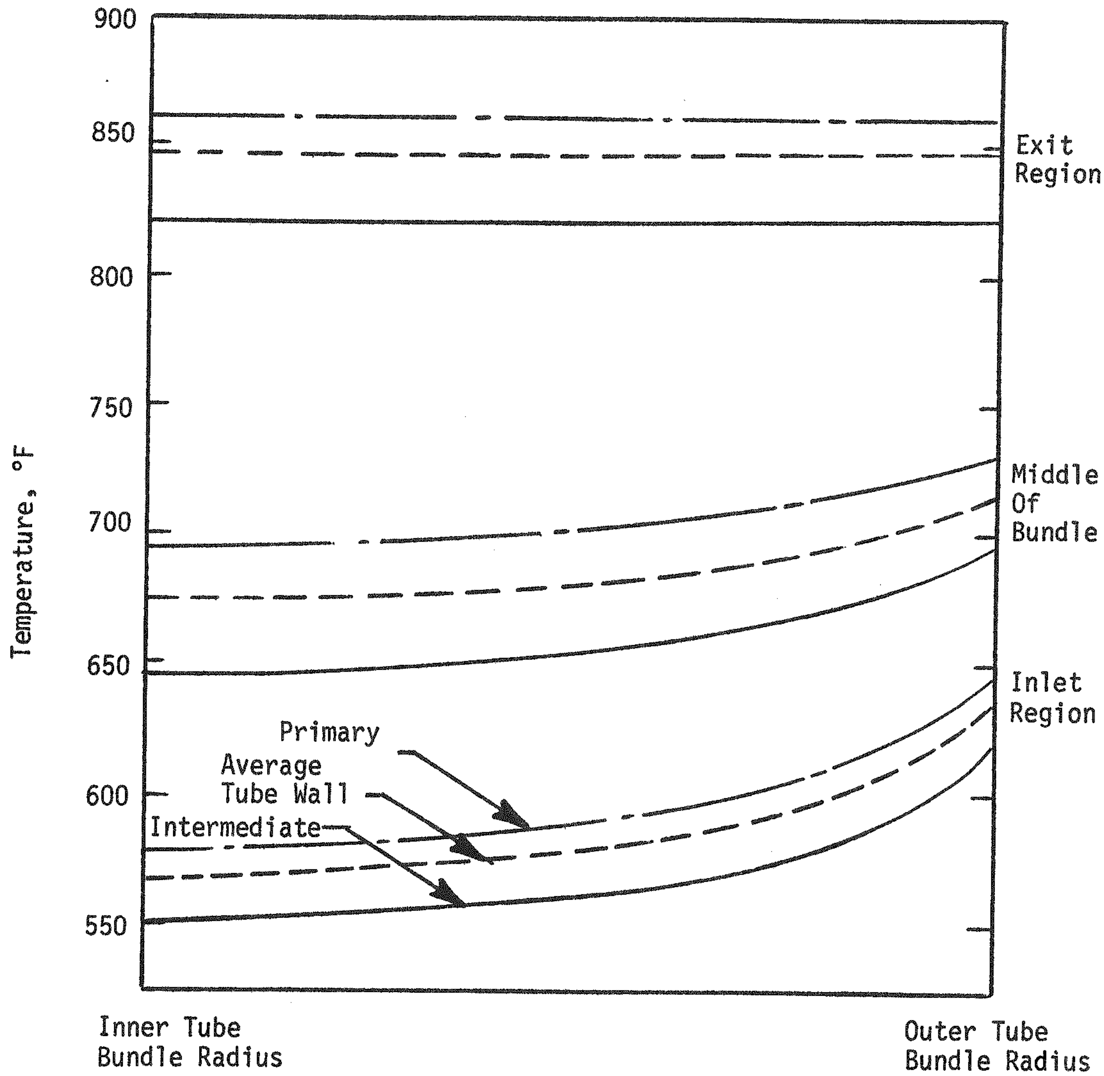


Figure 10 Temperature Distribution At Full Load

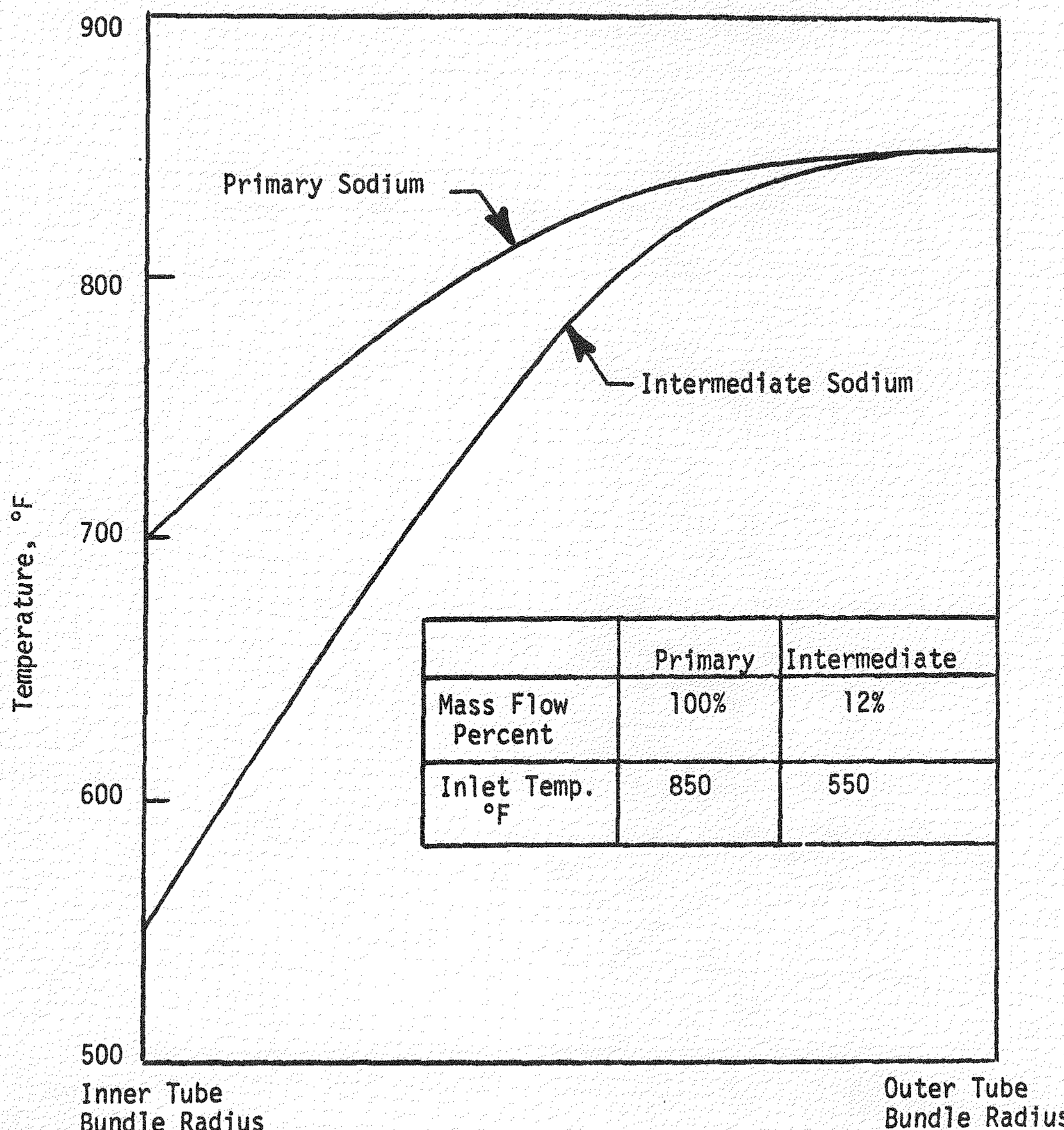


Figure 11 Temperature Distribution At Lower Tubesheet For Loss Of Intermediate Loop Conditions

PART V: HEAT TRANSPORT SYSTEM COMPONENTS

SECTION 3: IHX SEISMIC ANALYSIS

CONTENTS



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## FIGURES

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# INTRODUCTION AND SUMMARY

## 3.1.1 INTRODUCTION

A preliminary seismic analysis was performed on the straight-tube intermediate heat exchanger concept (the Reference design) developed during Phase A. Although an alternative bent tube design was considered late in Phase A Extension 1, the preliminary analysis made on the straight tube concept is valuable to guide the design and to provide a starting point for more detailed analysis. It also provides input information to the analysis of the reactor assembly, in which the IHX should be properly modeled.

The IHX was modeled as an assemblage of pipe and beam elements using the ANSYS computer code. Input seismic excitation spectra from a previous (Phase A) analysis by Bechtel was used in this analysis.

## 3.1.2 SUMMARY

A finite element seismic model was set up to analyze the straight tube intermediate heat exchanger (IHX) concept developed during Phase A of the pool-type LMFBR Plant Design.

Three different boundary conditions were considered:

1. The IHX flow shroud is rigidly attached to the reactor roof (deck) at the bottom of the deck and a seismic stop at the upper tubesheet is provided.

2. The IHX flow shroud is rigidly attached to the deck at the top of the deck and the seismic stop is provided.

3. The IHX flow shroud is rigidly attached to the deck at the top of the deck and no seismic stop is provided. This is to study the impact of eliminating the seismic stop.

The deck was assumed rigid. The seismic response spectra obtained for the reactor support then became the seismic excitation of the IHX. Only the effect of the added mass of the sodium on the structure was taken into account. The pressure effect of the sodium on the dynamic characteristics of the IHX was neglected in this preliminary analysis. The preliminary results indicate that the first three modes of vibration are the major contributing modes of the seismic response.

In the case of an operating-basis earthquake (OBE), the maximum stress intensity in the IHX is 16.0 ksi at the upper part of the downcomer. Without a seismic stop at the upper tubesheet, the stress field throughout the IHX is redistributed. The maximum stress intensity becomes 17.7 ksi and occurs at the upper part of the intermediate sodium return shell.

The OBE condition is the deciding factor in regard to the acceptability of this design. It appears that this design, with a seismic stop at the upper tubesheet, is acceptable. Without the seismic stop, the thickness of the IHX outer shell should be increased to prevent potential buckling of the tube bundle.

In the case of a horizontal safe-shutdown earthquake (SSE), the maximum combined (North-South and East-West) displacement in the IHX can reach a value of 3.0 inches peak-to-peak amplitude (at the mid-section of the downcomer). At the bottom of the IHX, however, the maximum peak-to-peak displacement is in the order of 1.6 inches. The maximum combined stress (at the top end of the downcomer) is 17.1 ksi. Stresses in the tube bundle are in the order of 10 ksi. Without a seismic stop at the upper tubesheet, the maximum combined displacement at the bottom of the IHX is increased to 4.6 inches peak-to-peak amplitude. The maximum stress is increased to 22.3 ksi at the top end of the downcomer and 14.3 ksi in the tube bundle.

Considering the SSE as a faulted condition, this design meets the code requirements for the faulted condition.

Displacements of points in the IHX are very small and stresses are minimal when an SSE vertical input spectrum is applied. This was espectially true when the tube-sheets were assumed rigid. The natural frequencies of vibration, in this case, exceed 33 Hz, the upper limit of interest of seismic frequency.

## V-3.2

## CONCLUSIONS

The reference IHX design will withstand an operating basis earthquake (OBE) if a seismic stop at the upper tubesheet is provided, or if the thickness of the outer shell is increased. With the seismic stop, maximum stress is 16 ksi and peak-to-peak displacement is 2.8 inches.

Under a safe-shutdown earthquake (SSE) maximum stress becomes 17.1 ksi and peak-to-peak displacement becomes 3 inches (with the seismic stop).

Support of the flow shroud at the top or the bottom of the deck has minor influence on seismic behaviour. The choice will be determined by considerations outside the seismic response.

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ANALYSIS

3.3.1
APPROACHES TO THE ANALYSIS

Analytical techniques generally accepted for computing structural responses (displacements, accelerations, stresses, etc.,) in the seismic analysis are (1) time history analysis which is a numerical step-by-step integration procedure, and (2) the response spectrum method. The time history analysis is usually more costly. In this analysis, the response spectrum method was used. The structural response in this case was obtained by modal superposition technique. A finite element computer code, ANSYS, was used.

3.3.2
THE MODEL

Description of the Model

The IHX is composed of the following major components:

(a) Tube bundle

(b) Inner bundle shroud

(c) Tube support plates

(d) Auxiliary IHX

(e) Tubesheets

(f) Shielding plug

(g) Upper and lower cylinder

(h) Shell liner

(i) Secondary sodium central downcomer

(j) Expansion bellows

(k) "Diving" bell

A model was set up to represent the IHX for analysis using the ANSYS computer code. Element types used are (1) Elastic Straight Pipe Element (Stif 9),

(2) 3-D Elastic Beam Element (Stif 4), (3) Lumped Mass Element (Sfif 21), and (4) Spring/Damper Element (Stif 14).

A spring element was used for the bellows with a spring constant of K=24,000 pounds/inch (Temp Flex Expansion Joints, Temp Flex Co., Compton, CA).

Lumped masses were calculated for sodium along the pipes which carry sodium, and for "rigid" components such as the tubesheets and the primary sodium outlet.

The tube bundle, shield plug, and the auxiliary IHX were represented by 3-D elastic beam elements. The rest of the structural components are cylinders and were modeled as pipe elements. The following list briefly describes some specific properties of the elements used.

| Component | Cross-Sectional Area ($inch^2$) | Moment of Inertia ($inch^4$) | "Thickness" (inch) | Weight/in. (lbs/in) | Concentrated Weight (lbs) |
|---|---|---|---|---|---|
| Tube bundle (beam) | 607 | 68.9 | 1 | 235 | |
| Aux. IHX (beam) weight at the end of the beam | 38.1 | 9.81 | 1 | 10.8 | 190 |
| Hangers for the Aux. IHX weight at the end of the beam | 34.0 | 206 | 8 | 9.6 | 2,278 |
| Upper tubesheet | | | | | 25,000 |
| Lower tubesheet | | | | | 16,000 |
| Shielding plug (beam) weight (with concrete) | 1,200 | 1,450,000 | | | 97,000 |

The details of the seismic model are given in Appendix V-3A. Figure 1 shows the finite element model layout and Figure 2 is a computer-generated "mesh" plot, with the neutral axes of the major components shifted to have a distinct picture of the model.

A seismic stop to limit relative (horizontal) motion between the upper tubesheet and the flow shroud is included in the present conceptual design. The stop is composed of three or four pads spaced equally around the upper tubesheet. The seismic analysis of the IHX has included the absence of this stop.

## Boundary Conditions

Three different boundary conditions were assumed in this analysis.

(1) The IHX flow shroud is rigidly attached at the bottom of the deck.

(2) The IHX flow shroud is rigidly attached at the top of the deck.

(3) The IHX flow shroud is rigidly attached at the top of the deck and the seismic stop is excluded from the model. This is to study the impact of eliminating the seismic stop.

Restraints of motion due to the tube bundle support plates and concrete in the shielding plug are accomplished by coupling of associated nodal points within the model. They are shown in Figure 2.

## Dynamic Degrees of Freedom

The nature of the structure is such that an acceptable accuracy is obtained by restricting the dynamic freedom of the structural model to translation only along a single horizontal axis. The natural frequencies for the first 45 modes were computed and the values for the first 12 are shown in Tables 1, 2, and 3. These include all the modes less than 33 Hz.

## Materials Properties

The following material properties were assumed for the components important to seismic analysis (see Appendix V-3A).

| | | |
|---|---|---|
| Modulus of elasticity, steel | = | $26 \times 10^6$ lbs/in$^2$ |
| Poisson's ratio, steel | = | 0.3 |
| Density, steel | = | 0.283 lb/in$^3$ |
| Density, sodium | = | 0.031 lb/in$^3$ |
| Coefficient of thermal expansion, steel | = | $9.87 \times 10^6$ in/in °F |

## Assumption Made In Modeling

In setting up this model, the following assumptions were made.

(1) The reactor roof (deck), to which the IHX is attached, is rigid.

(2) The system is linearly elastic.

(3) Pressure effects and the hydrodynamic mass effect of the sodium on the dynamic characteristics of the IHX are not controlling and are ignored to simplify the analyses.

(4) Materials properties are assumed independent of temperature, to simplify the analysis.

## Seismic Excitation

Although direct integration of the equations of motion, given the time-history of the forcing function, offers more detail of the transient response of the system, it is more practical to use the response spectrum approach from the point of view of stress analysis, where the maximum response is usually of greatest concern. In the seismic analysis of the IHX, the spectral analysis method was adopted. The spectral input was obtained by Bechtel from a time history analysis of the reactor building, which takes into account the coupling effect of the building and the reactor structure. The response spectrum of the building at the reactor support was used as the input for seismic analysis of the IHX, considering the deck as a rigid structure. Figures 4, 5, and 6 show seismic spectra used in this analysis as input to the IHX for the horizontal safe shutdown earthquake (SSE), the horizontal operating basis earthquake (OBE), and the vertical SSE respectively.

## V-3.4

## RESULTS

Based on the above description, with the given forcing functions (seismic response spectra), the structural responses of the IHX with different boundary conditions were calculated for OBE and SSE. Only horizontal excitations were examined.

### 3.4.1
### FREE VIBRATION

The free vibration analysis is fundamental in the seismic analysis of the IHX using the response spectrum method. Tables 1 through 3 show the natural frequencies of vibration of the IHX under the above mentioned boundary conditions. A few significant mode shapes associated with the natural frequencies of vibration are shown in Figures 7 through 10 for the case in which the IHX flow shroud is fixed at the bottom of the reactor roof (deck). The corresponding natural frequencies of vibration are 5.3 Hz, 7.1 Hz, 9.4 Hz, and 12.1 Hz. When the IHX flow shroud is fixed at the top of the deck, the natural frequencies drop to 4.7 Hz, 6.5 Hz, 9.3 Hz, and 12.1 Hz respectively. Without a seismic stop at the upper tubesheet, the natural frequencies of vibration drop further to 4.0 Hz, 6.2 Hz, 9.3 Hz, and 12.1 Hz correspondingly.

### 3.4.2
### SEISMIC RESPONSE

Seismic responses of the IHX are expressed in terms of displacement and stress fields. The mode shapes determine the relative displacements among points in the structure. Each mode of vibration has a definite level of "participation" depending on the stiffness and mass of the entire system (structure). Given an input seismic spectrum, the displacement field is completely determined for each mode of vibration. The frequency range of concern is between zero and 33 Hz during a seismic event. Up to 11 modes of vibration can be accommodated in the seismic responses of the model used here. However, only the first three modes of vibration contribute substantially to the seismic response.

Table 4, 5, and 6 show the deflections/accelerations and stresses at points of interest in the IHX for different boundary conditions described above for the horizontal OBE. The deflections, accelerations, and stresses represent the "square root of the sum of the squares" of all modes of interest. Tables 7-1, 7-2, and 7-3 summarize responses of the IHX for different boundary conditions at a few key locations, when the IHX is subjected to a horizontal SSE. Details of the result are shown in Appendix V-3B.

For any mode the combined response is the vector sum of the N-S response, the E-W response, and the vertical response. Only one analysis of the vertical response was made and it was, as expected, trivial compared to the horizontal response. For this reason the responses quoted are the vector sum of N-S and E-W responses unless otherwise stated.

For an OBE, with the shroud fixed at the top of the deck, and with a seismic stop, the maximum 'membrane plus bending' stress is 16 ksi (Table 5). This maximum stress occurs at the upper part of the secondary sodium return. Under Code Case 1592, the allowable stress, $K S_m$, for 304 SS at 900°F is 22 ksi, which is a limit for the combined stresses due to all kinds of loading including thermal and pressure. During a thermal transient, a high thermal stress is expected. Stresses in the upper part of the IHX are reduced further when the flow shroud is fixed at the bottom of the deck (Table 4).

In the case of an OBE and without a seismic stop at the upper tubesheet, the maximum 'membrane and bending' stress due to the seismic loading alone can reach a value of 17.7 ksi (Table 6). A preliminary evaluation indicates that the tube bundle might buckle due to the combined thermal and seismic (OBE) loading. With a seismic stop at the upper tubesheet, however, buckling of the tube bundle can be avoided.

Under an SSE with a seismic stop at the upper tubesheet, and with the shroud fixed at the top of the deck, the maximum membrane plus bending stress in the upper part of the downcomer is 17.1 ksi (Table 7-2). The peak stress in the tube bundle is 10 ksi. The maximum combined peak-to-peak displacement (at the mis-section of the downcomer) is 3.0 inches.

When the IHX shroud is fixed at the bottom of the deck, and with a seismic stop, the stress field is redistributed. Maximum stresses in this case are about the same and displacements are somewhat reduced. The reaction at the mounting flange of the IHX outer shell is substantially reduced.

In the case of a SSE and without a seismic stop at the upper tubesheet, the maximum 'membrane plus bending' stress can reach a value of 22.3 ksi (Table 7-3). The maximum stress occurs at the upper part of the downcomer. Under Code Case 1592 the allowable stress for elastic analysis under the faulted condition ($1.2\ K_t\ S_t$) for 304 SS at 900°F is 29 ksi. Without additional stresses due to loadings other than the SSE, the maximum stress is within the allowable limit. Stresses in the tube bundle can reach 14.3 ksi. The maximum displacement is 5.25 inches peak-to-peak. At the bottom of the IHX, the maximum peak-to-peak displacement is 4.6 inches. This maximum peak-to-peak displacement may be acceptable functionally.

Displacements of points in the IHX are very small and stresses are minimal when an SSE vertical response spectrum is applied. This is especially true when the tubesheets are assumed rigid. The natural frequencies of vibration (for vertical degrees of freedom) exceed 33 Hz, the upper limit of the seismic frequency range.

## V-3.5

## DISCUSSION

(a) This analysis is preliminary in nature. The model is subject to change upon any design change.

(b) The IHX components were assumed linearly elastic. The analysis was based on small deformation theory. The resulting stresses and deformations confirm the validity of these assumptions. Thus, superposition technique was applicable.

(c) The deck which supports the IHX was assumed rigid. Thus, the seismic response spectra of the reactor support becomes the input excitation at the IHX support. This is a conservative assumption. which has only minor influence on the results.

(d) Pressure on the tubesheets will affect the natural frequencies of vibration of the tube bundle. The hydrodynamic mass effect of sodium on the dynamic characteristics of the IHX components will be significant when there exists a small annulus between two cylinders such as the secondary sodium downcomer. Accounting for these effects would complicate the analysis beyond the scope of a preliminary study. It is believed that ignoring them has only minor effect on the results.

(e) Gaps at supports, such as those at the inner and outer edges of the tube bundle support plates, were neglected. Otherwise, a non-linear analysis would be necessary.

(f) Stress results obtained here should properly be combined with stresses obtained from other analyses (such as dead weight, pressure, and thermal) to check against the code requirements. It is outside the scope of this analysis.

Tables 1, 2, 3
IHX NATURAL FREQUENCIES - HORIZONTAL

Table 1 Shroud Fixed at Bottom of Deck - Seismic Stop at Upper Tubesheet

| MODE | FREQUENCY Hz |
|---|---|
| 1 | .53152+001 |
| 2 | .71032+001 |
| 3 | .93780+001 |
| 4 | .12133+002 |
| 5 | .14592+002 |
| 6 | .17071+002 |
| 7 | .20798+002 |
| 8 | .23266+002 |
| 9 | .24441+002 |
| 10 | .27072+002 |
| 11 | .33563+002 |
| 12 | .37605+002 |

Table 2 Shroud Fixed at Top of Deck - Seismic Stop at Upper Tubesheet

| MODE | FREQUENCY Hz |
|---|---|
| 1 | .47439+001 |
| 2 | .64520+001 |
| 3 | .93337+001 |
| 4 | .12133+002 |
| 5 | .14544+002 |
| 6 | .17045+002 |
| 7 | .20792+002 |
| 8 | .22721+002 |
| 9 | .23823+002 |
| 10 | .25107+002 |
| 11 | .33471+002 |
| 12 | .37605+002 |

Table 3 Shroud Fixed at Top of Deck - No Seismic Stop

| MODE | FREQUENCY Hz |
|---|---|
| 1 | .39855+001 |
| 2 | .62147+001 |
| 3 | .93168+001 |
| 4 | .12133+002 |
| 5 | .14523+002 |
| 6 | .17034+002 |
| 7 | .20790+002 |
| 8 | .22550+002 |
| 9 | .23777+002 |
| 10 | .25093+002 |
| 11 | .25720+002 |
| 12 | .3340[illegible]+002 |

TABLE 4

OBE, HORIZONTAL

FLOW SHROUD FIXED AT BOTTOM OF DECK

SEISMIC STOP AT UPPER TUBESHEET

(1) Contributing modes:

First 3 modes of vibration

(5.3 Hz, 7.1 Hz, 9.4 Hz)

(2) Displacement/Acceleration:

| Node | One Direction Ux(inch) | One Direction Ax(g) | Combined* $U_{(X+Y)}$(inch) | Combined* $A_{X+Y}$ (g) |
|---|---|---|---|---|
| 5 | 0.83 | 2.8 | 1.17 | 3.96 |
| 14 | 0.63 | 1.9 | .89 | 2.69 |
| 23 | 0.63 | 1.9 | .89 | 2.69 |
| 65 | 0.21 | 0.8 | .30 | 1.13 |

(3) Stresses:

| Element | Nodes | One Direction Stress (ksi) | Combined* Stress (ksi) |
|---|---|---|---|
| 7 | 4 - 5 | 6.5 | 9.2 |
| 10 | 7 - 8 | 11.0 | 15.5 |
| 17 | 11 - 10 | 6.5 | 9.2 |
| 29 | 24 - 25 | 2.6 | 3.7 |
| 30 | 25 - 26 | 4.3 | 6.1 |
| 31 | 26 - 27 | 5.5 | 7.8 |
| 32 | 27 - 28 | 5.6 | 7.9 |
| 46 | 39 - 38 | 1.5 | 2.1 |
| 47 | 40 - 39 | 1.6 | 2.3 |
| 48 | 41 - 40 | 1.7 | 2.4 |
| 67 | 56 - 55 | 1.2 | 1.7 |
| 68 | 57 - 56 | 1.4 | 2.0 |
| 69 | 58 - 57 | 1.6 | 2.3 |
| 70 | 59 - 58 | 1.9 | 2.5 |
| 91 | 69 - 70 | 2.4 | 3.4 |
| 96 | 73 - 74 | 3.3 | 4.7 |

(4) Reactions:

| Node | One Direction Fx (lbs) | One Direction Mz (in-lb) | Combined* Fx (lbs) | Combined* M (in-lbs) |
|---|---|---|---|---|
| 54 | 24,000 | $1.3 \times 10^6$ | 33,941 | $1.8 \times 10^6$ |
| 55 | 45,000 | $20 \times 10^6$ | 63,640 | $28 \times 10^6$ |
| 74 | 218,000 | $21 \times 10^6$ | 308,298 | $30 \times 10^6$ |

*Combined values are the vector sum of the one-direction values, that is $U_{(X+Y)} = \sqrt{2}\ U_X$.

TABLE 5

OBE, HORIZONTAL

FLOW SHROUD FIXED AT TOP OF DECK

SEISMIC STOP AT UPPER TUBESHEET

(1) Contributing modes:

First 3 modes of vibration
(4.7 Hz, 6.5 Hz, 9.4 Hz)

(2) Displacement/Acceleration:

| Node | One Direction | | Combined* | |
|---|---|---|---|---|
| | Ux(inch) | Ax(g) | $U_{(X+Y)}$(inch) | $A_{X+Y}$ (g) |
| 5 | 0.98 | 2.44 | 1.38 | 3.45 |
| 14 | 0.89 | 2.1 | 1.26 | 2.97 |
| 23 | 0.89 | 2.1 | 1.26 | 2.97 |
| 65 | 0.52 | 1.22 | .74 | 1.73 |

(3) Stresses:

| Element | Nodes | One Direction Stress (ksi) | Combined* Stress (ksi) |
|---|---|---|---|
| 7 | 4 - 5 | 6.5 | 9.2 |
| 10 | 7 - 8 | 11.3 | 16.0 |
| 17 | 11 - 10 | 8.1 | 11.4 |
| 29 | 24 - 25 | 3.1 | 4.4 |
| 30 | 25 - 26 | 5.2 | 7.3 |
| 31 | 26 - 27 | 6.7 | 9.5 |
| 32 | 27 - 28 | 6.8 | 9.6 |
| 46 | 39 - 38 | 6.0 | 8.5 |
| 47 | 40 - 39 | 5.0 | 7.1 |
| 48 | 41 - 40 | 4.1 | 5.8 |
| 67 | 56 - 55 | 4.8 | 6.8 |
| 68 | 57 - 56 | 4.4 | 6.2 |
| 69 | 58 - 57 | 4.1 | 5.8 |
| 70 | 59 - 58 | 3.8 | 5.4 |
| 91 | 69 - 70 | 4.5 | 6.4 |
| 96 | 75 - 76 | 5.8 | 8.2 |

(4) Reactions:

| Node | One Direction | | Combined* | |
|---|---|---|---|---|
| | Fx (lbs) | Mz (in-lb) | Fx (lbs) | M (in-lbs) |
| 54 | 33,000 | $6.11 \times 10^6$ | 46,669 | $8.65 \times 10^6$ |
| 55 | 74,000 | $72.3 \times 10^6$ | 104,652 | $102.2 \times 10^6$ |
| 74 | 231,000 | $60.3 \times 10^6$ | 326,683 | $85.3 \times 10^6$ |

*Combined values are the vector sum of the one-direction values, that is $U_{(X+Y)} = \sqrt{2}\ U_X$.

TABLE 6

OBE, HORIZONTAL

FLOW SHROUD FIXED AT TOP OF DECK

NO SEISMIC STOP

(1) Contributing modes:

First 3 modes of vibration
(4.0 Hz, 6.2 Hz)

(2) Displacement/Acceleration:

| Node | One Direction Ux (inch) | One Direction Ax (g) | Combined* $U_{(X+Y)}$ (inch) | Combined* $A_{X+Y}$ (g) |
|---|---|---|---|---|
| 5 | 0.85 | 1.46 | 1.20 | 2.06 |
| 14 | 0.92 | 1.52 | 1.30 | 2.15 |
| 23 | 0.92 | 1.52 | 1.30 | 2.15 |
| 65 | 0.88 | 1.43 | 1.24 | 2.02 |

(3) Stresses:

| Element | Nodes | One Direction Stress (ksi) | Combined* Stress (ksi) |
|---|---|---|---|
| 7 | 4 - 5 | 4.0 | 5.6 |
| 10 | 7 - 8 | 8.5 | 12.0 |
| 17 | 11 - 10 | 7.1 | 10.0 |
| 29 | 24 - 25 | 2.4 | 3.3 |
| 30 | 25 - 26 | 3.9 | 5.5 |
| 31 | 26 - 27 | 5.2 | 7.3 |
| 32 | 27 - 28 | 5.4 | 7.6 |
| 46 | 39 - 38 | 12.5 | 17.7 |
| 47 | 40 - 39 | 9.5 | 13.4 |
| 48 | 41 - 40 | 6.6 | 9.3 |
| 67 | 56 - 55 | 10.2 | 14.4 |
| 68 | 57 - 56 | 8.7 | 12.3 |
| 69 | 58 - 57 | 7.1 | 10.0 |
| 70 | 59 - 58 | 5.6 | 7.9 |
| 91 | 69 - 70 | 5.9 | 8.3 |
| 96 | 75 - 76 | 0 | 0 |

(4) Reactions:

| Node | One Direction Fx (lbs) | One Direction Mz (in-lb) | Combined* Fx (lbs) | Combined* M (in-lbs) |
|---|---|---|---|---|
| 51 | 46,000 | $13.6 \times 10^6$ | 65,000 | $19.2 \times 10^6$ |
| 55 | 320,000 | $154 \times 10^6$ | 452,500 | $217.8 \times 10^6$ |
| 76 | 0 | 0 | 0 | 0 |

*Combined values are the vector sum of the one-direction values, that is $U_{(X+Y)} = \sqrt{2}\ U_X$.

TABLE 7-1

SSE, HORIZONTAL

FLOW SHROUD FIXED AT BOTTOM OF DECK

SEISMIC STOP AT UPPER TUBESHEET

(1) Contributing modes:

First 3 modes of vibration

(5.3 Hz, 7.1 Hz, 9.4 Hz)

(2) Displacement/Acceleration:

| | One Direction | | Combined* | |
|---|---|---|---|---|
| Node | Ux(inch) | Ax(g) | $U_{(X+Y)}$(inch) | $A_{X+Y}$ (g) |
| 5 | 0.92 | 3.15 | 1.30 | 4.45 |
| 14 | 0.68 | 2.1 | .96 | 2.97 |
| 23 | 0.68 | 2.1 | .96 | 2.97 |
| 65 | 0.24 | 0.95 | .34 | 1.3 |

(3) Stresses:

| Element | Nodes | One Direction Stress (ksi) | Combined* Stress (ksi) |
|---|---|---|---|
| 7 | 4 - 5 | 7.7 | 10.9 |
| 10 | 7 - 8 | 12.2 | 17.1 |
| 17 | 11 - 10 | 7.1 | 10.0 |
| 31 | 26 - 27 | 6.1 | 8.6 |
| 32 | 27 - 28 | 6.1 | 8.6 |

(4) Reactions:

| | One Direction | | Combined* | |
|---|---|---|---|---|
| Node | Fx (lbs) | Mz (in-lb) | Fx (lbs) | M (in-lbs) |
| 51 | 28,000 | $1.5 \times 10^6$ | 39,598 | $2.12 \times 10^6$ |
| 55 | 57,000 | $20 \times 10^6$ | 80,610 | $28 \times 10^6$ |
| 74 | 248,000 | $49 \times 10^6$ | 350,725 | $69 \times 10^6$ |

*Combined values are the vector sum of the one-direction values, that is $U_{(X+Y)} = \sqrt{2}\ U_x$.

TABLE 7-2

SSE, HORIZONTAL

FLOW SHROUD FIXED AT TOP OF DECK

SEISMIC STOP AT UPPER TUBE SHEET

(1) Contributing modes:

First 3 modes of vibration

(4.744 Hz, 6.452 Hz, 9.37 Hz)

(2) Displacement/Acceleration:

| Node | One Direction | | Combined* | |
|---|---|---|---|---|
| | Ux(inch) | Ax(g) | $U_{(X+Y)}$(inch) | $A_{X+Y}$ (g) |
| 4 | 0.83 | 1.07 | 1.51 | 3.86 |
| 14 | 0.94 | 2.24 | 1.33 | 3.17 |
| 23 | 0.94 | 2.24 | 1.33 | 3.17 |
| 65 | 0.55 | 1.3 | .78 | 1.84 |

(3) Stresses:

| Element | Nodes | One Direction Stress (ksi) | Combined* Stress (ksi) |
|---|---|---|---|
| 10 | 7 - 8 | 12.1 | 17.1 |
| 17 | 11 - 10 | 9.6 | 13.6 |
| 31 | 26 - 27 | 7.0 | 9.9 |
| 32 | 27 - 28 | 7.2 | 10.2 |

(4) Reactions:

| Node | One Direction | | Combined* | |
|---|---|---|---|---|
| | Fx (lbs) | Mz (in-lb) | Fx (lbs) | M (in-lbs) |
| 51 | 35,000 | $6.46 \times 10^6$ | 49,497 | $9.13 \times 10^6$ |
| 55 | 76,000 | $75.95 \times 10^6$ | 107,480 | $107.4 \times 10^6$ |
| 76 | 243,000 | $79.3 \times 10^6$ | 343,654 | $112.1 \times 10^6$ |

*Combined values are the vector sum of the one-direction values, that is $U_{(X+Y)} = \sqrt{2}\ U_X$.

TABLE 7-3

SSE, HORIZONTAL

FLOW SHROUD FIXED AT TOP OF DECK

NO SEISMIC STOP AT THE UPPER TUBESHEET

(1) Contributing modes:

First 3 modes of vibration

(3.99 Hz, 6.21 Hz)

(2) Displacement/Acceleration:

| Node | One Direction Ux(inch) | One Direction Ax(g) | Combined* $U_{(X+Y)}$ (inch) | Combined* $A_{X+Y}$ (g) |
|---|---|---|---|---|
| 4 | 1.86 | 3.12 | 2.62 | 4.41 |
| 15 | 1.8 | 2.94 | 2.54 | 4.16 |
| 65 | 1.65 | 2.7 | 2.33 | 3.82 |

(3) Stresses:

| Element | Nodes | One Direction Stress (ksi) | Combined* Stress (ksi) |
|---|---|---|---|
| 10 | 7 - 8 | 15.8 | 22.3 |
| 17 | 11 - 10 | 13.3 | 18.8 |
| 31 | 26 - 27 | 9.7 | 13.7 |
| 32 | 27 - 28 | 10.1 | 14.3 |

(4) Reactions:

| Node | One Direction Fx (lbs) | One Direction Mz (in-lb) | Combined* Fx (lbs) | Combined* M (in-lbs) |
|---|---|---|---|---|
| 51 | 86,000 | $2.55 \times 10^7$ | 121,600 | $3.61 \times 10^7$ |
| 55 | 600,000 | $28.9 \times 10^7$ | 848,528 | $40.9 \times 10^7$ |
| 76 | 0 | 0 | 0 | 0 |

*Combined values are the vector sum of the one-direction values, that is $U_{(X+Y)} = \sqrt{2}\ U_X$.

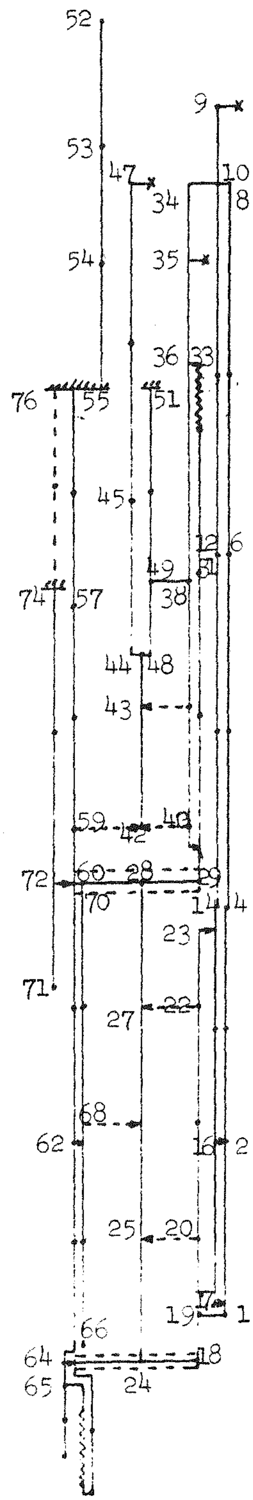


Figure 1 IHX Seismic Model

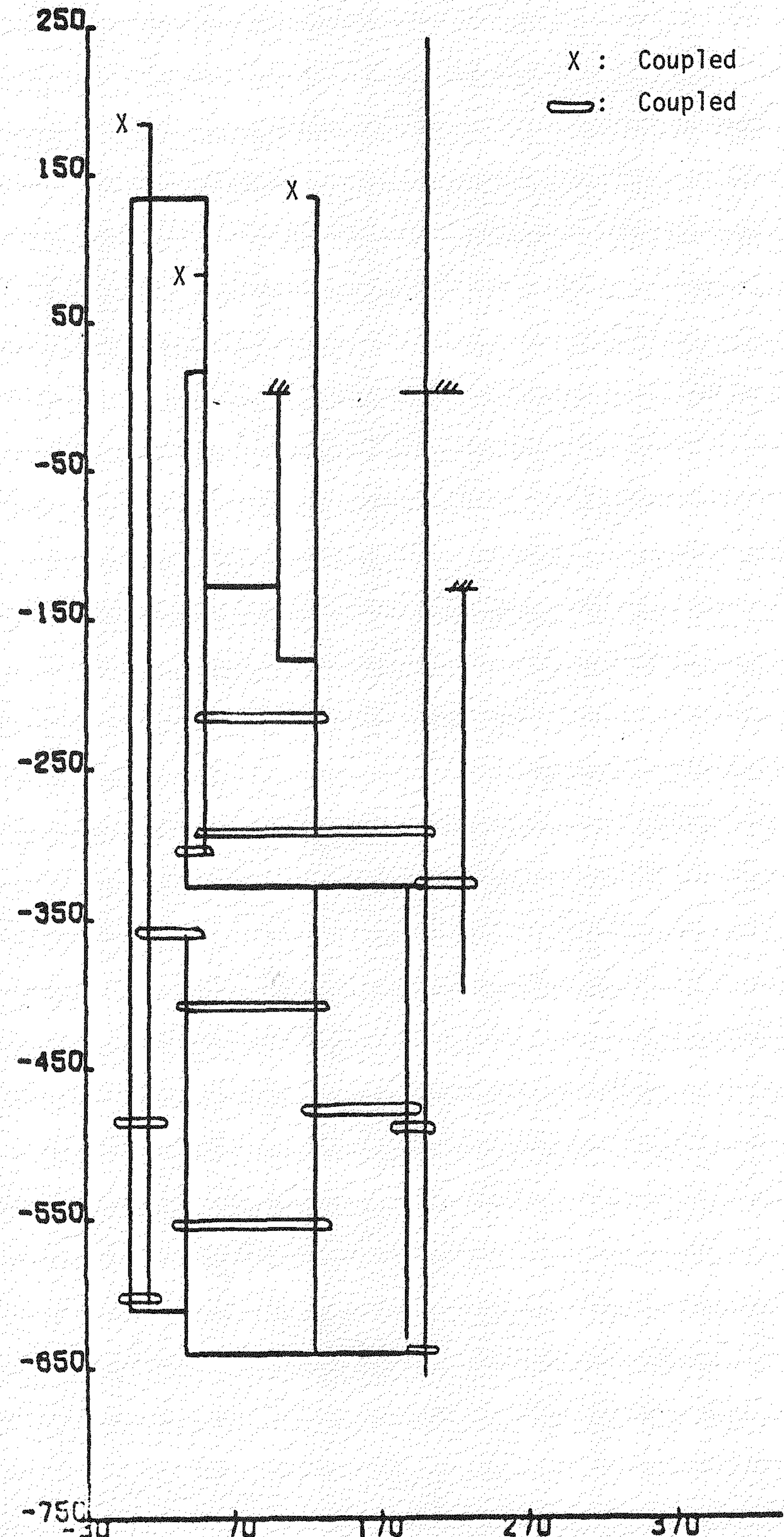


Figure 2 IHX Seismic Model, Coupled Degrees Of Freedom

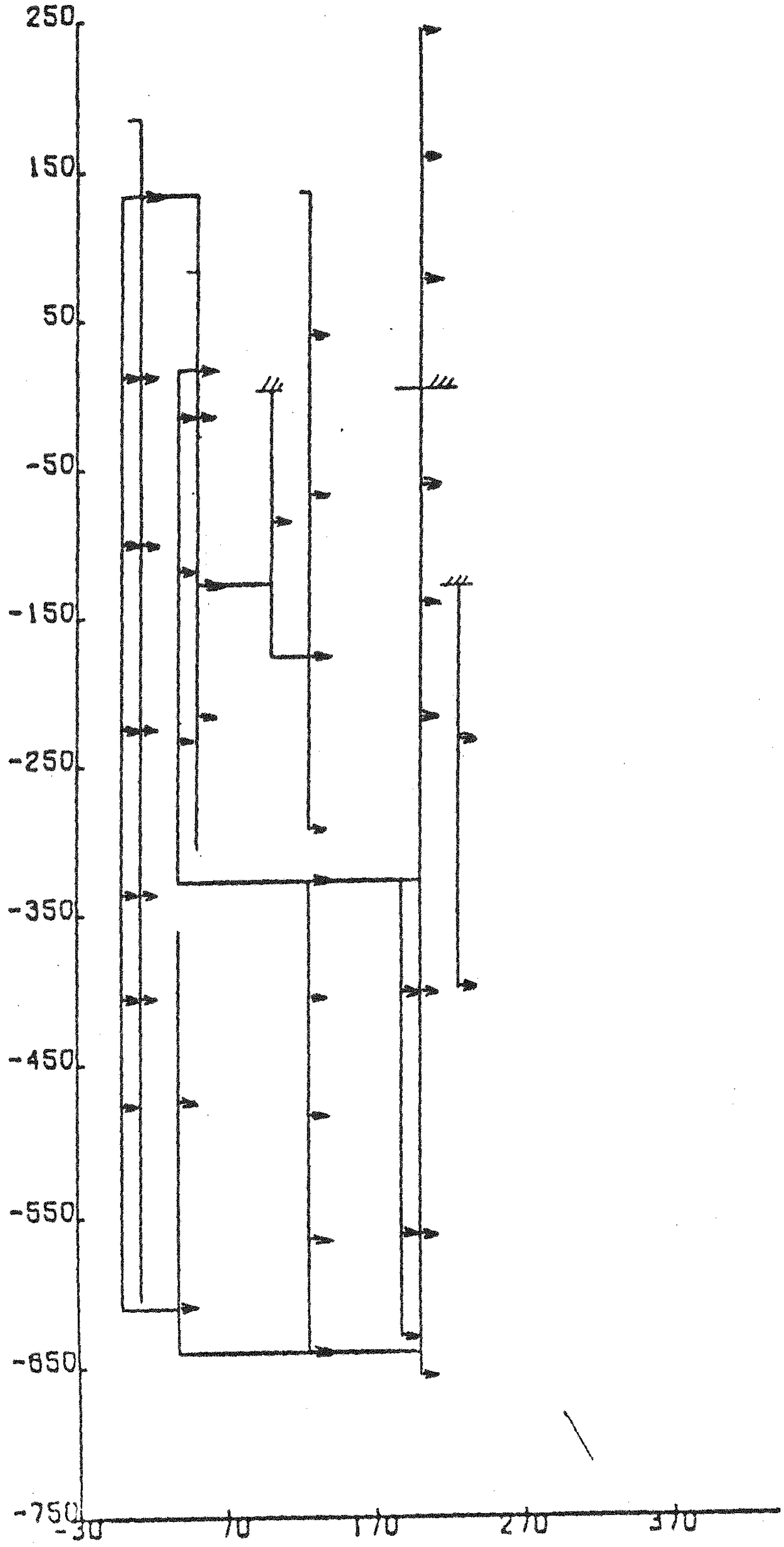


Figure 3  Dynamic Degrees of Freedom

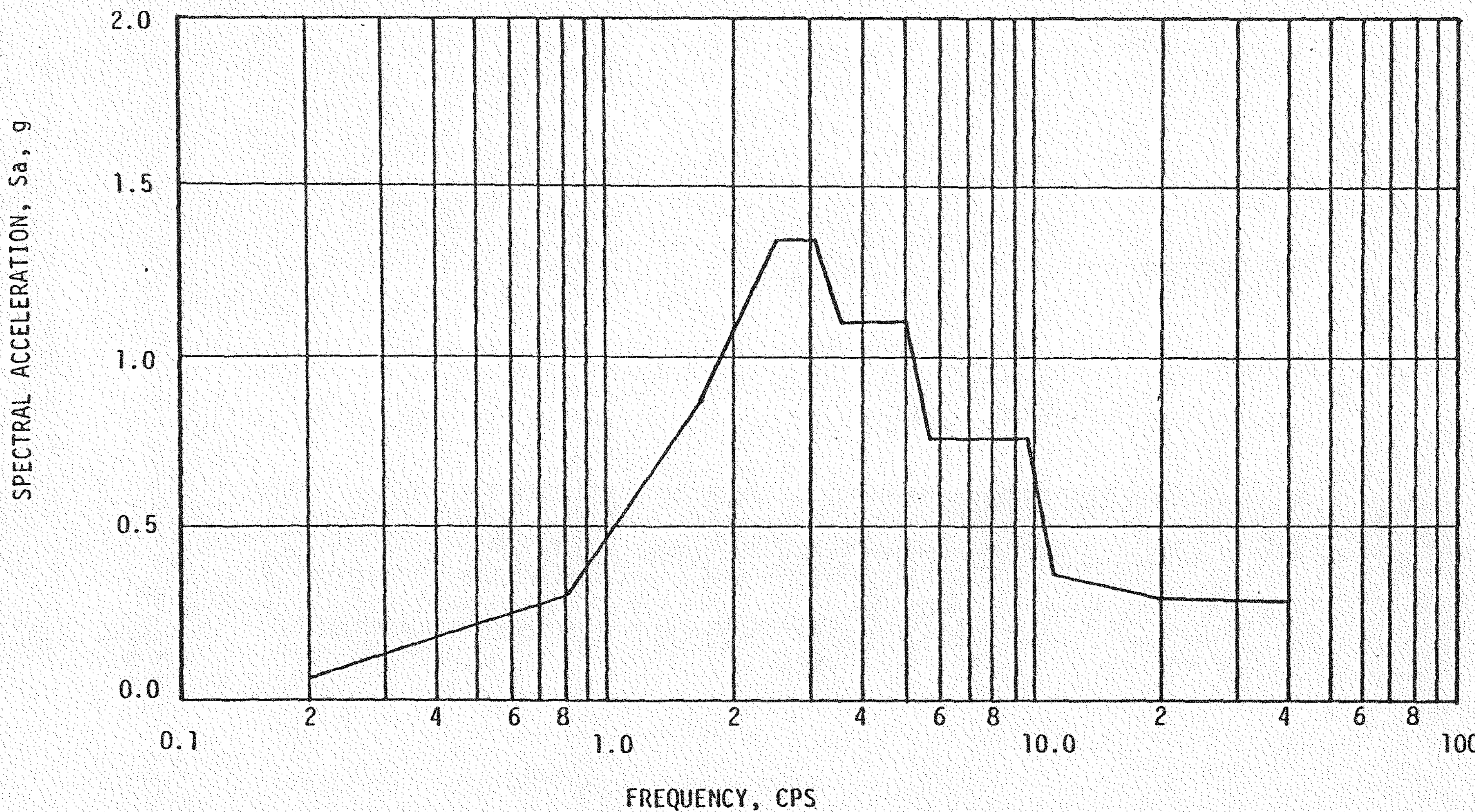


FIGURE 4 REVISED HORIZONTAL OBE DESIGN SPECTRUM AT REACTOR SUPPORT (2% DAMPING DESIGN ENVELOPE)

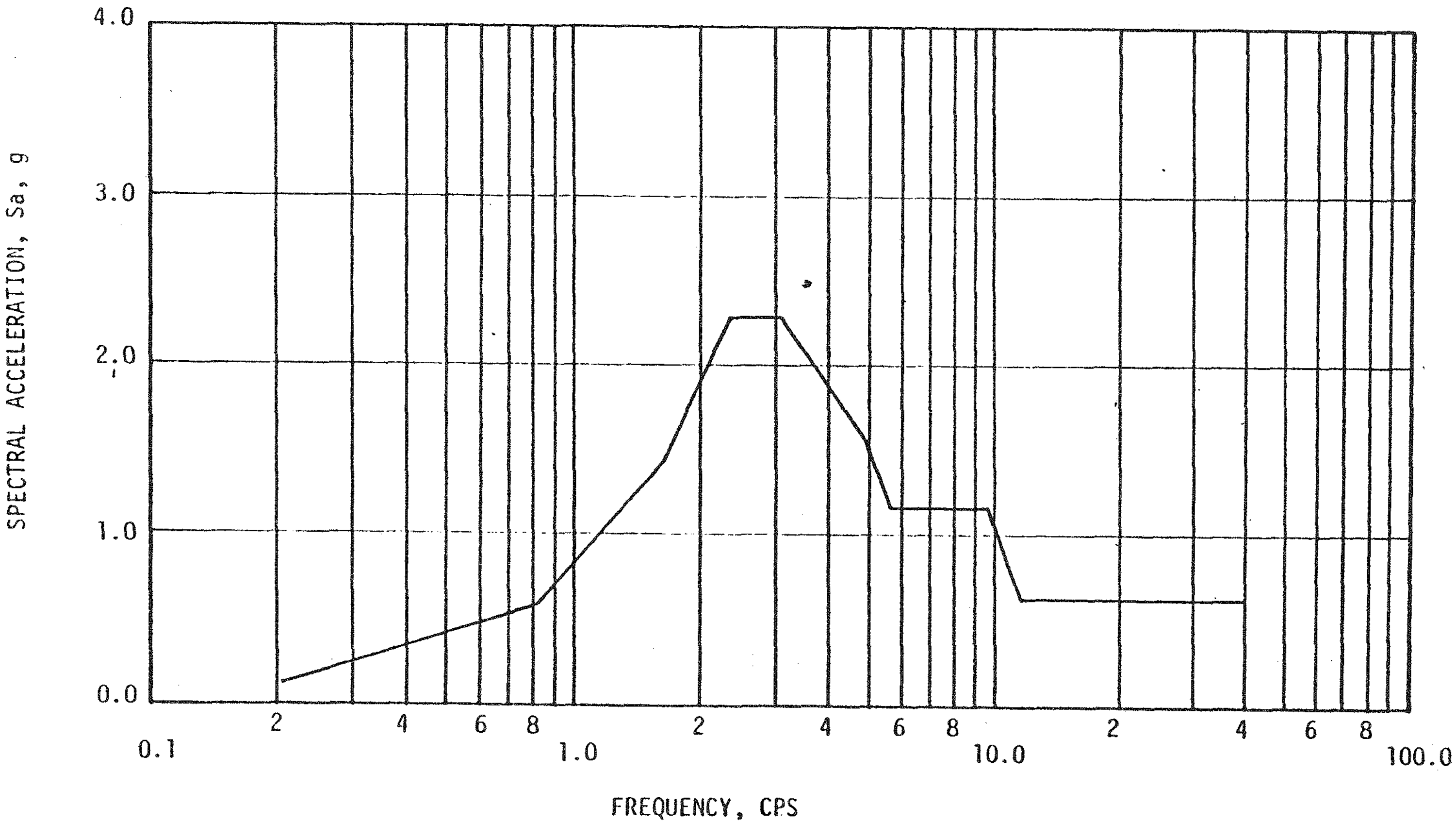


FIGURE 5 REVISED HORIZONTAL SSE DESIGN SPECTRUM AT REACTOR SUPPORT (3% DAMPING DESIGN ENVELOPE)

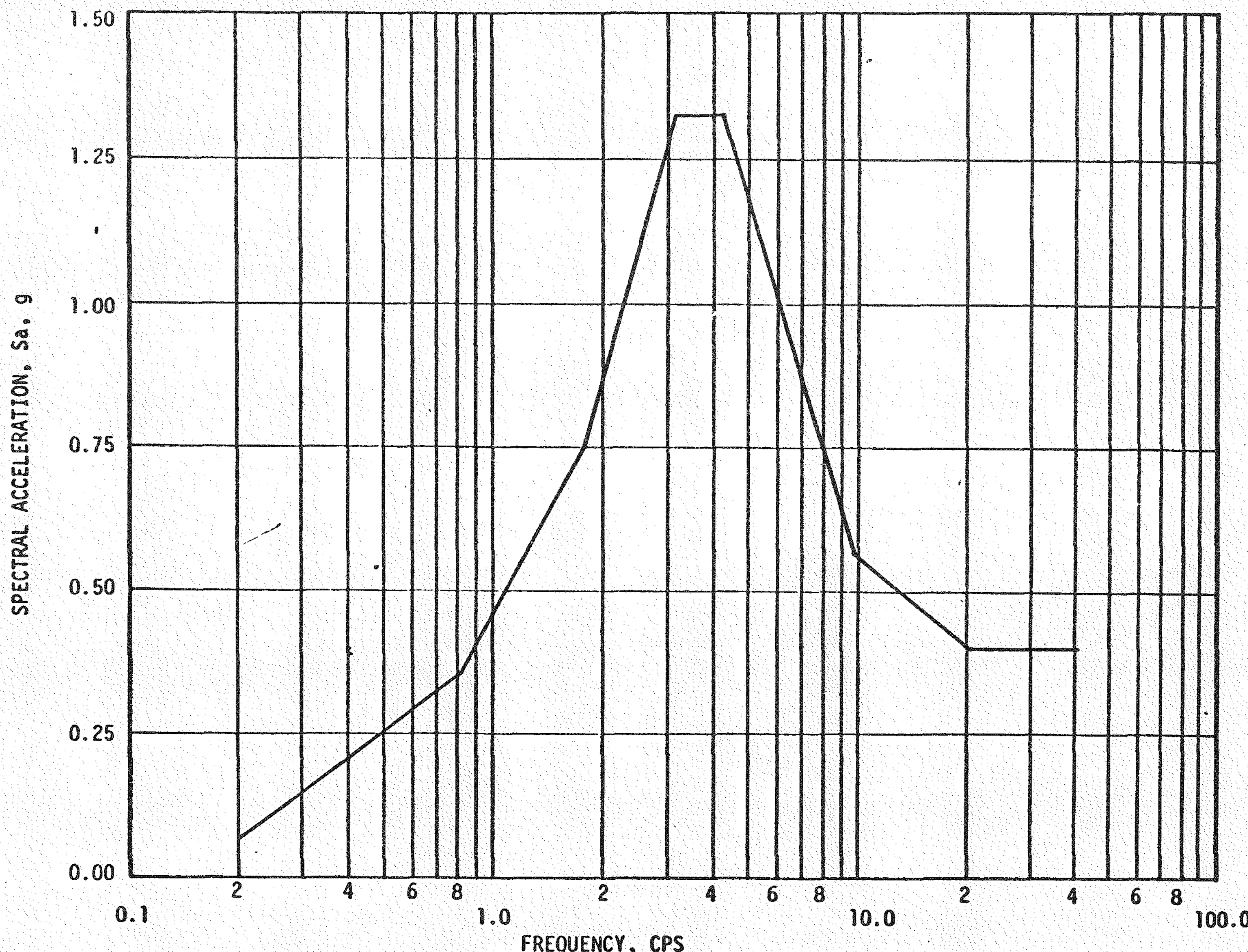


FIGURE 6 REVISED VERTICAL SSE DESIGN SPECTRUM AT REACTOR SUPPORT (4% DAMPING DESIGN ENVELOPE)

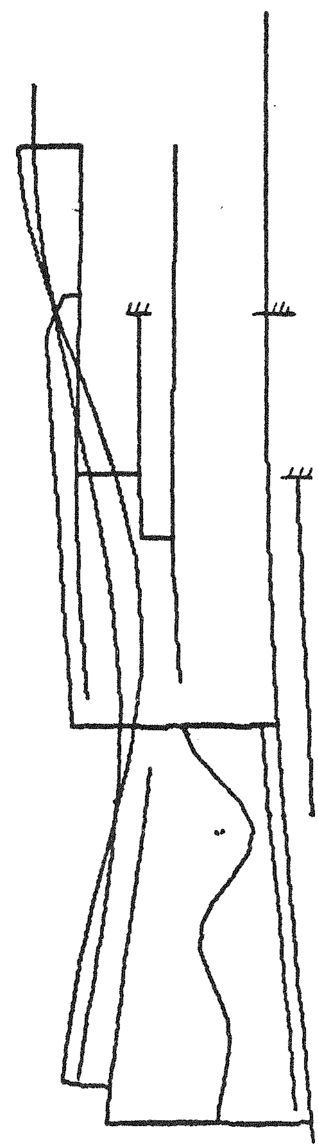

Figure 7   Mode Shape 1

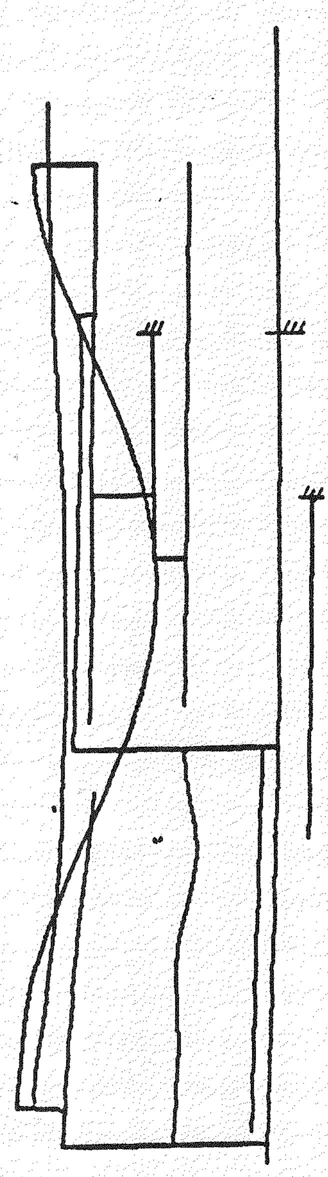

Figure 8 Mode Shape 2

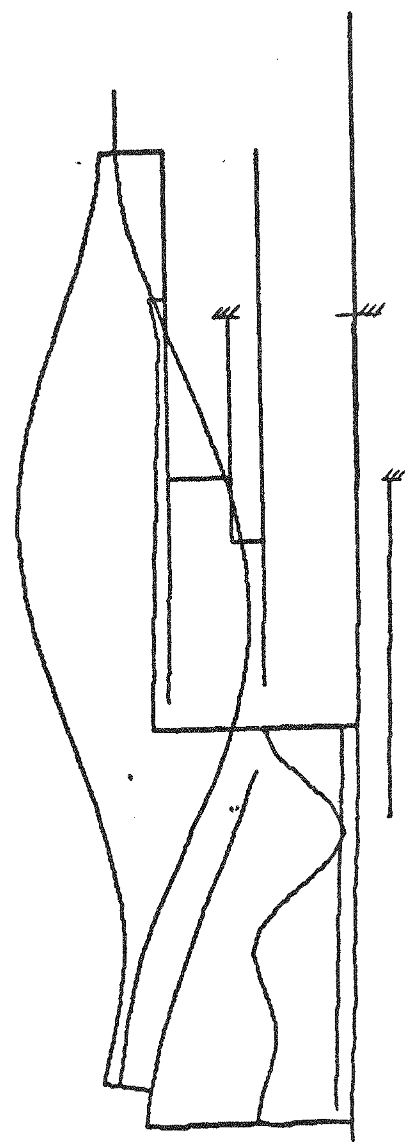

Figure 9   Mode Shape 3

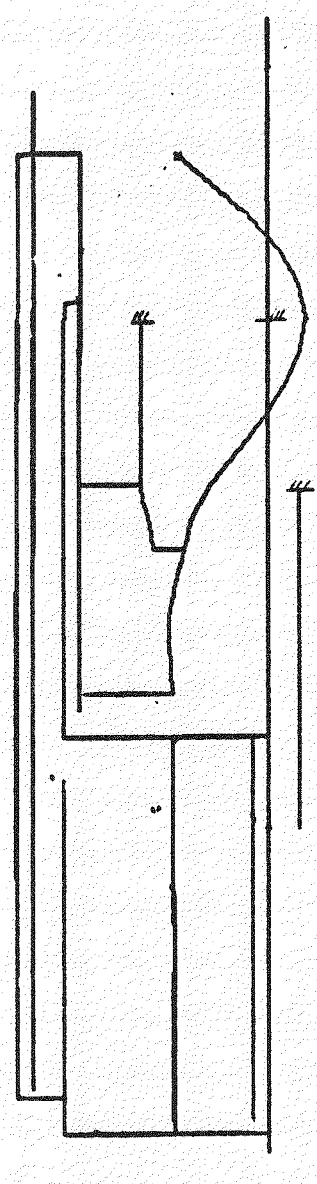

Figure 10   Mode Shape 4

# APPENDIX V-3A

# DATA DESCRIBING DETAILS OF THE IHX MODEL

ANSYS - ENGINEERING ANALYSIS SYSTEM UP180 REV 2 GE-HNYL JAN 1,1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

SEISMIC MODEL - INTERMEDIATE HEAT EXCHANGER 12.0567 6/17/78
CP = 0.224 PP = 0.

***** ANALYST = C. C. YANG

***** ANALYSIS OPTIONS (CARDS C1 AND C2) *****

| | VALUE | VARIABLE NAME | COLUMNS |
|---|---|---|---|
| NUMBER OF LOAD STEPS . . . . | -1 | NSTEPS | 1-4 |
| ANALYSIS TYPE . . . . . . . . | 2 | K20 | 5-7 |
| COUPLED DEGREES OF FREEDOM KEY | 1 | KCDF | 10 |
| ELEMENT CONSTANT TABLE . . . | 1 | KTB | 11-12 |
| REACTION FORCE KEY. . . . . . | 2 | K15 | 15-16 |
| BOUNDARY CONDITION KEY. . . . | 0 | K17 | 18 |
| POST-RUN PROCESS KEY . . . . | 7 | KYPOST | 27-28 |
| KAY( 1) . . . . . . . . . . . | 1 | KAY( 1) | 30 |
| KAY( 2) . . . . . . . . . . . | 5 | KAY( 2) | 32 |
| KAY( 4) . . . . . . . . . . . | 8 | KAY( 4) | 36 |
| KAY( 5) . . . . . . . . . . . | 2 | KAY( 5) | 38 |
| KAY( 6) . . . . . . . . . . . | 1 | KAY( 6) | 40 |
| COORD. SYSTEM ROTATION KEY . | 1 | K18 | 77 |
| REFERENCE TEMPERATURE . . . . | 650.00 | TREF | 1-12 |
| UNIFORM TEMPERATURE . . . . . | 650.00 | TUNIF | 13-24 |
| PLOT DEVICE TYPE. . . . . . . | 1 | KPDV | 79-80 |
| CORE SIZE PARAMETER. . . . . . | 25000 | ICORE | 75-80 (CARD B) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| BLOCK SIZES . . . . . . . . . | 600 | 600 | 1800 | 300 | 300 | 300 | 0 | 0 |
| WORK SPACE REQUESTED(DECIMAL) | 10000 | | | | | | | |

***** ELEMENT TYPES (CARD D) *****

| TYPE | STIF | DESCRIPTION | KEYSUB OPTIONS 1B | 1A | 1 | 2B | 2A | 2 | KC | INOTPR |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 9 | ELASTIC STRAIGHT PIPE5/25/73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 4 | ELASTIC BEAM, 3-D 8/05/74 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 21 | LUMPED MASS ELEMENT 10/10/73 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| 4 | 14 | SPRING/DAMPER ELEM. 10/10/73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

***** TABLE OF ELEMENT REAL CONSTANTS (CARD D2) *****

| NO. | | |
|---|---|---|
| 1 | 29.000 | 0.50000 |
| 2 | 24.000 | 0.50000 |
| 3 | 27.250 | 0.50000 |
| 4 | 32.000 | 0.50000 |
| 5 | 39.000 | 0.50000 |
| 6 | 46.000 | 1.0000 |
| 7 | 45.000 | 0.50000 |
| 8 | 110.25 | 1.0000 |
| 9 | 115.25 | 1.5000 |
| 10 | 110.75 | 0.50000 |
| 11 | 130.50 | 1.0000 |

***** ELEMENT DEFINITIONS (CARD E) *****

| ELEMENT | NODES | | MAT | TYPE | ELEMENT REAL CONSTANTS | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | OD | WALL | | | | |
| 1 | 1 | 2 | 1 | 1 | 29.0 | 0.500 | | | | |
| 2 | 2 | 3 | 1 | 1 | 29.0 | 0.500 | | | | |
| 3 | 3 | 4 | 1 | 1 | 29.0 | 0.500 | | | | |
| | | | | | MASS | | | | | |
| 4 | 1 | | 1 | 3 | 2.67 | | | | | |
| 5 | 2 | | 1 | 3 | 4.84 | | | | | |
| 6 | 3 | | 1 | 3 | 4.33 | | | | | |
| | | | | | OD | WALL | | | | |
| 7 | 4 | 5 | 1 | 1 | 24.0 | 0.500 | | | | |
| 8 | 5 | 6 | 1 | 1 | 24.0 | 0.500 | | | | |
| 9 | 6 | 7 | 1 | 1 | 24.0 | 0.500 | | | | |
| 10 | 7 | 8 | 1 | 1 | 24.0 | 0.500 | | | | |
| | | | | | MASS | | | | | |
| 11 | 4 | | 1 | 3 | 4.20 | | | | | |
| 12 | 5 | | 1 | 3 | 4.05 | | | | | |
| 13 | 6 | | 1 | 3 | 4.05 | | | | | |
| 14 | 7 | | 1 | 3 | 4.05 | | | | | |
| 15 | 8 | | 1 | 3 | 2.03 | | | | | |
| | | | | | OD | WALL | | | | |
| 16 | 10 | 9 | 1 | 1 | 27.3 | 0.500 | | | | |
| 17 | 11 | 10 | 1 | 1 | 27.3 | 0.500 | | | | |
| 18 | 12 | 11 | 1 | 1 | 27.3 | 0.500 | | | | |
| 19 | 13 | 12 | 1 | 1 | 27.3 | 0.500 | | | | |
| 20 | 14 | 13 | 1 | 1 | 27.3 | 0.500 | | | | |
| 21 | 15 | 14 | 1 | 1 | 32.0 | 0.500 | | | | |
| 22 | 16 | 15 | 1 | 1 | 32.0 | 0.500 | | | | |
| 23 | 17 | 16 | 1 | 1 | 32.0 | 0.500 | | | | |
| 24 | 18 | 19 | 1 | 1 | 39.0 | 0.500 | | | | |
| 25 | 19 | 20 | 1 | 1 | 39.0 | 0.500 | | | | |
| 26 | 20 | 21 | 1 | 1 | 39.0 | 0.500 | | | | |
| 27 | 21 | 22 | 1 | 1 | 39.0 | 0.500 | | | | |
| 28 | 22 | 23 | 1 | 1 | 39.0 | 0.500 | | | | |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 29 | 24 | 25 | 2 | 2 | 607. | 68.6 | 68.6 | 1.00 | 1.00 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 30 | 25 | 26 | 2 | 2 | 607. | 68.6 | 68.6 | 1.00 | 1.00 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 31 | 26 | 27 | 2 | 2 | 607. | 68.6 | 68.6 | 1.00 | 1.00 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 32 | 27 | 28 | 2 | 2 | 607. | 68.6 | 68.6 | 1.00 | 1.00 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASS | | | | | |
| 33 | 24 | | 1 | 3 | 98.6 | | | | | |
| 34 | 25 | | 1 | 3 | 45.8 | | | | | |
| 35 | 26 | | 1 | 3 | 45.8 | | | | | |
| 36 | 27 | | 1 | 3 | 45.8 | | | | | |
| 37 | 28 | | 1 | 3 | 87.8 | | | | | |
| | | | | | OD | WALL | | | | |
| 38 | 29 | 30 | 1 | 1 | 39.0 | 0.500 | | | | |
| 39 | 30 | 31 | 1 | 1 | 39.0 | 0.500 | | | | |
| 40 | 31 | 32 | 1 | 1 | 39.0 | 0.500 | | | | |
| | | | | | STIF | DMOD | | | | |
| 41 | 32 | 33 | 1 | 4 | 0.240E 05 | 0. | | | | |
| | | | | | OD | WALL | | | | |
| 42 | 35 | 34 | 1 | 1 | 46.0 | 1.00 | | | | |
| 43 | 36 | 35 | 1 | 1 | 46.0 | 1.00 | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 44 | 37 | 36 | 1 | 1 | 46.0 | 1.00 | | | | |
| 45 | 38 | 37 | 1 | 1 | 46.0 | 1.00 | | | | |
| 46 | 39 | 38 | 1 | 1 | 45.0 | 0.500 | | | | |
| 47 | 40 | 39 | 1 | 1 | 45.0 | 0.500 | | | | |
| 48 | 41 | 40 | 1 | 1 | 45.0 | 0.500 | | | | |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 49 | 42 | 43 | 3 | 2 | 38.1 | 9.83 | 9.83 | 1.50 | 1.50 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 50 | 43 | 44 | 3 | 2 | 38.1 | 9.83 | 9.83 | 1.50 | 1.50 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 51 | 44 | 45 | 4 | 2 | 16.8 | 145. | 145. | 8.00 | 8.00 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 52 | 45 | 46 | 4 | 2 | 16.8 | 145. | 145. | 8.00 | 8.00 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 53 | 46 | 47 | 4 | 2 | 16.8 | 145. | 145. | 8.00 | 8.00 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 54 | 48 | 49 | 5 | 2 | 17.2 | 60.6 | 60.6 | 5.00 | 5.00 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 55 | 49 | 50 | 6 | 2 | 0.120E 04 | 0.145E 07 | 0.145E 07 | 112. | 112. | 0. |
| | | | | | 0. | 0. | 1.11 | 1.11 | | |
| 56 | 50 | 51 | 6 | 2 | 0.120E 04 | 0.145E 07 | 0.145E 07 | 112. | 112. | 0. |
| | | | | | 0. | 0. | 1.11 | 1.11 | | |
| | | | | | MASS | | | | | |
| 57 | 42 | | 1 | 3 | 1.60 | | | | | |
| 58 | 43 | | 1 | 3 | 1.60 | | | | | |
| 59 | 44 | | 1 | 3 | 7.31 | | | | | |
| 60 | 45 | | 1 | 3 | 1.28 | | | | | |
| 61 | 46 | | 1 | 3 | 1.28 | | | | | |
| 62 | 47 | | 1 | 3 | 0.640 | | | | | |
| 63 | 50 | | 1 | 3 | 250. | | | | | |
| | | | | | OD | WALL | | | | |
| 64 | 53 | 52 | 1 | 1 | 110. | 1.00 | | | | |
| 65 | 54 | 53 | 1 | 1 | 110. | 1.00 | | | | |
| 66 | 55 | 54 | 1 | 1 | 110. | 1.00 | | | | |
| 67 | 56 | 55 | 1 | 1 | 115. | 1.50 | | | | |
| 68 | 57 | 56 | 1 | 1 | 115. | 1.50 | | | | |
| 69 | 58 | 57 | 1 | 1 | 115. | 1.50 | | | | |
| 70 | 59 | 58 | 1 | 1 | 115. | 1.50 | | | | |
| 71 | 60 | 59 | 1 | 1 | 115. | 1.50 | | | | |
| 72 | 61 | 60 | 1 | 1 | 115. | 1.50 | | | | |
| 73 | 62 | 61 | 1 | 1 | 115. | 1.50 | | | | |
| 74 | 63 | 62 | 1 | 1 | 115. | 1.50 | | | | |
| 75 | 64 | 63 | 1 | 1 | 115. | 1.50 | | | | |
| 76 | 65 | 64 | 1 | 1 | 115. | 1.50 | | | | |
| | | | | | MASS | | | | | |
| 77 | 55 | | 1 | 3 | 22.0 | | | | | |
| 78 | 56 | | 1 | 3 | 44.0 | | | | | |
| 79 | 57 | | 1 | 3 | 44.0 | | | | | |
| 80 | 58 | | 1 | 3 | 44.0 | | | | | |
| 81 | 59 | | 1 | 3 | 32.5 | | | | | |
| 82 | 60 | | 1 | 3 | 37.1 | | | | | |
| 83 | 61 | | 1 | 3 | 53.1 | | | | | |
| 84 | 62 | | 1 | 3 | 45.5 | | | | | |
| 85 | 63 | | 1 | 3 | 37.8 | | | | | |
| 86 | 64 | | 1 | 3 | 18.9 | | | | | |
| 87 | 65 | | 1 | 3 | 52.1 | | | | | |
| | | | | | OD | WALL | | | | |
| 88 | 66 | 67 | 1 | 1 | 111. | 0.500 | | | | |
| 89 | 67 | 68 | 1 | 1 | 111. | 0.500 | | | | |
| 90 | 68 | 69 | 1 | 1 | 111. | 0.500 | | | | |
| 91 | 69 | 70 | 1 | 1 | 111. | 0.500 | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 92 | 71 | 72 | 1 | 1 | 131. | 1.00 |
| 93 | 72 | 73 | 1 | 1 | 131. | 1.00 |
| 94 | 73 | 74 | 1 | 1 | 131. | 1.00 |
| 95 | 74 | 75 | 1 | 1 | 131. | 1.00 |
| 96 | 75 | 76 | 1 | 1 | 131. | 1.00 |

NUMBER OF ELEMENTS = 96 MAXIMUM NODE POINT USED = 76

*** ELEMENT STIFFNESS FORMULATION TIME ESTIMATE (HNY 6000) ***

| TYPE | STIF | NUMBER | TIME(EACH) | TIME(ALL) |
|---|---|---|---|---|
| 1 | 9 | 52 | 0.8640 | 44.928 |
| 2 | 4 | 12 | 0.8640 | 10.368 |
| 3 | 21 | 31 | 0.0540 | 1.674 |
| 4 | 14 | 1 | 0.2160 | 0.216 |

TOTAL TIME = 57.186 SECONDS.

ANSYS - ENGINEERING ANALYSIS SYSTEM UP180 REV 2 GE-HNYL JAN 1,1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

SEISMIC MODEL - INTERMEDIATE HEAT EXCHANGER 12.0583 6/17/78
CP = 1.296 PP = 0.

***** NODE DEFINITIONS (CARD F) *****

| NODE | LOCATION X (OR R) | LOCATION Y (OR THETA) | LOCATION Z (OR PHI) | ROTATION (DEGREES) THXY (OR RT) | ROTATION (DEGREES) THYZ (TZ OR TP) | ROTATION (DEGREES) THXZ (RZ OR RP) |
|---|---|---|---|---|---|---|
| 1 | 0. | -611.38 | 0. | 0. | 0. | 0. |
| 2 | 0. | -510.88 | 0. | 0. | 0. | 0. |
| 3 | 0. | -429.22 | 0. | 0. | 0. | 0. |
| 4 | 0. | -347.56 | 0. | 0. | 0. | 0. |
| 5 | 0. | -227.17 | 0. | 0. | 0. | 0. |
| 6 | 0. | -106.78 | 0. | 0. | 0. | 0. |
| 7 | 0. | 13.609 | 0. | 0. | 0. | 0. |
| 8 | 0. | 134.00 | 0. | 0. | 0. | 0. |
| 9 | 0. | 184.00 | 0. | 0. | 0. | 0. |
| 10 | 0. | 134.00 | 0. | 0. | 0. | 0. |
| 11 | 0. | 13.609 | 0. | 0. | 0. | 0. |
| 12 | 0. | -106.78 | 0. | 0. | 0. | 0. |
| 13 | 0. | -227.17 | 0. | 0. | 0. | 0. |
| 14 | 0. | -347.56 | 0. | 0. | 0. | 0. |
| 15 | 0. | -429.22 | 0. | 0. | 0. | 0. |
| 16 | 0. | -510.88 | 0. | 0. | 0. | 0. |
| 17 | 0. | -605.09 | 0. | 0. | 0. | 0. |
| 18 | 0. | -641.00 | 0. | 0. | 0. | 0. |
| 19 | 0. | -611.38 | 0. | 0. | 0. | 0. |
| 20 | 0. | -561.13 | 0. | 0. | 0. | 0. |
| 21 | 0. | -485.75 | 0. | 0. | 0. | 0. |
| 22 | 0. | -410.38 | 0. | 0. | 0. | 0. |
| 23 | 0. | -361.00 | 0. | 0. | 0. | 0. |
| 24 | 0. | -641.00 | 0. | 0. | 0. | 0. |
| 25 | 0. | -561.13 | 0. | 0. | 0. | 0. |
| 26 | 0. | -485.75 | 0. | 0. | 0. | 0. |
| 27 | 0. | -410.38 | 0. | 0. | 0. | 0. |
| 28 | 0. | -328.00 | 0. | 0. | 0. | 0. |
| 29 | 0. | -328.00 | 0. | 0. | 0. | 0. |
| 30 | 0. | -225.33 | 0. | 0. | 0. | 0. |
| 31 | 0. | -122.67 | 0. | 0. | 0. | 0. |
| 32 | 0. | -20.000 | 0. | 0. | 0. | 0. |
| 33 | 0. | 16.000 | 0. | 0. | 0. | 0. |
| 34 | 0. | 134.00 | 0. | 0. | 0. | 0. |
| 35 | 0. | 84.000 | 0. | 0. | 0. | 0. |
| 36 | 0. | 16.000 | 0. | 0. | 0. | 0. |
| 37 | 0. | -20.000 | 0. | 0. | 0. | 0. |
| 38 | 0. | -128.00 | 0. | 0. | 0. | 0. |
| 39 | 0. | -213.00 | 0. | 0. | 0. | 0. |
| 40 | 0. | -293.00 | 0. | 0. | 0. | 0. |
| 41 | 0. | -305.50 | 0. | 0. | 0. | 0. |
| 42 | 0. | -293.00 | 0. | 0. | 0. | 0. |
| 43 | 0. | -213.00 | 0. | 0. | 0. | 0. |
| 44 | 0. | -178.13 | 0. | 0. | 0. | 0. |
| 45 | 0. | -74.083 | 0. | 0. | 0. | 0. |
| 46 | 0. | 29.958 | 0. | 0. | 0. | 0. |
| 47 | 0. | 134.00 | 0. | 0. | 0. | 0. |
| 48 | 0. | -178.13 | 0. | 0. | 0. | 0. |
| 49 | 0. | -128.00 | 0. | 0. | 0. | 0. |

| | | | | | | |
|---|---|---|---|---|---|---|
| 50 | 0. | -64.000 | 0. | 0. | 0. | 0. |
| 51 | 0. | 0. | 0. | 0. | 0. | 0. |
| 52 | 0. | 242.00 | 0. | 0. | 0. | 0. |
| 53 | 0. | 161.33 | 0. | 0. | 0. | 0. |
| 54 | 0. | 80.667 | 0. | 0. | 0. | 0. |
| 55 | 0. | 0. | 0. | 0. | 0. | 0. |
| 56 | 0. | -73.250 | 0. | 0. | 0. | 0. |
| 57 | 0. | -146.50 | 0. | 0. | 0. | 0. |
| 58 | 0. | -219.75 | 0. | 0. | 0. | 0. |
| 59 | 0. | -293.00 | 0. | 0. | 0. | 0. |
| 60 | 0. | -328.00 | 0. | 0. | 0. | 0. |
| 61 | 0. | -419.44 | 0. | 0. | 0. | 0. |
| 62 | 0. | -510.88 | 0. | 0. | 0. | 0. |
| 63 | 0. | -575.94 | 0. | 0. | 0. | 0. |
| 64 | 0. | -641.00 | 0. | 0. | 0. | 0. |
| 65 | 0. | -656.25 | 0. | 0. | 0. | 0. |
| 66 | 0. | -631.25 | 0. | 0. | 0. | 0. |
| 67 | 0. | -558.50 | 0. | 0. | 0. | 0. |
| 68 | 0. | -485.75 | 0. | 0. | 0. | 0. |
| 69 | 0. | -406.88 | 0. | 0. | 0. | 0. |
| 70 | 0. | -328.00 | 0. | 0. | 0. | 0. |
| 71 | 0. | -400.00 | 0. | 0. | 0. | 0. |
| 72 | 0. | -328.00 | 0. | 0. | 0. | 0. |
| 73 | 0. | -230.00 | 0. | 0. | 0. | 0. |
| 74 | 0. | -132.00 | 0. | 0. | 0. | 0. |
| 75 | 0. | -66.000 | 0. | 0. | 0. | 0. |
| 76 | 0. | 0. | 0. | 0. | 0. | 0. |

XMIN= 0. XMAX= 0. YMIN= -656.3 YMAX= 242.0 ZMIN= 0. ZMAX= 0.

PLOT DEVICE 1 DEFINED FOR THIS RUN

***** MATERIAL PROPERTIES (CARD H) *****

MATERIAL 1
EX = 0.260000E 08
NUXY = 0.300000
ALPX = 0.987000E-05
DENS = 0.732400E-03

MATERIAL 2
EX = 0.260000E 08
NUXY = 0.300000
ALPX = 0.987000E-05
DENS = 0.

MATERIAL 3
EX = 0.260000E 08
NUXY = 0.300000
ALPX = 0.987000E-05
DENS = 0.

MATERIAL 4
EX = 0.260000E 08
NUXY = 0.300000
ALPX = 0.987000E-05
DENS = 0.

```
MATERIAL  5
 EX    =      0.260000E 08
 NUXY  =      0.300000
 ALPX  =      0.987000E-05
 DENS  =      0.

MATERIAL  6
 EX    =      0.260000E 08
 NUXY  =      0.300000
 ALPX  =      0.987000E-05
 DENS  =      0.

MATERIAL  9
 EX    =      0.260000E 08
 NUXY  =      0.300000
 ALPX  =      0.987000E-05
 DENS  =      0.
```

***** COUPLED DEG. OF FR. DEFINITIONS (CARD J) *****

| SET | D.O.F. | NUMBER | COUPLED NODES | | | | |
|---|---|---|---|---|---|---|---|
| 1 | UX | 3 | 10 | 8 | 34 | | |
| 2 | UY | 3 | 10 | 8 | 34 | | |
| 3 | UZ | 3 | 10 | 8 | 34 | | |
| 4 | ROTZ | 3 | 10 | 8 | 34 | | |
| 5 | UX | 2 | 2 | 16 | | | |
| 6 | UX | 3 | 19 | 17 | 1 | | |
| 7 | ROTZ | 3 | 19 | 17 | 1 | | |
| 8 | UX | 3 | 24 | 18 | 64 | | |
| 9 | UY | 2 | 24 | 18 | | | |
| 10 | UZ | 2 | 24 | 18 | | | |
| 11 | ROTZ | 2 | 24 | 18 | | | |
| 12 | UX | 3 | 9 | 35 | 47 | | |
| 13 | UX | 2 | 25 | 20 | | | |
| 14 | UX | 2 | 27 | 22 | | | |
| 15 | UX | 2 | 14 | 23 | | | |
| 16 | UX | 5 | 28 | 29 | 41 | 60 | 70 |
| 17 | UY | 4 | 28 | 29 | 60 | 70 | |
| 18 | UZ | 4 | 28 | 29 | 60 | 70 | |
| 19 | ROTZ | 4 | 28 | 29 | 60 | 70 | |
| 20 | UX | 3 | 42 | 40 | 59 | | |
| 21 | UX | 2 | 44 | 48 | | | |
| 22 | UY | 2 | 44 | 48 | | | |
| 23 | UZ | 2 | 44 | 48 | | | |
| 24 | ROTZ | 2 | 44 | 48 | | | |
| 25 | UX | 2 | 39 | 43 | | | |
| 26 | UX | 2 | 38 | 49 | | | |
| 27 | UY | 2 | 38 | 49 | | | |
| 28 | UZ | 2 | 38 | 49 | | | |
| 29 | ROTZ | 2 | 38 | 49 | | | |
| 30 | UX | 2 | 36 | 33 | | | |
| 31 | UY | 2 | 36 | 33 | | | |
| 32 | UZ | 2 | 36 | 33 | | | |
| 33 | ROTZ | 2 | 36 | 33 | | | |
| 34 | UX | 3 | 26 | 68 | 62 | | |

34 COUPLED SETS

***** DYNAMIC DEGREES OF FREEDOM (CARD K) *****

| NO. | NODE | D.O.F. |
|---|---|---|
| 1 | 2 | UY |
| 2 | 4 | UY |
| 3 | 6 | UY |
| 4 | 10 | UY |
| 5 | 12 | UY |
| 6 | 14 | UY |
| 7 | 16 | UY |
| 8 | 19 | UY |
| 9 | 21 | UY |
| 10 | 23 | UY |
| 11 | 24 | UY |
| 12 | 26 | UY |
| 13 | 28 | UY |
| 14 | 30 | UY |
| 15 | 32 | UY |
| 16 | 36 | UY |
| 17 | 38 | UY |
| 18 | 40 | UY |
| 19 | 42 | UY |
| 20 | 44 | UY |
| 21 | 45 | UY |
| 22 | 47 | UY |
| 23 | 50 | UY |
| 24 | 52 | UY |
| 25 | 54 | UY |
| 26 | 56 | UY |
| 27 | 58 | UY |
| 28 | 60 | UY |
| 29 | 62 | UY |
| 30 | 64 | UY |
| 31 | 66 | UY |
| 32 | 68 | UY |
| 33 | 71 | UY |
| 34 | 73 | UY |
| 35 | 75 | UY |

35 DYNAMIC DEGREES OF FREEDOM

ANSYS - ENGINEERING ANALYSIS SYSTEM UP180 REV 2 GE-HNYL JAN 1,1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

SEISMIC MODEL - INTERMEDIATE HEAT EXCHANGER 12.0583 6/17/78
CP = 2.534 PP = 0.

LOAD STEP NUMBER = 1

***** LOAD STEP OPTIONS (CARDS L AND M) *****

| | VALUE | VARIABLE NAME | COLUMNS |
|---|---|---|---|
| LOAD STEP KEY . . . . . . . . | 1 | KDIS | 2-3 |
| TEMPERATURE KEY . . . . . . . | 0 | KTEMP | 4-6 |
| NUMBER OF ITERATIONS. . . . . | 1 | NITTER | 7-9 |
| SOLUTION PRINTOUT FREQUENCY . | 1 | NPRINT | 10-12 |
| TIME AT END OF LOAD STEP. . . | 0. | TIME | 13-24 |
| SEISMIC EXCITATION DIRECTION | 0. | 1.0000 | 0. |
| SIGNIFICANCE CRITERION | 0.1000E-02 | | |

***** SPECTRUM DATA TABLE (CARD M1) *****

| FREQUENCY | SPECTRUM |
|---|---|
| 0.20 | 30.14 |
| 0.80 | 135.8 |
| 1.79 | 289.8 |
| 3.16 | 513.2 |
| 4.23 | 513.2 |
| 9.73 | 220.4 |
| 20.00 | 157.0 |
| 40.00 | 157.0 |

***** SPECIFIED DISPLACEMENTS (CARD N) *****

| NO. | NODE | DIRECTION | VALUE |
|---|---|---|---|
| 1 | 51 | UX | 0. |
| 2 | 51 | UY | 0. |
| 3 | 51 | UZ | 0. |
| 4 | 51 | ROTX | 0. |
| 5 | 51 | ROTY | 0. |
| 6 | 51 | ROTZ | 0. |
| 7 | 55 | UX | 0. |
| 8 | 55 | UY | 0. |
| 9 | 55 | UZ | 0. |
| 10 | 55 | ROTX | 0. |
| 11 | 55 | ROTY | 0. |
| 12 | 55 | ROTZ | 0. |
| 13 | 76 | UX | 0. |
| 14 | 76 | UY | 0. |
| 15 | 76 | UZ | 0. |
| 16 | 76 | ROTX | 0. |
| 17 | 76 | ROTY | 0. |
| 18 | 76 | ROTZ | 0. |

## Appendix V-3B

## ANALYTICAL RESULTS, DISPLACEMENTS AND STRESSES

B-1 Deck Penetration Rigidly Attached to Bottom of Deck

B-2 Deck Penetration Rigidly Attached to Top of Deck

B-3 No Seismic Support at the Upper Tubesheet

Appendix B-1

DECK PENETRATION RIGIDLY ATTACHED TO BOTTOM OF DECK

ANSYS - ENGINEERING ANALYSIS SYSTEM UP185EREV 2 ISD-EX8 JAN 1, 1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

PLBR POOL SEISMIC RESPONSES - SSE - HORIZONTAL 6423.0000 5719778
CP = 409.000 PP = .000

DISPLACEMENT SUMMATION

| NODE | UX | UY | UZ | ROTX | ROTY | ROTZ |
|---|---|---|---|---|---|---|
| 1 | .267556+00 | .000000 | .000000 | .000000 | .000000 | .235967-02 |
| 2 | .460111+00 | .000000 | .000000 | .000000 | .000000 | .262671-02 |
| 3 | .661710+00 | .000000 | .000000 | .000000 | .000000 | .270359-02 |
| 4 | .844354+00 | .000000 | .000000 | .000000 | .000000 | .210611-02 |
| 5 | .918907+00 | .000000 | .000000 | .000000 | .000000 | .963533-03 |
| 6 | .678435+00 | .000000 | .000000 | .000000 | .000000 | .297541-02 |
| 7 | .277593+00 | .000000 | .000000 | .000000 | .000000 | .310038-02 |
| 8 | .417550-01 | .000000 | .000000 | .000000 | .000000 | .122200-03 |
| 9 | .397536-01 | .000000 | .000000 | .000000 | .000000 | .503624-04 |
| 10 | .417550-01 | .000000 | .000000 | .000000 | .000000 | .122200-03 |
| 11 | .173582+00 | .000000 | .000000 | .000000 | .000000 | .180185-02 |
| 12 | .425030+00 | .000000 | .000000 | .000000 | .000000 | .208678-02 |
| 13 | .635246+00 | .000000 | .000000 | .000000 | .000000 | .120641-02 |
| 14 | .680892+00 | .000000 | .000000 | .000000 | .000000 | .697086-03 |
| 15 | .601491+00 | .000000 | .000000 | .000000 | .000000 | .149698-02 |
| 16 | .460111+00 | .000000 | .000000 | .000000 | .000000 | .228606-02 |
| 17 | .267556+00 | .000000 | .000000 | .000000 | .000000 | .235967-02 |
| 18 | .226195+00 | .000000 | .000000 | .000000 | .000000 | .239536-02 |
| 19 | .267556+00 | .000000 | .000000 | .000000 | .000000 | .235967-02 |
| 20 | .349606+00 | .000000 | .000000 | .000000 | .000000 | .211916-02 |
| 21 | .475554+00 | .000000 | .000000 | .000000 | .000000 | .189975-02 |
| 22 | .598414+00 | .000000 | .000000 | .000000 | .000000 | .181479-02 |
| 23 | .680892+00 | .000000 | .000000 | .000000 | .000000 | .181102-02 |
| 24 | .226195+00 | .000000 | .000000 | .000000 | .000000 | .239536-02 |
| 25 | .349606+00 | .000000 | .000000 | .000000 | .000000 | .216830-02 |
| 26 | .186466+00 | .000000 | .000000 | .000000 | .000000 | .344365-02 |
| 27 | .598414+00 | .000000 | .000000 | .000000 | .000000 | .705856-03 |
| 28 | .519921-01 | .000000 | .000000 | .000000 | .000000 | .403633-03 |
| 29 | .519921-01 | .000000 | .000000 | .000000 | .000000 | .403633-03 |
| 30 | .172130-01 | .000000 | .000000 | .000000 | .000000 | .494205-03 |
| 31 | .589619-01 | .000000 | .000000 | .000000 | .000000 | .562437-03 |
| 32 | .117242+00 | .000000 | .000000 | .000000 | .000000 | .578500-03 |
| 33 | .272957-01 | .000000 | .000000 | .000000 | .000000 | .194410-03 |
| 34 | .417550-01 | .000000 | .000000 | .000000 | .000000 | .122200-03 |
| 35 | .397536-01 | .000000 | .000000 | .000000 | .000000 | .628880-04 |
| 36 | .272957-01 | .000000 | .000000 | .000000 | .000000 | .194410-03 |
| 37 | .186495-01 | .000000 | .000000 | .000000 | .000000 | .203313-03 |
| 38 | .372480-03 | .000000 | .000000 | .000000 | .000000 | .497144-05 |
| 39 | .109749-01 | .000000 | .000000 | .000000 | .000000 | .255924-03 |
| 40 | .412241-01 | .000000 | .000000 | .000000 | .000000 | .511003-03 |
| 41 | .519921-01 | .000000 | .000000 | .000000 | .000000 | .531642-03 |
| 42 | .412241-01 | .000000 | .000000 | .000000 | .000000 | .519921-03 |
| 43 | .109749-01 | .000000 | .000000 | .000000 | .000000 | .733706-03 |
| 44 | .175379-01 | .000000 | .000000 | .000000 | .000000 | .366154-03 |
| 45 | .486500-01 | .000000 | .000000 | .000000 | .000000 | .463661-03 |
| 46 | .646592-01 | .000000 | .000000 | .000000 | .000000 | .314814-03 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 47 | .397536-01 | .000000 | .000000 | .000000 | .000000 | .735230-03 |
| 48 | .175379-01 | .000000 | .000000 | .000000 | .000000 | .366154-03 |
| 49 | .372480-03 | .000000 | .000000 | .000000 | .000000 | .497144-05 |
| 50 | .193555-03 | .000000 | .000000 | .000000 | .000000 | .200576-05 |
| 56 | .170433-02 | .000000 | .000000 | .000000 | .000000 | .700497-04 |
| 57 | .833811-02 | .000000 | .000000 | .000000 | .000000 | .150628-03 |
| 58 | .212459-01 | .000000 | .000000 | .000000 | .000000 | .242491-03 |
| 59 | .412241-01 | .000000 | .000000 | .000000 | .000000 | .346319-03 |
| 60 | .519921-01 | .000000 | .000000 | .000000 | .000000 | .403633-03 |
| 61 | .959358-01 | .000000 | .000000 | .000000 | .000000 | .494327-03 |
| 62 | .146466+00 | .000000 | .000000 | .000000 | .000000 | .556862-03 |
| 63 | .185971+00 | .000000 | .000000 | .000000 | .000000 | .582737-03 |
| 64 | .226195+00 | .000000 | .000000 | .000000 | .000000 | .591399-03 |
| 65 | .235312+00 | .000000 | .000000 | .000000 | .000000 | .591499-03 |
| 66 | .228748+00 | .000000 | .000000 | .000000 | .000000 | .563601-03 |
| 67 | .187656+00 | .000000 | .000000 | .000000 | .000000 | .563027-03 |
| 68 | .146466+00 | .000000 | .000000 | .000000 | .000000 | .560316-03 |
| 69 | .961561-01 | .000000 | .000000 | .000000 | .000000 | .518970-03 |
| 70 | .519921-01 | .000000 | .000000 | .000000 | .000000 | .403633-03 |
| 71 | .675435-01 | .000000 | .000000 | .000000 | .000000 | .215425-03 |
| 72 | .519921-01 | .000000 | .000000 | .000000 | .000000 | .215278-03 |
| 73 | .207468-01 | .000000 | .000000 | .000000 | .000000 | .161311-03 |

ANSYS - ENGINEERING ANALYSIS SYSTEM UP185EREV 2 ISD-EX8 JAN 1, 1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

PLSR POOL SEISMIC RESPONSES - SSE - HORIZONTAL 6455.0000 5/19/78
CP = 420.000 PP = .000

SUMMATION RESULTS (WRITTEN ON TAPE11)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 1 FORCES | .00000 | 9060.5 | .00000 | .00000 | .00000 | 70035. | | |
| | .00000 | 9060.5 | .00000 | .00000 | .00000 | .91455+06 | | |
| ELEM 1 STRESSES | 223.35 | 223.35 | .00 | .00 | 2916.59 | 2916.59 | .00 | .00 |
| ELEM 2 FORCES | .00000 | 15345. | .00000 | .00000 | .00000 | .91455+06 | | |
| | .00000 | 15345. | .00000 | .00000 | .00000 | .69115+06 | | |
| ELEM 2 STRESSES | 2916.59 | 2916.59 | .00 | .00 | 2204.16 | 2204.16 | .00 | .00 |
| ELEM 3 FORCES | .00000 | 10411. | .00000 | .00000 | .00000 | .69115+06 | | |
| | .00000 | 10411. | .00000 | .00000 | .00000 | .13728+07 | | |
| ELEM 3 STRESSES | 2204.16 | 2204.16 | .00 | .00 | 4378.02 | 4378.02 | .00 | .00 |
| ELEM 7 FORCES | .00000 | 3585.2 | .00000 | .00000 | .00000 | .13728+07 | | |
| | .00000 | 3585.2 | .00000 | .00000 | .00000 | .16372+07 | | |
| ELEM 7 STRESSES | 6461.89 | 6461.89 | .00 | .00 | 7706.22 | 7706.22 | .00 | .00 |
| ELEM 8 FORCES | .00000 | 6581.7 | .00000 | .00000 | .00000 | .16372+07 | | |
| | .00000 | 6581.7 | .00000 | .00000 | .00000 | .89591+06 | | |
| ELEM 8 STRESSES | 7706.22 | 7706.22 | .00 | .00 | 4217.13 | 4217.13 | .00 | .00 |
| ELEM 9 FORCES | .00000 | 13009. | .00000 | .00000 | .00000 | .89591+06 | | |
| | .00000 | 13009. | .00000 | .00000 | .00000 | .71367+06 | | |
| ELEM 9 STRESSES | 4217.13 | 4217.13 | .00 | .00 | 3359.31 | 3359.31 | .00 | .00 |
| ELEM 10 FORCES | .00000 | 15885. | .00000 | .00000 | .00000 | .71367+06 | | |
| | .00000 | 15885. | .00000 | .00000 | .00000 | .25925+07 | | |
| ELEM 10 STRESSES | 3359.31 | 3359.31 | .00 | .00 | 12202.92 | 12202.92 | .00 | .00 |
| ELEM 16 FORCES | .00000 | 9065.8 | .00000 | .00000 | .00000 | .45329+06 | | |
| | .00000 | 9065.8 | .00000 | .00000 | .00000 | .13207-01 | | |
| ELEM 16 STRESSES | 1642.71 | 1642.71 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 17 FORCES | .00000 | 10006. | .00000 | .00000 | .00000 | .77695+06 | | |
| | .00000 | 10006. | .00000 | .00000 | .00000 | .19644+07 | | |
| ELEM 17 STRESSES | 2815.63 | 2815.63 | .00 | .00 | 7118.88 | 7118.88 | .00 | .00 |
| ELEM 18 FORCES | .00000 | 9098.2 | .00000 | .00000 | .00000 | .36588+06 | | |
| | .00000 | 9098.2 | .00000 | .00000 | .00000 | .77695+06 | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ELEM | 18 STRESSES | 1325.94 | 1325.94 | .00 | .00 | 2815.63 | 2815.63 | .00 | .00 |
| ELEM | 19 FORCES | .00000 | 7173.2 | .00000 | | .00000 | .00000 | | .11788+07 |
| | | .00000 | 7173.2 | .00000 | | .00000 | .00000 | | .36588+06 |
| ELEM | 19 STRESSES | 4271.92 | 4271.92 | .00 | .00 | 1325.94 | 1325.94 | .00 | .00 |
| ELEM | 20 FORCES | .00000 | 4725.0 | .00000 | | .00000 | .00000 | | .16964+07 |
| | | .00000 | 4725.0 | .00000 | | .00000 | .00000 | | .11788+07 |
| ELEM | 20 STRESSES | 6147.81 | 6147.81 | .00 | .00 | 4271.92 | 4271.92 | .00 | .00 |
| ELEM | 21 FORCES | .00000 | 2383.5 | .00000 | | .00000 | .00000 | | .16607+07 |
| | | .00000 | 2383.5 | .00000 | | .00000 | .00000 | | .16964+07 |
| ELEM | 21 STRESSES | 4328.48 | 4328.48 | .00 | .00 | 4421.67 | 4421.67 | .00 | .00 |
| ELEM | 22 FORCES | .00000 | 3436.7 | .00000 | | .00000 | .00000 | | .14991+07 |
| | | .00000 | 3436.7 | .00000 | | .00000 | .00000 | | .16607+07 |
| ELEM | 22 STRESSES | 3907.27 | 3907.27 | .00 | .00 | 4328.48 | 4328.48 | .00 | .00 |
| ELEM | 23 FORCES | .00000 | 24222. | .00000 | | .00000 | .00000 | | .12765+07 |
| | | .00000 | 24222. | .00000 | | .00000 | .00000 | | .14991+07 |
| ELEM | 23 STRESSES | 3327.26 | 3327.26 | .00 | .00 | 3907.27 | 3907.27 | .00 | .00 |
| ELEM | 24 FORCES | .00000 | 18734. | .00000 | | .00000 | .00000 | | .18446+06 |
| | | .00000 | 18734. | .00000 | | .00000 | .00000 | | .65408+06 |
| ELEM | 24 STRESSES | 320.96 | 320.96 | .00 | .00 | 1138.10 | 1138.10 | .00 | .00 |
| ELEM | 25 FORCES | .00000 | 14592. | .00000 | | .00000 | .00000 | | .17192+07 |
| | | .00000 | 14592. | .00000 | | .00000 | .00000 | | .11954+07 |
| ELEM | 25 STRESSES | 2991.36 | 2991.36 | .00 | .00 | 2079.97 | 2079.97 | .00 | .00 |
| ELEM | 26 FORCES | .00000 | 6519.8 | .00000 | | .00000 | .00000 | | .11954+07 |
| | | .00000 | 6519.8 | .00000 | | .00000 | .00000 | | .71521+06 |
| ELEM | 26 STRESSES | 2079.97 | 2079.97 | .00 | .00 | 1244.47 | 1244.47 | .00 | .00 |
| ELEM | 27 FORCES | .00000 | 8328.9 | .00000 | | .00000 | .00000 | | .71521+06 |
| | | .00000 | 8328.9 | .00000 | | .00000 | .00000 | | .16663+06 |
| ELEM | 27 STRESSES | 1244.47 | 1244.47 | .00 | .00 | 289.93 | 289.93 | .00 | .00 |
| ELEM | 28 FORCES | .00000 | 3374.7 | .00000 | | .00000 | .00000 | | .16663+06 |
| | | .00000 | 3374.7 | .00000 | | .00000 | .00000 | | .56361 |
| ELEM | 28 STRESSES | 289.93 | 289.93 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM | 29 FORCES | .00000 | 7127.7 | .00000 | | .00000 | .00000 | | .18446+06 |
| | | .00000 | 7127.7 | .00000 | | .00000 | .00000 | | .38487+06 |
| ELEM | 29 STRESSES | 1345.06 | 1345.06 | 1345.06 | 1345.06 | 2806.42 | 2806.42 | 2806.42 | 2806.42 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 30 FORCES | .00000 | 13689. | | .00000 | .00000 | .00000 | | .38487+06 |
| | .00000 | 13689. | | .00000 | .00000 | .00000 | | .64692+06 |
| ELEM 30 STRESSES | 2806.42 | 2806.42 | 2806.42 | 2806.42 | 4717.19 | 4717.19 | 4717.19 | 4717.19 |
| ELEM 31 FORCES | .00000 | 19606. | | .00000 | .00000 | .00000 | | .64692+06 |
| | .00000 | 19606. | | .00000 | .00000 | .00000 | | .83090+06 |
| ELEM 31 STRESSES | 4717.19 | 4717.19 | 4717.19 | 4717.19 | 6058.80 | 6058.80 | 6058.80 | 6058.80 |
| ELEM 32 FORCES | .00000 | 20296. | | .00000 | .00000 | .00000 | | .83090+06 |
| | .00000 | 20296. | | .00000 | .00000 | .00000 | | .84104+06 |
| ELEM 32 STRESSES | 6058.80 | 6058.80 | 6058.80 | 6058.80 | 6132.70 | 6132.70 | 6132.70 | 6132.70 |
| ELEM 38 FORCES | .00000 | 3723.7 | | .00000 | .00000 | .00000 | | .84078+06 |
| | .00000 | 3723.7 | | .00000 | .00000 | .00000 | | .46188+06 |
| ELEM 38 STRESSES | 1462.97 | 1462.97 | .00 | .00 | 803.68 | 803.68 | .00 | .00 |
| ELEM 39 FORCES | .00000 | 3273.9 | | .00000 | .00000 | .00000 | | .46188+06 |
| | .00000 | 3273.9 | | .00000 | .00000 | .00000 | | .12624+06 |
| ELEM 39 STRESSES | 803.68 | 803.68 | .00 | .00 | 219.67 | 219.67 | .00 | .00 |
| ELEM 40 FORCES | .00000 | 1229.7 | | .00000 | .00000 | .00000 | | .12625+06 |
| | .00000 | 1229.7 | | .00000 | .00000 | .00000 | | .31328-01 |
| ELEM 40 STRESSES | 219.67 | 219.67 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 41 FORCES | .00000 | | | | | | | |
| ELEM 42 FORCES | .00000 | 32779. | | .00000 | .00000 | .00000 | | .25413+07 |
| | .00000 | 32779. | | .00000 | .00000 | .00000 | | .41637+07 |
| ELEM 42 STRESSES | 1632.60 | 1632.60 | .00 | .00 | 2674.81 | 2674.81 | .00 | .00 |
| ELEM 43 FORCES | .00000 | 26425. | | .00000 | .00000 | .00000 | | .74918+06 |
| | .00000 | 26425. | | .00000 | .00000 | .00000 | | .25413+07 |
| ELEM 43 STRESSES | 481.29 | 481.29 | .00 | .00 | 1632.60 | 1632.60 | .00 | .00 |
| ELEM 44 FORCES | .00000 | 27201. | | .00000 | .00000 | .00000 | | .27876+06 |
| | .00000 | 27201. | | .00000 | .00000 | .00000 | | .74918+06 |
| ELEM 44 STRESSES | 179.08 | 179.08 | .00 | .00 | 481.29 | 481.29 | .00 | .00 |
| ELEM 45 FORCES | .00000 | 27347. | | .00000 | .00000 | .00000 | | .32002+07 |
| | .00000 | 27347. | | .00000 | .00000 | .00000 | | .27876+06 |
| ELEM 45 STRESSES | 2055.86 | 2055.86 | .00 | .00 | 179.08 | 179.08 | .00 | .00 |
| ELEM 46 FORCES | .00000 | 2492.3 | | .00000 | .00000 | .00000 | | .13890+07 |
| | .00000 | 2492.3 | | .00000 | .00000 | .00000 | | .13022+07 |
| ELEM 46 STRESSES | 1806.03 | 1806.03 | .00 | .00 | 1693.19 | 1693.19 | .00 | .00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 47 FORCES | .00000 | 2276.8 | .00000 | .00000 | .00000 | .14941+07 | | |
| | .00000 | 2276.8 | .00000 | .00000 | .00000 | .13890+07 | | |
| ELEM 47 STRESSES | 1942.67 | 1942.67 | .00 | .00 | 1806.03 | 1806.03 | .00 | .00 |
| ELEM 48 FORCES | .00000 | .11953+06 | .00000 | .00000 | .00000 | .83299-01 | | |
| | .00000 | .11953+06 | .00000 | .00000 | .00000 | .14941+07 | | |
| ELEM 48 STRESSES | .00 | .00 | .00 | .00 | 1942.67 | 1942.67 | .00 | .00 |
| ELEM 49 FORCES | .00000 | 78.797 | .00000 | .00000 | .00000 | .27267-04 | | |
| | .00000 | 78.797 | .00000 | .00000 | .00000 | 6303.8 | | |
| ELEM 49 STRESSES | .00 | .00 | .00 | .00 | 480.96 | 480.96 | 480.96 | 480.96 |
| ELEM 50 FORCES | .00000 | 769.81 | .00000 | .00000 | .00000 | 6303.8 | | |
| | .00000 | 769.81 | .00000 | .00000 | .00000 | 20726. | | |
| ELEM 50 STRESSES | 480.96 | 480.96 | 480.96 | 480.96 | 1581.32 | 1581.32 | 1581.32 | 1581.32 |
| ELEM 51 FORCES | .00000 | 502.99 | .00000 | .00000 | .00000 | 34612. | | |
| | .00000 | 502.99 | .00000 | .00000 | .00000 | 19714. | | |
| ELEM 51 STRESSES | 954.94 | 954.94 | 954.94 | 954.94 | 543.90 | 543.90 | 543.90 | 543.90 |
| ELEM 52 FORCES | .00000 | 142.18 | .00000 | .00000 | .00000 | 19714. | | |
| | .00000 | 142.18 | .00000 | .00000 | .00000 | 32627. | | |
| ELEM 52 STRESSES | 543.90 | 543.90 | 543.90 | 543.90 | 900.18 | 900.18 | 900.18 | 900.18 |
| ELEM 53 FORCES | .00000 | 313.60 | .00000 | .00000 | .00000 | 32627. | | |
| | .00000 | 313.60 | .00000 | .00000 | .00000 | .51255-03 | | |
| ELEM 53 STRESSES | 900.18 | 900.18 | 900.18 | 900.18 | .00 | .00 | .00 | .00 |
| ELEM 54 FORCES | .00000 | 1865.5 | .00000 | .00000 | .00000 | 39477. | | |
| | .00000 | 1865.5 | .00000 | .00000 | .00000 | 46789. | | |
| ELEM 54 STRESSES | 1628.31 | 1628.31 | 1628.31 | 1628.31 | 1929.93 | 1929.93 | 1929.93 | 1929.93 |
| ELEM 55 FORCES | .00000 | 27713. | .00000 | .00000 | .00000 | .28958+07 | | |
| | .00000 | 27713. | .00000 | .00000 | .00000 | .14662+07 | | |
| ELEM 55 STRESSES | 111.94 | 111.94 | 111.94 | 111.94 | 56.68 | 56.68 | 56.68 | 56.68 |
| ELEM 56 FORCES | .00000 | 27873. | .00000 | .00000 | .00000 | .14662+07 | | |
| | .00000 | 27873. | .00000 | .00000 | .00000 | .14968+07 | | |
| ELEM 56 STRESSES | 56.68 | 56.68 | 56.68 | 56.68 | 57.86 | 57.86 | 57.86 | 57.86 |
| ELEM 64 FORCES | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| ELEM 64 STRESSES | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 65 FORCES | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 65 STRESSES | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 66 FORCES | .00000 | .00000 | .00000 | | .00000 | .00000 | | .00000 |
| | .00000 | .00000 | .00000 | | .00000 | .00000 | | .00000 |
| ELEM 66 STRESSES | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 67 FORCES | .00000 | 56849. | .00000 | | .00000 | .00000 | | .23176+08 |
| | .00000 | 56849. | .00000 | | .00000 | .00000 | | .20031+08 |
| ELEM 67 STRESSES | 1540.18 | 1540.18 | .00 | .00 | 1331.14 | 1331.14 | .00 | .00 |
| ELEM 68 FORCES | .00000 | 55595. | .00000 | | .00000 | .00000 | | .26604+08 |
| | .00000 | 55595. | .00000 | | .00000 | .00000 | | .23176+08 |
| ELEM 68 STRESSES | 1767.97 | 1767.97 | .00 | .00 | 1540.18 | 1540.18 | .00 | .00 |
| ELEM 69 FORCES | .00000 | 53516. | .00000 | | .00000 | .00000 | | .30214+08 |
| | .00000 | 53516. | .00000 | | .00000 | .00000 | | .26604+08 |
| ELEM 69 STRESSES | 2007.90 | 2007.90 | .00 | .00 | 1767.97 | 1767.97 | .00 | .00 |
| ELEM 70 FORCES | .00000 | 58507. | .00000 | | .00000 | .00000 | | .33982+08 |
| | .00000 | 58507. | .00000 | | .00000 | .00000 | | .30214+08 |
| ELEM 70 STRESSES | 2258.31 | 2258.31 | .00 | .00 | 2007.90 | 2007.90 | .00 | .00 |
| ELEM 71 FORCES | .00000 | .17498+06 | .00000 | | .00000 | .00000 | | .40105+08 |
| | .00000 | .17498+06 | .00000 | | .00000 | .00000 | | .33982+08 |
| ELEM 71 STRESSES | 2665.22 | 2665.22 | .00 | .00 | 2258.31 | 2258.31 | .00 | .00 |
| ELEM 72 FORCES | .00000 | 82949. | .00000 | | .00000 | .00000 | | .18811+08 |
| | .00000 | 82949. | .00000 | | .00000 | .00000 | | .26228+08 |
| ELEM 72 STRESSES | 1250.08 | 1250.08 | .00 | .00 | 1742.98 | 1742.98 | .00 | .00 |
| ELEM 73 FORCES | .00000 | 70775. | .00000 | | .00000 | .00000 | | .12456+08 |
| | .00000 | 70775. | .00000 | | .00000 | .00000 | | .18811+08 |
| ELEM 73 STRESSES | 827.77 | 827.77 | .00 | .00 | 1250.08 | 1250.08 | .00 | .00 |
| ELEM 74 FORCES | .00000 | .10201+06 | .00000 | | .00000 | .00000 | | .58220+07 |
| | .00000 | .10201+06 | .00000 | | .00000 | .00000 | | .12456+08 |
| ELEM 74 STRESSES | 386.90 | 386.90 | .00 | .00 | 827.77 | 827.77 | .00 | .00 |
| ELEM 75 FORCES | .00000 | 84736. | .00000 | | .00000 | .00000 | | .31550+06 |
| | .00000 | 84736. | .00000 | | .00000 | .00000 | | .58220+07 |
| ELEM 75 STRESSES | 20.97 | 20.97 | .00 | .00 | 386.90 | 386.90 | .00 | .00 |
| ELEM 76 FORCES | .00000 | 20689. | .00000 | | .00000 | .00000 | | 3.8297 |
| | .00000 | 20689. | .00000 | | .00000 | .00000 | | .31550+06 |
| ELEM 76 STRESSES | .00 | .00 | .00 | .00 | 20.97 | 20.97 | .00 | .00 |

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ELEM   88 FORCES      .00000       1544.7        .00000        .00000        .00000       .64166
                      .00000       1544.7        .00000        .00000        .00000       .11238+06
ELEM   88 STRESSES       .00         .00       .00        .00     23.65      23.65      .00         .00

ELEM   89 FORCES      .00000       4218.7        .00000        .00000        .00000       .11238+06
                      .00000       4218.7        .00000        .00000        .00000       .41893+06
ELEM   89 STRESSES     23.65       23.65       .00        .00     88.16      88.16      .00         .00

ELEM   90 FORCES      .00000       80861.        .00000        .00000        .00000       .41893+06
                      .00000       80861.        .00000        .00000        .00000       .67800+07
ELEM   90 STRESSES     88.16       88.16       .00        .00   1426.82    1426.82      .00         .00

ELEM   91 FORCES      .00000       82165.        .00000        .00000        .00000       .67800+07
                      .00000       82165.        .00000        .00000        .00000       .13260+08
ELEM   91 STRESSES   1426.82     1426.82       .00        .00   2790.59    2790.50      .00         .00

ELEM   92 FORCES      .00000       2389.3        .00000        .00000        .00000       .20336
                      .00000       2389.3        .00000        .00000        .00000       .17203+06
ELEM   92 STRESSES       .00         .00       .00        .00     13.16      13.16      .00         .00

ELEM   93 FORCES      .00000     .84737+06       .00000        .00000        .00000       .17203+06
                      .00000     .84737+06       .00000        .00000        .00000       .24333+08
ELEM   93 STRESSES     13.16       13.16       .00        .00   1861.54    1861.54      .00         .00

ELEM   94 FORCES      .00000     .84834+06       .00000        .00000        .00000       .24333+08
                      .00000     .84834+06       .00000        .00000        .00000       .48670+08
ELEM   94 STRESSES   1861.54     1861.54       .00        .00   3723.45    3723.45      .00         .00


***** PROBLEM COMPLETED *****  CP =  422.000    PP =      .000

***** RUN COMPLETED *****  CP =  422.000    PP =      .000

@CAT IMXPUMP.

@CAT YANG.

@COPY 2.,IMXPUMP.
     4 BLOCKS COPIED

@COPY 3.,IMXPUMP.
    19 BLOCKS COPIED
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Appendix B-2

DECK PENETRATION RIGIDLY ATTACHED TO TOP OF DECK

ANSYS - ENGINEERING ANALYSIS SYSTEM UP185EREV 2 ISD-EX8 JAN 1, 1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

PHASE A EXTENSION - IHX SEISMIC ANALYSI - SHROUD FIXED AT TOP - HORIZ SSE ********* 6/ 5/78
CP = 435.000 PP = .000

DISPLACEMENT SUMMATION

| NODE | UX | UY | UZ | ROTX | ROTY | ROTZ |
|---|---|---|---|---|---|---|
| 1 | .586225+00 | .000000 | .000000 | .000000 | .000000 | .210065-02 |
| 2 | .777974+00 | .000000 | .000000 | .000000 | .000000 | .219007-02 |
| 3 | .943033+00 | .000000 | .000000 | .000000 | .000000 | .201766-02 |
| 4 | .106606+01 | .000000 | .000000 | .000000 | .000000 | .130469-02 |
| 5 | .103692+01 | .000000 | .000000 | .000000 | .000000 | .163862-02 |
| 6 | .715944+00 | .000000 | .000000 | .000000 | .000000 | .345758-02 |
| 7 | .279332+00 | .000000 | .000000 | .000000 | .000000 | .324542-02 |
| 8 | .396049-01 | .000000 | .000000 | .000000 | .000000 | .156850-03 |
| 9 | .380327-01 | .000000 | .000000 | .000000 | .000000 | .546273-04 |
| 10 | .396049-01 | .000000 | .000000 | .000000 | .000000 | .156850-03 |
| 11 | .200347+00 | .000000 | .000000 | .000000 | .000000 | .224119-02 |
| 12 | .520724+00 | .000000 | .000000 | .000000 | .000000 | .274632-02 |
| 13 | .814873+00 | .000000 | .000000 | .000000 | .000000 | .188328-02 |
| 14 | .935401+00 | .000000 | .000000 | .000000 | .000000 | .403055-03 |
| 15 | .892815+00 | .000000 | .000000 | .000000 | .000000 | .110402-02 |
| 16 | .777974+00 | .000000 | .000000 | .000000 | .000000 | .193627-02 |
| 17 | .586225+00 | .000000 | .000000 | .000000 | .000000 | .210065-02 |
| 18 | .528837+00 | .000000 | .000000 | .000000 | .000000 | .215629-02 |
| 19 | .586225+00 | .000000 | .000000 | .000000 | .000000 | .210065-02 |
| 20 | .673206+00 | .000000 | .000000 | .000000 | .000000 | .181178-02 |
| 21 | .782105+00 | .000000 | .000000 | .000000 | .000000 | .149910-02 |
| 22 | .875118+00 | .000000 | .000000 | .000000 | .000000 | .136918-02 |
| 23 | .935401+00 | .000000 | .000000 | .000000 | .000000 | .135872-02 |
| 24 | .528837+00 | .000000 | .000000 | .000000 | .000000 | .215629-02 |
| 25 | .673206+00 | .000000 | .000000 | .000000 | .000000 | .309189-02 |
| 26 | .367571+00 | .000000 | .000000 | .000000 | .000000 | .329200-02 |
| 27 | .875118+00 | .000000 | .000000 | .000000 | .000000 | .146769-02 |
| 28 | .167072+00 | .000000 | .000000 | .000000 | .000000 | .933306-03 |
| 29 | .167072+00 | .000000 | .000000 | .000000 | .000000 | .933306-03 |
| 30 | .716956-01 | .000000 | .000000 | .000000 | .000000 | .981181-03 |
| 31 | .537153-01 | .000000 | .000000 | .000000 | .000000 | .102212-02 |
| 32 | .151799+00 | .000000 | .000000 | .000000 | .000000 | .103245-02 |
| 33 | .264681-01 | .000000 | .000000 | .000000 | .000000 | .182206-03 |
| 34 | .396049-01 | .000000 | .000000 | .000000 | .000000 | .156850-03 |
| 35 | .380327-01 | .000000 | .000000 | .000000 | .000000 | .812207-04 |
| 36 | .264681-01 | .000000 | .000000 | .000000 | .000000 | .182206-03 |
| 37 | .182749-01 | .000000 | .000000 | .000000 | .000000 | .191083-03 |
| 38 | .148060-02 | .000000 | .000000 | .000000 | .000000 | .149997-04 |
| 39 | .415184-01 | .000000 | .000000 | .000000 | .000000 | .849937-03 |
| 40 | .138530+00 | .000000 | .000000 | .000000 | .000000 | .150051-02 |
| 41 | .167072+00 | .000000 | .000000 | .000000 | .000000 | .154620-02 |
| 42 | .138530+00 | .000000 | .000000 | .000000 | .000000 | .130663-02 |
| 43 | .415184-01 | .000000 | .000000 | .000000 | .000000 | .134779-02 |
| 44 | .230793-01 | .000000 | .000000 | .000000 | .000000 | .484351-03 |
| 45 | .479452-01 | .000000 | .000000 | .000000 | .000000 | .447842-03 |
| 46 | .610965-01 | .000000 | .000000 | .000000 | .000000 | .346559-03 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 47 | .380327-01 | .000000 | .000000 | .000000 | .000000 | .767685-03 |
| 48 | .230793-01 | .000000 | .000000 | .000000 | .000000 | .484351-03 |
| 49 | .148060-02 | .000000 | .000000 | .000000 | .000000 | .149997-04 |
| 50 | .511493-03 | .000000 | .000000 | .000000 | .000000 | .914404-05 |
| 56 | .109369-01 | .000000 | .000000 | .000000 | .000000 | .237667-03 |
| 57 | .385766-01 | .000000 | .000000 | .000000 | .000000 | .457106-03 |
| 58 | .815569-01 | .000000 | .000000 | .000000 | .000000 | .658757-03 |
| 59 | .138530+00 | .000000 | .000000 | .000000 | .000000 | .843600-03 |
| 60 | .167072+00 | .000000 | .000000 | .000000 | .000000 | .933306-03 |
| 61 | .262648+00 | .000000 | .000000 | .000000 | .000000 | .106371-02 |
| 62 | .367571+00 | .000000 | .000000 | .000000 | .000000 | .115486-02 |
| 63 | .447696+00 | .000000 | .000000 | .000000 | .000000 | .119317-02 |
| 64 | .528837+00 | .000000 | .000000 | .000000 | .000000 | .120594-02 |
| 65 | .547381+00 | .000000 | .000000 | .000000 | .000000 | .120608-02 |
| 66 | .543497+00 | .000000 | .000000 | .000000 | .000000 | .120581-02 |
| 67 | .455617+00 | .000000 | .000000 | .000000 | .000000 | .120496-02 |
| 68 | .367571+00 | .000000 | .000000 | .000000 | .000000 | .120091-02 |
| 69 | .262153+00 | .000000 | .000000 | .000000 | .000000 | .113080-02 |
| 70 | .167072+00 | .000000 | .000000 | .000000 | .000000 | .933306-03 |
| 71 | .209345+00 | .000000 | .000000 | .000000 | .000000 | .586199-03 |
| 72 | .167072+00 | .000000 | .000000 | .000000 | .000000 | .585961-03 |
| 73 | .998528-01 | .000000 | .000000 | .000000 | .000000 | .533538-03 |
| 74 | .427157-01 | .000000 | .000000 | .000000 | .000000 | .376889-03 |
| 75 | .151526-01 | .000000 | .000000 | .000000 | .000000 | .212274-03 |

ANSYS - ENGINEERING ANALYSIS SYSTEM UP185EREV 2 ISO-EX8 JAN 1, 1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

PHASE A EXTENSION - IHX SEISMIC ANALYSI - SHROUD FIXED AT TOP - HORIZ SSE ********* 6/ 5/78
CP = 446.000 PP = .000

SUMMATION RESULTS (WRITTEN ON TAPE11)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 1 FORCES | .00000 | 4408.0 | | .00000 | .00000 | .00000 | | 76745. |
| | .00000 | 4408.0 | | .00000 | .00000 | .00000 | | .49386+06 |
| ELEM 1 STRESSES | 244.75 | 244.25 | .00 | .00 | 1574.98 | 1574.98 | .00 | .00 |
| ELEM 2 FORCES | .00000 | 15684. | | .00000 | .00000 | .00000 | | .49386+06 |
| | .00000 | 15684. | | .00000 | .00000 | .00000 | | .90058+06 |
| ELEM 2 STRESSES | 1574.98 | 1574.98 | .00 | .00 | 2872.06 | 2872.06 | .00 | .00 |
| ELEM 3 FORCES | .00000 | 7930.1 | | .00000 | .00000 | .00000 | | .90058+06 |
| | .00000 | 7930.1 | | .00000 | .00000 | .00000 | | .14779+07 |
| ELEM 3 STRESSES | 2872.07 | 2872.07 | .00 | .00 | 4713.09 | 4713.09 | .00 | .00 |
| ELEM 7 FORCES | .00000 | 2813.1 | | .00000 | .00000 | .00000 | | .14779+07 |
| | .00000 | 2813.1 | | .00000 | .00000 | .00000 | | .14944+07 |
| ELEM 7 STRESSES | 6956.44 | 6956.44 | .00 | .00 | 7034.49 | 7034.49 | .00 | .00 |
| ELEM 8 FORCES | .00000 | 7366.4 | | .00000 | .00000 | .00000 | | .14944+07 |
| | .00000 | 7366.4 | | .00000 | .00000 | .00000 | | .67243+06 |
| ELEM 8 STRESSES | 7034.48 | 7034.48 | .00 | .00 | 3165.19 | 3165.19 | .00 | .00 |
| ELEM 9 FORCES | .00000 | 12311. | | .00000 | .00000 | .00000 | | .67243+06 |
| | .00000 | 12311. | | .00000 | .00000 | .00000 | | .85845+06 |
| ELEM 9 STRESSES | 3165.19 | 3165.19 | .00 | .00 | 4040.81 | 4040.81 | .00 | .00 |
| ELEM 10 FORCES | .00000 | 14526. | | .00000 | .00000 | .00000 | | .85845+06 |
| | .00000 | 14526. | | .00000 | .00000 | .00000 | | .25698+07 |
| ELEM 10 STRESSES | 4040.81 | 4040.81 | .00 | .00 | 12096.45 | 12096.45 | .00 | .00 |
| ELEM 16 FORCES | .00000 | 15597. | | .00000 | .00000 | .00000 | | .67986+06 |
| | .00000 | 15597. | | .00000 | .00000 | .00000 | | .11020-01 |
| ELEM 16 STRESSES | 2463.79 | 2463.79 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 17 FORCES | .00000 | 11253. | | .00000 | .00000 | .00000 | | .10339+07 |
| | .00000 | 11253. | | .00000 | .00000 | .00000 | | .23684+07 |
| ELEM 17 STRESSES | 3746.77 | 3746.77 | .00 | .00 | 8583.15 | 8583.15 | .00 | .00 |
| ELEM 18 FORCES | .00000 | 10411. | | .00000 | .00000 | .00000 | | .30418+06 |
| | .00000 | 10411. | | .00000 | .00000 | .00000 | | .10339+07 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| ELEM | 18 | STRESSES | 1102.32 | 1102.32 | .00 | .00 | 3746.77 | 3746.77 | .00 | .00 |
| ELEM | 19 | FORCES | .00000 | 8526.5 | | .00000 | .00000 | .00000 | | .12413+07 |
| | | | .00000 | 8526.5 | | .00000 | .00000 | .00000 | | .30418+06 |
| ELEM | 19 | STRESSES | 4498.54 | 4498.54 | .00 | .00 | 1102.32 | 1102.32 | .00 | .00 |
| ELEM | 20 | FORCES | .00000 | 6100.2 | | .00000 | .00000 | .00000 | | .19155+07 |
| | | | .00000 | 6100.2 | | .00000 | .00000 | .00000 | | .12413+07 |
| ELEM | 20 | STRESSES | 4941.63 | 4941.63 | .00 | .00 | 4498.54 | 4498.54 | .00 | .00 |
| ELEM | 21 | FORCES | .00000 | 2871.8 | | .00000 | .00000 | .00000 | | .18261+07 |
| | | | .00000 | 2871.8 | | .00000 | .00000 | .00000 | | .19155+07 |
| ELEM | 21 | STRESSES | 4759.57 | 4759.57 | .00 | .00 | 4992.60 | 4992.60 | .00 | .00 |
| ELEM | 22 | FORCES | .00000 | 3872.4 | | .00000 | .00000 | .00000 | | .15711+07 |
| | | | .00000 | 3872.4 | | .00000 | .00000 | .00000 | | .18261+07 |
| ELEM | 22 | STRESSES | 4095.05 | 4095.05 | .00 | .00 | 4759.57 | 4759.57 | .00 | .00 |
| ELEM | 23 | FORCES | .00000 | 27110. | | .00000 | .00000 | .00000 | | .10075+07 |
| | | | .00000 | 27110. | | .00000 | .00000 | .00000 | | .15711+07 |
| ELEM | 23 | STRESSES | 2625.88 | 2625.88 | .00 | .00 | 4095.05 | 4095.05 | .00 | .00 |
| ELEM | 24 | FORCES | .00000 | 29639. | | .00000 | .00000 | .00000 | | .21556+06 |
| | | | .00000 | 29639. | | .00000 | .00000 | .00000 | | .96515+06 |
| ELEM | 24 | STRESSES | 375.07 | 375.07 | .00 | .00 | 1679.36 | 1679.36 | .00 | .00 |
| ELEM | 25 | FORCES | .00000 | 8629.3 | | .00000 | .00000 | .00000 | | .18350+07 |
| | | | .00000 | 8629.3 | | .00000 | .00000 | .00000 | | .16577+07 |
| ELEM | 25 | STRESSES | 3192.84 | 3192.84 | .00 | .00 | 2884.48 | 2884.48 | .00 | .00 |
| ELEM | 26 | FORCES | .00000 | 8670.0 | | .00000 | .00000 | .00000 | | .16577+07 |
| | | | .00000 | 8670.0 | | .00000 | .00000 | .00000 | | .10111+07 |
| ELEM | 26 | STRESSES | 2884.48 | 2884.48 | .00 | .00 | 1759.26 | 1759.26 | .00 | .00 |
| ELEM | 27 | FORCES | .00000 | 11136. | | .00000 | .00000 | .00000 | | .10111+07 |
| | | | .00000 | 11136. | | .00000 | .00000 | .00000 | | .21600+06 |
| ELEM | 27 | STRESSES | 1759.26 | 1759.26 | .00 | .00 | 375.85 | 375.85 | .00 | .00 |
| ELEM | 28 | FORCES | .00000 | 4374.8 | | .00000 | .00000 | .00000 | | .21600+06 |
| | | | .00000 | 4374.8 | | .00000 | .00000 | .00000 | | .54932 |
| ELEM | 28 | STRESSES | 375.85 | 375.85 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM | 29 | FORCES | .00000 | 8299.4 | | .00000 | .00000 | .00000 | | .21556+06 |
| | | | .00000 | 8299.4 | | .00000 | .00000 | .00000 | | .44736+06 |
| ELEM | 29 | STRESSES | 1571.81 | 1571.81 | 1571.81 | 1571.81 | 3262.08 | 3262.08 | 3262.08 | 3262.08 |

Moore Business Forms, Inc. SV 14127

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 30 FORCES | .00000 | 19844. | .00000 | .00000 | .00000 | .44736+06 | | |
| | .00000 | 19844. | .00000 | .00000 | .00000 | .74688+06 | | |
| ELEM 30 STRESSES | 3262.08 | 3262.08 | 3262.08 | 3262.08 | 5446.09 | 5446.09 | 5446.09 | 5446.09 |
| ELEM 31 FORCES | .00000 | 23732. | .00000 | .00000 | .00000 | .74688+06 | | |
| | .00000 | 23732. | .00000 | .00000 | .00000 | .96658+06 | | |
| ELEM 31 STRESSES | 5446.09 | 5446.09 | 5446.09 | 5446.09 | 7048.14 | 7048.14 | 7048.14 | 7048.14 |
| ELEM 32 FORCES | .00000 | 23736. | .00000 | .00000 | .00000 | .96658+06 | | |
| | .00000 | 23736. | .00000 | .00000 | .00000 | .98071+06 | | |
| ELEM 32 STRESSES | 7048.14 | 7048.14 | 7048.14 | 7048.14 | 7209.49 | 7209.49 | 7209.49 | 7209.49 |
| ELEM 38 FORCES | .00000 | 3210.6 | .00000 | .00000 | .00000 | .83465+06 | | |
| | .00000 | 3210.6 | .00000 | .00000 | .00000 | .45602+06 | | |
| ELEM 38 STRESSES | 1692.36 | 1692.30 | .00 | .00 | 793.47 | 793.47 | .00 | .00 |
| ELEM 39 FORCES | .00000 | 3438.9 | .00000 | .00000 | .00000 | .45602+06 | | |
| | .00000 | 3438.9 | .00000 | .00000 | .00000 | .12374+06 | | |
| ELEM 39 STRESSES | 793.47 | 793.47 | .00 | .00 | 219.31 | 219.31 | .00 | .00 |
| ELEM 40 FORCES | .00000 | 1305.5 | .00000 | .00000 | .00000 | .12374+06 | | |
| | .00000 | 1305.3 | .00000 | .00000 | .00000 | .10668 | | |
| ELEM 40 STRESSES | 219.31 | 219.31 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 41 FORCES | .00000 | | | | | | | |
| ELEM 42 FORCES | .00000 | 36691. | .00000 | .00000 | .00000 | .25705+07 | | |
| | .00000 | 36691. | .00000 | .00000 | .00000 | .43732+07 | | |
| ELEM 42 STRESSES | 1651.33 | 1651.33 | .00 | .00 | 2809.40 | 2809.40 | .00 | .00 |
| ELEM 43 FORCES | .00000 | 26381. | .00000 | .00000 | .00000 | .78242+06 | | |
| | .00000 | 26381. | .00000 | .00000 | .00000 | .25705+07 | | |
| ELEM 43 STRESSES | 502.64 | 502.64 | .00 | .00 | 1651.33 | 1651.33 | .00 | .00 |
| ELEM 44 FORCES | .00000 | 27398. | .00000 | .00000 | .00000 | .28925+06 | | |
| | .00000 | 27398. | .00000 | .00000 | .00000 | .78242+06 | | |
| ELEM 44 STRESSES | 185.82 | 185.82 | .00 | .00 | 502.64 | 502.64 | .00 | .00 |
| ELEM 45 FORCES | .00000 | 27594. | .00000 | .00000 | .00000 | .32129+07 | | |
| | .00000 | 27594. | .00000 | .00000 | .00000 | .28925+06 | | |
| ELEM 45 STRESSES | 2064.00 | 2064.00 | .00 | .00 | 185.82 | 185.82 | .00 | .00 |
| ELEM 46 FORCES | .00000 | 9323.8 | .00000 | .00000 | .00000 | .40296+07 | | |
| | .00000 | 9323.8 | .00000 | .00000 | .00000 | .48136+07 | | |
| ELEM 46 STRESSES | 5239.38 | 5239.38 | .00 | .00 | 6258.72 | 6258.72 | .00 | .00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 47 FORCES | .00000 | 9352.8 | .00000 | .00000 | .00000 | .32905+07 | | |
| | .00000 | 9352.8 | .00000 | .00000 | .00000 | .40296+07 | | |
| ELEM 47 STRESSES | 4278.41 | 4276.41 | .00 | .00 | 5239.38 | 5239.38 | .00 | .00 |
| ELEM 48 FORCES | .00000 | .26324+06 | .00000 | .00000 | .00000 | .80489 | | |
| | .00000 | .26324+06 | .00000 | .00000 | .00000 | .32905+07 | | |
| ELEM 48 STRESSES | .00 | .00 | .00 | .00 | 4278.41 | 4278.41 | .00 | .00 |
| ELEM 49 FORCES | .00000 | 88.553 | .00000 | .00000 | .00000 | .26536-03 | | |
| | .00000 | 88.553 | .00000 | .00000 | .00000 | 7084.3 | | |
| ELEM 49 STRESSES | .00 | .00 | .00 | .00 | 540.51 | 540.51 | 540.51 | 540.51 |
| ELEM 50 FORCES | .00000 | 905.46 | .00000 | .00000 | .00000 | 7084.3 | | |
| | .00000 | 905.46 | .00000 | .00000 | .00000 | 25442. | | |
| ELEM 50 STRESSES | 540.51 | 540.51 | 540.51 | 540.51 | 1941.18 | 1941.18 | 1941.18 | 1941.18 |
| ELEM 51 FORCES | .00000 | 511.51 | .00000 | .00000 | .00000 | 36996. | | |
| | .00000 | 511.51 | .00000 | .00000 | .00000 | 22032. | | |
| ELEM 51 STRESSES | 1020.73 | 1020.73 | 1020.73 | 1020.73 | 607.88 | 607.88 | 607.88 | 607.88 |
| ELEM 52 FORCES | .00000 | 149.33 | .00000 | .00000 | .00000 | 22032. | | |
| | .00000 | 149.33 | .00000 | .00000 | .00000 | 32789. | | |
| ELEM 52 STRESSES | 607.88 | 607.88 | 607.88 | 607.88 | 904.66 | 904.66 | 904.66 | 904.66 |
| ELEM 53 FORCES | .00000 | 315.15 | .00000 | .00000 | .00000 | 32789. | | |
| | .00000 | 315.15 | .00000 | .00000 | .00000 | .45229-03 | | |
| ELEM 53 STRESSES | 904.66 | 904.66 | 904.66 | 904.66 | .00 | .00 | .00 | .00 |
| ELEM 54 FORCES | .00000 | 1880.1 | .00000 | .00000 | .00000 | 42267. | | |
| | .00000 | 1880.1 | .00000 | .00000 | .00000 | 55681. | | |
| ELEM 54 STRESSES | 1743.38 | 1743.38 | 1743.38 | 1743.38 | 2296.68 | 2296.68 | 2296.68 | 2296.68 |
| ELEM 55 FORCES | .00000 | 36194. | .00000 | .00000 | .00000 | .29355+07 | | |
| | .00000 | 36194. | .00000 | .00000 | .00000 | .44221+07 | | |
| ELEM 55 STRESSES | 113.48 | 113.48 | 113.48 | 113.48 | 170.95 | 170.95 | 170.95 | 170.95 |
| ELEM 56 FORCES | .00000 | 36387. | .00000 | .00000 | .00000 | .44221+07 | | |
| | .00000 | 36387. | .00000 | .00000 | .00000 | .64289+07 | | |
| ELEM 56 STRESSES | 170.95 | 170.95 | 170.95 | 170.95 | 248.53 | 248.53 | 248.53 | 248.53 |
| ELEM 64 FORCES | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| ELEM 64 STRESSES | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 65 FORCES | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 65 STRESSES | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 66 FORCES | .00000 | .00000 | | .00000 | .00000 | .00000 | | .00000 |
| | .00000 | .00000 | | .00000 | .00000 | .00000 | | .00000 |
| ELEM 66 STRESSES | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 67 FORCES | .00000 | 79689. | | .00000 | .00000 | .00000 | | .70334+08 |
| | .00000 | 79689. | | .00000 | .00000 | .00000 | | .75974+08 |
| ELEM 67 STRESSES | 4674.06 | 4674.06 | .00 | .00 | 5048.88 | 5048.88 | .00 | .00 |
| ELEM 68 FORCES | .00000 | 78747. | | .00000 | .00000 | .00000 | | .64771+08 |
| | .00000 | 78747. | | .00000 | .00000 | .00000 | | .70334+08 |
| ELEM 68 STRESSES | 4304.38 | 4304.38 | .00 | .00 | 4674.06 | 4674.06 | .00 | .00 |
| ELEM 69 FORCES | .00000 | 75584. | | .00000 | .00000 | .00000 | | .59416+08 |
| | .00000 | 75584. | | .00000 | .00000 | .00000 | | .64771+08 |
| ELEM 69 STRESSES | 3948.54 | 3948.54 | .00 | .00 | 4304.38 | 4304.38 | .00 | .00 |
| ELEM 70 FORCES | .00000 | 60430. | | .00000 | .00000 | .00000 | | .54462+08 |
| | .00000 | 60430. | | .00000 | .00000 | .00000 | | .59416+08 |
| ELEM 70 STRESSES | 3619.32 | 3619.32 | .00 | .00 | 3948.54 | 3948.54 | .00 | .00 |
| ELEM 71 FORCES | .00000 | .19327+06 | | .00000 | .00000 | .00000 | | .61224+08 |
| | .00000 | .19327+06 | | .00000 | .00000 | .00000 | | .54462+08 |
| ELEM 71 STRESSES | 4068.65 | 4068.65 | .00 | .00 | 3619.32 | 3619.32 | .00 | .00 |
| ELEM 72 FORCES | .00000 | .11660+06 | | .00000 | .00000 | .00000 | | .26907+08 |
| | .00000 | .11660+06 | | .00000 | .00000 | .00000 | | .37531+08 |
| ELEM 72 STRESSES | 1788.12 | 1788.12 | .00 | .00 | 2494.12 | 2494.12 | .00 | .00 |
| ELEM 73 FORCES | .00000 | 95528. | | .00000 | .00000 | .00000 | | .18193+08 |
| | .00000 | 95528. | | .00000 | .00000 | .00000 | | .26907+08 |
| ELEM 73 STRESSES | 1209.03 | 1209.03 | .00 | .00 | 1788.12 | 1788.12 | .00 | .00 |
| ELEM 74 FORCES | .00000 | .14945+06 | | .00000 | .00000 | .00000 | | .84703+07 |
| | .00000 | .14945+06 | | .00000 | .00000 | .00000 | | .18193+08 |
| ELEM 74 STRESSES | 562.90 | 562.90 | .00 | .00 | 1209.03 | 1209.03 | .00 | .00 |
| ELEM 75 FORCES | .00000 | .12372+06 | | .00000 | .00000 | .00000 | | .42274+06 |
| | .00000 | .12372+06 | | .00000 | .00000 | .00000 | | .84703+07 |
| ELEM 75 STRESSES | 28.09 | 28.09 | .00 | .00 | 562.90 | 562.90 | .00 | .00 |
| ELEM 76 FORCES | .00000 | 27721. | | .00000 | .00000 | .00000 | | 25.605 |
| | .00000 | 27721. | | .00000 | .00000 | .00000 | | .42272+06 |
| ELEM 76 STRESSES | .00 | .00 | .00 | .00 | 28.09 | 28.09 | .00 | .00 |

V-3B-21

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ELEM   88 FORCES      .00000        2806.1        .00000        .00000         .00000        .23001
                      .00000        2806.1        .00000        .00000         .00000        .16049+06
ELEM   88 STRESSES       .00           .00    .00        .00     33.77     33.77       .00           .00

ELEM   89 FORCES      .00000        6134.5        .00000        .00000         .00000        .16049+06
                      .00000        6134.5        .00000        .00000         .00000        .60668+06
ELEM   89 STRESSES     33.78         33.78    .00        .00    127.67    127.67       .00           .00

ELEM   90 FORCES      .00000        .13897+06     .00000        .00000         .00000        .60668+06
                      .00000        .13897+06     .00000        .00000         .00000        .11564+08
ELEM   90 STRESSES    127.67        127.67    .00        .00   2433.55   2433.55       .00           .00

ELEM   91 FORCES      .00000        .14133+06     .00000        .00000         .00000        .11564+08
                      .00000        .14133+06     .00000        .00000         .00000        .22711+08
ELEM   91 STRESSES   2433.55       2433.55    .00        .00   4779.45   4779.45       .00           .00

ELEM   92 FORCES      .00000        2529.8        .00000        .00000         .00000        2.0297
                      .00000        2529.8        .00000        .00000         .00000        .16774+06
ELEM   92 STRESSES       .00           .00    .00        .00     12.83     12.83       .00           .00

ELEM   93 FORCES      .00000        .23909+06     .00000        .00000         .00000        .16775+06
                      .00000        .23909+06     .00000        .00000         .00000        .23577+08
ELEM   93 STRESSES     12.83         12.83    .00        .00   1803.77   1803.77       .00           .00

ELEM   94 FORCES      .00000        .24222+06     .00000        .00000         .00000        .23577+08
                      .00000        .24222+06     .00000        .00000         .00000        .47315+08
ELEM   94 STRESSES   1803.77       1803.77    .00        .00   3619.81   3619.81       .00           .00

ELEM   95 FORCES      .00000        .24222+06     .00000        .00000         .00000        .47315+08
                      .00000        .24222+06     .00000        .00000         .00000        .63302+08
ELEM   95 STRESSES   3619.81       3619.81    .00        .00   4842.86   4842.86       .00           .00

ELEM   96 FORCES      .00000        .24302+06     .00000        .00000         .00000        .63302+08
                      .00000        .24302+06     .00000        .00000         .00000        .79341+08
ELEM   96 STRESSES   4842.86       4842.86    .00        .00   6069.95   6069.95       .00           .00


***** PROBLEM COMPLETED ***** CP = 449.000   PP =     .000

***** RUN COMPLETED ***** CP = 449.000   PP =     .000

@FIN
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Appendix B-3

NO SEISMIC SUPPORT AT THE UPPER TUBESHEET

ANSYS - ENGINEERING ANALYSIS SYSTEM UP185EREV 2 ISD-EXB JAN 1, 1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

PHASE A EXTENSION - IHX SEISMIC ANALYSI - SHROUD FIXED AT TOP - HORIZ SSE ********* 6/ 5/78
CP = 446.000 PP = [illegible]000

DISPLACEMENT SUMMATION

| NODE | UX | UY | UZ | ROTX | ROTY | ROTZ |
|---|---|---|---|---|---|---|
| 1 | .164651+01 | .000000 | .000000 | .000000 | .000000 | .128449-02 |
| 2 | .177053+01 | .000000 | .000000 | .000000 | .000000 | .119436-02 |
| 3 | .185101+01 | .000000 | .000000 | .000000 | .000000 | .683634-03 |
| 4 | .185600+01 | .000000 | .000000 | .000000 | .000000 | .663826-03 |
| 5 | .159276+01 | .000000 | .000000 | .000000 | .000000 | .370727-02 |
| 6 | .101305+01 | .000000 | .000000 | .000000 | .000000 | .547168-02 |
| 7 | .368416+00 | .000000 | .000000 | .000000 | .000000 | .455807-02 |
| 8 | .366291-01 | .000000 | .000000 | .000000 | .000000 | .259681-03 |
| 9 | .374611-01 | .000000 | .000000 | .000000 | .000000 | .586713-04 |
| 10 | .366291-01 | .000000 | .000000 | .000000 | .000000 | .259681-03 |
| 11 | .297721+00 | .000000 | .000000 | .000000 | .000000 | .363723-02 |
| 12 | .835239+00 | .000000 | .000000 | .000000 | .000000 | .480137-02 |
| 13 | .138777+01 | .000000 | .000000 | .000000 | .000000 | .395605-02 |
| 14 | .173371+01 | .000000 | .000000 | .000000 | .000000 | .149743-02 |
| 15 | .180149+01 | .000000 | .000000 | .000000 | .000000 | .319960-03 |
| 16 | .177053+01 | .000000 | .000000 | .000000 | .000000 | .936218-03 |
| 17 | .164651+01 | .000000 | .000000 | .000000 | .000000 | .128449-02 |
| 18 | .160332+01 | .000000 | .000000 | .000000 | .000000 | .130139-02 |
| 19 | .164651+01 | .000000 | .000000 | .000000 | .000000 | .128449-02 |
| 20 | .169936+01 | .000000 | .000000 | .000000 | .000000 | .853414-03 |
| 21 | .173401+01 | .000000 | .000000 | .000000 | .000000 | .356860-03 |
| 22 | .173631+01 | .000000 | .000000 | .000000 | .000000 | .263588-03 |
| 23 | .173371+01 | .000000 | .000000 | .000000 | .000000 | .268525-03 |
| 24 | .160332+01 | .000000 | .000000 | .000000 | .000000 | .130139-02 |
| 25 | .169936+01 | .000000 | .000000 | .000000 | .000000 | .566323-02 |
| 26 | .116236+01 | .000000 | .000000 | .000000 | .000000 | .280896-02 |
| 27 | .173631+01 | .000000 | .000000 | .000000 | .000000 | .400813-02 |
| 28 | .596589+00 | .000000 | .000000 | .000000 | .000000 | .280454-02 |
| 29 | .596589+00 | .000000 | .000000 | .000000 | .000000 | .280454-02 |
| 30 | .308910+00 | .000000 | .000000 | .000000 | .000000 | .282130-02 |
| 31 | .461245-01 | .000000 | .000000 | .000000 | .000000 | .284448-02 |
| 32 | .282125+00 | .000000 | .000000 | .000000 | .000000 | .285181-02 |
| 33 | .277107-01 | .000000 | .000000 | .000000 | .000000 | .160567-03 |
| 34 | .366291-01 | .000000 | .000000 | .000000 | .000000 | .259681-03 |
| 35 | .374611-01 | .000000 | .000000 | .000000 | .000000 | .661469-04 |
| 36 | .277107-01 | .000000 | .000000 | .000000 | .000000 | .160567-03 |
| 37 | .199830-01 | .000000 | .000000 | .000000 | .000000 | .172853-03 |
| 38 | .574550-02 | .000000 | .000000 | .000000 | .000000 | .679309-04 |
| 39 | .157792+00 | .000000 | .000000 | .000000 | .000000 | .307696-02 |
| 40 | .503697+00 | .000000 | .000000 | .000000 | .000000 | .514999-02 |
| 41 | .596589+00 | .000000 | .000000 | .000000 | .000000 | .528307-02 |
| 42 | .503697+00 | .000000 | .000000 | .000000 | .000000 | .443346-02 |
| 43 | .157792+00 | .000000 | .000000 | .000000 | .000000 | .419703-02 |
| 44 | .523430-01 | .000000 | .000000 | .000000 | .000000 | .128284-02 |
| 45 | .540070-01 | .000000 | .000000 | .000000 | .000000 | .513657-03 |
| 46 | .619260-01 | .000000 | .000000 | .000000 | .000000 | .455908-03 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 47 | .374611-01 | .000000 | .000000 | .000000 | .000000 | .920129-03 |
| 48 | .923430-01 | .000000 | .000000 | .000000 | .000000 | .128244-02 |
| 49 | .574350-02 | .000000 | .000000 | .000000 | .000000 | .679309-04 |
| 55 | .178786-01 | .000000 | .000000 | .000000 | .000000 | .385627-04 |
| 56 | .490458-01 | .000000 | .000000 | .000000 | .000000 | .867578-03 |
| 57 | .156362+00 | .000000 | .000000 | .000000 | .000000 | .159261-02 |
| 58 | .311405+00 | .000000 | .000000 | .000000 | .000000 | .217615-02 |
| 59 | .503697+00 | .000000 | .000000 | .000000 | .000000 | .262071-02 |
| 60 | .596589+00 | .000000 | .000000 | .000000 | .000000 | .280454-02 |
| 61 | .870946+00 | .000000 | .000000 | .000000 | .000000 | .304183-02 |
| 62 | .116236+01 | .000000 | .000000 | .000000 | .000000 | .321719-02 |
| 63 | .138186+01 | .000000 | .000000 | .000000 | .000000 | .329471-02 |
| 64 | .160332+01 | .000000 | .000000 | .000000 | .000000 | .332051-02 |
| 65 | .165429+01 | .000000 | .000000 | .000000 | .000000 | .332080-02 |
| 66 | .166285+01 | .000000 | .000000 | .000000 | .000000 | .343254-02 |
| 67 | .141279+01 | .000000 | .000000 | .000000 | .000000 | .343075-02 |
| 68 | .116236+01 | .000000 | .000000 | .000000 | .000000 | .342810-02 |
| 69 | .867562+00 | .000000 | .000000 | .000000 | .000000 | .326091-02 |
| 70 | .596589+00 | .000000 | .000000 | .000000 | .000000 | .280454-02 |

ANSYS - ENGINEERING ANALYSIS SYSTEM UP185EREV 2 180-EXB JAN 1, 1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

PHASE A EXTENSION 3 IHX SEISMIC ANALYSI - SHROUD FIXED AT TOP - HORIZ SSE ********* 6/ 5/78
CP = 458.000 PP = .000

SUMMATION RESULTS (WRITTEN ON TAPE11)

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 1 FORCES | .00000 | 3885.0 | .00000 | | .00000 | .00000 | | 61861. |
| | .00000 | 3885.0 | .00000 | | .00000 | .00000 | | .30285+06 |
| ELEM 1 STRESSES | 196.01 | 196.01 | .00 | .00 | 1220.94 | 1220.94 | .00 | .00 |
| ELEM 2 FORCES | .00000 | 18086. | .00000 | | .00000 | .00000 | | .30285+06 |
| | .00000 | 18086. | .00000 | | .00000 | .00000 | | .14104+07 |
| ELEM 2 STRESSES | 1220.94 | 1220.94 | .00 | .00 | 4498.06 | 4498.06 | .00 | .00 |
| ELEM 3 FORCES | .00000 | 6819.6 | .00000 | | .00000 | .00000 | | .14104+07 |
| | .00000 | 6819.6 | .00000 | | .00000 | .00000 | | .18925+07 |
| ELEM 3 STRESSES | 4498.06 | 4498.06 | .00 | .00 | 6035.50 | 6035.50 | .00 | .00 |
| ELEM 7 FORCES | .00000 | 3811.8 | .00000 | | .00000 | .00000 | | .18925+07 |
| | .00000 | 3811.8 | .00000 | | .00000 | .00000 | | .15842+07 |
| ELEM 7 STRESSES | 6035.50 | 6035.50 | .00 | .00 | 7457.00 | 7457.00 | .00 | .00 |
| ELEM 8 FORCES | .00000 | 18080. | .00000 | | .00000 | .00000 | | .15842+07 |
| | .00000 | 18080. | .00000 | | .00000 | .00000 | | .41905+06 |
| ELEM 8 STRESSES | 7457.00 | 7457.00 | .00 | .00 | 1972.50 | 1972.50 | .00 | .00 |
| ELEM 9 FORCES | .00000 | 14687. | .00000 | | .00000 | .00000 | | .41905+06 |
| | .00000 | 14687. | .00000 | | .00000 | .00000 | | .13877+07 |
| ELEM 9 STRESSES | 1972.50 | 1972.50 | .00 | .00 | 6531.79 | 6531.79 | .00 | .00 |
| ELEM 10 FORCES | .00000 | 18527. | .00000 | | .00000 | .00000 | | .13877+07 |
| | .00000 | 18527. | .00000 | | .00000 | .00000 | | .33973+07 |
| ELEM 10 STRESSES | 6531.79 | 6531.79 | .00 | .00 | 15803.29 | 15803.29 | .00 | .00 |
| ELEM 16 FORCES | .00000 | 23773. | .00000 | | .00000 | .00000 | | .11887+07 |
| | .00000 | 23773. | .00000 | | .00000 | .00000 | | .21535-01 |
| ELEM 16 STRESSES | 4307.67 | 4307.67 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 17 FORCES | .00000 | 15405. | .00000 | | .00000 | .00000 | | .18244+07 |
| | .00000 | 15405. | .00000 | | .00000 | .00000 | | .36685+07 |
| ELEM 17 STRESSES | 6611.61 | 6611.61 | .00 | .00 | 13294.52 | 13294.52 | .00 | .00 |
| ELEM 18 FORCES | .00000 | 14633. | .00000 | | .00000 | .00000 | | .19470+06 |
| | .00000 | 14633. | .00000 | | .00000 | .00000 | | .18244+07 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ELEM | 18 STRESSES | 705.60 | 705.60 | .00 | .00 | 6611.61 | 6611.61 | .00 | .00 |
| ELEM | 19 FORCES | .00000 | 18642. | | .00000 | .00000 | .00000 | | .14567+07 |
| | | .00000 | 18642. | | .00000 | .00000 | .00000 | | .19470+06 |
| ELEM | 19 STRESSES | 5279.14 | 5279.14 | .00 | .00 | 705.60 | 705.60 | .00 | .00 |
| ELEM | 20 FORCES | .00000 | 9508.2 | | .00000 | .00000 | .00000 | | .25737+07 |
| | | .00000 | 9508.2 | | .00000 | .00000 | .00000 | | .14567+07 |
| ELEM | 20 STRESSES | 9326.86 | 9326.86 | .00 | .00 | 5279.14 | 5279.14 | .00 | .00 |
| ELEM | 21 FORCES | .00000 | 2697.5 | | .00000 | .00000 | .00000 | | .23944+07 |
| | | .00000 | 2697.5 | | .00000 | .00000 | .00000 | | .25737+07 |
| ELEM | 21 STRESSES | 6241.00 | 6241.00 | .00 | .00 | 6708.12 | 6708.12 | .00 | .00 |
| ELEM | 22 FORCES | .00000 | 5527.4 | | .00000 | .00000 | .00000 | | .19684+07 |
| | | .00000 | 5527.4 | | .00000 | .00000 | .00000 | | .23944+07 |
| ELEM | 22 STRESSES | 5130.56 | 5130.56 | .00 | .00 | 6240.99 | 6240.99 | .00 | .00 |
| ELEM | 23 FORCES | .00000 | 28849. | | .00000 | .00000 | .00000 | | .76261+06 |
| | | .00000 | 28849. | | .00000 | .00000 | .00000 | | .19684+07 |
| ELEM | 23 STRESSES | 1987.70 | 1987.70 | .00 | .00 | 5130.56 | 5130.56 | .00 | .00 |
| ELEM | 24 FORCES | .00000 | 45993. | | .00000 | .00000 | .00000 | | .29370+06 |
| | | .00000 | 45993. | | .00000 | .00000 | .00000 | | .16543+07 |
| ELEM | 24 STRESSES | 511.03 | 511.03 | .00 | .00 | 2878.51 | 2878.51 | .00 | .00 |
| ELEM | 25 FORCES | .00000 | 7531.9 | | .00000 | .00000 | .00000 | | .24238+07 |
| | | .00000 | 7531.9 | | .00000 | .00000 | .00000 | | .27224+07 |
| ELEM | 25 STRESSES | 4217.42 | 4217.42 | .00 | .00 | 4737.03 | 4737.03 | .00 | .00 |
| ELEM | 26 FORCES | .00000 | 13834. | | .00000 | .00000 | .00000 | | .27224+07 |
| | | .00000 | 13834. | | .00000 | .00000 | .00000 | | .16819+07 |
| ELEM | 26 STRESSES | 4737.03 | 4737.03 | .00 | .00 | 2926.42 | 2926.42 | .00 | .00 |
| ELEM | 27 FORCES | .00000 | 17695. | | .00000 | .00000 | .00000 | | .16819+07 |
| | | .00000 | 17695. | | .00000 | .00000 | .00000 | | .36013+06 |
| ELEM | 27 STRESSES | 2926.42 | 2926.42 | .00 | .00 | 626.62 | 626.62 | .00 | .00 |
| ELEM | 28 FORCES | .00000 | 7293.7 | | .00000 | .00000 | .00000 | | .36013+06 |
| | | .00000 | 7293.7 | | .00000 | .00000 | .00000 | | .95030 |
| ELEM | 28 STRESSES | 626.62 | 626.62 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM | 29 FORCES | .00000 | 11279. | | .00000 | .00000 | .00000 | | .29370+06 |
| | | .00000 | 11279. | | .00000 | .00000 | .00000 | | .60721+06 |
| ELEM | 29 STRESSES | 2141.60 | 2141.60 | 2141.60 | 2141.60 | 4427.69 | 4427.69 | 4427.69 | 4427.69 |

Moore Business Forms, Inc.

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 30 FORCES | .00000 | 21419. | | .00000 | .00000 | .00000 | | .60721+06 |
| | .00000 | 21419. | | .00000 | .00000 | .00000 | | .10073+07 |
| ELEM 30 STRESSES | 4427.69 | 4427.69 | 4427.69 | 4427.69 | 7344.77 | 7344.77 | 7344.77 | 7344.77 |
| ELEM 31 FORCES | .00000 | 30991. | | .00000 | .00000 | .00000 | | .10073+07 |
| | .00000 | 30991. | | .00000 | .00000 | .00000 | | .13287+07 |
| ELEM 31 STRESSES | 7344.77 | 7344.77 | 7344.77 | 7344.77 | 9688.80 | 9688.80 | 9688.80 | 9688.80 |
| ELEM 32 FORCES | .00000 | 30891. | | .00000 | .00000 | .00000 | | .13287+07 |
| | .00000 | 30891. | | .00000 | .00000 | .00000 | | .13807+07 |
| ELEM 32 STRESSES | 9688.80 | 9688.80 | 9688.80 | 9688.80 | 10067.90 | 10067.90 | 10067.90 | 10067.90 |
| ELEM 36 FORCES | .00000 | 3493.2 | | .00000 | .00000 | .00000 | | .77129+06 |
| | .00000 | 3493.2 | | .00000 | .00000 | .00000 | | .42297+06 |
| ELEM 36 STRESSES | 1342.04 | 1342.04 | .00 | .00 | 735.98 | 735.98 | .00 | .00 |
| ELEM 39 FORCES | .00000 | 2495.8 | | .00000 | .00000 | .00000 | | .42297+06 |
| | .00000 | 2495.8 | | .00000 | .00000 | .00000 | | .11634+06 |
| ELEM 39 STRESSES | 735.98 | 735.98 | .00 | .00 | 202.43 | 202.43 | .00 | .00 |
| ELEM 40 FORCES | .00000 | 1133.2 | | .00000 | .00000 | .00000 | | .11634+06 |
| | .00000 | 1133.2 | | .00000 | .00000 | .00000 | | .67853-01 |
| ELEM 40 STRESSES | 202.43 | 202.43 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 41 FORCES | .00000 | | | | | | | |
| ELEM 42 FORCES | .00000 | 54681. | | .00000 | .00000 | .00000 | | .31784+07 |
| | .00000 | 54681. | | .00000 | .00000 | .00000 | | .80916+07 |
| ELEM 42 STRESSES | 2041.85 | 2041.85 | .00 | .00 | 3784.87 | 3784.87 | .00 | .00 |
| ELEM 43 FORCES | .00000 | 32301. | | .00000 | .00000 | .00000 | | .98583+06 |
| | .00000 | 32301. | | .00000 | .00000 | .00000 | | .31784+07 |
| ELEM 43 STRESSES | 633.31 | 633.31 | .00 | .00 | 2041.85 | 2041.85 | .00 | .00 |
| ELEM 44 FORCES | .00000 | 32976. | | .00000 | .00000 | .00000 | | .27546+06 |
| | .00000 | 32976. | | .00000 | .00000 | .00000 | | .98583+06 |
| ELEM 44 STRESSES | 176.96 | 176.96 | .00 | .00 | 633.31 | 633.31 | .00 | .00 |
| ELEM 45 FORCES | .00000 | 33117. | | .00000 | .00000 | .00000 | | .37984+07 |
| | .00000 | 33117. | | .00000 | .00000 | .00000 | | .27546+06 |
| ELEM 45 STRESSES | 2440.13 | 2440.13 | .00 | .00 | 176.96 | 176.96 | .00 | .00 |
| ELEM 46 FORCES | .00000 | 51532. | | .00000 | .00000 | .00000 | | .13738+08 |
| | .00000 | 51532. | | .00000 | .00000 | .00000 | | .10117+08 |
| ELEM 46 STRESSES | 17862.64 | 17862.64 | .00 | .00 | 23556.43 | 23556.43 | .00 | .00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 47 FORCES | .00000 | 51994. | .00000 | .00000 | .00000 | .95801+07 | | |
| | .00000 | 51994. | .00000 | .00000 | .00000 | .13738+08 | | |
| ELEM 47 STRESSES | 12456.25 | 12456.25 | .00 | .00 | 17862.64 | 17862.64 | .00 | .00 |
| ELEM 48 FORCES | .00000 | .16641+06 | .00000 | .00000 | .00000 | 2.4742 | | |
| | .00000 | .16641+06 | .00000 | .00000 | .00000 | .95801+07 | | |
| ELEM 48 STRESSES | .00 | .00 | .00 | .00 | 12456.25 | 12456.25 | .00 | .00 |
| ELEM 49 FORCES | .00000 | 88.809 | .00000 | .00000 | .00000 | .54871-03 | | |
| | .00000 | 88.809 | .00000 | .00000 | .00000 | 7184.7 | | |
| ELEM 49 STRESSES | .00 | .00 | .00 | .00 | 548.17 | 548.17 | 548.17 | 548.17 |
| ELEM 50 FORCES | .00000 | 1199.7 | .00000 | .00000 | .00000 | 7184.7 | | |
| | .00000 | 1199.7 | .00000 | .00000 | .00000 | 46584. | | |
| ELEM 50 STRESSES | 548.17 | 548.17 | 548.17 | 548.17 | 3554.21 | 3554.21 | 3554.21 | 3554.21 |
| ELEM 51 FORCES | .00000 | 517.26 | .00000 | .00000 | .00000 | 53312. | | |
| | .00000 | 517.26 | .00000 | .00000 | .00000 | 35283. | | |
| ELEM 51 STRESSES | 1470.87 | 1470.87 | 1470.87 | 1470.87 | 973.46 | 973.46 | 973.46 | 973.46 |
| ELEM 52 FORCES | .00000 | 162.49 | .00000 | .00000 | .00000 | 35283. | | |
| | .00000 | 162.49 | .00000 | .00000 | .00000 | 35865. | | |
| ELEM 52 STRESSES | 973.46 | 973.46 | 973.46 | 973.46 | 990.06 | 990.06 | 990.06 | 990.06 |
| ELEM 53 FORCES | .00000 | 344.91 | .00000 | .00000 | .00000 | 35865. | | |
| | .00000 | 344.91 | .00000 | .00000 | .00000 | .68502-03 | | |
| ELEM 53 STRESSES | 990.06 | 990.06 | 990.06 | 990.06 | .00 | .00 | .00 | .00 |
| ELEM 54 FORCES | .00000 | 2520.9 | .00000 | .00000 | .00000 | 41782. | | |
| | .00000 | 2520.9 | .00000 | .00000 | .00000 | 89173. | | |
| ELEM 54 STRESSES | 1723.39 | 1723.39 | 1723.39 | 1723.39 | 3678.16 | 3678.16 | 3678.16 | 3678.16 |
| ELEM 55 FORCES | .00000 | 85350. | .00000 | .00000 | .00000 | .14642+08 | | |
| | .00000 | 85350. | .00000 | .00000 | .00000 | .20029+08 | | |
| ELEM 55 STRESSES | 566.02 | 566.02 | 566.02 | 566.02 | 774.27 | 774.27 | 774.27 | 774.27 |
| ELEM 56 FORCES | .00000 | 85657. | .00000 | .00000 | .00000 | .20029+08 | | |
| | .00000 | 85657. | .00000 | .00000 | .00000 | .25466+08 | | |
| ELEM 56 STRESSES | 774.27 | 774.27 | 774.27 | 774.27 | 984.46 | 984.46 | 984.46 | 984.46 |
| ELEM 64 FORCES | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| ELEM 64 STRESSES | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 65 FORCES | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| ELEM 65 STRESSES | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 66 FORCES | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| | .00000 | .00000 | .00000 | .00000 | .00000 | .00000 | | |
| ELEM 66 STRESSES | .00 | .00 | .00 | .00 | .00 | .00 | .00 | .00 |
| ELEM 67 FORCES | .00000 | .20018+06 | .00000 | .00000 | .00000 | .24505+09 | | |
| | .00000 | .20018+06 | .00000 | .00000 | .00000 | .28900+09 | | |
| ELEM 67 STRESSES | 16285.19 | 16285.19 | .00 | .00 | 19205.66 | 19205.66 | .00 | .00 |
| ELEM 68 FORCES | .00000 | .59822+06 | .00000 | .00000 | .00000 | .20126+09 | | |
| | .00000 | .59822+06 | .00000 | .00000 | .00000 | .24505+09 | | |
| ELEM 68 STRESSES | 13374.58 | 13374.58 | .00 | .00 | 16285.19 | 16285.19 | .00 | .00 |
| ELEM 69 FORCES | .00000 | .59126+06 | .00000 | .00000 | .00000 | .15797+09 | | |
| | .00000 | .59126+06 | .00000 | .00000 | .00000 | .20126+09 | | |
| ELEM 69 STRESSES | 10498.05 | 10498.05 | .00 | .00 | 13374.58 | 13374.58 | .00 | .00 |
| ELEM 70 FORCES | .00000 | .57716+06 | .00000 | .00000 | .00000 | .11872+09 | | |
| | .00000 | .57716+06 | .00000 | .00000 | .00000 | .15797+09 | | |
| ELEM 70 STRESSES | 7690.34 | 7690.34 | .00 | .00 | 10498.05 | 10498.05 | .00 | .00 |
| ELEM 71 FORCES | .00000 | .15599+06 | .00000 | .00000 | .00000 | .12116+09 | | |
| | .00000 | .15559+06 | .00000 | .00000 | .00000 | .11872+09 | | |
| ELEM 71 STRESSES | 8051.42 | 8051.82 | .00 | .00 | 7690.34 | 7690.34 | .00 | .00 |
| ELEM 72 FORCES | .00000 | .19156+06 | .00000 | .00000 | .00000 | .49790+08 | | |
| | .00000 | .19156+06 | .00000 | .00000 | .00000 | .67290+08 | | |
| ELEM 72 STRESSES | 3308.81 | 3308.81 | .00 | .00 | 4471.78 | 4471.78 | .00 | .00 |
| ELEM 73 FORCES | .00000 | .14258+06 | .00000 | .00000 | .00000 | .36755+08 | | |
| | .00000 | .14258+06 | .00000 | .00000 | .00000 | .49790+08 | | |
| ELEM 73 STRESSES | 2442.54 | 2442.54 | .00 | .00 | 3308.81 | 3308.81 | .00 | .00 |
| ELEM 74 FORCES | .00000 | .30336+06 | .00000 | .00000 | .00000 | .17018+08 | | |
| | .00000 | .30336+06 | .00000 | .00000 | .00000 | .36755+08 | | |
| ELEM 74 STRESSES | 1130.91 | 1130.91 | .00 | .00 | 2442.54 | 2442.54 | .00 | .00 |
| ELEM 75 FORCES | .00000 | .24813+06 | .00000 | .00000 | .00000 | .87401+06 | | |
| | .00000 | .24813+06 | .00000 | .00000 | .00000 | .17018+08 | | |
| ELEM 75 STRESSES | 58.08 | 58.08 | .00 | .00 | 1130.91 | 1130.91 | .00 | .00 |
| ELEM 76 FORCES | .00000 | 57313. | .00000 | .00000 | .00000 | 16.996 | | |
| | .00000 | 57313. | .00000 | .00000 | .00000 | .87401+06 | | |
| ELEM 76 STRESSES | .00 | .00 | .00 | .00 | 58.08 | 58.08 | .00 | .00 |

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ELEM  88 FORCES     .00000        4843.9        .00000        .00000        .00000       1.9683
                    .00000        4643.9        .00000        .00000        .00000       .33784+06
ELEM  88 STRESSES      .00        .00       .00        .00       71.10      71.10       .00        .00

ELEM  89 FORCES     .00000        13076.        .00000        .00000        .00000       .33784+06
                    .00000        13076.        .00000        .00000        .00000       .12891+07
ELEM  89 STRESSES    71.10      71.10       .00        .00      271.28     271.28       .00        .00

ELEM  90 FORCES     .00000        .12187+06     .00000        .00000        .00000       .12891+07
                    .00000        .12187+06     .00000        .00000        .00000       .26676+08
ELEM  90 STRESSES   271.28     271.28       .00        .00     5613.85    5613.85       .00        .00

ELEM  91 FORCES     .00000        .12737+06     .00000        .00000        .00000       .26676+08
                    .00000        .12737+06     .00000        .00000        .00000       .52498+08
ELEM  91 STRESSES  5613.85    5613.85       .00        .00    11047.90   11047.90       .00        .00

ELEM  92 FORCES     .00000        .00000        .00000        .00000        .00000       .00000
                    .00000        .00000        .00000        .00000        .00000       .00000
ELEM  92 STRESSES      .00        .00       .00        .00         .00        .00       .00        .00

ELEM  93 FORCES     .00000        .00000        .00000        .00000        .00000       .00000
                    .00000        .00000        .00000        .00000        .00000       .00000
ELEM  93 STRESSES      .00        .00       .00        .00         .00        .00       .00        .00

ELEM  94 FORCES     .00000        .00000        .00000        .00000        .00000       .00000
                    .00000        .00000        .00000        .00000        .00000       .00000
ELEM  94 STRESSES      .00        .00       .00        .00         .00        .00       .00        .00

ELEM  95 FORCES     .00000        .00000        .00000        .00000        .00000       .00000
                    .00000        .00000        .00000        .00000        .00000       .00000
ELEM  95 STRESSES      .00        .00       .00        .00         .00        .00       .00        .00

ELEM  96 FORCES     .00000        .00000        .00000        .00000        .00000       .00000
                    .00000        .00000        .00000        .00000        .00000       .00000
ELEM  96 STRESSES      .00        .00       .00        .00         .00        .00       .00        .00


***** PROBLEM COMPLETED *****  CP =  461.000   PP =      .000

***** RUN COMPLETED *****  CP =  462.000   PP =      .000

@FIN
```

## PART V: HEAT TRANSPORT SYSTEM COMPONENTS

## SECTION 4: PRIMARY PUMP VALVE

CONTENTS



A table of contents for all volumes of this report appears at the back of each volume.

## V-4.1

## INTRODUCTION

Connected to the outlet nozzle of each main primary pump is a manually operated shut-off valve. Its purpose is to prevent backflow through a disabled pump, and thus to enable the plant to operate at part load with three pumps. Part load operation with three pumps is desirable for higher availability, especially if constant speed sodium pumps were to be used. Furthermore the valve does not have to be an automatically actuated check valve, a device which might be thought necessary to prevent reverse flow immediately following a scram caused by pump failure. Even though some reverse flow does occur, the post-scram core temperatures do not exceed full power operating temperatures, the pumps are not hermed, and thus automatic action is unnecessary.

V-4.2

## REQUIREMENTS

The functional and design requirements of the valve are as follows:

- Operate at pump outlet pressure:
  Thermal-hydraulic 90 psig to 120 psig; Design pressure 200 psig.
- Normal operation submerged in cold-pool sodium at 600°F.
- Shut-off flow with pressure in either direction at pump shut-off head.
- Minimize pressure drop through valve in forward direction to preserve natural circulation.
- Maximum valve $\Delta P \leq 2$ psi at rated flow in normal direction.
- Seat leakage shall be minimized and shall not exceed 2000 gpm at maximum pump head.
- Provide means to limit "water hammer" or flow decelerations to not exceed valve design pressure.
- Valve shall be attached to pump outlet nozzle and shall be withdrawn and inserted with the pump.
- Valve shall be attached to flexible coupling at its outlet. Coupling shall be withdrawn and inserted with pump and valve.
- Maximum valve length - flange-to-flange in direction of flow 95 inches.
- Diameter: No part of valve or actuating assembly shall extend beyond 40 inches from the pump centerline.
- Valve shall withstand plant duty cycle requirement with respect to thermal transients and seismic events, etc.
- Valve shall not resonate with flow-induced vibrations in the valve or the pump, and in addition shall not resonate with any frequency caused by pump rotation.
- The valve shall be seismic Class 2 and is non-safety-related.
- Attention shall be paid in design to enhancing drainability.

- The material of the valve shall be 304 stainless steel. Other materials for moving surfaces, hard facing of seats, etc., shall be approved in advance by buyer.
- Leakage at the actuator mechanism, valve seat, or other parts is not prohibited except that erosion or cavitation by the leaking fluid shall not cause erosion damage.
- The design life shall be forty years.
- Leakage from the valve body shall be minimized and shall not exceed 1000 gallons per minute at normal rated conditions.
- Positive actuation force will be provided from top of shield deck and transmitted mechanically to the valve.
- Valve position shall be full open or full closed.
- Actuating forces transmitted to pump outlet nozzle by the valve operating mechanism shall not damage the pump.
- The actuation may be by hydraulic or mechanical mechanisms. If hydraulic, the actuating fluid shall be sodium.

## V-4.3

## DESCRIPTION OF VALVE

The valve is an axial flow cylindrical sleeve valve and is shown on Figure 1. It is operated mechanically from above the shield deck through two rods passing down through the body of the pump. The top inlet end of the valve is attached to the pump and the outlet is attached to the articulating joint which in turn connects to the 36-inch diameter piping to the reactor inlet plenum.

The valve was shown in Phase A as a butterfly with a single rod operator. A sliding cylindrical valve is considered in the present work to take advantage of the fact that hydraulic pressures exert insignificant net force on the valve operator. The moving part of the valve is a 36-inch inside diameter cylinder guided at its bottom end by piston rings and at its top by a rod through a bushing in the valve body. Leakage at both the piston ring guide and the operating rod is permissible providing it is small enough to avoid damage due to cavitation erosion or vibration. The flow is blocked when the cylinder at its upper end is seated against the top of the valve body. The operating rods, in tension, hold the seat closed. The valve is open when the cylinder is at the bottom of its stroke at which position it is steadied and supported on a back seat. To operate the valve, a horizontal crossbar, or lifting yoke is pinned to the vertically sliding rod which is coincident with the control vertical axis of the valve. Two rods are attached, one at each end, to the crossbar and extend vertically upward through the pump tank and the shield deck to the operating mechanism. The rods do not penetrate the high pressure conduits. The vertical travel of the seat is about 10 inches.

## V-4.4

## ALTERNATIVE DESIGN FEATURES

One alternative to the sliding cylinder design is a valve in which the valve seats are held closed by back pressure. This design is impractical because the hydraulic force on a 36" seat at 200 psi would be about 200,000 lbs. and the shield deck cannot tolerate such a load.

Another alternative feature is hydraulic operation of the sleeve valve. In this alternative the central valve rod would be equipped with a hydraulic cylinder mounted at the top of the valve body. In one method the cylinder has an inlet port for admitting pressurized sodium. When a pump fails the back pressure from the reactor inlet plenum closes the valve. When all pumps are producing the same pressure the hydraulic cylinder is neutralized and the valve drops open by gravity. If operated hydraulically the valve could be semi-automatic, but one or more auxiliary solenoid valves would be used to control the hydraulic piston and thereby provide manual control of the main valve. In any case the mechanical actuator would be retained and would override the hydraulic actuator.

## V-4.5

## ATTACHING VALVE TO PUMP

Figure 908E514 shows the valve in operating position at the outlet end of the pump. The six downward directed diffuser sections are separate channels, which mate with six matching channels in the valve body. The valve is joined to the pump using bolted flanges. The space between the high pressure downcomers is used to accommodate the horizontal bar, or lifting yoke, which is centrally attached to the valve operating shaft.

Lifting rods, operating in tension, are attached to either end of the lifting yoke. From there they pass through the pump tank up to the top of the shield deck. Within the drive motor mount on the shield deck, the rods connect to actuating motors which impart vertical motion to them, raising and lowering the valve seat.

To accommodate the lifting rods and provide a path for them within the pump to the top of the shield deck it is proposed to change the shape of the outside of the pump tank. The reference design is a truncated cone and the proposed change is to make the pump tank a right circular cylinder. The cylinder, flange, valve, and lifting linkage are all within the original maximum pump diameter - 80 inches. The previous design, drawing 273R274, depicted a butterfly with a single operating rod which penetrated the pump tank part way up its length. The penetration required an idler crank and pivot. By its position external to the tank the operating linkage was exposed to possible damage during handling. The present design protects the rods over most of their length.

The valve outlet is attached to the articulating expansion joint by another bolted flange. This joint couples the pump and valve to the reactor inlet plenum piping.

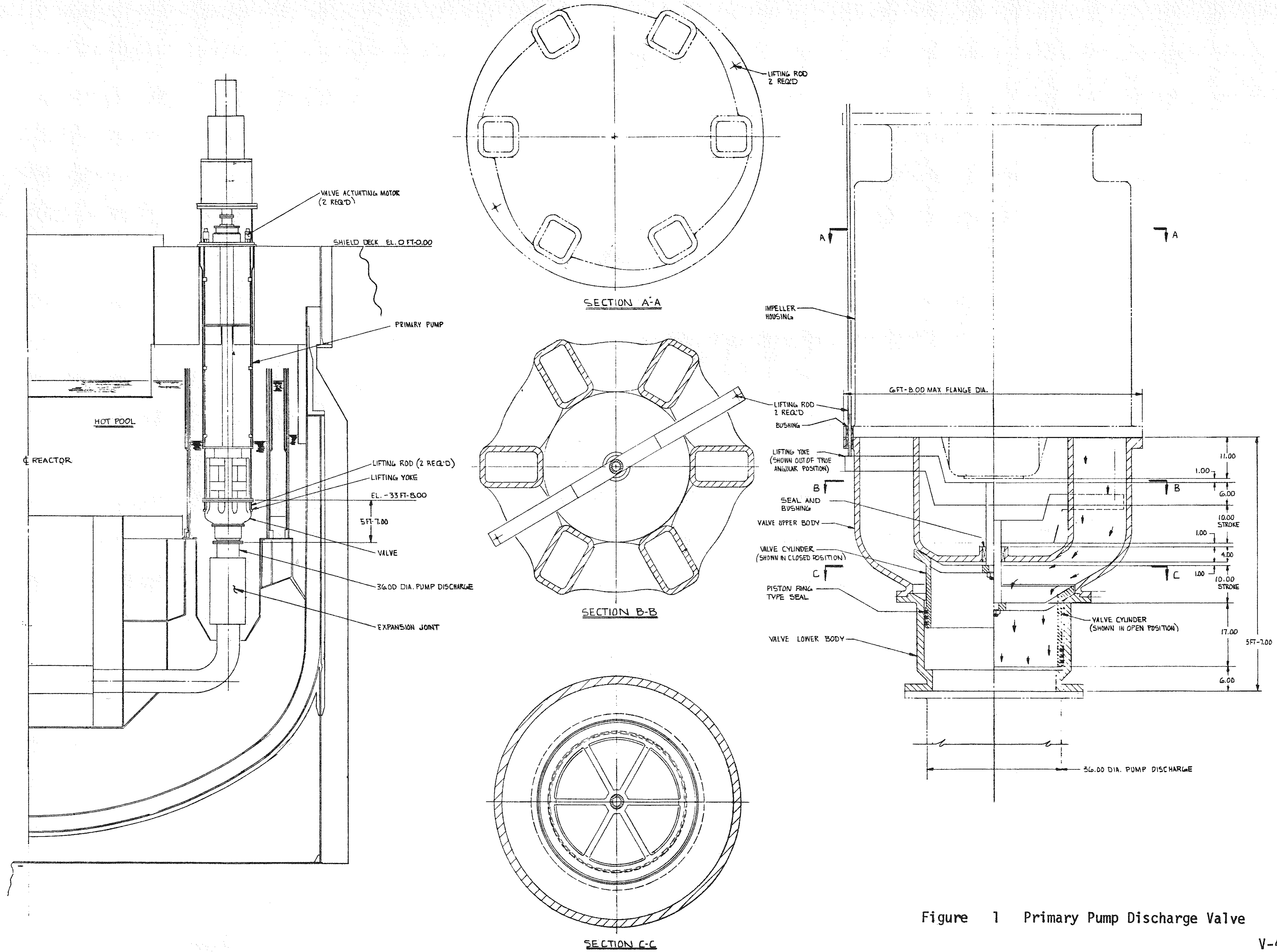


Figure 1 Primary Pump Discharge Valve

PART V: HEAT TRANSPORT SYSTEM COMPONENTS

SECTION 5: PRIMARY PUMP SEISMIC ANALYSIS

## CONTENTS



A table of contents for all volumes of this report appears at the back of each volume.

FIGURES

TABLES

# INTRODUCTION AND SUMMARY

## 5.1.1 INTRODUCTION

A preliminary seismic analysis was performed on the mechanical pump concept developed during Phase A. The purpose of this analysis was to investigate the behavior of the pump design under seismic conditions. The finite element method was used in this analysis. The pump was modeled as an assemblage of pipe and beam elements. Input seismic excitation spectra obtained from a previous (Phase A) analysis by Bechtel was used.

Seismic stresses should be combined with stresses from thermal and mechanical loadings to establish the overall integrity of the design. This model can be used as a tool to examine the effect of design changes. Other important areas of analysis are the unbalance responses and torsional vibrations of the rotating shaft. They are however, outside the scope of this preliminary analysis.

## 5.1.2 SUMMARY

A finite element seismic model was set up to analyze the primary heat transport system mechanical pump concept developed during Phase A.

The reactor roof (deck) was assumed rigid. Thus, the seismic response spectra obtained for the reactor support could be used as the seismic excitation at the pump support. This preliminary analysis indicates that only the first five modes of vibration are within the seismic excitation frequency range and the first mode, a cantilever beam mode, is the major contributing mode of the seismic response.

In the case of the horizontal SSE, the maximum combined (in two directions) displacement at the bottom of the pump can reach a value of 3.76 inches peak-to-peak amplitude. The maximum combined stress can reach a value of 20,000 psi. In the case of horizontal OBE the maximum combined displacement and stress are 2.5 inches and 13,000 respectively.

Based on these results, it appears that this pump concept is acceptable structurally and functionally as far as seismic capability is concerned. A more detailed analysis is needed, however, to include response of pump shaft to the torsional vibration, unbalance response of the rotating system, and transient thermal stress responses to complete evaluation of this pump concept.

## V-5.2

## CONCLUSIONS

This analysis is preliminary in nature and is intended to serve as a guide in the conceputal design of a primary heat transport system mechanical pump for the Pool Type LMFBR applications. Within these limitations, the analysis shows that this pump concept, without additional structural supports is acceptable structurally and functionally as far as seismic capability is concerned.

Other areas of interest, such as torsional vibration, pump shaft unbalance responses, and transient thermal responses of the pump components, have yet to be addressed. Progress on the design of the pump and pump/deck interface have not proceeded sufficiently to draw any other conclusions from this analysis.

V-5.3

## ANALYSIS

### 5.3.1
### BASIS OF ANALYSIS

The analytical technique adopted here is the response spectrum method. A response spectrum is defined as the envelope of maximum values of a response parameter, of a family of linearly elastic single-degree-of-freedom systems, which can be used to represent a continuum structure. The response of a structure to a source of excitation varies, depending on the frequency characteristics and damping properties of the structure. The structural response is generally obtained by the modal superposition technique, and thus the free vibration analysis is fundamental in the seismic analysis of the pump.

### 5.3.2
### THE SEISMIC MODEL

Description of the Model

The pump is composed of the following major components:

(a) Pony Motor

(b) Main Motor

(c) Motor Stand

(d) Pump Support Structure

(e) The Hydraulic Assembly

Impeller
Volute Casing
Suction Pieces

(f) Pump Shaft

A "stick" model was set up to represent the pump for seismic analysis using the ANSYS computer code. Three element types were used, i.e., (1) 3-D Elastic Beam (Stif 4), (2) Stiffness Matrix (Stif 27), and (3) Lumped Mass Element (Stif 21).

Spring elements were used to represent bearing supports and other structural supporting members. The lumped mass element was used to account for the sodium mass and mass of a "rigid" structural member with a complicated geometry, such as the impeller. Most of the structural members were modeled as beams of equivalent stiffness. Weight of the main motor was based on 7000 HP wound rotor motor with decay heat removal drive, rated at 900 RPM.

Data describing details of the seismic model are given in Appendix V-5A. Figure 1 shows the finite element model layout and Figure 2 is a computer generated "mesh" plot, with the neutral axes of the major components shitfted to have a distinct picture of the model.

Boundary Condition and Restraint

The pump assembly is supported by a support plate and rigidly attached to the reactor roof (deck) at the top of the deck. The foundation support plate is treated as infinitely rigid for lateral motion but flexible for "rocking" motion at the base of the motor support stand and/or the top of the pump support structure. The rotating shaft is connected to the outer casing through springs which represent bearings.

Assumptions and Limitations

In setting up the model, the following assumptions were made:

(1) The system is linearly elastic.

(2) The pump structure is axisymmetric.

(3) Hydrodynamic mass effect of the sodium on the structure is neglected. (Added mass effect is, however, included.)

(4) The motor bearings and the pump hydrostatic bearings act as linear elastic springs independent of the shaft speed.

(5) All bolted joints in the structure are rigid.

(6) Fluid pumping forces and nozzle loads are ignored.

(7) Sloshing of liquid sodium inside and outside the pump is neglected.

(8) Restraint by the exit flexible joint is neglected and the new shut-off valve is excluded from the model.

### Dynamic Degrees Of Freedom

The nature of the structure is such that an acceptable accuracy is obtained by restricting the dynamic freedom of the structural model to translation only along a single horizontal axis.

### Materials Properties

The material properties adopted here were assumed to be temperature independent. (See Appendix V-5A.) Accuracy of analytical results can be improved by taking into account temperature dependence of the material properties. The accuracy as a result of this assumption (temperature independence) suffices to serve as a guide at this stage of the conceptual design.

## 5.3.3 SEISMIC EXCITATION

Seismic response spectra obtained for the reactor support from an analysis of a reactor building under a specified ground motion were used as the excitation. The reactor deck was assumed rigid. Thus the response spectrum for the reactor support was applied at the pump support. Figures 3 and 4 show seismic acceleration response spectrum used in this analysis for the horizontal safe shutdown earthquake (SSE) and operating basis earthquake (OBE) respectively. Responses of pump components in the vertical direction are less significant and are ignored.

## V-5.4

## RESULTS

### 5.4.1
### FREE VIBRATION

The free vibration analysis is fundamental in the seismic analysis of the pump using the response spectrum method. Ignoring the vertical modes of vibration, the natural frequencies of vibration were calculated. The following list shows a partial result of the calculation.

Natural Frequencies of Vibration

| Mode | Frequencies (Hz) |
|---|---|
| 1 | 4.3 |
| 2 | 17.4 |
| 3 | 25.8 |
| 4 | 25.9 |
| 5 | 29.3 |
| 6 | 36.0 |
| 7 | 38.9 |

A few significant mode shapes associated with the natural frequencies of vibration are shown in Figures 5 through 10.

### 5.4.2
### SEISMIC RESPONSES

Seismic responses of the pump are obtained from solving a system of equations of motion describing the dynamic behavior of the pump system under a specified seismic excitation. Responses of the pump are expressed in the form of a displacement field or a stress field. The mode shapes determine the relative displacements among points in the structure. Each mode of vibration has a definite level of "participation" depending on the stiffness and mass of the entire system. Given an acceleration response spectrum, the displacement field is completely determined for each mode of vibration. The frequency range of interest is 0-33Hz during the seismic event. Only the first five modes of vibration of the pump lie within this frequency range.

Under an operating-basis earthquake (OBE) the reference design pump experiences values of maximum peak-to-peak displacement, and stress which are fully acceptable, namely 2.5 inches (Table 1)*, and 13,200 psi (Table 5)* respectively.

Under the SSE these values become 3.76 inches (Table 2) and 20,000 psi (Table 5).

These displacements and stresses are the appropriate sums of the values for all the first five modes.

Table 5 shows stress intensities (membrane plus bending) at selected locations of the pump due to a uniaxial seismic excitation. The first column shows stress intensities at the first nodal point of an element (3-D beam element), and the second is for the second nodal point. The allowable stress intensity for the faulted condition, 0.7 $S_m$, is 51.3 ksi for 304 SS at 700°F.

The corresponding criterion for the upset condition, 3 $S_m$, is 48.9 ksi for 304 SS at 700°F.

The comparison of the computed stress intensities for the OBE (upset) condition and for the SSE (faulted) condition with the quoted allowable shows a substantial margin for stress contributions not yet evaluated such as thermal stresses.

*Values in these tables are uni-directional (i.e., N-S or E-W); the combined maximum values include the factor $2\sqrt{2}$ for displacement and $\sqrt{2}$ for stress.

## V-5.5

## DISCUSSION

(a) This analysis is preliminary in nature and is intended to serve as a guide in the conceptual design of a pump for a large pool-type LMFBR. More detailed analysis is needed to assess the adequacy of design. This analysis serves also as a basis to facilitate proper modeling of the pump in the reactor seismic analysis.

(b) The pump components were assumed linearly elastic. The analysis was based on small deformation theory. Results confirm the validity of this assumption. Thus, superposition technique was applicable.

(c) The deck which supports the pump was assumed rigid. Thus the seismic response spectra obtained for the reactor support becomes the input excitation to the pump support. This assumption is conservative and has very minor effect on accuracy. The vertical displacement of the pump will be dominated by the vertical displacement of the deck.

(d) Gaps and/or clearances provided at the bearings were neglected, to permit use of a linear theory in this preliminary analysis.

(e) Stress results obtained here must ultimately be combined with those obtained from other analyses to check against the code requirements. It is outside the scope of this analysis.

Table 1

DISPLACEMENT FIELD - OBE

| NODE | UX (inches) |
|---|---|
| 1 | .605626-02 |
| 2 | .705443-02 |
| 3 | .764397-02 |
| 4 | .676245-02 |
| 5 | .447785-02 |
| 6 | .695568-02 |
| 7 | .178380-01 |
| 8 | .428267-01 |
| 9 | .770753-01 |
| 10 | .128779+00 |
| 11 | .214355+00 |
| 12 | .299864+00 |
| 13 | .438293+00 |
| 14 | .493003+00 |
| 15 | .550538+00 |
| 16 | .880584+00 |
| 17 | .791257+00 |
| 18 | .701480+00 |
| 19 | .611803+00 |
| 20 | .678656+00 |
| 21 | .611803+00 |
| 22 | .594507+00 |
| 23 | .594507+00 |
| 24 | .489659+00 |
| 25 | .429832+00 |
| 26 | .376812+00 |
| 27 | .310653+00 |
| 28 | .258529+00 |
| 29 | .209388+00 |
| 30 | .149589+00 |
| 31 | .991538-01 |
| 32 | .613730-01 |
| 33 | .278301-01 |
| 34 | .696684-02 |
| 40 | .231014-03 |
| 41 | .546537-03 |
| 42 | .950163-03 |
| 43 | .950163-03 |
| 44 | .142691-02 |
| 45 | .950163-03 |
| 46 | .189219-02 |
| 47 | .305252-02 |
| 48 | .340299-02 |
| 49 | .340299-02 |
| 50 | .340299-02 |
| 51 | .439868-02 |
| 52 | .433832-02 |
| 53 | .622817-02 |
| 54 | .622817-02 |
| 55 | .851294-02 |

Table 2

DISPLACEMENT FIELD - SSE

| NODE | UX (inches) |
|---|---|
| 1 | .112303-01 |
| 2 | .130673-01 |
| 3 | .141478-01 |
| 4 | .125197-01 |
| 5 | .834119-02 |
| 6 | .121867-01 |
| 7 | .294363-01 |
| 8 | .670263-01 |
| 9 | .117674+00 |
| 10 | .194608+00 |
| 11 | .323188+00 |
| 12 | .452156+00 |
| 13 | .660802+00 |
| 14 | .743264+00 |
| 15 | .830031+00 |
| 16 | .132759+01 |
| 17 | .119292+01 |
| 18 | .105757+01 |
| 19 | .922366+00 |
| 20 | .102316+01 |
| 21 | .922366+00 |
| 22 | .896292+00 |
| 23 | .896292+00 |
| 24 | .738221+00 |
| 25 | .648026+00 |
| 26 | .568092+00 |
| 27 | .468352+00 |
| 28 | .389770+00 |
| 29 | .315685+00 |
| 30 | .225532+00 |
| 31 | .149494+00 |
| 32 | .925342-01 |
| 33 | .419622-01 |
| 34 | .105056-01 |
| 40 | .428350-03 |
| 41 | .101336-02 |
| 42 | .176169-02 |
| 43 | .176169-02 |
| 44 | .264624-02 |
| 45 | .176169-02 |
| 46 | .350801-02 |
| 47 | .565907-02 |
| 48 | .630873-02 |
| 49 | .630873-02 |
| 50 | .630873-02 |
| 51 | .815361-02 |
| 52 | .804286-02 |
| 53 | .115469-01 |
| 54 | .115469-01 |
| 55 | .157832-01 |

Table 3

ACCELERATION - OBE

| NODE | UX (in. $sec^{-2}$) |
|---|---|
| 1 | .160334+03 |
| 2 | .186472+03 |
| 3 | .201809+03 |
| 4 | .178648+03 |
| 5 | .115617+03 |
| 6 | .846788+02 |
| 7 | .115515+03 |
| 8 | .171193+03 |
| 9 | .184763+03 |
| 10 | .159409+03 |
| 11 | .177462+03 |
| 12 | .274582+03 |
| 13 | .342808+03 |
| 14 | .365634+03 |
| 15 | .410729+03 |
| 16 | .651986+03 |
| 17 | .585045+03 |
| 18 | .518078+03 |
| 19 | .451683+03 |
| 20 | .501094+03 |
| 21 | .451683+03 |
| 22 | .438942+03 |
| 23 | .438942+03 |
| 24 | .362212+03 |
| 25 | .318974+03 |
| 26 | .281149+03 |
| 27 | .234421+03 |
| 28 | .197739+03 |
| 29 | .162953+03 |
| 30 | .119586+03 |
| 31 | .816846+02 |
| 32 | .525666+02 |
| 33 | .254890+02 |
| 34 | .725695+01 |
| 40 | .612889+01 |
| 41 | .145021+02 |
| 42 | .252146+02 |
| 43 | .252146+02 |
| 44 | .378246+02 |
| 45 | .252146+02 |
| 46 | .502258+02 |
| 47 | .810243+02 |
| 48 | .903241+02 |
| 49 | .903241+02 |
| 50 | .903241+02 |
| 51 | .116701+03 |
| 52 | .115155+03 |
| 53 | .165332+03 |
| 54 | .165332+03 |
| 55 | .225998+03 |

Table 4

ACCELERATION - SSE

| NODE | UX (in. $sec^{-2}$) |
|---|---|
| 1 | .297365+03 |
| 2 | .345784+03 |
| 3 | .374187+03 |
| 4 | .331233+03 |
| 5 | .214651+03 |
| 6 | .162030+03 |
| 7 | .229557+03 |
| 8 | .338245+03 |
| 9 | .358017+03 |
| 10 | .290139+03 |
| 11 | .282411+03 |
| 12 | .460600+03 |
| 13 | .533893+03 |
| 14 | .554991+03 |
| 15 | .654885+03 |
| 16 | .984574+03 |
| 17 | .882798+03 |
| 18 | .781241+03 |
| 19 | .680974+03 |
| 20 | .755519+03 |
| 21 | .680974+03 |
| 22 | .661788+03 |
| 23 | .661788+03 |
| 24 | .546671+03 |
| 25 | .482260+03 |
| 26 | .426298+03 |
| 27 | .357539+03 |
| 28 | .303619+03 |
| 29 | .252258+03 |
| 30 | .187358+03 |
| 31 | .129574+03 |
| 32 | .846135+02 |
| 33 | .419358+02 |
| 34 | .123374+02 |
| 40 | .113639+02 |
| 41 | .268892+02 |
| 42 | .467519+02 |
| 43 | .467519+02 |
| 44 | .701339+02 |
| 45 | .467519+02 |
| 46 | .931280+02 |
| 47 | .150236+03 |
| 48 | .167480+03 |
| 49 | .167480+03 |
| 50 | .167480+03 |
| 51 | .216390+03 |
| 52 | .213524+03 |
| 53 | .306566+03 |
| 54 | .306566+03 |
| 55 | .419058+03 |

Table 5

STRESS INTENSITIES AT SELECTED LOCATIONS

Stress Intensity, psi

| Element No. | Node Nos. | OBE | | SSE | |
|---|---|---|---|---|---|
| | | Node 1 | Node 2 | Node 1 | Node 2 |
| 4 | 3-2 | 858 | 0 | 1577 | 0 |
| 10 | 6-5 | 1663 | 1774 | 2528 | 3029 |
| 14 | 8-7 | 1194 | 841 | 1965 | 1310 |
| 18 | 10-9 | 1187 | 968 | 1813 | 1551 |
| 21 | 12-11 | 1128 | 2107 | 1717 | 3192 |
| 23 | 13-12 | 1714 | 5700 | 2876 | 8680 |
| 24 | 14-13 | 1727 | 1714 | 2753 | 2876 |
| 25 | 15-14 | 0 | 1727 | 0 | 2753 |
| 45 | 25-26 | 1136 | 1367 | 1713 | 2061 |
| 47 | 26-27 | 6396 | 7952 | 9646 | 11992 |
| 51 | 28-29 | 7512 | 8692 | 11326 | 13105 |
| 54 | 29-30 | 7566 | 9099 | 11408 | 13718 |
| 56 | 30-31 | 7904 | 9248 | 11917 | 13942 |
| 58 | 31-32 | 8127 | 9310 | 12253 | 14035 |
| 60 | 32-33 | 5497 | 6386 | 8288 | 9628 |
| 61 | 33-34 | 6386 | 7284 | 9628 | 10982 |
| 64 | 34-36 | 6164 | 6782 | 9293 | 10225 |

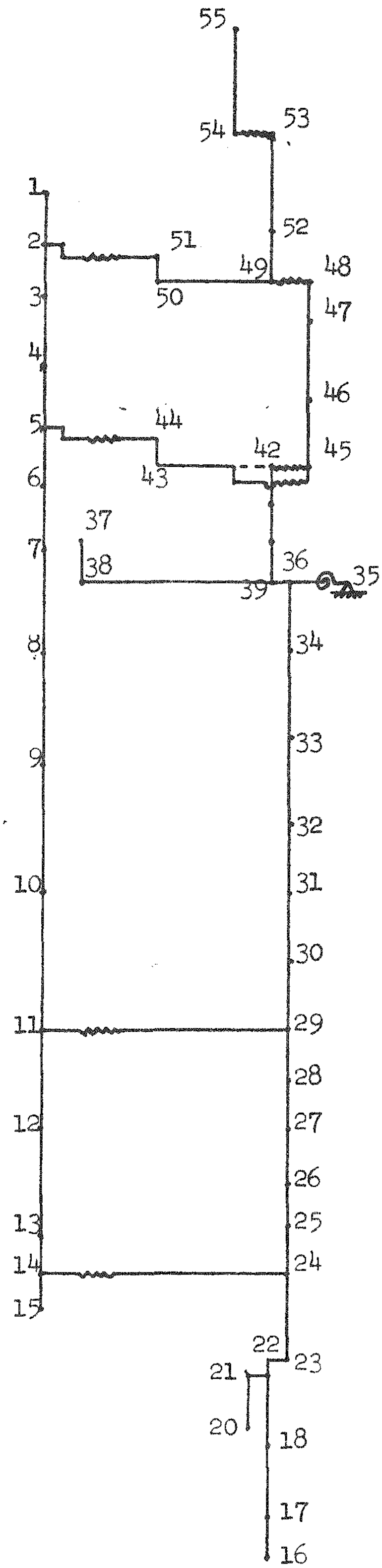


Figure 1    Pump Model Layout

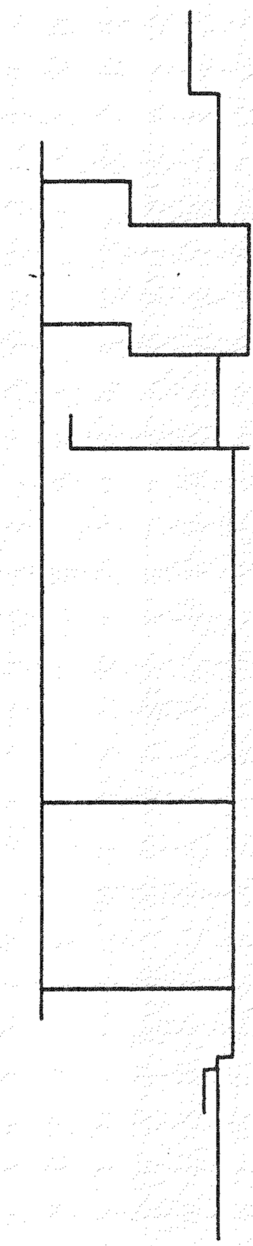

Figure 2 Finite Element Mesh Plot Of Pump Model

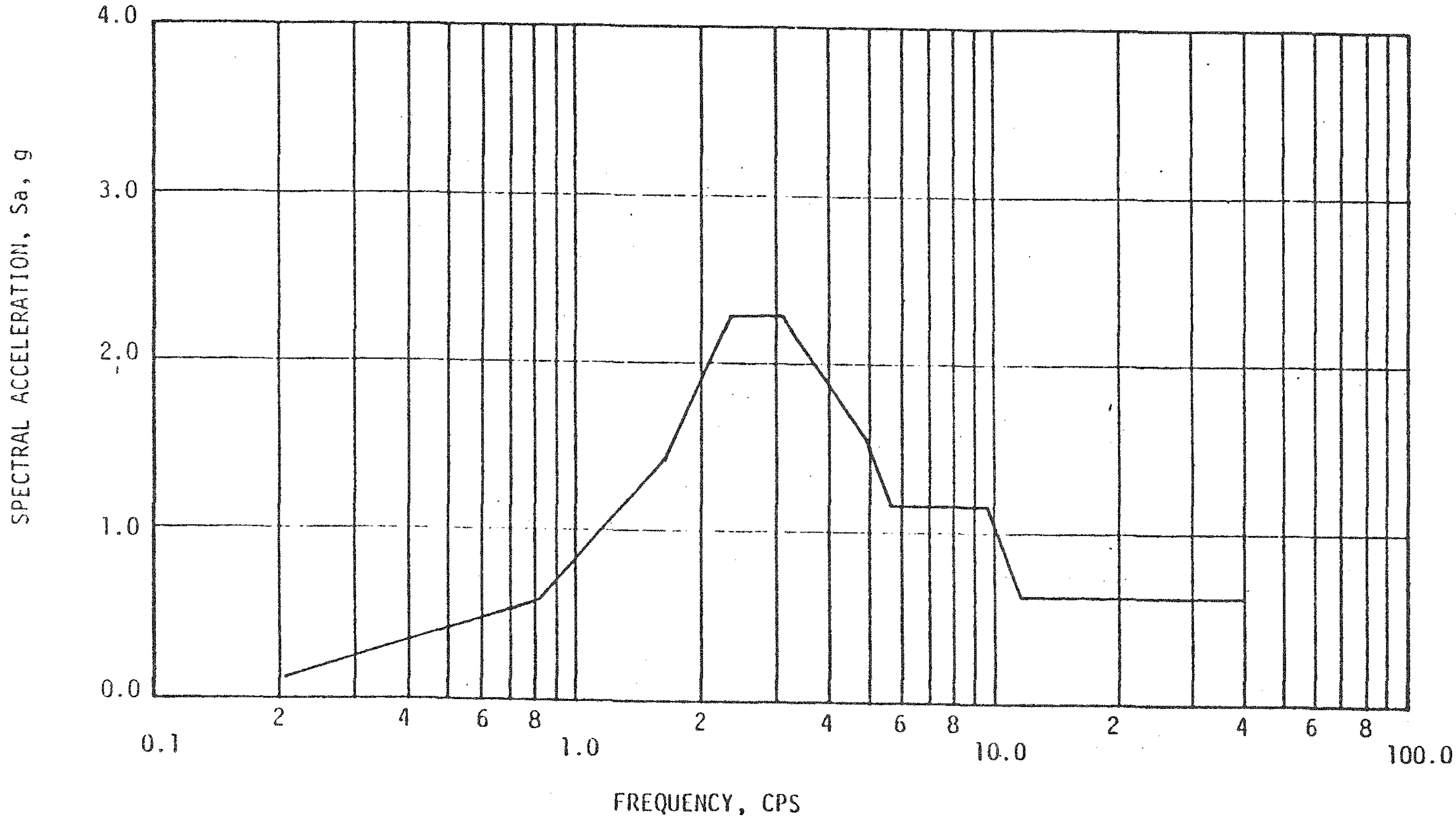


FIGURE 3 REVISED HORIZONTAL SSE DESIGN SPECTRUM AT REACTOR SUPPORT (3% DAMPING DESIGN ENVELOPE)

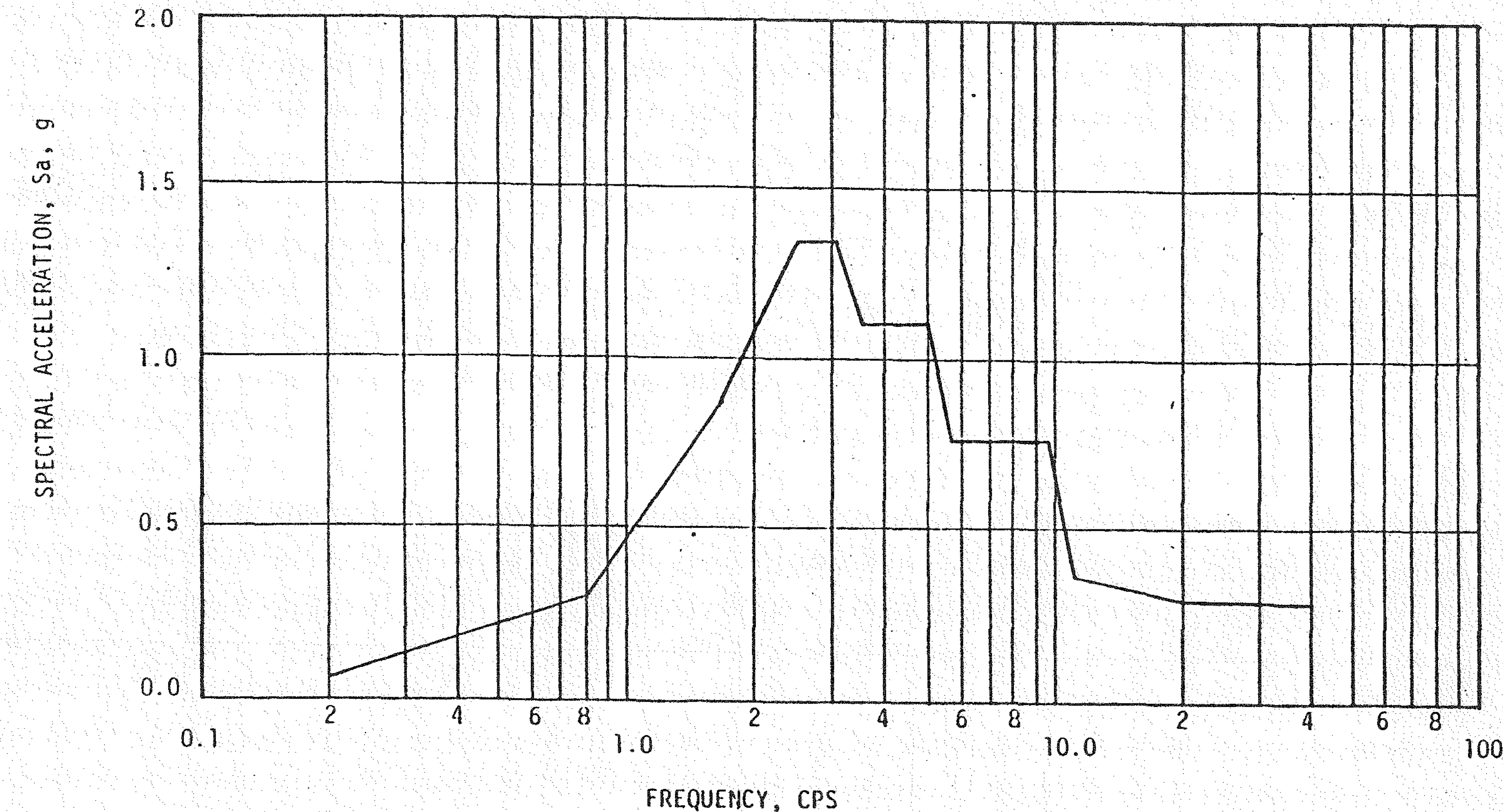


FIGURE 4 REVISED HORIZONTAL OBE DESIGN SPECTRUM AT REACTOR SUPPORT (2% DAMPING DESIGN ENVELOPE)

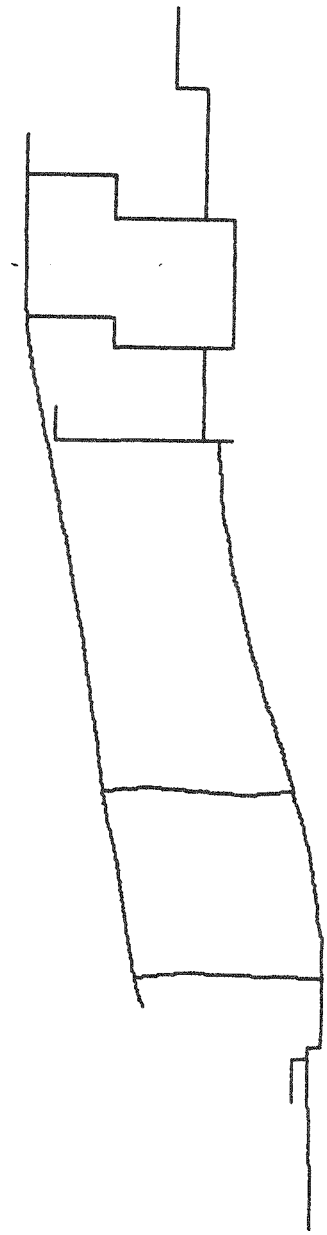

Figure 5 First Mode Of Vibration

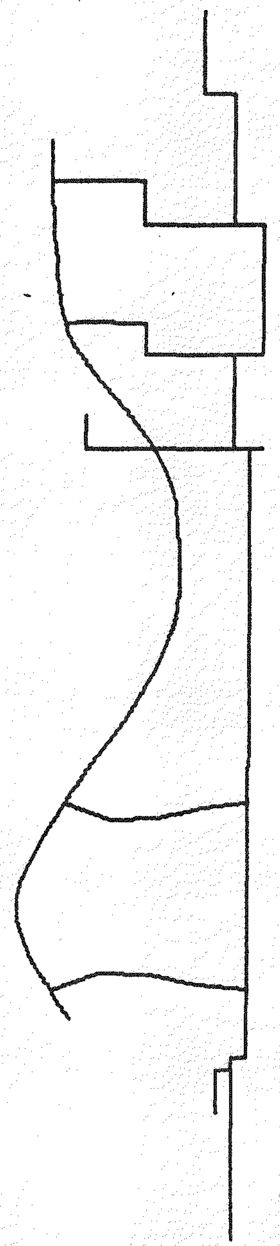

Figure 6   Second Mode Of Vibration

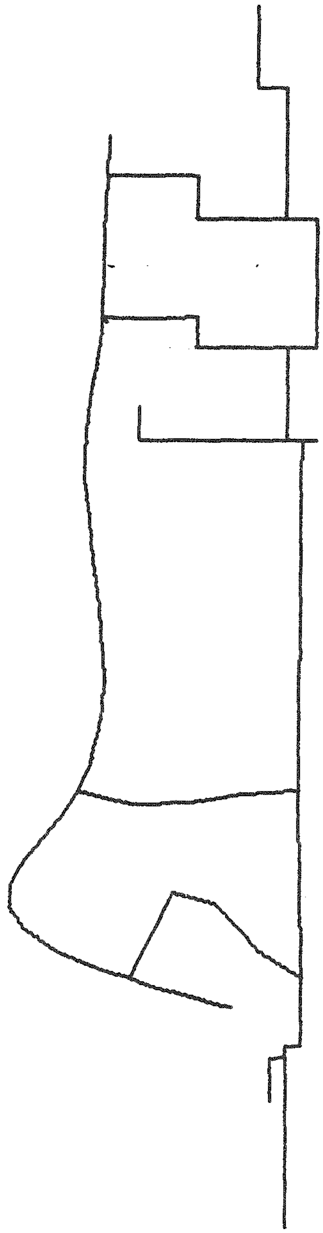

Figure 7 Third Mode Of Vibration

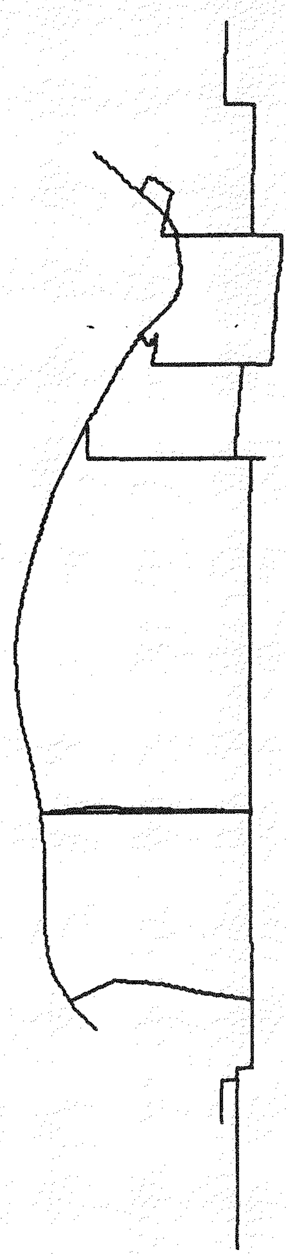

Figure 8 Fourth Mode Of Vibration

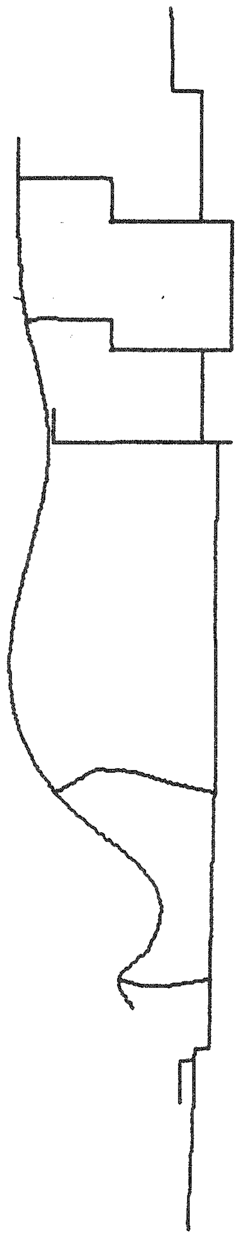

Figure 9 Fifth Mode Of Vibration

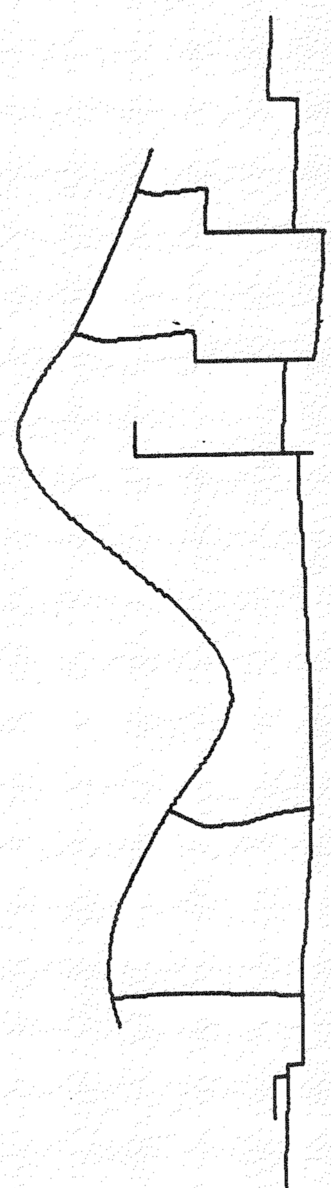

Figure 10 Sixth Mode Of Vibration

Appendix V-5A

Details of The Pump Model

ANSYS - ENGINEERING ANALYSIS SYSTEM UP180 REV 2 GE-HNYL JAN 1,1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

PHASE A EXTENSION - PUMP SEISMIC ANALYSIS - HORIZONTAL OBE 6.2717 6/24/78
CP = 0.263 PP = 0.

***** ANALYST = CHARLES YANG

***** ANALYSIS OPTIONS (CARDS C1 AND C2) *****

| | VALUE | VARIABLE NAME | COLUMNS |
|---|---|---|---|
| NUMBER OF LOAD STEPS . . . . | -1 | NSTEPS | 1-4 |
| ANALYSIS TYPE . . . . . . . . | 2 | K20 | 5-7 |
| COUPLED DEGREES OF FREEDOM KEY | 1 | KCDF | 10 |
| REACTION FORCE KEY. . . . . . | 2 | K15 | 15-16 |
| BOUNDARY CONDITION KEY. . . . | 0 | K17 | 18 |
| POST-RUN PROCESS KEY . . . . | 2 | KYPOST | 27-28 |
| KAY( 1) . . . . . . . . . . . | 1 | KAY( 1) | 30 |
| KAY( 2) . . . . . . . . . . . | 6 | KAY( 2) | 32 |
| KAY( 3) . . . . . . . . . . . | 10 | KAY( 3) | 34 |
| KAY( 5) . . . . . . . . . . . | 2 | KAY( 5) | 38 |
| KAY( 6) . . . . . . . . . . . | 1 | KAY( 6) | 40 |
| COORD. SYSTEM ROTATION KEY . | 1 | K18 | 77 |
| REFERENCE TEMPERATURE . . . . | 650.00 | TREF | 1-12 |
| UNIFORM TEMPERATURE . . . . . | 650.00 | TUNIF | 13-24 |
| PLOT DEVICE TYPE. . . . . . . | 1 | KPDV | 79-80 |
| CORE SIZE PARAMETER. . . . . . | 25000 | ICORE | 75-80 (CARD B) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| BLOCK SIZES . . . . . . . . . | 600 | 600 | 1800 | 300 | 300 | 300 | 0 | 0 |
| WORK SPACE REQUESTED(DECIMAL) | 10000 | | | | | | | |

***** ELEMENT TYPES (CARD D) *****

| TYPE | STIF | DESCRIPTION | | KEYSUB OPTIONS 1B | 1A | 1 | 2B | 2A | 2 | KC | INOTPR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | ELASTIC BEAM, 3-D | 8/05/74 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 2 | 27 | STIFFNESS MATRIX | 7/01/70 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 21 | LUMPED MASS ELEMENT | 10/10/73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

***** ELEMENT DEFINITIONS (CARD E) *****

```
ELEMENT     NODES                 MAT  TYPE              ELEMENT REAL CONSTANTS
                                            MASX      MASY       MASZ       IXX      IYY     IZZ
   1     2                         1    3   12.5      0.         0.         0.       0.      0.
                                            AREA      IZ         IY         THKZ     THKY    THET
                                                      IP         SHRZ       SHRY
   2     2    1                    1    1   50.3      0.163E 04  0.163E 04  16.0     16.0    0.
                                          0.        0.           1.12       1.12
                                            MASX      MASY       MASZ       IXX      IYY     IZZ
   3     3                         1    3   5.34      0.         0.         0.       0.      0.
                                            AREA      IZ         IY         THKZ     THKY    THET
                                                      IP         SHRZ       SHRY
   4     3    2                    1    1   108.      936.       936.       16.0     16.0    0.
                                          0.        0.           1.12       1.12
```

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 5 | 4 | | 1 | 3 | 46.5 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 6 | 4 | 3 | 1 | 1 | 142. | 0.992E 04 | 0.992E 04 | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 1.89 | 1.89 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 7 | 5 | | 1 | 3 | 6.39 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 8 | 5 | 4 | 1 | 1 | 95.0 | 0.273E 04 | 0.273E 04 | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 1.12 | 1.12 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 9 | 6 | | 1 | 3 | 4.56 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 10 | 6 | 5 | 1 | 1 | 236. | 496. | 496. | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 1.12 | 1.12 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 11 | 7 | | 1 | 3 | 4.42 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 12 | 7 | 6 | 1 | 1 | 71.2 | 0.204E 04 | 0.204E 04 | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 13 | 8 | | 1 | 3 | 5.77 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 14 | 8 | 7 | 1 | 1 | 71.2 | 0.120E 04 | 0.120E 04 | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 1.33 | 1.33 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 15 | 9 | | 1 | 3 | 3.81 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 16 | 9 | 8 | 1 | 1 | 68.3 | 0.875E 04 | 0.875E 04 | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 17 | 10 | | 1 | 3 | 3.58 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 18 | 10 | 9 | 1 | 1 | 68.3 | 0.182E 04 | 0.182E 04 | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 19 | 11 | 10 | 1 | 1 | 68.3 | 0.182E 04 | 0.182E 04 | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 20 | 12 | | 1 | 3 | 3.96 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 21 | 12 | 11 | 1 | 1 | 34.0 | 0.138E 04 | 0.138E 04 | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 22 | 11 | | 1 | 3 | 5.09 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 23 | 13 | 12 | 1 | 1 | 34.0 | 272. | 272. | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 24 | 14 | 13 | 1 | 1 | 34.0 | 272. | 272. | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 25 | 15 | 14 | 1 | 1 | 34.0 | 272. | 272. | 16.0 | 16.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 26 | 13 | | 1 | 3 | 8.60 | 0. | 0. | 0. | 0. | 0. |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 27 | 14 | | 1 | 3 | 0.771 | 0. | 0. | 0. | 0. | 0. |
| 28 | 15 | | 1 | 3 | 7.52 | 0. | 0. | 0. | 0. | 0. |
| 29 | 16 | | 1 | 3 | 29.1 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 30 | 16 | 17 | 1 | 1 | 395. | 0.254E 06 | 0.254E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 31 | 17 | 18 | 1 | 1 | 395. | 0.254E 06 | 0.254E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 32 | 18 | 19 | 1 | 1 | 395. | 0.254E 06 | 0.254E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 33 | 17 | | 1 | 3 | 58.2 | 0. | 0. | 0. | 0. | 0. |
| 34 | 18 | | 1 | 3 | 53.8 | 0. | 0. | 0. | 0. | 0. |
| 35 | 20 | | 1 | 3 | 10.3 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 36 | 20 | 21 | 1 | 1 | 0.100E 05 | 0.450E 07 | 0.450E 07 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 37 | 21 | | 1 | 3 | 34.7 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 38 | 21 | 19 | 1 | 1 | 0.200E 05 | 0.900E 11 | 0.900E 11 | 100. | 100. | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| 39 | 19 | 22 | 1 | 1 | 0.100E 05 | 0.450E 07 | 0.450E 07 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| 40 | 22 | 23 | 1 | 1 | 0.200E 05 | 0.900E 11 | 0.900E 11 | 100. | 100. | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 41 | 23 | | 1 | 3 | 45.6 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 42 | 23 | 24 | 1 | 1 | 0.100E 05 | 0.450E 07 | 0.450E 07 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| 43 | 24 | 25 | 1 | 1 | 0.100E 05 | 0.450E 07 | 0.450E 07 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 44 | 24 | | 1 | 3 | 50.5 | 0. | 0. | 0. | 0. | 0. |
| | | | | | K | | | | | |
| 45 | 24 | 14 | 1 | 2 | 0.110E 07 | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 46 | 25 | | 1 | 3 | 35.2 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 47 | 25 | 26 | 1 | 1 | 129. | 0.563E 06 | 0.563E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 48 | 26 | | 1 | 3 | 24.3 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 49 | 26 | 27 | 1 | 1 | 307. | 0.120E 06 | 0.120E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 50 | 27 | | 1 | 3 | 11.6 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 51 | 27 | 28 | 1 | 1 | 319. | 0.134E 06 | 0.134E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 52 | 28 | | 1 | 3 | 27.6 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 53 | 28 | 29 | 1 | 1 | 330. | 0.149E 06 | 0.149E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 54 | 29 | | 1 | 3 | 40.1 | 0. | 0. | 0. | 0. | 0. |
| | | | | | K | | | | | |
| 55 | 29 | 11 | 1 | 2 | 0.110E 07 | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 56 | 29 | 30 | 1 | 1 | 346. | 0.171E 06 | 0.171E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 57 | 30 | | 1 | 3 | 9.67 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 58 | 30 | 31 | 1 | 1 | 263. | 0.197E 06 | 0.197E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 59 | 31 | | 1 | 3 | 10.1 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 60 | 31 | 32 | 1 | 1 | 379. | 0.225E 06 | 0.225E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 61 | 32 | | 1 | 3 | 62.7 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 62 | 32 | 33 | 1 | 1 | 493. | 0.380E 06 | 0.380E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 63 | 33 | 34 | 1 | 1 | 493. | 0.380E 06 | 0.380E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 64 | 33 | | 1 | 3 | 91.0 | 0. | 0. | 0. | 0. | 0. |
| 65 | 34 | | 1 | 3 | 84.1 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 66 | 34 | 36 | 1 | 1 | 522. | 0.449E 06 | 0.449E 06 | 80.0 | 80.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 67 | 36 | | 1 | 3 | 41.5 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 68 | 38 | 37 | 1 | 1 | 181. | 0.645E 06 | 0.645E 06 | 32.0 | 32.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 69 | 37 | | 1 | 3 | 13.6 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 70 | 38 | 39 | 1 | 1 | 0.200E 05 | 0.900E 11 | 0.900E 11 | 100. | 100. | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 71 | 39 | | 1 | 3 | 9.35 | 0. | 0. | 0. | 0. | 0. |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 72 | 39 | 36 | 1 | 1 | 0.200E 05 | 0.900E 11 | 0.900E 11 | 100. | 100. | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| 73 | 36 | 35 | 1 | 1 | 0.200E 05 | 0.900E 11 | 0.900E 11 | 100. | 100. | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| 74 | 39 | 40 | 1 | 1 | 961. | 0.703E 06 | 0.703E 06 | 64.0 | 64.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 75 | 40 | 41 | 1 | 1 | 961. | 0.703E 06 | 0.703E 06 | 64.0 | 64.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 76 | 41 | 42 | 1 | 1 | 961. | 0.703E 06 | 0.703E 06 | 64.0 | 64.0 | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 77 | 40 | | 1 | 3 | 13.9 | 0. | 0. | 0. | 0. | 0. |
| 78 | 41 | | 1 | 3 | 14.0 | 0. | 0. | 0. | 0. | 0. |
| 79 | 42 | | 1 | 3 | 20.2 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 80 | 43 | 44 | 1 | 1 | 142. | 0.500E 06 | 0.500E 06 | 32.0 | 32.0 | 0. |
| | | | | | 0. | 0. | 1.53 | 1.53 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 81 | 44 | | 1 | 3 | 28.6 | 0. | 0. | 0. | 0. | 0. |
| | | | | | K | | | | | |
| 82 | 44 | 5 | 1 | 2 | 0.240E 07 | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 83 | 43 | 45 | 1 | 1 | 0.200E 05 | 0.900E 11 | 0.900E 11 | 100. | 100. | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| 84 | 45 | 46 | 1 | 1 | 418. | 0.564E 07 | 0.564E 07 | 102. | 102. | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 85 | 46 | | 1 | 3 | 68.1 | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 86 | 46 | 47 | 1 | 1 | 418. | 0.529E 06 | 0.529E 06 | 102. | 102. | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| 87 | 47 | 48 | 1 | 1 | 418. | 0.529E 06 | 0.529E 06 | 102. | 102. | 0. |
| | | | | | 0. | 0. | 2.00 | 2.00 | | |
| | | | | | MASX | MASY | MASZ | IXX | IYY | IZZ |
| 88 | 47 | | 1 | 3 | 136. | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |
| 89 | 50 | 49 | 1 | 1 | 0.200E 05 | 0.900E 11 | 0.900E 11 | 100. | 100. | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| 90 | 49 | 48 | 1 | 1 | 0.200E 05 | 0.900E 11 | 0.900E 11 | 100. | 100. | 0. |
| | | | | | 0. | 0. | 1.00 | 1.00 | | |
| 91 | 50 | 51 | 1 | 1 | 142. | 0.118E 05 | 0.118E 05 | 32.0 | 32.0 | 0. |
| | | | | | 0. | 0. | 1.89 | 1.89 | | |
| | | | | | K | | | | | |
| 92 | 51 | 2 | 1 | 2 | 0.220E 07 | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | 0. | 0. | 0. | 0. | 0. | 0. |
| | | | | | AREA | IZ | IY | THKZ | THKY | THET |
| | | | | | | IP | SHRZ | SHRY | | |

```
 93   49   52                                        1    1  294.       0.144E 06 0.144E 06  64.0        64.0        0.
                                                             0.         0.         1.89      1.89
                                                               MASX        MASY       MASZ      IXX         IYY         IZZ
 94   52                                             1    3  12.4        0.         0.        0.          0.          0.
                                                               AREA         IZ         IY       THKZ        THKY        THET
                                                                            IP        SHRZ      SHRY
 95   52   53                                        1    1  198.       0.982E 05 0.982E 05  64.0        64.0        0.
                                                             0.         0.         1.89      1.89
                                                               MASX        MASY       MASZ      IXX         IYY         IZZ
 96   53                                             1    3  15.4        0.         0.        0.          0.          0.
                                                               AREA         IZ         IY       THKZ        THKY        THET
                                                                            IP        SHRZ      SHRY
 97   53   54                                        1    1 0.200E 05 0.900E 11 0.900E 11  100.        100.         0.
                                                             0.         0.         1.00      1.00
                                                               MASX        MASY       MASZ      IXX         IYY         IZZ
 98   54                                             1    3  6.33       0.         0.        0.          0.          0.
                                                               AREA         IZ         IY       THKZ        THKY        THET
                                                                            IP        SHRZ      SHRY
 99   54   55                                        1    1  157.       0.124E 05 0.124E 05  21.8        21.8        0.
                                                             0.         0.         1.89      1.89
                                                               MASX        MASY       MASZ      IXX         IYY         IZZ
100   55                                             1    3  9.47       0.         0.        0.          0.          0.
NUMBER OF ELEMENTS =    100     MAXIMUM NODE POINT USED =     55


          *** ELEMENT STIFFNESS FORMULATION TIME ESTIMATE (HNY 6000) ***

TYPE        STIF       NUMBER   TIME(EACH)    TIME(ALL)
  1           4          52       0.8640       44.928
  2          27           4       0.8640        3.456
  3          21          44       0.2160        9.504

                             TOTAL TIME =      57.888 SECONDS.
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ANSYS - ENGINEERING ANALYSIS SYSTEM UP180 REV 2 GE-HNYL JAN 1,1972
SWANSON ANALYSIS SYSTEMS, INC. ELIZABETH, PENNSYLVANIA 15037 PHONE (412) 751-1940

PHASE A EXTENSION - PUMP SEISMIC ANALYSIS - HORIZONTAL OBE 6.2733 6/24/78
CP = 2.337 PP = 0.

***** NODE DEFINITIONS (CARD F) *****

| NODE | LOCATION X (OR R) | Y (OR THETA) | Z (OR PHI) | ROTATION (DEGREES) THXY (OR RT) | THYZ (TZ OR TP) | THXZ (RZ OR RP) |
|---|---|---|---|---|---|---|
| 1 | 0. | 209.30 | 0. | 0. | 0. | 0. |
| 2 | 0. | 181.50 | 0. | 0. | 0. | 0. |
| 3 | 0. | 153.80 | 0. | 0. | 0. | 0. |
| 4 | 0. | 118.00 | 0. | 0. | 0. | 0. |
| 5 | 0. | 84.600 | 0. | 0. | 0. | 0. |
| 6 | 0. | 53.500 | 0. | 0. | 0. | 0. |
| 7 | 0. | 19.000 | 0. | 0. | 0. | 0. |
| 8 | 0. | -36.500 | 0. | 0. | 0. | 0. |
| 9 | 0. | -95.000 | 0. | 0. | 0. | 0. |
| 10 | 0. | -162.30 | 0. | 0. | 0. | 0. |
| 11 | 0. | -235.00 | 0. | 0. | 0. | 0. |
| 12 | 0. | -286.00 | 0. | 0. | 0. | 0. |
| 13 | 0. | -343.00 | 0. | 0. | 0. | 0. |
| 14 | 0. | -362.00 | 0. | 0. | 0. | 0. |
| 15 | 0. | -381.00 | 0. | 0. | 0. | 0. |
| 16 | 0. | -529.00 | 0. | 0. | 0. | 0. |
| 17 | 0. | -491.00 | 0. | 0. | 0. | 0. |
| 18 | 0. | -453.00 | 0. | 0. | 0. | 0. |
| 19 | 0. | -415.00 | 0. | 0. | 0. | 0. |
| 20 | 0. | -444.00 | 0. | 0. | 0. | 0. |
| 21 | 0. | -415.00 | 0. | 0. | 0. | 0. |
| 22 | 0. | -407.50 | 0. | 0. | 0. | 0. |
| 23 | 0. | -407.50 | 0. | 0. | 0. | 0. |
| 24 | 0. | -362.00 | 0. | 0. | 0. | 0. |
| 25 | 0. | -336.00 | 0. | 0. | 0. | 0. |
| 26 | 0. | -315.00 | 0. | 0. | 0. | 0. |
| 27 | 0. | -286.00 | 0. | 0. | 0. | 0. |
| 28 | 0. | -261.00 | 0. | 0. | 0. | 0. |
| 29 | 0. | -235.00 | 0. | 0. | 0. | 0. |
| 30 | 0. | -198.70 | 0. | 0. | 0. | 0. |
| 31 | 0. | -162.30 | 0. | 0. | 0. | 0. |
| 32 | 0. | -126.00 | 0. | 0. | 0. | 0. |
| 33 | 0. | -80.500 | 0. | 0. | 0. | 0. |
| 34 | 0. | -35.000 | 0. | 0. | 0. | 0. |
| 35 | 0. | 1.9000 | 0. | 0. | 0. | 0. |
| 36 | 0. | 1.9000 | 0. | 0. | 0. | 0. |
| 37 | 0. | 24.500 | 0. | 0. | 0. | 0. |
| 38 | 0. | 1.9000 | 0. | 0. | 0. | 0. |
| 39 | 0. | 1.9000 | 0. | 0. | 0. | 0. |
| 40 | 0. | 23.750 | 0. | 0. | 0. | 0. |
| 41 | 0. | 43.750 | 0. | 0. | 0. | 0. |
| 42 | 0. | 64.000 | 0. | 0. | 0. | 0. |
| 43 | 0. | 64.000 | 0. | 0. | 0. | 0. |
| 44 | 0. | 84.600 | 0. | 0. | 0. | 0. |
| 45 | 0. | 64.000 | 0. | 0. | 0. | 0. |
| 46 | 0. | 98.000 | 0. | 0. | 0. | 0. |
| 47 | 0. | 138.30 | 0. | 0. | 0. | 0. |
| 48 | 0. | 151.80 | 0. | 0. | 0. | 0. |
| 49 | 0. | 151.80 | 0. | 0. | 0. | 0. |

| | | | | | | |
|---|---|---|---|---|---|---|
| 50 | 0. | 151.80 | 0. | 0. | 0. | 0. |
| 51 | 0. | 181.50 | 0. | 0. | 0. | 0. |
| 52 | 0. | 185.80 | 0. | 0. | 0. | 0. |
| 53 | 0. | 240.90 | 0. | 0. | 0. | 0. |
| 54 | 0. | 240.90 | 0. | 0. | 0. | 0. |
| 55 | 0. | 296.90 | 0. | 0. | 0. | 0. |

XMIN= 0.    XMAX= 0.    YMIN= -529.0    YMAX= 296.9    ZMIN= 0.    ZMAX= 0.

PLOT DEVICE 1 DEFINED FOR THIS RUN

***** MATERIAL PROPERTIES (CARD H) *****

MATERIAL 1
EX = 0.260000E 08
ALPX = 0.900000E-05
NUXY = 0.300000
DENS = 0.

***** COUPLED DEG. OF FR. DEFINITIONS (CARD J) *****

| SET | D.O.F. | NUMBER | COUPLED NODES | | | |
|---|---|---|---|---|---|---|
| 1 | UX | 2 | 19 | 21 | | |
| 2 | UY | 2 | 19 | 21 | | |
| 3 | UZ | 2 | 19 | 21 | | |
| 4 | ROTZ | 2 | 19 | 21 | | |
| 5 | UX | 2 | 22 | 23 | | |
| 6 | UY | 2 | 22 | 23 | | |
| 7 | UZ | 2 | 22 | 23 | | |
| 8 | ROTZ | 2 | 22 | 23 | | |
| 9 | UX | 4 | 35 | 36 | 38 | 39 |
| 10 | UY | 4 | 35 | 36 | 38 | 39 |
| 11 | UZ | 4 | 35 | 36 | 38 | 39 |
| 12 | ROTZ | 4 | 35 | 36 | 38 | 39 |
| 13 | UX | 3 | 49 | 50 | 48 | |
| 14 | UY | 3 | 49 | 50 | 48 | |
| 15 | UZ | 3 | 49 | 50 | 48 | |
| 16 | ROTZ | 3 | 49 | 50 | 48 | |
| 17 | UX | 3 | 42 | 43 | 45 | |
| 18 | UY | 3 | 42 | 43 | 45 | |
| 19 | UZ | 3 | 42 | 43 | 45 | |
| 20 | ROTZ | 3 | 42 | 43 | 45 | |
| 21 | UX | 2 | 53 | 54 | | |
| 22 | UY | 2 | 53 | 54 | | |
| 23 | UZ | 2 | 53 | 54 | | |
| 24 | ROTZ | 2 | 53 | 54 | | |

24 COUPLED SETS

***** DYNAMIC DEGREES OF FREEDOM (CARD K) *****

| NO. | NODE | D.O.F. |
|---|---|---|
| 1 | 2 | UX |
| 2 | 3 | UX |
| 3 | 4 | UX |

| | | |
|---|---|---|
| 4 | 5 | UX |
| 5 | 6 | UX |
| 6 | 7 | UX |
| 7 | 8 | UX |
| 8 | 9 | UX |
| 9 | 10 | UX |
| 10 | 11 | UX |
| 11 | 12 | UX |
| 12 | 13 | UX |
| 13 | 14 | UX |
| 14 | 15 | UX |
| 15 | 16 | UX |
| 16 | 17 | UX |
| 17 | 18 | UX |
| 18 | 19 | UX |
| 19 | 20 | UX |
| 20 | 22 | UX |
| 21 | 24 | UX |
| 22 | 25 | UX |
| 23 | 26 | UX |
| 24 | 27 | UX |
| 25 | 28 | UX |
| 26 | 29 | UX |
| 27 | 30 | UX |
| 28 | 31 | UX |
| 29 | 32 | UX |
| 30 | 33 | UX |
| 31 | 34 | UX |
| 32 | 37 | UX |
| 33 | 40 | UX |
| 34 | 41 | UX |
| 35 | 42 | UX |
| 36 | 44 | UX |
| 37 | 46 | UX |
| 38 | 47 | UX |
| 39 | 52 | UX |
| 40 | 53 | UX |
| 41 | 55 | UX |

41 DYNAMIC DEGREES ØF FREEDOM

## PART V: HEAT TRANSPORT SYSTEM COMPONENTS

## SECTION 6: OPERATION WITH COMPONENTS OUT OF SERVICE

CONTENTS



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## FIGURES

# V-6.1

# INTRODUCTION AND SUMMARY

## 6.1.1 INTRODUCTION

During the operating life of the plant, various major components will be out of service from time to time due to forced outages. In order to maximize plant availability, it will be necessary to operate the plant with these components out of service. This results in operation with one or more of the main heat transport loops out of service. Within various constraints, it is desirable to operate the remaining inservice loops at maximum power levels.

This study was conducted to investigate the characteristics, to identify limitations, and to determine potential capacity of plant operation with various combinations of major components out of service. The components and combinations thereof selected were those which would envelope the conditions of plant operation with one or two intermediate heat transport loops out of service. The general combinations of components selected for plant operational outage cases were the following:

1. One IHX out of service.
2. Two IHX's out of service.
3. One primary pump out of service.

An IHX out of service causes the connecting intermediate heat transport loop to also be out of service. This envelops plant operation with an intermediate pump or steam generator out of service. Operation with one or two loops out of service is commonly referred to as N-1 or N-2 operation, respectively. For the pool-type primary system, the N-1 or N-2 designation must refer to the intermediate loops since the pool concept under study by G.E. is a hot/cold pool arrangement having no piped hot leg loops between the primary pumps and the intermediate heat exchangers. For the case with one primary pump out of service, all intermediate loops can be in operation.

The general approach to this study was to conduct plant heat balances for the various operating combinations. This provided the power output capabilities when operating with one or more loops out of service. Various primary flow conditions were investigated to determine the range of primary flow quantities available as limited by such items as NPSH, pump runout, pump speed and power, and relative hot and cold pool level changes. Plant conditions were also calculated for operation at 100% of rated power with one IHX out of service. The conditions determined for all of the operational cases were then studied and compared to known requirements to determine existing problems, operational flexibility, and to recommend items which should be further investigated.

In this section only steady state conditions are considered. The transient effects resulting from the loss of an IHX, primary pump or secondary pump are determined in Part V, Section 8 of this report.

### 6.1.2 SUMMARY

In order to maximize plant energy availability, it will be necessary to operate the plant from time to time with some major components of the heat transport system out-of-service. The maximum achievable energy output depends upon the type of component out-of-service, the stretch capability of the components remaining in service, and the limitations imposed by the heat transport system. Several operational cases were studied, enveloping a variety of components and related loops out-of-service. For these cases, power outputs were determined and component and system imposed limitations were studied, including maximum capability for primary pump runout, primary system hot and cold pool level influence on available NPSH, and the option to vary pump flow to reduce hot pool and core outlet temperatures. Also, the potential to operate the plant at 100% of rated power with one loop out-of-service was investigated.

Operation with one component, either an intermediate heat exchanger or primary pump, out-of-service appears acceptable. Operation with two IHX's out-of-service requires further study due to temperature limitations. The pool-type primary system offers the flexibility to operate all of the intermediate heat exchangers and intermediate heat transport loops when a primary system pump is out-of-service. Loss of one primary pump out of four does not constitute a 25% loss of plant power due to augmented flow possible by virtue of runout capability of the three remaining pumps. It was found that the NPSH available in the cold pool constitutes the most predominate limitation to maximizing power output for operation with one primary pump or one intermediate system loop out-of-service. With slight departures from normal plant full load conditions, it is possible to operate the pool-type plant at 100% power output when one loop is out of service.

## V-6.2

## REQUIREMENTS

In conducting a study of plant operation with major components out-of-service, the following are the requirements which were utilized to guide the study scope of work and to evaluate the resulting characteristics of the operational cases:

- The operational modes should not require major changes to the existing plant equipment or control scheme.
- Plant power output should be maximized to the extent possible when operating with component outages.
- The pool thermal barriers must be effective during all operating modes.
- The potential for thermal transients should be minimized and thermal conditions should not depart substantially from normal operating conditions.
- The cases studied should envelope and typify plant operation involving all types of major components being out-of-service, but compound or simultaneous failures of different types of equipment need not be considered.
- Operational modes of the main sodium pumps for cases requiring stretch flow capability shall not exceed the design conditions of the pumps.

## V-6.3

## CASES STUDIED

The operational cases that were evaluated in this study are the following:

Case I - 1 IHX out-of-service, 100% primary flow, 468.5 MWt/loop*

Case IA - 1 IHX out-of-service, 100% primary flow, 486 MWt/loop

Case II - 2 IHX's out-of-service, 100% primary flow, 436 MWt/loop

Case IIA - 2 IHX's out-of-service, 100% primary flow, 486 MWt/loop

Case III - 1 IHX out-of-service, 83.3% primary flow, 486 MWt/loop

Case IV - 2 IHX's out-of-service, 66.6% primary flow, 486 MWt/loop

Case V - 1 primary pump out-of-service, 85.5% primary flow, 428 MWt/loop

Case VI - 1 IHX out-of-service, 110% primary flow, 571 MWt/loop

Case VII - 1 IHX out-of-service, 110% primary flow, 589 MWt/loop

The heat balance flow and temperature conditions of these cases are given by Figure 1. Cases I through IIA are options which involve running all primary pumps at 100%. This provides greater than normal sodium flow through the operational IHX's, but provides the option to operate with a lower core $\Delta T$ and cooler plant hot leg temperature if desired. Cases III and IV are cases where the primary flow is reduced proportional to the power reduction, one-sixth reduction for one loop out, and one-third reduction for two loops out. Case V represents operation with one of four primary pumps out-of-service. Since the primary pumps and IHX's are not directly coupled with a pipe loop, it is possible in a pool system to operate all IHX's and intermediate heat transport loops when a primary pump is out-of-service. This was done for Case V in order to maximize power output. Cases VI and VII are cases which show the conditions that would have to exist to operate the plant at 100% power with one IHX out-of-service.

*"Loop" in all cases refers to intermediate heat transport loop.

# V-6.4

## DESCRIPTION AND ANALYSIS OF OPERATION

### 6.4.1
### GENERAL

The modes of operation for this study are those which require plant operation with some components out-of-service. In general, this requires reduced power operation except where circumstances can be altered to stretch the plant power output. The modes of operation studied were those cases listed and briefly described in Section V-6.3. These cases will be explained in more detail here along with a discussion of the implications and limitations of each case.

During normal operation there are four primary pumps in the pool-type primary system, six intermediate heat exchangers (IHX's) and six independent intermediate heat transport loops. Any IHX taken out-of-service causes the connecting intermediate heat transport system to be down. An IHX is taken out-of-service by increasing the gas pressure in the IHX until the sodium level is reduced to a level which uncovers the upper tubesheet and thus prevents further flow from the hot pool from entering the IHX upper shroud. Each IHX receives flow from the hot pool. Primary sodium from the hot pool flows in parallel by gravity head through each IHX. There is no pipe coupling between the core outlet flow and IHX inlet.

The four primary pumps all operate in parallel. Sodium is taken from the cold pool and pumped in parallel to the core inlet plenum, and then through the core to the hot pool. There is a shutoff valve integral with each pump in order to prevent sodium backflow when one or more pumps are not operational. It is characteristic of the pool-type plant that one or more primary pumps can be taken out-of-service without losing an intermediate heat transport loop since there is no direct coupling between a pump and an IHX as there is for the loop-type primary system.

### 6.4.2
### CASES I, IA, II, IIA

Cases I, IA, II, and IIA involve operating the plant with one and two IHX's out-of-service. These cases basically differ from Cases III and IV in that the primary flow is maintained at 100%. This represents an upper bound for operational flexibility if desired. It allows operation with reduced core $\Delta T$ and hot pool temperature.

The limitation of operating with 100% primary sodium flow is found in the hot-cold pool level relationship. This relationship was analyzed and reported in Appendix V-6A "Cold Pool Level Analysis", of this report. The basic difficulty of operating with augmented flow through an IHX is due to the greater drop in cold pool level which reduces NPSH available to the primary pumps. This is more pronounced in the hot-cold pool primary system compared to an EBR-II type cold pool system, because 79% of the total hot-colg pool level change occurs as a reduction in cold pool level. This directly reduces the available NPSH. As shown by the level analysis, however, the option is available to operated Cases I, IA, II, and IIA at 100% primary flow without exceeding the available NPSH.

Regarding temperature conditions, augmented IHX flow has the disadvantage of causing a relatively high terminal temperature difference at the cold end of the IHX. Figure 1 shows a terminal temperature range of 68°F to 103°F for these cases. These values are considerably higher than the normal 100% load IHX cold end operating $\Delta T$ of 45°F. However, the log mean temperature difference at these conditions is less than normal operating conditions, due to the decrease in $\Delta T$ at the IHX hot end. It can also be seen that the cold end $\Delta T$ increases as the plant power increases. The $\Delta T$ also increases as the number of IHX's out-of-service increases.

Larger than normal IHX terminal temperature differences have the potential to cause an increase in both steady state and transient induced thermal stresses. Although it is not expected that these temperature conditions cited in Cases I, IA, and II will prevent operational feasibility of these modes, the conditions need to be analyzed for operational validation.

Case IIA shows a cold pool temperature of 652°F, which is almost 60°F above the normal operating temperature at 100% power operation. The effects of this increased temperature on the cold pool support structures and the resulting thermal transients should be determined and evaluated. During a plant scram, the cold pool temperature reduction will be larger when operating in the Phase IIA mode in comparison to normal full power operation.

### 6.4.3 CASES III AND IV

For these cases, the primary flow is reduced in proportion to the power reduction to maintain system temperature conditions equal to those of normal plant full load operation. This has the effect of operating the remaining IHX's and connecting intermediate heat transport loops at their normal full load power, but plant power is reduced by one-sixth for one IHX out-of-service, and one-third for two IHX's out-of-service. Case III is feasible, but further analysis will be required to verify Case IV. The reason for this is that while the temperature of the hot pool is the same as that for full load conditions, cooling flow in the thermal barrier is reduced. These thermal conditions have not yet been calculated for operation with 875°F sodium on the hot pool side and reduced sodium flow through the thermal barrier. Sodium flow through the thermal barrier is nomially 4% of total sodium flow. For Case IV, the flow would be only 2.7% of full load flow conditions.

### 6.4.4 CASE V

Case V involves operating the plant at the largest power possible with the outage of one primary pump. Due to the characteristics of the pool primary system, all of the IHX's and IHTS loops can be operational. Because of this, the largest power achievable for Case V depends upon the maximum flow that can be obtained from the three operational pumps. The determination of maximum flow is shown by the calculation presented in Appendix V-6A "Primary Pump Calculations", of this report. It was found that 85.5% of full load flow can be obtained with three pump operation. The factor that determined maximum flow was the available NPSH offered by the cold pool. A comparison of pump conditions operating under Case V, full load normal conditions, and pump design conditions are as follows:

| | Case V | Normal | Design |
|---|---|---|---|
| Flow | 75,000 gpm | 65,820 gpm | 72,000 gpm |
| Speed | 867 rpm | 870 rpm | 900 rpm |
| Head | 218 ft. | 237 ft. | 250 ft. |
| NPSH (Available) | 47 ft. | 46 ft. | 45 ft. |
| NPSH (Required) | 47 ft. | 40 ft. | 45 ft. |
| Pump Power | 4776 hp | 4557 hp | 6000 hp |

As a byproduct of this analysis, it can be seen from Figure 2 that a loss of one pump would cause the other three operating normally at 870 rpm to run out slightly beyond the pump conditions noted for Case V and the NPSH available would be slightly less than required. The runout deficiency in NPSH would probably be so slight that no action would need to be taken to prevent runout due to loss of only one pump.

The plant power output for Case V is slightly larger than the proportion of primary system flow referenced to normal operation, i.e., 87.4% power, 85.5% flow. This is due to slightly larger ΔT in the PHTS and IHTS systems, made possible by reduced heat transfer duty of the IHX's and steam generators in comparison to the duty at full power operation. The primary system ΔT is about 10°F larger than normal operation. This should not be a restraint since the primary hot leg temperature is under 875°F. In regard to the IHX conditions, the hot and cold end terminal temperature differences and the LMTD are all less than normal full load conditions.

### 6.4.5 CASES VI AND VII

These cases were studied to determine the potential for achieving 100% power output when operating with one loop out-of-service. This was accomplished by lowering the recirculation ratio from 6 to 4 in order to lower the water temperature into the evaporator, and by operating all pumps to produce 10% greater than normal flows. Unlike the loop primary system, the pool-type plant can stretch more because all of the primary pumps theoretically can be operated at full rating when an intermediate loop is out-of-service. For a loop-type primary system, the primary pump in the loop, common to the out-of-service IHX and its directly connected IHTS loop, cannot be operated at all.

As seen from Figure 1, with some departure from normal full power operating conditions, the plant could reach full rated power with one IHX out-of-service. The basic differences between Cases VI and VII is the temperature of intermediate sodium entering the steam generators. For Case VI it is 830°F and Case VII 840°F. The major impediment in reaching 100% power is the deficiency between required and available NPSH, 45 ft. vs 42 ft. respectively. Accommodation of this deficiency would require design changes to the pump or system. The intermediate pumps should not experience NPSH difficulties since system cover gas pressure can be applied with more latitude than is possible in the primary system. Other areas of departure are: higher than normal IHX cold end terminal temperature differences and IHX LMTD. Also the 4:1 in place of 6:1 recirculation ratio is a departure and would reduce the margin between exit quality and the DNB quality.

Since the plant has six intermediate loops, designing to operate at full power with one-loop down is easier and thus more attractive than it would be for a three-loop plant. The idea is attractive from an availability standpoint.

## V-6.5

## CONCLUSIONS AND RECOMMENDATIONS

The operational cases and results are shown in Figure 1. The following conclusions are drawn:

1. For Case III, one of six IHX's out-of-service with plant power and main loop sodium flows equal to 83% of full power, the plant can be operated satisfactorily with no departure from normal full power operating temperatures.

2. For Case IV, two of six IHX's out-of-service with plant power and main loop sodium flows equal to 67% of full power, the ability to operate this case is uncertain due to the fact that heat transfer calculations have not yet been carried out for the existing conditions. The concern exists that the primary vessel wall temperature rise could be excessive due to the reduction in primary sodium flow to the thermal barriers.

3. For Case V, one primary pump out-of-service, the three operational primary pumps can be run out within the allowable constraints to produce 85% of normal full power primary system flow. This allows the plant to also operate at approximately 87% of full power.

4. For Cases I and IA, involving operating the plant with one IHX out-of-service but with 100% primary flow, the option to operate in this mode appears acceptable. A possible limitation requiring further investigation is the larger than normal terminal temperature difference at the cold end of the IHX's. The cold pool temperatures are slightly higher than normal operation, but the increase is not considered significant.

5. For Cases II and IIA, two IHX's out-of-service and primary flow at 100%, the concern of reduced sodium flow through the thermal barrier does not exist. These cases are tentative, however, due to the increases in the cold pool temperature and IHX cold end terminal temperature, both being about 50°F higher than normal full power operating conditions.

6. In situations where it is desirable to extend primary pump flow beyond 100% of normal operating flow, the limiting factor on ultimate capacity is NPSH. The NPSH available to the primary pumps is quite sensitive to the total level swing between the hot and cold pools because the cold pool level assumes about 80% of the total change. For these reasons, the hydraulic conditions of the pool should be accurately determined in the final design, and/or considerable NPSH margin should be provided in the primary pump design.

7. When operating plants with one or more IHX's out-of-service, the pool-type plant can produce more power than a comparable loop-type plant. This is due to the fact that all primary pumps of the pool can be operated under these circumstances because the pumps are not directly coupled to a given IHX. An IHX out-of-service in a loop-type plant also requires shutdown of the primary pump in the same loop.

8. It is possible with slight departures from normal operating conditions to achieve close to 100% power with one loop out-of-service. The only change to the existing plant design needed to achieve a power close to 100% is to provide greater NPSH for the primary pumps, or to design the primary pumps for a lower required NPSH.

The following are recommendations offered based on this report.

1. Since operating flexibility can be enhanced if temperature variations can be permitted in the cold pool, further study of cold pool structures should be accomplished to determine limits on elevated temperature and temperature changes.

2. Analysis of hydraulic characteristics of the hot-cold pool system should be refined and periodically updated to provide accurate and current data to define NPSH requirements for the primary system pumps.

3. In order to enhance operating flexibility, the IHX design should be analyzed to determine the sensitivity and limitations of the design to off-normal hot and cold end terminal temperature differences.

4. Since the potential exists for the pool primary - six intermediate loop plant to operate at 100% power with one loop out-of-service, a trade-off study should be conducted to weigh the value of additional plant availability against the cost of incrementally increasing capacity of the loops.

5. Additional thermal barrier heat transport calculations should be carried out to encompass all thermal-hydraulic conditions possible for part load and component outage operational modes.

## Appendix V-6A

## SYSTEM CALCULATIONS

The calculational work for this study consisted of three basic calculations:

1. Plant conditions for each case.
2. Primary pump calculations.
3. Cold pool level analysis.

These calculations are provided in this appendix.

### CALCULATION OF PLANT CONDITIONS

The plant conditions are shown by Figure 1 for the cases under study as listed in Section V-6.3 of this report. In addition, the normal full load plant conditions with all components in operation are shown for ready reference and comparison. In calculating the thermal-hydraulic conditions, the G.E. computer code STMGEN was used for the steam generator conditions. Gross plant power output was calculated for each case in order to provide relative power among the cases and normal power of 1000 MWe. Net power was not calculated because of time limitations and uncertainties involving parasitic power under part load conditions. In general, net plant efficiency is about 2% less than gross plant efficiency. A value of 34% was used here for gross plant efficiency.

In calculating heat transfer across the IHX tubes, the overall heat transfer coefficient was held constant for each study case. The heat transfer coefficient was that obtained at normal full load operating conditions. This was considered to be sufficiently accurate to establish the trends and characteristics of the plant operating conditions. The overall heat transfer coefficient of the IHX does not change very much with modest sodium flow variations since the tube wall constitutes the largest thermal resistance.

### PRIMARY PUMP CALCULATIONS

This analysis was conducted to determine the maximum flow achievable with three out-of-four primary pumps in service. In Case V of this study, the plant is operated at steady state with one primary pump out-of-service due to an unscheduled outage. The ultimate capacity of the three pumps operating in parallel is limited by one or more of the following factors:

1) The NPSH required vs NPSH available.

2) Maximum power output of the pump motor.

3) Maximum pump speed.

Each of these items is investigated here to determine the maximum primary system flow.

In determining the maximum capability, data relating to system resistance, required NPSH, pump power input, and pump head curves at various speeds are plotted using the usual head vs flow plots for the system resistance and the pump speed-head operating curves. The results are shown by Figure 2. The NPSH required and pump speed operating curves are obtained from the manufacturer's data as found in Reference (1). The system resistance for primary system operation with three pumps in place of four was calculated and will be explained in the following paragraph. The intersection of the pump curves at a given speed and the system resistance curve provides a determination of the NPSH required, pump head and power, and pump flow.

Calculation of system resistance for the pool primary system in which one pump is out-of-service involves determining and adding the resistances of the piping and core pressure drops as a function of flow. The flow capability of three pumps ouf-of-four operation is greater than 75% of full flow because, although the resistance of the individual piping between the pump and core increases, the flow resistance through the core upon loss of one pump is reduced due to the approximate loss of 25% of total core flow. A general form of the equation for calculating the total pressure drop when operating the system with one or more pumps out-of-service was derived resulting in:

$$(\Delta P_t)_{N-N_i} = \left(\frac{Q_p}{Q_{p\ 100}}\right)^2 [(\frac{N-N_i}{N})^2\ 60\text{ psi} + 30\text{ psi}]$$

where N = number of pumps in the system and $N_i$ is the number of pumps out-of-service. The core pressure drop at full load conditions is 60 psi and the pressure drop of piping connecting the pump is 30 psi. The equation

$(\Delta P_t)_3 = \left(\frac{Q_p}{Q_{p\ 100}}\right)^2 (63.75\ \text{psi})$ was used to calculate total system resistance of three pump operation as a function of the ratio of pump flow $Q_p$ at a given flow, to the pump flow ($Q_{p\ 100}$) operating at 100% normal reactor flow-power under four pump operation. For the pool plant, $Q_{p\ 100}$ is 65,820 gpm.

The following set of values were calculated using the above system pressure drop equation for the three primary pump operations.

Table 1

| Flow Per Pump (gpm) | Total ΔP (psi) | Total Head Loss (ft) |
|---|---|---|
| 87,760 | 113.4 | 298 |
| 78,948 | 91.85 | 241 |
| 74,596 | 81.88 | 215 |
| 70,596 | 73.34 | 193 |
| 65,890 | 63.75 | 168 |

The points at which the pump speed-head curves intersect the system resistance curve and the power calculated from these points are as given in the following Table 2:

Table 2

| Pump Speed (RPM) | Head (FT) | Flow (gpm) | Power (HP) |
|---|---|---|---|
| 800 | 179 | 68,000 | 3556 |
| 825 | 200 | 72,000 | 4206 |
| 867 | 218 | 75,000 | 4776 |
| 900 | 238 | 78,500 | 5458 |
| 950 | 263 | 82,500 | 6338 |

Examination of Figure 2 shows that NPSH is the limiting factor in determining maximum pump flow. The conditions of maximum pump flow are 75,000 gpm, 218 ft. total pump head, and 4776 horsepower, all at 867 RPM. The NPSH required and available at this operating point is 47 feet.

Since the three pumps operate in parallel, the total primary sodium flow through the core is 225,000 gpm at cold pool conditions, which is 85.5% of primary core flow under full power conditions. To achieve this total flow, each of the three primary pumps is operated at a flow which is 114% of that which occurs at normal 100% power operation with all four pumps operating.

COLD POOL LEVEL ANALYSIS

In order to determine the primary pump flow capability, it is necessary to know the sodium levels in the cold pool at various operating conditions. Since the primary pump takes suction from the cold pool, the cold pool level directly determines the pump inlet submergence, and thus the NPSH available to the pumps. For Cases I, IA, II, and IIA, the option to operate at 100% primary sodium flow with one or two IHX's out-of-service is investigated. This option would permit operating the plant at reduced core $\Delta T$. Under these conditions, operating 5 IHX's with full primary system flow requires flowing sodium through each IHX at a rate of 120% of normal, and 150% of normal for 4 IHX's in service.

The analysis is carried out by determining the pressure drop of each IHX at the augmented flow conditions and relating this to level changes in the primary vessel's hot and cold pools. Since these two levels constitute free surfaces in the primary vessel, the two surfaces are free to seek a differential level which is a function of the pressure drop through the IHX's, and the relative volumes of sodium in the cold and hot pools.

In Figure 3, the relative hot/cold pool levels are shown. At no flow conditions, the level of the hot and cold pools are equal. During power operation the total differential level between hot and cold pools shown as $h_t$, is determined by the pressure drop through the IHX's. Although the total change in level $h_t$ is equal to the sum of $h_c$ and $h_h$, the rise in the hot pool level ($h_h$) and the drop in cold pool ($h_c$) is determined by the relative displaced volumes of the hot and cold pools. Upon starting the primary pumps, the increase in hot pool level is $h_h = \frac{Vh}{Ah}$, and the decrease in cold pool level is $h_c = \frac{Vc}{Ac}$ where $V_h$ is the increase in sodium in the hot pool to achieve the level rise, and $V_c$ is the decrease in sodium volume of the cold pool to supply sodium for the hot pool level increase. The relationship $V = Ah$ holds for the cylindrical configuration of the primary vessel and cold-hot pool thermal barrier shrouds. Since $V_c = V_h$, $\frac{Ah}{Ac} = \frac{h_c}{h_h}$, which shows that the level change of the hot or cold pool is inversely proportional to the ratio of fluid surface areas

Estimates of the surface areas of the hot and cold pool are $A_h = 3630\ ft^2$ and $A_c = 968\ ft^2$. Thus, $h_c = 3.75\ h_h$. Since $h_t = h_c + h_h$, $h_c = 0.79\ h_t$, $h_h = 0.21\ h_t$.

This shows that the cold pool level constitutes 79% of the total level change. This is an undesirable feature since the cold pool level drop reduces the available NPSH to the primary pump.

The pressure drop of the IHX's, which are hydraulically in parallel, is 2.5 psi or about 6.6 ft. of head at the operating temperature of the sodium and 100% of rated flow. For flows of 120% and 150% of rated through the IHX, the head losses, pressure drops, hot and cold pool level changes would be as given in Table 3. It should be noted that even though the flows are 120% and 150% of rated through the IHX's, the flow through each primary pump remains at 100% of its rated.

Table 3

| | 6 IHX | 6 IHX | 5 IHX | 4 IHX |
|---|---|---|---|---|
| Flow/IHX (%) | 100 | 110* | 120 | 150 |
| $\Delta P$ (psi) | 2.5 | 3.0 | 3.6 | 5.6 |
| $h_t$ (ft) | 6.6 | 7.9 | 9.5 | 14.9 |
| $h_h$ (ft) | 1.4 | 1.6 | 2.0 | 3.1 |
| $h_c$ (ft) | 5.2 | 6.3 | 7.5 | 11.8 |
| NPSH (ft) Available | 46.1 | 45.0 | 43.8 | 39.5 |
| NPSH (ft) Required(1) | 40 | 45 | 40 | 40 |

*Pump flow at 110% of normal full power operating conditions. All other flows shown are 100% flow through each pump.

(1) Taken from Figure on page 11-4-7 of Reference 1.

At pump design conditions the pump requires 45 ft. of NPSH. The system will be designed to provide 45 feet of NPSH at the 110% flow condition. The makeup of this NPSH is 40 ft. due to pressure at the cover gas, and 5 ft. of pump submergence in the cold pool. At 100% flow the reduction in level is one foot less than the 110% so the NPSH available is 46 feet.

The equation for determining the available NPSH as a function of cold pool level drop is $45 + 6.3 - h_c = \text{NPSH}$. For the 4 and 5 IHX cases in the table, the available NPSH becomes, 43.8 ft. and 39.7 ft., respectively.

From the available and required NPSH values for each of the flow conditions as seen from Table 3, it is apparent that the option does exist to operate the primary pumps at 100% when one IHX is out-of-service. The case with two IHX's out-of-service indicates marginally close values between available and required (39.7 ft vs 40 ft), and within the accuracy of these calculations is considered feasible considering that slight design accommodations could be made.

| Items | All Components In Service | N-1 1-IHX 100% Flow | N-1 1-IHX 100% Flow | N-2 2-IHX 100% Flow | N-2 2-IHX 100% Flow | N-1 1-IHX 83.3% Flow | N-2 2-IHX 66.6% Flow | All Loops In Service 1-Pri. Pump 85.5% Flow | N-1 1-IHX 110% Flow | N-1 1-IHX 110% Flow |
|---|---|---|---|---|---|---|---|---|---|---|
| Case Number | Normal Full Load Conditions | Case I | Case IA | Case II | Case IIA | Case III | Case IV | Case V | Case VI | Case VII |
| Gross Power Putout, MWe | 1000 | 801 | 831 | 596.4 | 665 | 833 | 666 | 874 | 977 | 100.4 |
| % Of Plant Rated Power Output | 100 | 80.1 | 83.1 | 59.6 | 66.5 | 83.3 | 66.6 | 87.4 | 97.7 | 100.7 |
| Steam Conditions, psia/°F | 1040/545 | 1043/550 | 1043/550 | 1040/545 | 1042/545 | 1040/545 | 1040/545 | 1043/550 | 1043/550 | 1043/550 |
| Recirculation Ratio | 6/1 | 6/1 | 6/1 | 6/1 | 6/1 | 6/1 | 6/1 | 6/1 | 4/1 | 4/1 |
| Water Into Evaporator, Temp., °F | 529 | 529 | 529 | 526 | 529 | 529 | 529 | 529 | 520 | 520 |
| Primary Sodium Conditions | | | | | | | | | | |
| Hot Leg/Cold Leg Temp., °F | 875/595 | 836/612 | 851/620 | 800/634 | 837/652 | 875/595 | 875/595 | 870/580 | 875/627 | 886/631 |
| Total Primary Flow, lb/hr | $115.47\times10^{6}$ | $115.47\times10^{6}$ | $115.47\times10^{6}$ | $115.47\times10^{6}$ | $115.47\times10^{6}$ | $96.18\times10^{6}$ | $77.0\times10^{6}$ | $98.7\times10^{6}$ | $127.0\times10^{6}$ | $127.0\times10^{6}$ |
| Primary Flow Per Pump, gpm | 65,820 | 65,820 | 65,820 | 65,820 | 65,820 | 54,828 | 43,876 | 75,000 | 72,900 | 72,900 |
| % Of Full Load Operating Flow Per Pump | 100 | 100 | 100 | 100 | 100 | 83.3 | 66.6 | 114 | 111 | 111 |
| NPSH - Available, Ft. | 46 | 44 | 44 | 40 | 40 | 46 | 46 | 47 | 42 | 42 |
| Required, Ft. | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 47 | 45 | 45 |
| Intermediate Sodium Conditions | | | | | | | | | | |
| Hot Leg/Cold Leg Temp., °F | 815/549 | 800/544 | 815/549 | 780/542 | 815/549 | 815/549 | 815/549 | 815/542 | 830/546 | 840/547 |
| Total Int. Flow, lb/hr | $121.73\times10^{6}$ | $101.5\times10^{6}$ | $101.5\times10^{6}$ | $81.2\times10^{6}$ | $81.2\times10^{6}$ | $101.40\times10^{6}$ | $81.15\times10^{6}$ | $104.0\times10^{6}$ | $111.5\times10^{6}$ | $111.5\times10^{6}$ |
| Int. Flow Per Pump/gpm | 45,900 | 45,900 | 45,900 | 45,900 | 45,900 | 45,900 | 45,900 | 39,215 | 50,490 | 50,490 |
| % Of Full Load Operating Flow Per Pump | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 85.5 | 110 | 110 |
| IHX Terminal Temperatures | | | | | | | | | | |
| Hot End $\Delta T$, °F | 60 | 36 | 36 | 20 | 22 | 60 | 60 | 55 | 45 | 46 |
| Cold End $\Delta T$, °F | 45 | 68 | 71 | 92 | 103 | 45 | 45 | 38 | 81 | 84 |
| IHX LMTD, °F | 52 | 42 | 52 | 47 | 46 | 52 | 52 | 46 | 61 | 63 |
| Primary System $\Delta T$, °F | 280 | 224 | 231 | 166 | 185 | 280 | 280 | 290 | 248 | 255 |
| Intermediate System $\Delta T$, °F | 266 | 256 | 266 | 238 | 266 | 266 | 266 | 273 | 284 | 293 |

Case I - 1 IHX* Out-Of-Service, 100% Primary Flow, 468.5 MWt Power/IHX
Case IA - 1 IHX Out-Of Service, 100% Primary Flow, 486 MWt Power/IHX
Case II - 2 IHX's Out-Of-Service, 100% Primary Flow, 436 MWt Power/IHX
Case IIA - 2 IHX's Out-Of-Service, 100 Primary Flow, 486 MWt Power/IHX
Case III - 1 IHX Out-Of-Service, 83.3% Primary Flow, 486 MWt Power/IHX
Case IV - 2 IHX's Out-Of-Service, 66.6% Primary Flow, 486 MWt Power/IHX
Case V - 1 Primary Pump Out-Of-Service, 85.5% Primary Flow, 428 MWt Power/IHX
Case VI - 1 IHX Out-Of-Service, 110% Primary Flow, 571 MWt Power/IHX
Case VII - 1 IHX Out-Of-Service, 110% Primary Flow, 589 MWt Power/IHX

*An IHX Out-Of-Service also negates use of connecting intermediate sodium loop.

Figure 1 Plant Heat Balance For Operation With Major Components Out-Of-Service

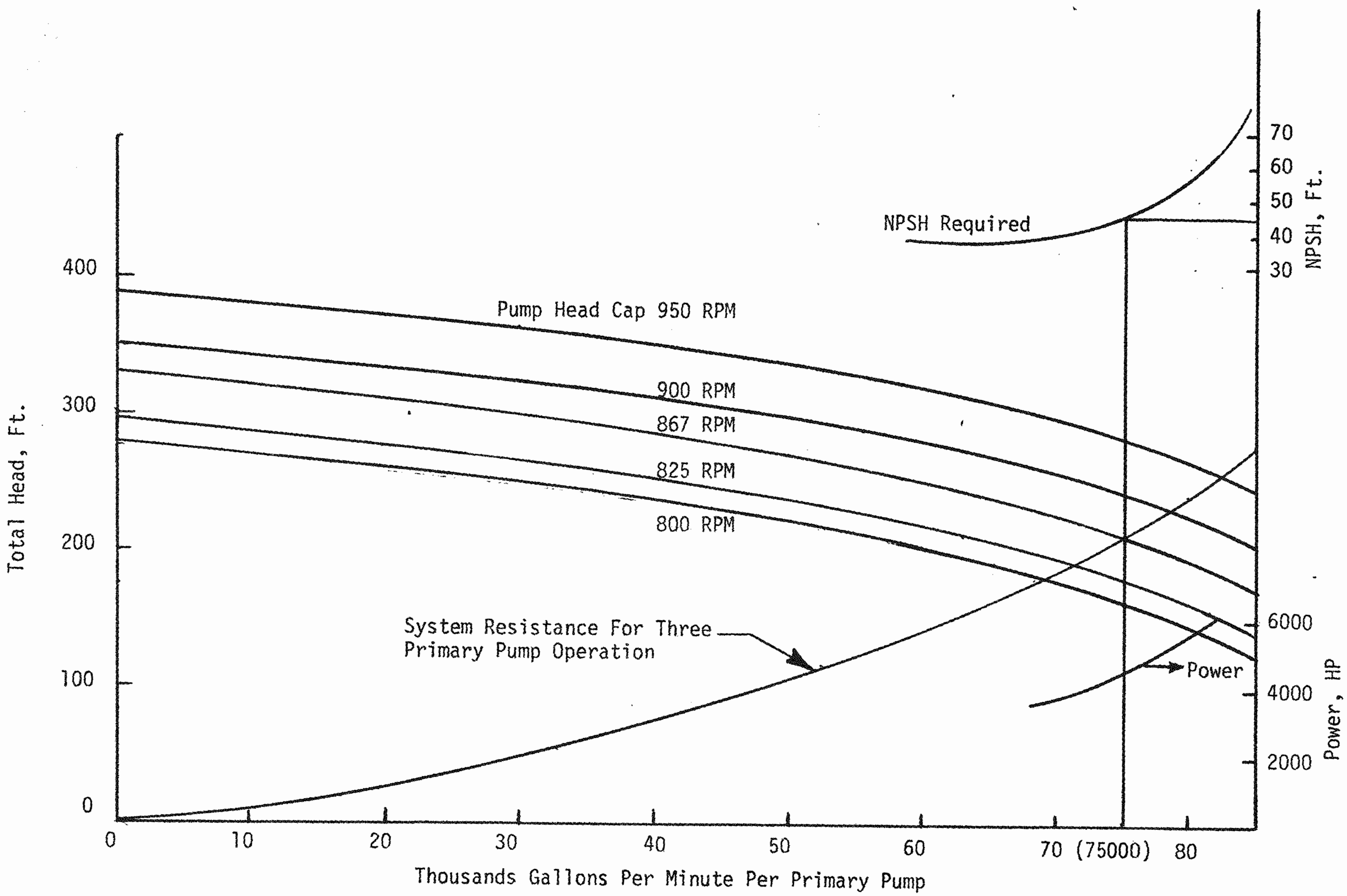


Figure 2 Head vs Flow Curve Pool Primary System Three Primary Pump Operation

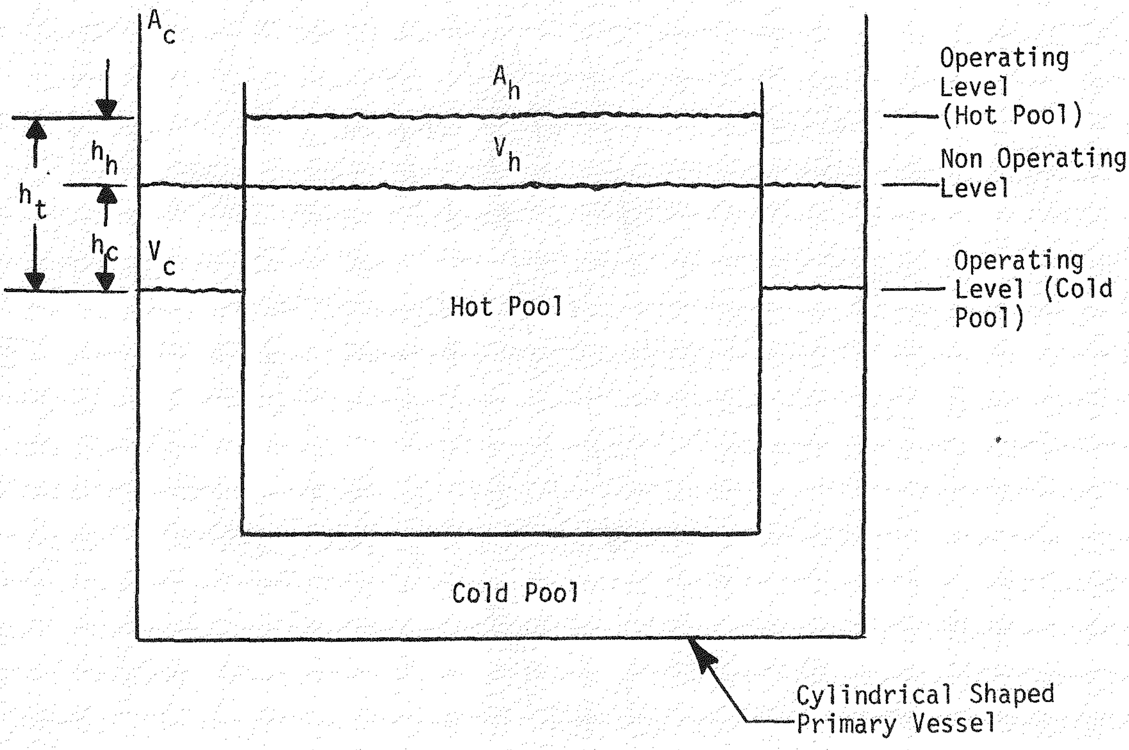


Figure 3 Schematic Diagram Of Primary Vessel Hot And Cold Pool Levels, Volumes, and Surface Areas

## REFERENCES

(1) "Pool-Type LMFBR Plant, 1000 MWe Phase A Design", Part II, Appendix B; EPRI-NP-646, April, 1978.

PART V: HEAT TRANSPORT SYSTEM COMPONENTS

SECTION 7: PLANT DUTY CYCLE

CONTENTS



A table of contents for all volumes of this report appears at the back of each volume.

## V-7.1

## INTRODUCTION AND SUMMARY

This document describes the type of operation and the plant operational transients which will be considered in evaluating and analyzing the structural design of the components of the nuclear steam supply system for the GE/Bechtel design saturated cycle pool-type LMFBR plant. The work reported here is based upon much of the work done for the GE/Bechtel design of the saturated cycle loop-type LMFBR plant's duty cycle.

The selected transients are representative of conditions which are sufficiently severe or frequent to be of possible significance to the cyclic behavior of plant components. The transients described herein are based on conservative assumptions; they are meant primarily for use in component stress analysis and do not necessarily represent actual plant operation. These transients, when used as a basis for component structural design, will provide confidence that the component is appropriate for its application over the design life of the plant.

The duty cycle is based on Phase A Extension I design of the 1000 MWe pool-type LMFBR with variable speed primary and intermediate sodium pumps and recirculation pumps (an option with constant speed pumps is discussed in Appendix V-7-A). For both cases, variable and constant speed pumps, the primary and intermediate sodium flow will be reduced to about 50% of full flow upon reactor scram; pony motors would be depended on in case all off-site power is lost. Important parameters for this design are given in Table 1.

In addition to selected transients there is a listing of seismic events to be analyzed for load combinations.

The Level B events which cause plant shutdowns number 618 in the 40 year design life including 556 reactor trips from full power. There are 12 Level C events and 8 Level D events. Comparison of Level B events for a pool-type LMFBR with those for a loop-type LMFBR reveals that the pool-type plant is at a slight disadvantage for the 40 year design life.

The frequency for the loop-type plant for Level B service includes 459 reactor trips from full power. The frequency totals are less that those for a pool plant but the consequences for a loop plant may be more severe.

In this section only the number and kinds of plant transients are considered. Thermal effects resulting from many of the transinets are discussed in Part V, Section 8.

Table 1

SATURATED POOL CONFIGURATION

| | |
|---|---|
| Primary Pumps | 4 |
| IHX's | 6 |
| Per Intermediate Loop: | |
| Evaporators | 1 |
| Superheaters | 0 |
| Steam Drums | 1 |
| Recirc. Pumps* | 1 |
| Dump Valves | 1 |
| Isolation Valves | 2 |
| Power Relief Valves | 1 |
| Turbine - Generators | 1 |
| Turbine - Generator Bypass | 45% |
| Steam Generator Tubes | Double Wall |
| Primary Pump* | Cold Leg |
| Intermediate Pump* | Cold Leg |
| Feedwater Pumps | 2 Feeding all 6 Loops Simultaneously; Turbine Driven; Capable of 75% Flow each; 2 Auxiliary Pumps Capable of 5% Flow each. |

*Variable Speed;
See Appendix V-7-A for constant speed option

## V-7.2

## PLANT OPERATION

The plant will operate as a base-loaded plant but will be capable of part-load operations during its forty (40) year design life. The plant will not be operated as a load-follow plant, i.e., respond directly to the utility system's demand. The plant will be capable of changing loads between 60% and 100% at rates determined by the plant operators. The maximum rate is still to be determined, but is tentatively taken as ±3% per minute.

The plant will be capable of a weekly plant loading and unloading from 60% to 100% as desired. Load changes between 60% to 100% take place at a continuous ramp power change rate not to exceed ±3% per minute. For the range of 10% to 60% the load, changes take place at power change rates less than ±0.25% per minute. The design weekly load cycle is shown in Figure 1. The design load factor for this loading is 94%. With the expected availability factor of 85%, the design plant capacity is 80%.

The NSSS shall be designed for a service life of 40 years comprised of the following operating conditions:

| CONDITION | HOURS | YEARS |
|---|---|---|
| 100% Power Operation | 252,831 | 28.8 |
| 80% Power Operation | 884 | 0.1 |
| 60% Power Operation | 42,432 | 4.9 |
| 40% Power Operation | 877 | 0.1 |
| Hot Standby, 7% flow, 550°F | 9,936 | 1.1 |
| Refueling, 7% flow, 550°F | 28,800 | 3.3 |
| Maintenance, Drained, Ambient | 14,880 | 1.7 |
| Total Life | 350,640 | 40.0 |

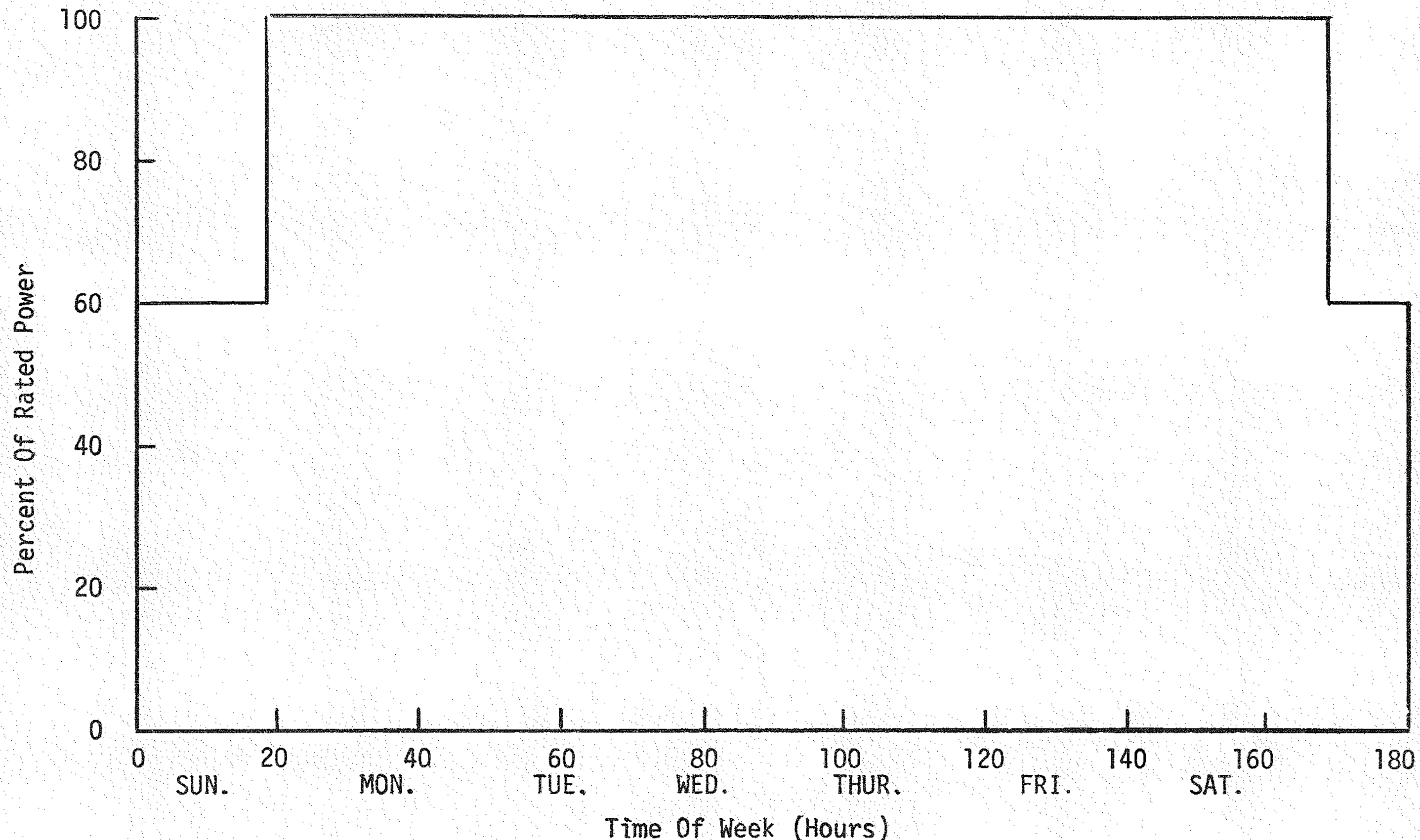


Figure 1 Load Cycle Variable Speed

V-7.3

## LEVEL A SERVICE LIMITS (NORMAL CONDITIONS)

### 7.3.1 DEFINITIONS

According to Section III of the American Society of Mechanical Engineers' Boiler and Pressure Vessel Code, Level A Service Limits are all loadings to which the component may be subjected in the performance of its specified service function. This was formerly referred to as Normal Conditions which were any condition in the course of system startup, operation in the design power range, hot standby and system shutdown, other than Upset, Emergency, Faulted or Testing Conditions.

According to the American National Standards Institute (ANSI); Standard N18.2: "Condition I (normal operation) occurrences are operations that are expected frequently or regularly in the course of power operation, refueling, maintenance, or maneuvering of the plant".

### 7.3.2 EVENTS

Frequencies for Category A events are given in Table A-1.

A-1 - Dry System Heatup and Cooldown

At the present stage of the large pool-type LMFBR design the exact methods for heating the dry system and filling with hot sodium have not been defined. However it is probably safe to say that it will not be accomplished by electrically heating the primary vessel exterior, because of the large size of the vessel and internals. Following heatup, the primary and intermediate systems will be filled with ∿400°F sodium.

A-2 - Startup From Refueling or Hot Standby Temperatures

The plant startup from 550°F to the temperatures that exist at the beginning of the normal operating range, 60% power, is accomplished at 0.25%/min. power change. Below are tabular values of important parameters during this process.

| TIME | REACTOR POWER | PRIMARY SODIUM PUMP SPEED | INTERMEDIATE SODIUM PUMP SPEED | RECIRCULATION PUMP SPEED | STEAM PRESSURE |
|---|---|---|---|---|---|
| (hrs.) | (%) | (%) | (%) | (%) | (psia) |
| 0 | 0 | ∿66 | ∿72 | Variable* | 1015 |
| 4.0 | 60 | ∿66 | ∿72 | 100 | 1015 |

*The present design has variable speed recirculation pumps which will maintain a recirculation ratio near 6:1. This is necessitated by use of a BWR steam drum but steam drums can be designed to accommodate two speed recirculation pumps.

## A-3 - Normal Shutdown

The normal shutdown from temperatures existing at the lowest point of the normal operating range, 60% power, to 550°F is accomplished at 0.25%/min. power change. Below are tabular values of important parameters during this process.

| TIME | REACTOR POWER | PRIMARY SODIUM PUMP SPEED | INTERMEDIATE SODIUM PUMP SPEED | RECIRCULATION PUMP SPEED | STEAM PRESSURE |
|---|---|---|---|---|---|
| (hrs.) | (%) | (%) | (%) | (%) | (psia) |
| o | 60 | ∿66 | ∿72 | 100 | 1015 |
| 4.0 | 0 | ∿66 | ∿72 | Variable* | 1015 |

Decay heat removal is normally through the steam generator, bypassing turbine steam flow to the condenser.

*The present design has variable speed recirculation pumps which will maintain a recirculation ratio near 6:1. This is necessitated by use of a BWR steam drum but steam drums can be designed to accommodate two speed recirculation pumps.

## A-4 - Loading and Unloading

The plant design loading and unloading events are conservatively represented by a continuous and uniform ramp power change of less than 3% rated power per minute between 60% load and full load. Load changes in this region are accomplished by linearly varying primary and intermediate sodium flows with power while holding turbine inlet pressure and temperature constant.

A-5 - Steady-State Temperature Fluctuations

This event consists of the sodium temperature variations produced by power and flow fluctuations within the plant control system deadbands. This fluctuation is taken to be ±12°F for the primary and ±15°F for the intermediate loop for $1 \times 10^7$ cycles. Since the system is not expected to exhibit major temperature variations within the control deadband, this frequency is considered to be conservative.

A-6 - Steady-State Flow Induced Vibrations

This event consists of the vibrations in the system produced, for example, by the fluctuations in sodium pressure due to the interaction between the vanes in the impellers and the turning and diffusion vanes in the pumps.

A-7 - Loop Out of Service

The plant may be operated at a reduced power level with a single primary pump or one or two IHTS loops out of service for limited periods of time. This will be accomplished by a method which will result in minimum effects on the active components.

# LEVEL B SERVICE LIMITS (UPSET CONDITIONS)

## 7.4.1 DEFINITIONS

According to the ASME, Level B Service Limits are all specified loadings which the component or support must withstand without damage requiring repair. These were previously considered Upset Conditions which are "any deviation from Normal Conditions anticipated to occur often enough that design should include a capability to withstand the conditions without operational impairment. The Upset Conditions include those transients which result from any single operator error or control malfunction, transients caused by a fault in a system component requiring its isolation from the system and transients due to loss of load or power. Upset Conditions include any abnormal incidents not resulting in a forced outage and also forced outages for which the corrective action does not include any repair of mechanical damage. The estimated duration of an Upset Condition shall be included in the Design Specifications."

According to ANSI Standard N18.2, Condition II, Incidents of Moderate Frequency: "Condition II occurrences include incidents, any of which may occur during a calendar year for a particular plant."

## 7.4.2 EVENTS

Frequencies for Category B events are given in Table A-1.

### B-1 - Reactor Trip

This transient category includes anticipated trips due to malfunctions (including rapid reactivity transients) which cause a Plant Protection System (PPS) trip level to be exceeded, as well as spurious trips covering those situations in which a PPS trip level is not actually exceeded but a trip occurs due to a fault in the control system or the plant instrumentation.

### B-1a - Reactor Trip From Full Power With Nominal Decay Heat

This transient involves a trip of the reactor (release of primary and secondary rods) followed in less than 500 msec by the tripping of the main sodium pumps to half speed. The turbine is tripped when the turbine throttle admission pressure decreases to a low pressure trip setting. The initial decay heat level for this transient is nominal decay heat which is associated with a reactor in operation for a significant time.

B-1b - Reactor Trip from Full Power with Minimum Decay Heat

The operational sequence of event B-1a is assumed for this transient. Minimum decay heat levels are to be used. Minimum time to reach full power level and appropriate uncertainties are to be used in calculating the minimum decay heat.

B-2 - Uncontrolled Control Rod Movement

This is a general category of events which result from control system malfunctions. The B-2 category includes four events: an uncontrolled rod insertion from full $\Delta T$ initial conditions, an excessive startup step power change, and two rod withdrawal cases. These events are identified in the duty cycle to provide assurance of their consideration in the overall transient analysis task and as a basis for the determination of plant protection system requirements.

B-2a - Uncontrolled Rod Insertion

A single rod is inserted at a rate which causes a 40% per minute reduction in thermal power due to an assumed malfunction of the controller on that rod. (This event is not to be confused with a rod drop, which is an unlatching of the rod resulting in a free fall of the control rod.) The sodium flows and the turbine admission valve inlet pressure are held constant. It is assumed that this event occurs when full system $\Delta T$'s are present. The thermal power level at the beginning of the transient is 100%. The operator manually trips the plant at 300 seconds.

B-2b - Uncontrolled Rod Withdrawal from Startup with Automatic Trip

The initial conditions for this event are hot standby with minimum decay heat. Primary and intermediate main pump motors are operating at $\sim$66 and $\sim$72% speed respectively. Uncontrolled withdrawal of one control rod at ∿0.5% nuclear power/second then occurs. During the withdrawal, all sodium flows remain at initial values. A reactor trip is initiated by the rapid increase in reactivity trip.

B-2c - Plant Loading at Maximum Rod Withdrawal Rate

From initial plant conditions of 60% reactor thermal power, ∿60-70% sodium flow, and ∿60% electrical output, the station supervisory controller requires the plant to increase in load. During the rod withdrawal, a mechanical malfunction results in maximum mechanical rod withdrawal speed. Sodium flows and reactor power increase from 60% to 100% at a rate greater than 3% per minute. The turbine increases output at the same rate. Feedwater flow will be a function of steam flow. No trip occurs.

B-2d - Reactor Startup with an Excessive Step Power Change

During a normal startup, as defined in event A-2a, there is a power change resulting in temperature changes at a rate of 1°F/second for 50 seconds followed by a constant reactor outlet temperature for 1150 seconds. No action required. These events are part of the startups specified for event A-2a and should not be added as separate startups.

B-3 - Complete or Partial Loss of One Primary Pump

There are two events in the category: partial loss of primary flow for one pump and the loss of power to one primary pump main motor.

B-3a - Partial Loss of Primary Pump

The primary flow for one pump is assumed to decrease from 100% to a level immediately above the trip settings due to a ramp down in pump speed. The primary sodium flows for the three unaffected pumps as well as the intermediate flows in all six loops remain at their initial values. No action is taken to terminate the event for 10 minutes. A manual trip terminates the event at that point. This transient provides an envelope to encompass control malfunction and operator errors causing mismatches in the primary to intermediate flow ratio at design values. The transient will result in an increased reactor outlet temperature and a redistribution of temperatures within the IHXs.

B-3b - Loss of Power to One Primary Pump

One primary pump is assumed to coastdown to pony motor speed. The other primary pumps are assumed to operate at their initial values. The intermediate pump speeds in all loops remain at initial values until reactor trip. Following the reactor trip, the remainder of the pumps and the steam/water side are treated as for normal scram.

This transient provides an envelope to encompass those events that would cause the pump to be tripped or those which result from control failures more severe than those in B-3a or from significant operator errors in controlling primary loop flow.

B-4 - Complete or Partial Loss of One Intermediate Pump

There are two events in this category: a partial loss of intermediate flow in one loop, and the coastdown of one intermediate pump to pony motor speed.

B-4a - Partial Loss of Intermediate Pump

The intermediate flow in one loop is assumed to ramp down at 1% per second from 100% flow to the flow level just above that which would cause a trip on high IHX primary outlet sodium temperature. All other flows remain controlled at their initial values. No action is taken to terminate the event for 10 minutes. At this point, the incident is terminated by a manual trip.

B-4b - Loss of Power to One Intermediate Pump

The intermediate pump in one loop is assumed to coastdown to pony motor speed. The other primary and intermediate pump speeds are assumed to remain at initial values until the reactor/pump trip. A reactor trip is initiated by pump under voltage relays or pump drive shaft tachometers. Following the trip, the remainder of the pumps and the steam/water side are treated as for the normal trip.

B-5 - Trip of One Steam Driven Feedwater Pump

The steam plant is assumed to include two 75% capacity (of full flow) turbine driven feedwater pumps and two 5% capacity auxiliary feedwater pumps. Upon loss of one operating feed pump a reactor trip will occur on low drum level. The remaining feedwater pump will be turned off and the auxiliary feedwater pump turned on to maintain adequate water inventory for decay heat removal.

B-6-Sodium Pump Speed Increases

B-6a - Primary Pump Speed Increase

The event is assumed to involve a control system malfunction that demands 100% from an initial condition of ∿66% primary flow and 60% reactor power. All primary pumps increase their speeds at a rate of 1% per second. If no trip levels are reached, manual trip in 300 seconds is assumed. The event results in a down ramp of core outlet temperature. This event provides envelope coverage for speed increase of a single pump under the same conditions as well as for startup of a main pump motor from pony motor speed.

B-6b - Intermediate Pump Speed Increase

This event assumes an increase in all intermediate pump speeds from an initial condition of ∿72% flow and 60% reactor power at a rate of 1% per second. Manual trip at 300 seconds is assumed. This event provides envelope coverage for speed increase of a single intermediate pump under the same conditions as well as for startup of a main pump motor from pony motor speed.

B-7 - Primary Pump Reduced Speed Failure

Following a normal plant trip, the reduced speed for one of the primary pumps fails to operate. The affected pump coasts down to pony motor speed. Pumping action in the other pumps results in flow reversal in the affected pump. The flow in the unaffected pumps is assumed to continue as it would following a normal trip.

B-8 - Intermediate Pump Reduced Speed Failure

Following a normal plant trip, the reduced speed for one of the intermediate pumps fails to operate. The affected pump coasts down to pony motor speed.

B-9 - Inadvertent Closure of Steam Generator Water-Side Isolation Valve

This event category includes single loop steam-side isolation valve closures.

B-9b - Single Loop Saturated Steam Line Isolation Valve Closure

For one loop a normally open outlet isolation valve on the saturated steam line is assumed to instantaneously close. The steam flow from the affected loop will stop, resulting in a pressure and temperature increase in the affected loop. Turbine steam flow will be reduced accordingly. Steam flow will be re-established through the steam line safety relief valves. A manual reactor trip is assumed at 300 seconds.

## B-10 - Isolation and Blowdown of Steam Generator Components

The events are assumed to be initiated by operator action or spurious activiation caused by equipment failure. This transient results in the water-side isolation and dumping of the steam generators in an individual loop. The water-side of the drained component is filled with nitrogen gas at 300 psig to maintain water-side pressure higher than the sodium side.

The event is assumed to be initiated by instantaneous closure of the normally open isolation valves in affected loop feedwater and steam lines. Simultaneously, the inlet water dump and power relief valves in the affected loop are assumed to open. The steam/water side pressure decreases until the power relief and pump valves shut. The modules are then pressurized on the water/steam sides with nitrogen at 300 psig. A reactor trip is assumed to occur based on low steam drum level. The event is characterized by an up-transient of the affected steam generator and its intermediate sodium loop. The unaffected loops see transients similar to a reactor trip from full power.

## B-11 - Loss of Feedwater Flow to One Steam Generator Loop

This event is specified as an inadvertent closure of the feedwater control valves or isolation valve to one of the steam generator loops. The reactor will trip on low steam drum level. The transient results in water-side dryout of the affected loop.

## B-12 - Feedwater Throttle Valve Failed Open

This event assumes that the feedwater control valve for one steam generator fails in the open position with the plant at 100% power. The plant will be tripped manually in 300 seconds.

## B-13b - Turbine Trip with Reactor Trip

This event assumes that the turbine is tripped from full power (turbine stop valves close instantaneously). This causes the steam flow to decrease to zero initially. The steam system pressures then increase and the steam generator outlet pressure relief valves open, returining the steam flow to about 100%. A reactor trip occurs coincident with turbine trip. The sodium pumps coastdown to half speed, and steam flow and pressure are reduced. The steam generators see down transients in sodium temperature similar to the Reactor Trip from Full Power.

B-14 - Loss of All Off-Site Power

Loss of main sodium pump motor power occurs and the sodium flow will decrease to pony motor flow (driven by emergency power) in all loops.

A reactor trip, loss of main condenser and turbine trip follow. Two auxiliary feed pumps (of 5% capacity each) are available to initially maintain feed flow. Sufficient stored water is available to make up for water lost to remove decay and stored heat by dumping steam until the Reactor Auxiliary Cooling Systems are brought on-line.

B-15 - Turbine Bypass Valve Openings

B-15a - Inadvertent Opening of One Turbine Bypass Valve

From initial power operation, it is assumed that one turbine bypass valve is fully opened. The bypassing of the steam results in a demand to increase steam flow from the steam generators. The excess steam to intermediate sodium flow results in a decrease of steam pressure at the steam generator outlet. The control system decreases the main turbine steam flow to compensate. For conservatism a manual trip at 300 seconds is assumed.

B-15b - Turbine Bypass Valve Fails Open Following Reactor Trip

This transient is included as it is representative of the transients that can blow down and cool the steam generating system. Following reactor and subsequent turbine trip, the steam bypass system is used to maintain correct steam pressures and flows. Failure of a valve in this system in the open direction causes excessive steam flow with decreasing steam generator pressures and temperatures. The feedwater system will supply adequate water. It is assumed that after 10 minutes operator action results in closure of the bypass valve or a series isolation valve.

B-16 - Inadvertent Opening of Steam Generator Outlet Steam Line Safety/Power Relief Valves

A steam relief valve opening at a steam generator outlet steam line is assumed to occur. Loop steam flow will increase, but turbine steam flow will decrease. It is assumed that the valve cannot be closed, and at 600 seconds the plant is manually tripped.

Affected loop feedwater is shut-off to limit loss of water inventory. This event will be used to provide coverage for small steam line breaks up to a size to be determined later.

B-18 - Inadvertent Opening of a Steam Generator Water Dump Valve

A dump valve in one steam generator loop opens instantaneously. The feedwater system increases flow attempting to maintain the steam drum level. If scram is not initiated on low drum level, a manual scram at 600 seconds is assumed. It is assumed that the valve cannot be closed and the affected loop feedwater is shut-off to limit affected loop blowdown. Steam-side dryout of the affected loop follows. This event will be used to provide coverage for small water line breaks up to a size to be determined later.

B-19 - Inadvertent Activation of Primary Reactor Auxiliary Cooling

With the plant operating at full power, one PRACS loop is accidently activated. Operation continues for 5 minutes at which time the PRACS loop is manually shut-down by the operator. No plant trip occurs.

B-20 - Plant Shutdown in Response to Small Sodium-Steam/Water Leak Indication

This transient describes plant shutdown and affected loop depressurization for those sodium leak indications where immediate isolation and blowdown are not considered necessary but where a normal shutdown sequence is considered to be too slow.

The operational sequence will first reduce the system temperature differentials so that the thermal transients resulting from blowdown and dryout of the affected loop will be reduced. For defining this transient, an initial reactor trip is assumed, followed by affected loop isolation and blowdown/dump when loop $\Delta T$'s are $\leq$ 100°F. Steam system pressures and temperatures will then be reduced at normal shutdown rates until hot standby refueling conditions are reached.

B-22 - Loss of One Recirculation Pump

Each loop is equipped with one recirculation pump which circulates water providing a recirculation ratio of ~6:1 at full loop power. This event assumes instantaneous stoppage of the recirculation pump in one loop. The event includes loss of power to the pump, shaft seizure, and other pump malfunctions resulting in loss of forced recirculation through the evaporators. The natural circulation following the pump loss is sufficient to maintain a two-phase flow through the affected loop evaporators and no significant thermal transient results. It is assumed that operator action to unload to 60% power (as in event A-4) and shutdown to hot standby/refueling temperatures (as in event A-3A) follows.

This event is included as part of the unloading and shutdown events A-4 and A-3a and should not be included as a separate shutdown.

B-23 - Uncontrolled Control Rod Movements

B-23a - Uncontrolled Rod Withdrawal from 100% Power

An uncontrolled withdrawal of one control rod causes the reactor power to increase at a rapid rate from 100% to 115% (just below the high flux trip point.) A manual reactor trip occurs after 5 minutes. Sodium flows are maintained at initial values until the trip occurs. Initial decay heat level is the nominal level. The transient results in temperatures similar to a normal trip, but from higher initial values.

B-23b - Uncontrolled Rod Withdrawal from Startup to Trip Point with Delayed Manual Trip

The initial conditions for this event are hot standby with nominal decay heat. Primary and intermediate main pump motors are started and sodium flows are increased to $\sim$66 and 72% in the primary and intermediate loops respectively. Uncontrolled withdrawal of one control rod at greater than 0.5% nuclear power/second then occurs. The power ramp is terminated just before any trip point is reached. After 5 minutes, the event is terminated by a manual trip.

## LEVEL C SERVICE LIMITS (EMERGENCY CONDITIONS)

### 7.5.1 DEFINITIONS

According to the ASME Code, Level C Service Limits are all loadings which permit large deformations in areas of structural discontinuity. The occurrence of stress to Level C Limits may necessitate the removal of the component from service for inspection or repair of damage to the component or support. This was formerly referred to as Emergency Conditions which are "those deviations from Normal Conditions which require shutdown for correction of the conditions or repair of damage in the system. The conditions have a low probability of occurrence but are included to provide assurance that no gross loss of structural integrity will result as a concomitant effect of any damage developed in the system. The total number of postulated occurrences for such events shall not cause more than 25 stress cycles having an $S_a$ value greater than that for $10^6$ cycles from the applicable fatigue design curves of Figure I-9.0 (ASME B&PV Code, Section III)."

According to ANSI N18.2, Condition III occurrences include incidents, any one of which may occur during the lifetime of a particular plant.

### 7.5.2 FREQUENCY

Since the individual Emergency events are not expected to occur, the number of event occurrences specified as a design basis is based on conservative judgement. Therefore, it is recommended that each plant component be designed to accommodate five occurrences of the most severe Emergency event, plus two consecutive occurrences of the most severe event (or conservative occurrences of two unlike events if the unlike events provide a more severe effect than consecutive occurrences of the most severe event).

All emergency events that result in a reactor trip shall be considered to result in a transient followed by a cooldown to hot standby/refueling conditions.

7.5.3
EVENTS

C-1 - Primary Pump Mechanical Failure

The event involves an instantaneous stoppage of the impeller of one primary pump while the system is operating at 100% power. The failure may be a seizure or breakage of the shaft or impeller. Primary system sodium flow in the affected pump and piping decreases rapidly. A reactor trip will be initiated by the rapid decrease in inlet plenum pressure.

C-2 - Intermediate Pump Mechanical Failure

The impeller of one of the intermediate system pumps is assumed to stop, causing the flow in that loop to decrease rapidly and a reactor trip is initiated.
The event is characterized by an up transient in the IHX primary outlet of the affected loop and by down transients to the steam generator modules of the affected loop, since intermediate flow is limited to that produced by natural circulation.

C-4 - Loss of Feedwater Flow to All Steam Generators

This transient includes two cases: (a) loss of one feedwater pump with failure of its outlet check valve and (b) loss of feed pump suction. A reactor trip will be initiated on low steam drum level. Dryout of the water side of all steam generators is assumed. The RACS is used to remove stored and decay heat in the system.

C-5 - Rupture Disk Failure in Sodium - Water Reactor Protection System

Flow of intermediate sodium or cover gas through the failed rupture disks will initiate plant trip based on pressure sensors downstream of the double rupture disk and activation of the steam generator water side blowdown system as in event B-10. The affected steam generators will be automatically isolated and blown down. Pressure and temperature builds up in the sodium-water reaction products relief system (SWRPRS) downstream of the rupture disks.

C-6 - Water-Steam Isolation & Dump of a Steam Generator with Failure of an Outlet Isolation Valve to Close

If the outlet isolation valve fails to close, the transient is essentially the same as B-9 since there is a check valve downstream of the outlet isolation valve and the check valve stops backflow from the main steam header.

C-7 - Water Side Isolation of a Steam Generator Module with Failure of the Dump Valves to Open

This transient assumes the same conditions as B-10 except the water and steam dump valves at the steam generator fail to open. The water/steam flow will stop and the input heat will raise the pressure until the saturated steam line safety relief valves open, drying the units at pressure (instead of a dump and dryout at low pressure).

For the unaffected loops, the event is similar to a reactor trip from full power. Decay heat removal is maintained through the unaffected loops.

C-8 - Closure of a Steam Generator Outlet Isolation Valve with Failure of One Relief Valve to Open

This transient assumes a saturated steam line isolation valve in one loop has closed as in B-9b. However, due to a delay in the opening time or failure of the safety relief valve with the lowest pressure setting to open, the pressure in the steam generator reaches a peak pressure greater than in B-9b before sufficient valves open to relieve the steam generated. The transient is assumed to be the same as B-9b for the remainder of the system.

C-11 - Natural Circulation

From initial conditions of full power operation, complete loss of forced sodium circulation in all primary and intermediate systems is assumed. A reactor trip is initiated. The turbine trips on low pressure. Following the turbine trip steam pressure increases. Sodium pumps coastdown and stop, and natural circulation flow is established in all sodium loops and the steam recirculation loops. Feedwater is initially available for plant heat removal. Terminal conditions include decay heat removal through the RACS if the feedwater supply has been exhausted.

C-12 - Natural Circulation with Three Primary Pumps

From an initial condition of three primary pumps operating and the plant at reduced power, complete loss of forced sodium circulation is assumed. A reactor trip is initiated. Steam is relieved through the power operated relief and/or safety valves. The three primary pumps coast down and stop, and natural circulation flow is established. Feedwater is initially available for plant heat removal. Terminal conditions include decay heat removal through the RACS if the feedwater supply has been exhausted.

C-13 - RACS Activation 24 Hours After Scram

This event postulates that none of the main heat transport systems are available for decay heat removal following plant cooldown. It assumes that the plant has been tripped and that 24 hours later, with the system temperatures brought to the hot standby temperature of ~550°F the main heat sink is lost and the RACS is activated. The resulting system temperatures following initiation of the RACS are based on full power operation prior to scram and maximum decay power. Primary system sodium temperatures are based on the heat capacity of the reactor assembly. At least one primary pump is assumed to be operating at pony motor speed to assure mixing of the primary sodium. Intermediate system sodium temperatures are based on the heat capacity of the reactor assembly and one intermediate loop.

C-15 - Design Basis Steam Generator Sodium-Water Reaction

This event consists of a postulated instantaneous double-ended guillotine rupture of a steam generator tube. This results in rupture disk actuation, automatic isolation and blowdown of the affected steam generator, and may result in manual activation of the sodium dump system in the affected intermediate loop. In addition, a trip of the reactor, turbine, and sodium pumps occurs. The intermediate sodium system experiences a pressure transient resulting from the reaction. Pressure and temperature build-up in the sodium-water relief system downstream of the rupture disk.

The plant is tripped on the same signal which activated the emergency blowdown system. For the unaffected loops, the event is similar to a reactor trip from full power. Decay heat removal is maintained through the five remaining loops.

This event is classified as a Level D Service Event for the affected steam generator module and the injected reaction products separation tank. For the rest of the loop, (and plant) the occurrence is classified as a Level C Service Limit Event.

C-16 - Plant Shutdown in Response to Sodium/Water Leak Indication

This transient describes manual plant shutdown and affected loop depressurization for those water-to-sodium leak indications where immediate isolation and drainage is considered necessary to prevent wastage producing a large leak which will cause the rupture disks to blow.

A reactor trip is initiated by the operator following the alarm from the steam generator leak detection system or by an automatic trip. Following trip, affected loop feedwater isolation valves are closed and the loop will be blown down using the steam generator water dump valve and saturated steam line power relief valves. This is followed by intermediate loop drain and cooldown. The temperatures and pressures of the unaffected loops will be reduced at normal shutdown rates until hot standby/refueling conditions are reached. The system response is similar to the B-10 event.

## V-7.6

## LEVEL D SERVICE LIMITS (FAULTED CONDITIONS)

### 7.6.1 DEFINITIONS

According to the ASME Code, Level D Service Limit events permit gross general deformation with some consequent loss of dimensional stability and damage requiring repair, which may require removal of the component from service. These events were formerly referred to as Faulted Conditions, which are those conditions or combination of conditions associated with extremely low probability postulated events whose consequences are such that the integrity and operability of the system may be impaired to the extent that considerations of public health and safety are involved. Such considerations require compliance with safety criteria as may be specified by jurisdictional authorities.

According to ANSI Standard N18.2, "Condition IV occurrences are faults that are not expected to occur, but are postulated because their consequences would include the potential for the release of significant amounts of radioactive material. Condition IV faults are the most drastic that must be designed against, and thus represent the limiting design case."

### 7.6.2 FREQUENCY

These events are postulated to occur once in the 40 year plant design life.

### 7.6.3 EVENTS*

<u>D-1 - Main Feedwater Line Rupture</u>

This event will cause loss of feedwater flow to all steam generators and water side dry out. A reactor trip will be initiated on low steam drum level. The RACS is used to remove stored and decay heat.

*The Level D Service Limit steam side line break events provide coverage for complete double-ended guillotine line breaks down to break sizes covered by events B-16 and B-17.

## D-3 - Steam Line Breaks

### D-3a - Main Steam Line Break

A steam line break is postulated to occur between the manifold connecting the six loop steam generator lines together and the main steam line isolation valve. The turbine will trip. Since the pressures have dropped, the turbine bypass will not open. Feedwater flow will increase rapidly through the units by operation of the flow controller but will lag behind the steam flows. Low steam drum level will initiate reactor trip. The steam generator outlet isolation valves will be closed by the operator in 300 seconds. The steam side pressure will increase and the steam produced will be relieved through the safety relief valves. The RACS will be used to remove stored and decay heat.

### D-3b - Break Between Steam Generator Outlet and Steam Generator Outlet Isolation Valve

A break in this location will cause an immediate increase in affected loop steam flow, unit depressurization, outlet check valve closure and reduction of turbine steam flow by approximately one-sixth. A reactor trip is assumed on low drum level in the affected loop. The affected loop feedwater isolation valve is assumed to be closed by the operator in 300 seconds. The other loops will provide plant cooling.

### D-3c - Break Between Steam Generator Outlet Isolation Valve and Main Steam Line

This event is similar to events D-3a and D-3b with the major difference being one of rate. For the unaffected loops, the event is essentially the same as event D-3a, Main Steam Line rupture; but steam flow rate is somewhat reduced. For the affected loop, the steam flow rate is slightly higher than that for D-3a (but not quite as rapid as that for D-3b, Rupture Between Steam Generator Module Outlet and Steam Generator Outlet Isolation Valve).

## V-7.7

## SEISMIC

The criteria specified herein shall be used to evaluate the adequacy of the design of the systems and components.

### 7.7.1
### CRITERIA

All structures, systems, and components important to safety shall be capable of withstanding the effects of the Operating Basis Earthquake (OBE) without loss of capability to remain functional and to withstand the effects of the Safe Shutdown Earthquake (SSE) without loss of capability to perform their safety functions. Characteristics of the OBE and SSE are given in Part III, Section 5, "Seismic Analysis."

### 7.7.2
### LOAD COMBINATIONS

<u>OBE/Plant Condition Load Combinations</u>

A. OBE horizontal and vertical maximum ground accelerations are 0.15g.

B. Five OBE's, each with 10 maximum peak response cycles, shall be assumed to occur over the design life of the plant.

Four of these OBE's shall be assumed to occur during the most adverse normal operating conditions determined on a component limiting basis. The other one OBE shall be assumed to occur during the most adverse upset event determined on a component limiting basis, and at the most adverse time in the upset event.

<u>SSE/Plant Condition Load Combination (Level D Service Limit)</u>

A. SSE horizontal and vertical maximum ground acceleration are 0.3g.

B. One SSE, with 10 maximum peak response cycles shall be assumed to occur over the design life of the plant.

This SSE shall be assumed to occur during the most adverse normal operation determined on a component limiting basis. Furthermore, this same SSE shall also be assumed to occur simultaneously with the intermediate sodium pipe design basis leak event or water/steam leak events, dependent on which one of these events is the most adverse determined on a component basis, and to start at the same time as the selected event. The probability of the SSE implies a faulted event. During and following the SSE the pony motors are assumed to be functioning.

## V-7.8

## TABLES

A listing of the duty cycle events and their frequencies is contained in the following tables.

## Variable Speed Sodium Pumps

| EVENT | TRANSIENT | FREQUENCY |
|---|---|---|
| Level A Service | | |
| A-1 | Dry System Heatup, and Cooldown | 33 heatups, 33 cooldowns per each IHTS exclusive of IHX, 14 times total plant |
| A-2 | Startup from Refueling / Hot Standby Temperatures | 908 |
| A-3 | Normal Shutdown | 290 |
| A-4 | Loading and Unloading | 2988 up<br>2370 down |
| A-5 | Steady State Temperature Fluctuations | $1 \times 10^7$ |
| A-6 | Steady State Flow Induced Vibrations | TBD |
| A-7 | Loop Out of Service | 80 occurrences. (Each loop 40 as active loop + 40 as inactive loop) |

## Variable Speed Sodium Pumps

| EVENT | TRANSIENT | EVENTS PER 40 YRS. | SHUTDOWNS CAUSED PER 40 YRS. | FULL POWER TRIPS CAUSED PER 40 YRS. |
|---|---|---|---|---|
| Level B Service | | | | |
| B-1a | Reactor Trip from Full Power with Nominal Decay Heat | 60 | 60 | 60 |
| B-1b | Reactor Trip from Full Power with Minimum Decay Heat | 105 | 105 | 105 |
| B-2a | Uncontrolled Rod Insertion | 10 | 10 | 10 |
| B-2b | Uncontrolled Rod Withdrawal from Startup with Automatic Trip | 17 | 17 | 17 |
| B-2c | Plant Loading at Maximum Rod Withdrawal Rate | 10 | 0 | 0 |
| B-2d | Reactor Startup with an Excessive Step Power Change (Event is part of startups specified for A-2b and should not be added as a separate event) | [50] | 0 | 0 |
| B-3a* | Partial Loss of Primary Pump | 8 | 8 | 8 |
| B-3b* | Loss of Power to One Primary Pump | 20 | 20 | 20 |
| B-4a | Partial Loss of Intermediate Pump | 12 | 12 | 12 |
| B-4b | Loss of Power to One Intermediate Pump | 30 | 30 | 30 |
| B-5 | Trip of One Steam Driven Feedwater Pump | 25 | 25 | 25 |
| B-6a | Primary Pump Speed Increase | 7 | 7 | 0 |
| B-6b | Intermediate Pump Speed Increase | 7 | 7 | 0 |

*Inadvertent or Operator Error

(Continued)

Variable Speed Sodium Pumps

| EVENT | TRANSIENT | EVENTS PER 40 YRS. | SHUTDOWNS CAUSED PER 40 YRS. | FULL POWER TRIPS CAUSED PER 40 YRS. |
|---|---|---|---|---|
| Level B Service | | | | |
| B-7 | Primary Pump Reduced Speed Failure | 20 | 0 | 0 |
| B-8 | Intermediate Pump Reduced Speed Failure | 30 | 0 | 0 |
| B-9b* | Single Loop Saturated Steam Line Isolation Valve Closure | 12 | 12 | 12 |
| B-10* | Isolation and Blowdown of Steam Generator Components | 36 | 36 | 36 |
| B-11* | Loss of Feedwater Flow to One Steam Generator Loop | 12 | 12 | 12 |
| B-12 | Feedwater Throttle Valve Failed Open | 36 | 36 | 36 |
| B-13b | Turbine Trip with Reactor Trip (Loss of Main Condenser or Similar Problem) | 70 | 70 | 70 |
| B-14 | Loss of All Offsite Power | 16 | 16 | 16 |
| B-15a* | Inadvertent Opening of One Turbine Bypass Valve | 5 | 5 | 5 |
| B-15b | Turbine Bypass Valve Fails Open Following Reactor Trip | 5 | 0 | 0 |
| B-16* | Inadvertent Opening of Steam Generator Outlet Steam Line Safety/Power Relief Valves | 30 | 30 | 30 |
| B-18* | Inadvertent Opening of a Steam Generator Water Dump Valve | 9 | 9 | 9 |

*Inadvertent or Operator Error

(Continued)

Variable Speed Sodium Pumps

| EVENT | TRANSIENT | EVENTS PER 40 YRS. | SHUTDOWNS CAUSED PER 40 YRS. | FULL POWER TRIPS CAUSED PER 40 YRS. |
| --- | --- | --- | --- | --- |
| Level B Service | | | | |
| B-19* | Inadvertent Activation of Primary Reactor Auxiliary Cooling System | 30 | 0 | 0 |
| B-20 | Plant Shutdown in Response to Small Sodium-Steam/Water Leak Indication | 30 | 30 | 30 |
| B-22 | Loss of One Recirculation Pump | 48 | 48 | 0 |
| B-23a | Uncontrolled Rod Withdrawal from 100% Power | 10 | 10 | 10 |
| B-23b | Uncontrolled Rod Withdrawal from Startup to Trip Point with Delayed Manual Trip | 3 | 3 | 3 |
| | TOTALS | | 618 | 556 |

*Inadvertent or Operator Error

| EVENT | TRANSIENT | FREQUENCY |
|---|---|---|
| Level C Service | | |
| C-1 | Primary Pumps Mechanical Failure | Each component must accommodate 5 occurrences of the most severe emergency transient for that component plus two consecutive occurrences of the most severe event (or consecutive occurrences of 2 unlike events if the unlike events provide a more severe effect than consecutive occurrences of the most severe event). |
| C-2 | Intermediate Pump Mechanical Failure | |
| C-4 | Loss of Feedwater to All Steam Generators | |
| C-5 | Rupture Disk Failure in SGS Sodium-Water Reaction Protection System | |
| C-6 | Isolation and Dump of Steam Generator Failure of Outlet Isolation Valve | |
| C-7 | Water Side Isolation of a Steam Generator with Failure of the Dump Valves to Open | |
| C-8 | Closure of a Steam Generator Outlet Isolation Valve with Failure of One Relief Valve to Open | |
| C-11 | Natural Circulation | |
| C-12 | Natural Circulation with Three Primary Pumps | |
| C-13 | RACS Activation 24 Hours After Scram | |
| C-15 | Design Basis Steam Generator Sodium Water Reaction | |
| C-16 | Plant Shutdown in Response to Sodium/Water Leak Indications | |

| EVENT | TRANSIENT | FREQUENCY |
|---|---|---|
| Level D Service | | |
| D-1 | Main Feedwater Line Rupture | 1 |
| D-3a | Main Steam Line Break | |
| D-3b | Break Between Steam Generator Outlet and Steam Generator Outlet Isolation Valve | 1 |
| D-3c | Break Between Steam Generator Outlet Valve and Main Steam Line | 1 |
| Load Combinations | | |
| | Operating Base Earthquakes (Upset) | 5 |
| | Safe Shutdown Earthquake (Faulted) | 1 |

Appendix V-7A

Option 1 is a case with constant speed primary and intermediate sodium pumps and recirculation pumps. The duty cycle is changed due to the altered components which affect various transients. The Level B events cause 598 shutdowns in the 40 year plant life including 536 reactor trips from full power. The frequency totals are slightly smaller than those for the variable speed pumps.

Differences arise in plant operation as the plant will be capable of changing loads at a rate not exceeding $\pm$0.25% per minute. The events that require a change due to the constant speed pumps are listed below.

## Level A Service Limits

### A-2 Startup from Refueling or Hot Standby Temperatures

The pump speeds are at 100% and all temperature changes are accomplished by at 0.25%/min. power change:

| Time (hrs) | Reactor Power (% Rated) | Primary Sodium Pump Speed (% Rated) | Intermediate Sodium Pump Speed (% Rated) | Recirculation Pump Speed (% Rated) | Steam Pressure (psia) |
|---|---|---|---|---|---|
| 0 | 0 | 100 | 100 | Variable* | 1015 |
| 6.7 | 100 | 100 | 100 | 100 | 1015 |

*The present design has variable speed recirculation pumps which will maintain a recirculation ratio near 6:1. This is necessitated by use of a BWR steam drum but steam drums can be designed to accommodate two speed recirculation pumps.

### A-3 Normal Shutdown

The pump speeds are at 100% and all temperature changes are accomplished at 0.25%/min. power change:

| Time (hrs) | Reactor Power (% Rated) | Primary Sodium Pump Speed (% Rated) | Intermediate Sodium Pump Speed (% Rated) | Recirculation Pump Speed (% Rated) | Steam Pressure (psia) |
|---|---|---|---|---|---|
| 0 | 100 | 100 | 100 | 100 | 1015 |
| 6.7 | 0 | 100 | 100 | Variable* | 1015 |

*The present design has variable speed recirculation pumps which will maintain a recirculation ratio near 6:1. This is necessitated by use of a BWR steam drum but steam drums can be designed to accommodate two speed recirculation pumps.

A-4 Loading and Unloading

This event is contained in A-2 and A-3 events.

Level B Service Limits*

B-2b - Uncontrolled Rod Withdrawal from Startup with Automatic Trip

The pump motors are operating at 100% speed.

B-2c - Plant Loading at Maximum Rod Withdrawal Rate

The sodium flow is 100%. Reactor power is increased from 60% to 100% at a rate greater than 0.25% per minute.

B-3a - Partial Loss of Primary Pump

Not applicable to option 1.

B-4a - Partial Loss of Intermediate Pump

Not applicable to option 1.

B-6a - Primary Pump Speed Increase

Not applicable to option 1.

B-6b - Intermediate Pump Speed Increase

Not applicable to option 1.

B-23b - Uncontrolled Rod Withdrawal from Startup to Trip Point with Delayed Manual Trip

The sodium flows are increased to 100% in primary and intermediate loops.

---

*See table following for frequency changes.

## Constant Speed Sodium Pumps

| EVENT | TRANSIENT | FREQUENCY |
|---|---|---|
| Level A Service | | |
| A-1 | Dry System Heatup, and Cooldown | 33 heatups, 33 Cooldowns per each IHTS exclusive of IHX, 14 times total plant |
| A-2 | Startup from Refueling/Hot Standby Temperatures | 888 |
| A-3 | Normal Shutdown | 290 |
| A-4 | Loading and Unloading | 2370 up<br>2370 down |
| A-5 | Steady State Temperature Fluctuations | $1 \times 10^7$ |
| A-6 | Steady State Flow Induced Vibrations | TBD |
| A-7 | Loop Out of Service | 80 occurrences. (Each loop 40 + 40 as inactive loop) |

## Constant Speed Sodium Pumps

| EVENT | TRANSIENT | EVENTS PER 40 YRS. | SHUTDOWNS CAUSED PER 40 YRS. | FULL POWER TRIPS CAUSED PER 40 YRS. |
|---|---|---|---|---|
| Level B Service | | | | |
| B-1a | Reactor Trip from Full Power with Nominal Decay Heat | 60 | 60 | 60 |
| B-1b | Reactor Trip from Full Power with Minimum Decay Heat | 105 | 105 | 105 |
| B-2a | Uncontrolled Rod Insertion | 10 | 10 | 10 |
| B-2b | Uncontrolled Rod Withdrawal from Startup with Automatic Trip | 17 | 17 | 17 |
| B-2c | Plant Loading at Maximum Rod Withdrawal Rate | 10 | 0 | 0 |
| B-2d | Reactor Startup with an Excessive Step Power Change (Event is part of startups specified for A-2b and should not be added as a separate event) | [50] | 0 | 0 |
| B-3b* | Loss of Power to One Primary | 20 | 20 | 20 |
| B-4b | Loss of Power to One Intermediate Pump | 30 | 30 | 30 |
| B-5 | Trip of One Steam Driven Feedwater Pump | 25 | 25 | 25 |
| B-7 | Primary Pump Reduced Speed Failure | 20 | 0 | 0 |
| B-8 | Intermediate Pump Reduced Speed Failure | 30 | 0 | 0 |

*Inadvertent or Operator Error

(Continued)

Constant Speed Sodium Pumps

| EVENT | TRANSIENT | EVENTS PER 40 YRS. | SHUTDOWNS CAUSED PER 40 YRS. | FULL POWER TRIPS CAUSED PER 40 YRS. |
|---|---|---|---|---|
| Level B Service | | | | |
| B-9b* | Single Loop Saturated Steam Line Isolation Valve Closure | 12 | 12 | 12 |
| B-10* | Isolation and Blowdown of Steam Generator Components | 36 | 36 | 36 |
| B-11* | Loss of Feedwater Flow to One Steam Generator Loop | 12 | 12 | 12 |
| B-12 | Feedwater Throttle Valve Failed Open | 36 | 36 | 36 |
| B-13b | Turbine Trip with Reactor Trip (Loss of Main Condensor or Similar Problem) | 70 | 70 | 70 |
| B-14 | Loss of All Offsite Power | 16 | 16 | 16 |
| B-15a* | Inadvertent Opening of One Turbine Bypass Valve | 5 | 5 | 5 |
| B-15b | Turbine Bypass Valve Fails Open Following Reactor Trip | 5 | 0 | 0 |
| B-16* | Inadvertent Opening of Steam Generator Outlet Steam Line Safety/Power Relief Valves | 30 | 30 | 30 |
| B-18* | Inadvertent Opening of a Steam Generator Water Dump Valve | 9 | 9 | 9 |
| B-19* | Inadvertent Activation of Primary Reactor Auxiliary Cooling System | 30 | 0 | 0 |
| B-20 | Plant Shutdown in Response to Small Sodium-Steam/Water Leak Indication | 30 | 30 | 30 |

*Inadvertent or Operator Error

(Continued)

Constant Speed Sodium Pumps

| EVENT | TRANSIENT | EVENTS PER 40 YRS. | SHUTDOWNS CAUSED PER 40 YRS. | FULL POWER TRIPS CAUSED PER 40 YRS. |
|---|---|---|---|---|
| Level B Service | | | | |
| B-22 | Loss of One Recirculation Pump | 48 | 48 | 0 |
| B-23a | Uncontrolled Rod Withdrawal from 100% Power | 10 | 10 | 10 |
| B-23b | Uncontrolled Rod Withdrawal from Stratup to Trip Point with Delayed Manual Trip | 3 | 3 | 3 |
| | TOTALS | | 598 | 536 |

PART V: HEAT TRANSPORT SYSTEM COMPONENTS

SECTION 8: PLANT TRANSIENTS

CONTENTS



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## FIGURES

FIGURES (CONT'D.)

FIGURES (CONT'D.)

FIGURES (CONT'D.)

FIGURES (CONT'D.)

FIGURES (CONT'D.)

V-8.1

INTRODUCTION AND SUMMARY

8.1.1
INTRODUCTION

A system model applicable to pool-type LMFBRs was prepared and checked out during the Phase A Design effort.(1) The model called DEMO-POOL(2) is based on the DEMO simulation model(4) prepared for the CRBRP with changes necessary to represent a pool system. The present effort is directed toward using that model to examine selected transients for the 1000 MWe Pool-type LMFBR.

The transients under consideration are the reactor scram, loss of one intermediate pump, loss of plant power, primary pipe break and single primary pump failure after scram. The intent is to scope the pool reactor system behavior for each of the five types of transients. These events cover areas where a pool-type reactor could be expected to exhibit characteristics different from a loop-type reactor.

Due to the much larger sodium volumes contained in the pool system, it may be desirable to maintain a high enough post-scram primary flow to ensure mixing in the large volumes while providing an improved temperature transient compared to those characteristic of plenum stratification. In addition, the thermal barriers of the reactor vessel cooling system are supplied with sodium coolant from the primary sodium pumps. This system may not have sufficient capacity in a low flow post-scram state with a stratified hot-pool. The objective is to reduce hot pool temperatures slowly and uniformly following a reactor scram while maintaining sufficient thermal barrier capacity.

The behavior of the pool-type system following the loss of an intermediate sodium pump is also somewhat different than that of a loop-type system. This difference in behavior is the result of having all the primary pumps in parallel and having all the IHX primary flows driven by the liquid level difference between the hot and cold pool surfaces. Loss of an intermediate sodium pump can cause a severe transient at the IHX primary outlet. This transient is one of several necessary to support the IHX design effort.

The transition to natural convection following a total loss of plant power can be significantly different for a pool and a loop system due to the shorter distances and smaller elevation differences in the primary sodium system of the pool design. The smaller elevation differences can reduce the usefulness of the main heat transfer system for emergency decay heat removal in a natural circulation mode.

The primary pipe rupture accident for the pool-type system has several major differences from the characteristics of a loop-type system and a major similarity. The pool-type primary system has only one short pipe per pump that connects the pump and the core inlet plenum rather than a number of long pipes that connect all the primary components in a loop-type system. The primary pipe for the pool system is entirely within the reactor vessel. Therefore, primary pipe break events for a pool system are not loss of coolant accidents. They are potentially loss of flow accidents. The pool and loop reactors can have similar behavior for primary pipe breaks near the core inlet plenum. This is the worst break location in the pool system because a large break at that location causes a larger core coolant flow reduction than large breaks elsewhere in the primary pipe.

Due to the difference in arrangement of primary system components in a pool-type LMFBR as compared to a loop-type LMFBR, failure of a primary pump after a reactor scram in a pool-type system does not cause a primary flow reversal in any of the IHXs and no major temperature changes occur at the primary pumps even without primary check valves. The main concerns in this case for the pool-type LMFBR are the bypass of core coolant through the affected pump and the adequacy of the resulting core coolant flow. System components other than the core experience a temperature transient essentially the same as an ordinary reactor scram transient.

The purpose of this effort is to provide data on the transient behavior of the 1000 MWe Pool-Type LMFBR for component design input and to evaluate alternative modes of post-scram operation with the intent of maximizing the benefits of the pool system characteristics during transients.

## 8.1.2
## SUMMARY

The DEMO-POOL plant simulation code has been used to examine selected transients for the 1000 MWe Pool-Type LMFBR. The transient-initiating events selected for analysis include reactor scram, loss of one intermediate pump, loss of plant power and single primary pump failure after a scram. The results show either satisfactory consequences, a range of satisfactory consequences (depending on operating assumptions) or marginal consequences that can be made acceptable by minor changes or more detailed analysis.

Several modes of post-scram sodium pump operation were examined. These include keeping the pumps at full speed, reducing them to half speed or tripping them to pony motor speed. Tripping the sodium pumps to pony motor speed results in a stratified hot-pool but relatively low rates for temperature changes. The stratified hot-pool requires a high capacity for the reactor vessel cooling system (thermal barriers) during low speed primary sodium pump operation. This is presently not within the design capability of the thermal barriers. Other modes of sodium pump operation (higher speed) show temperature rates within component design capability and hot-pool temperatures with thermal barrier capability.

Loss of power to one intermediate heat transfer system pump has been examined for several possible modes of post-event operation. These include continued power operation at reduced load and initiation of a reactor scram including several modes of post-scram pump operation. Continued power operation at reduced load without isolating the primary side of the affected IHX causes a severe temperature rise (230°F with a maximum rate of 8°F/sec) at the affected IHX primary outlet. If a reactor scram is initiated and the sodium pump speed is reduced to 50 percent, the temperature increase at the affected IHX outlet is reduced considerably (146°F with a maximum rate of 2.7°F/sec). This appears to be well within the design capability of the IHX.

Loss of plant power has been examined to determine whether core temperatures remain within suitable limits during the transition to natural convection in the sodium and water/steam systems. The results show that core cladding and coolant

temperature remain below 1600°F which should be satisfactory for this event. Therefore, the present plant design is probably adequate in terms of elevations and hydraulic profiles for emergency decay heat removal from the core by natural circulation.

Primary sodium system pipe breaks were examined. A primary pipe break in the pool-type primary system does not cause a loss of sodium from the reactor vessel but causes a reduction in core coolant flow. The break location examined is near the core inlet plenum which would result in the greatest bypass of core coolant. A double-ended guillotine pipe leak was considered for cores with plenum-to-plenum pressure drops of 75 and 100 psi. The results show marginal results unless the pumps are operated at full speed after the reactor scram. Several core inlet plenum inlet nozzle modifications were examined. These have the potential for mitigating the marginal or unacceptable results.

Single primary pump failure events (such as pony motor failures) after a reactor scram were evaluated to provide data on the need for primary sodium system check valves. The affected pump was assumed to coast down and stop while the other sodium pumps were coasting down to the prescribed post-scram speed. Post-scram pump speeds of 50 and 7 percent were examined. In both cases calculated core cladding and sodium temperatures did not exceed normal full power values (without primary check valves). This event, therefore, does not establish a need for primary sodium system check valves.

## V-8.2

## CONCLUSIONS

### 8.2.1
### REACTOR SCRAM TRANSIENT

Several modes of post-scram pump operation were examined. These include tripping the sodium pumps to pony motor speed, an intermediate speed or keeping them at full speed. The results show the lowest average rates of temperature reduction are associated with a pump trip to pony motor speed. Other modes of pump operation also show temperature rates that appear to be within component design capability.

Tripping the pumps to pony motor speed results in a stratified hot-pool that remains hot for a long time. The result is a nearly full heat load on the reactor vessel thermal barriers during pony motor operation. This is not within the thermal barrier design capability when supplied with sodium from the primary pumps at pony motor speed. It is necessary to either keep the primary pumps running at a relatively high speed or supply the sodium for the thermal barriers from a separate pump or pumps. The choice of high post scram pump speed definitely tends to cause higher temperature rates and larger temperature changes.

### 8.2.2
### LOSS OF ONE INTERMEDIATE PUMP

The primary IHX outlet temperature transient caused by a loss of one intermediate sodium pump depends upon the mode of operation following the event. Without a reactor scram, the IHX primary outlet temperature rises toward the hot leg temperature. The results show a maximum temperature increase of 230°F at a maximum rate of approximately 8°F/sec. An immediate reactor scram reduces both the temperature rate and the maximum temperature change but the results are dependent on post-scram sodium pump speed. A post-scram pump trip to pony motor speed would eliminate the primary IHX outlet temperature increase. A pump trip to half speed results in a maximum IHX primary outlet temperature increase of 146°F with a maximum rate of 2.7°F/sec.

A complication of high post-scram pump speed is the loss of power to one IHTS pump event which causes a large temperature increase at the primary outlet of the affected IHX. The resulting hot sodium flowing into the cold-pool can also impinge on a primary pump, the core support structure or the reactor vessel. The advantage of high post-scram pump speed for maintaining the capability of the reactor vessel cooling system (the thermal barriers) must be weighed against its apparent transient disadvantages.

### 8.2.3 LOSS OF PLANT POWER

The reactor transient during the transition to natural convection has been calculated for the 1000 MWe Pool-Type LMFBR. Cladding and sodium temperatures remain below 1600°F which satisfies the CRBRP criteria for this event. The results suggest a transition to stable natural convection decay heat removal.

This indicates the present plant design is probably adequate in terms of elevations and hydraulic profiles for decay heat removal from the core. The same conclusions may be true for the blanket assemblies but the DEMO-POOL model for the blanket assemblies is not sufficiently detailed to provide an adequate basis for that conclusion.

### 8.2.4 PRIMARY PIPE BREAK

The present analysis scopes the primary pipe break (DEG) for the Phase A pool design. Calculations using CRBRP hot channel factors and the CRBRP criterion for acceptability indicate acceptable consequences or nearly acceptable consequences assuming no post-scram pump trip (or a sufficiently delayed pump trip). The analysis results also show the event with a post-scram pump trip are borderline or not acceptable. A more detailed analysis using hot channel factors and a criterion for the Phase A core could possibly show the borderline cases are also acceptable. Should such analyses show the results are not acceptable, some minor changes can be made to increase the reverse flow pressure drop between the core inlet plenum and the break. Results show that minor nozzle changes are able to potentially provide a margin for obtaining acceptability even if hot channel factors or criteria do not improve.

### 8.2.5 SINGLE PRIMARY PUMP FAILURE AFTER SCRAM

The results of calculations for this event with post-scram pump speeds of 50 and 7 percent show that post-scram core temperatures do not exceed full power operating temperatures. These results are most likely acceptable. Since the results are based on calculations without primary check valves, the single primary pump failure event after a scram does not establish a need for primary check valves.

V-8.3

## SCRAM TRANSIENT

### 8.3.1 INTRODUCTION

There are a number of approaches to post-scram plant operation that can be used. These include tripping the primary and intermediate sodium pumps to low speed (pony motor) operation to reduce the rate of heat removal and hopefully the rate of temperature reduction following the scram. This approach results in a stratified hot pool and a more severe than desired hot leg temperature time gradient. Another approach to post-scram cooling is to maintain relatively high sodium flow rates which tends to promote hot pool mixing and to reduce temperatures more uniformly. Keeping temperatures uniform and temperature rates low are both advantages from the standpoint of component design. There are also intermediate approaches to post-scram cooling such as a sodium pump trip to a mid-range pump speed or a delayed pump trip to low speed. All of these approaches have been evaluated for the 1000 MWe Pool-Type LMFBR.

### 8.3.2 ANALYSIS

Pump Trip to Pony Motor Speed

The reactor scram transient with pump trip to pony motor speed was evaluated first to provide a basis for comparison with other approaches. The assumptions used in this evaluation included the use of minimum decay heat, 4 percent pony motor speed, 100 percent mixing in the hot pool prior to stratification and mixing in 50 percent of the hot-pool volume below the chimney tops in the reactor upper internals initially following stratification. The two-zone mixing model[(2)] in DEMO-POOL was used to represent hot-pool mixing. These are best estimate mixing assumptions.

The pumps can be tripped almost immediately after the reactor scram or the pump trip can be delayed to allow the hot pool to cool a certain amount prior to the pump trip. Pump trip delays used in the present analysis include 0.5, 34 and 78 seconds. The 0.5 second delay represents a pump trip shortly after the control rods begin to drop into the core. The other two delays are intended to cover a range of hot-pool cooldown prior to the pump trip. The 34 and 78 second delays allow the hot-pool to cool 75 and 150°F, respectively, before the pump trip. Cooling the hot-pool is an advantage when considering the load on the reactor vessel thermal barriers during pony motor operation but may be a disadvantage when viewed from the standpoint of temperature transients on system components. The temperature transient for the reactor is shown in Figures 3-3, 3-8 and 3-13 for pump trip delays of 0.5, 34 and 78 seconds, respectively. The transient in other parts of the system is shown in Figures 3-1 to 3-15.

High Post-Scram Pump Speed and 100 Percent Mixing

The assumptions used in this analysis include minimum decay heating and 100 percent mixing in the hot pool. Two reactor scram transients were evaluated using these assumptions. The first assumed a post-scram sodium pump speed of 100 percent and the second assumed a post-scram sodium pump speed of 50 percent. These pump speeds result in post-scram sodium flow rates of approximately 100 and 50 percent, respectively, of rated flows. In these cases the DEMO-POOL mixing model did not predict stratification of the hot pool. The temperature transient for the reactor is shown in Figures 3-18 and 3-23 for the two cases. The transients at other locations are shown in Figures 3-16 to 3-25.

High Post-Scram Pump Speed and 50 Percent Hot Pool Mixing

The assumptions used in this analysis include minimum decay heating and 50 percent mixing in the hot pool. Three reactor scram transients were evaluated using these assumptions. They correspond to post-scram sodium pump speeds of 100, 50 and 25 percent. These pump speeds result in post-scram sodium flow rates of approximately 100, 50 and 25 percent, respectively, of rated flows. In these cases the DEMO-POOL mixing model did not predict stratification of the hot pool. The temperature transient for the reactor is shown in Figures 3-28, 3-33 and 3-38 for the three cases. The transient in other parts of the system is shown in Figures 3-26 to 3-40.

### 8.3.3 RESULTS AND CONCLUSIONS

The temperature changes during the first 500 seconds after the scram and the maximum temperature rates for several locations in the hot legs of the 1000 MWe Pool-Type LMFBR are summarized in Table 3-1. The temperature changes during the first 500 seconds can be used to estimate average temperature rates but very crudely. The data show the lowest average rates are associated with a pump trip to pony motor speed, however, other cases listed in Table 3-1 do not appear to cause design problems.

Tripping the pumps to pony motor speed results in a stratified hot-pool that remains hot for a long time. The result is a nearly full heat load on the reactor vessel thermal barriers during pony motor operation. This is not within the thermal barrier design capability when supplied with sodium from the primary pumps at pony motor speed. It is necessary either to keep the primary pumps running at a relatively high speed or to supply the sodium for the thermal barriers from a separate pump or pumps. The choice of high post-scram pump speed definitely tends to cause higher temperature rates and larger temperature changes as shown in Table 3-1 but they appear to be within the design capability of the components.

Table 3-1

TEMPERATURE CHANGES AND MAXIMUM RATES DURING THE REACTOR SCRAM TRANSIENT

| | TEMPERATURE CHANGES* (°F) | | | MAXIMUM RATES** (°F/sec) | | |
|---|---|---|---|---|---|---|
| DELAYED PUMP TRIP TO PONY MOTOR SPEED | HOT POOL | IHX PRIMARY INLET | IHX INTERMEDIATE OUTLET | HOT POOL | IHX PRIMARY INLET | IHX INTERMEDIATE OUTLET |
| 0.5 sec | 14 | 156 | 157 | 0.9 | 0.9 | 2.3 |
| 34 sec | 92 | 187 | 167 | 2.5 | 2.5 | 1.9 |
| 78 sec | 162 | 203 | 179 | 2.5 | 2.5 | 1.9 |
| POST-SCRAM PUMP SPEED (100% MIXING) | | | | | | |
| 100 | 300 | 300 | 242 | 2.5 | 2.5 | 1.9 |
| 50 | 274 | 273 | 218 | 1.2 | 1.2 | 1.3 |
| POST-SCRAM PUMP SPEED (50% MIXING) | | | | | | |
| 100 | 300 | 300 | 242 | 4.9 | 4.5 | 3.4 |
| 50 | 298 | 298 | 241 | 2.3 | 2.1 | 1.9 |
| 25 | 265 | 264 | 207 | 1.1 | 1.0 | 0.8 |

*In the first 500 seconds
**They are all negative

## V-8.4

## LOSS OF ONE INTERMEDIATE PUMP

### 8.4.1 INTRODUCTION

There has been a need to evaluate the loss of a single intermediate heat transfer system pump for input to support the IHX design. Loss of an intermediate pump could cause the primary IHX outlet temperature to increase rapidly toward the hot-leg temperature. The actual behavior is determined by the mode of operation following the event. Several modes of operation are possible. These include continued power operation at a reduced level using the remaining heat transfer loops, a scram with pump trip to pony motor speed or a scram with high post-scram pump speed.

### 8.4.2 ANALYSIS

Loss of Power to One IHTS Pump Without Scram

This event is intended to demonstrate the transient at the IHX that would result from a loss of power to one intermediate heat transfer system (IHTS) pump with continued reactor operation. In the interest of generating a conservative transient for the affected IHX primary outlet temperature, the affected pump is assumed to coast down to 7 percent pony motor speed with a 6 second half-time. Primary flow in the affected IHX remains high because the IHX primary side was not isolated. Reactor power was assumed to be reduced from 100 to 83 percent at 10 percent per minute in order to prevent an eventual increase in reactor outlet temperature.

There is some uncertainty as to whether the hot sodium leaving the affected IHX primary outlet will mix in the cold pool or go directly to the pump inlets. Therefore, 100 percent bypass of the hot sodium from the affected IHX to the primary pump inlets was assumed. This tends to maintain the hot pool temperature relatively constant during the power reduction. The resulting system transient is shown in Figure 4-1 to 4-5. The IHX primary outlet temperature transient is shown in Figure 4-4. The maximum temperature rate for the affected IHX primary outlet is approximately 8°F/sec and the temperature change is approximately 230°F.

Note that DEMO-POOL calculates the primary pump temperatures (Figure 4-4) based on mixing the hot sodium from the affected IHX with cold sodium from the other 5 IHXs before reaching the pumps. This greatly attenuates the temperature transient at the primary pumps. A very conservative approach would be to assume one of the primary pumps experiences the temperature transient at the primary IHX outlet of the affected loop.

Loss of Power to One IHTS Pump with Scram and Pump Trip to Half Speed

This event is intended to demonstrate the IHX response. The assumptions used to produce a conservative IHX primary outlet temperature transient following loss of power to one IHTS pump with a subsequent scram are as follows: 1) the maximum decay heat, 2) 100 percent hot-pool mixing, 3) the most rapid coastdown of the affected IHTS pump (a 6 second half-time) and 4) the cold-pool bypass of the hot sodium from the affected IHX to the core inlet plenum. These assumptions tend to maintain the highest IHX primary inlet temperature and cause the most rapid IHTS flow coastdown. The affected pump coasts down to 7 percent pony motor speed. The other primary and intermediate sodium pump speeds are reduced to 50 percent following the reactor scram.

The resulting system transient is shown in Figures 4-6 to 4-10. The IHX primary outlet temperature transient is shown in Figure 4-9. The maximum temperature rate for the affected IHX is 2.7°F/sec and the temperature change at the affected IHX primary outlet is 146°F. The hot sodium from the affected IHX is assumed in the analysis to mix with cold sodium from the other 5 IHXs (after they mix in the cold pool) before reaching the primary pumps.

Loss of Power to One IHTS Pump with Scram and Delayed Sodium Pump Trip

The assumptions used in this evaluation include the use of minimum decay heat, 7 percent pony motor speed, 100 percent mixing in the hot pool prior to stratification and mixing in 50 percent of the hot-pool volume below the chimney tops in the reactor upper internals initially following stratification. The two-zone mixing model in DEMO-POOL[2] is assumed to apply. The affected IHTS pump begins coasting down to 7 percent pony motor speed at the start of the calculation.

Sodium pump trip delays of 34 and 78 seconds were evaluated. The results are shown in Figures 4-11 to 4-20. They are intended to cover a range of hot-pool cooldown prior to the pump trip and to show the effect of the delay on the primary IHX outlet temperature in the affected loop. The resulting IHX primary side temperatures are shown in Figures 4-14 and 4-19. The primary side of the affected IHX fills with hot sodium prior to the pump trip. The pump trip causes the hot and cold pool levels to equalize. This allows some of the hot sodium in the affected IHX to be displaced back into the hot pool. This displacement (flow reversal) causes the temperature fluctuations shown in Figures 4-14 and 4-19.

# LOSS-OF-PLANT-POWER TRANSIENT

## 8.5.1 INTRODUCTION

This event involves the complete loss of electric power in the plant and, therefore, a complete loss of power for the sodium and recirculation pumps. The feedwater pump is turbine driven and, therefore, continues to operate. Since the event causes a reactor scram, the main concern is whether or not the core is adequately cooled during the transition to natural circulation in the sodium and steam/water systems. This determines whether or not the main heat transfer systems are capable of emergency decay heat removal in the natural circulation mode.

## 8.5.2 BASIS

Since the usual intent of the analysis of the loss of power event is the determination of whether or not the core is adequately cooled during the transition to natural convection, several assumptions were made to conservatively maximize core power and minimize core flow during the calculation. The assumptions are as follows:

1. Maximum decay heat (the CRBRP decay power[3] fraction for the average fuel assembly including the positive uncertainties of 25% on fission product decay power and 10% on U-239 and Np-239 decay power).

2. Conservatively fast sodium pump coastdown (pump speed half-times of 5 and 6 seconds, respectively, for the primary and intermediate sodium pumps).

3. CRBRP DEMO Rev. 3 hot channel factors[4] for the core fuel assemblies.

| | | | |
|---|---|---|---|
| Radial nuclear factor (assembly) | FNRA | = | 1.351 |
| Radial nuclear factor (fuel rod), | FNRP | = | 1.003 |
| Flow maldistribution factor, | FMD | = | 1.15 |
| Flow orificing factor, | FOR | = | 1.10 |
| Heat flux factor, | FQ | = | 1.1613 |
| Fuel conductivity factor, | FFUEL | = | 1.10 |
| Gap conductivity factor, | FGAP | = | 1.3745 |
| Clad conductivity factor, | FCLAD | = | 1.514 |

| | | | |
|---|---|---|---|
| Film conductivity factor, | FFILM | = | 1.575 |
| Channel enthalpy rise factor, | FDH | = | 1.298 |

4. Maximum locked rotor flow impedance for primary and intermediate sodium pumps which coast to a stop (350 ft at rated flow was assumed).

The CRBRP decay heat analysis is believed to conservatively apply to the present analysis. CRBRP hot channel factors were used because no complete set of hot channel factors is available for the 1000 MWe pool-type LMFBR and because the CRBRP values appear to be conservative. The pump coastdown characteristics and locked rotor impedances were chosen based on current ANL E-spec data for the large component development program.

### 8.5.3 ANALYSIS

The reactor transient for the 1000 MWe Pool-Type LMFBR during the transition to natural convection is shown in Figures 5-1 to 5-7. Figure 5-1 shows the reactor power and the flow rates at the sodium pumps. The pumps coast down and stop in approximately 60 seconds. When the pumps stop, the additional locked-rotor flow impedance is inserted into the hydraulic calculations which causes the flow reductions shown in Figure 5-1 at 60 seconds into the transient. Figure 5-2 shows the core and IHX primary sodium flows. The IHX flows tend to oscillate slightly after the flow reduction but the oscillations damp out fairly rapidly. The average core outlet temperature cools rapidly then increases to approximately 985°F before again beginning to cool. The sodium exit temperatures from the average, peak and maximum fuel assemblies are shown in Figure 5-4. The average and peak assemblies represent the average and peak powered fuel assemblies in the core. The maximum assembly represents a hot channel. The corresponding cladding temperatures are shown in Figure 5-5. These temperatures remain below 1600°F and are, therefore, acceptable for this event based on CRBRP criteria. The transient in the rest of the plant rapidly approaches a relatively steady condition which indicates that the longer-term natural convection transient would be quite stable.

### 8.5.4 CONCLUSIONS

The reactor transient during the transition to natural convection has been calculated for the 1000 MWe Pool-Type LMFBR. Cladding and sodium temperatures remain below 1600°F which satisfies the CRBRP criteria for this event. The results suggest a transition to stable natural convection decay heat removal.

This indicates the present plant design is probably adequate in terms of elevations and hydraulic profiles for decay heat removal from the core. The same conclusions may be true for the blanket assemblies but the DEMO-POOL model for the blanket assemblies is not sufficiently detailed to provide an adequate basis for that conclusion.

## V-8.6

## PRIMARY PIPE BREAK ACCIDENT

### 8.6.1 INTRODUCTION

This hypothetical event involves a double-ended guillotine (DEG) pipe break in one of the four primary pump outlet pipes near the core inlet plenum. This event does not cause leakage of sodium from the reactor vessel and is, therefore, not a loss of coolant accident. It does cause a reduction in core coolant flow due to removal of the core coolant supply from one pump (the affected pump) and due to some core coolant from the other pumps being diverted through the plenum inlet of the affected pipe and out the rupture to the cold pool (rather than going through the core). The flow through the affected pump increases due to the lower back-pressure on the pump caused by the break but no temperature changes occur in the pump due to circulating cold pool sodium.

### 8.6.2 BASIS

Since the usual intent of the analysis is the determination of whether or not the core is adequately cooled, several assumptions were made to conservatively maximize core power and minimize core flow during the calculation. The assumptions are as follows:

1. Maximum decay heat (the CRBRP decay power[3] fraction for the average fuel assembly including the positive uncertainties of 25% of fission product decay power and 10% of U-239 and Np-239 decay power).

2. Conservatively fast sodium pump coastdown (pump speed half-times of 5 and 6 seconds, respectively, for the primary and intermediate sodium pumps).

3. CRBRP DEMO Rev. 3 hot channel factors[4] for the core fuel assemblies.

| | | | |
|---|---|---|---|
| Radial nuclear factor (assembly) | FNRA | = | 1.351 |
| Radial nuclear factor (fuel rod), | FNRP | = | 1.003 |
| Flow maldistribution factor, | FMD | = | 1.15 |
| Flow orificing factor, | FOR | = | 1.10 |
| Heat flux factor, | FQ | = | 1.1613 |

| | | |
|---|---|---|
| Fuel conductivity factor, | FFUEL = | 1.10 |
| Gap conductivity factor, | FGAP = | 1.3745 |
| Clad conductivity factor, | FCLAD = | 1.514 |
| Film conductivity factor, | FFILM = | 1.575 |
| Channel enthalpy rise factor, | FDH = | 1.298 |

4. Minimum hydraulic resistance from the core inlet plenum to the break (assumes the break is near the inlet plenum).

The CRBRP decay heat analysis is believed to conservatively apply to the present analysis. The pump coastdown characteristics were chosen based on current ANL E-spec data for the large component development program. The CRBRP hot channel factors were used because no complete set of 1000 MWe Pool-type LMFBR hot channel factors was available and because the CRBRP values appear to be conservative. The lowest hydraulic resistance between the core inlet plenum and the break results in the most diversion of core coolant from its intended purpose. This results in the highest calculated core temperatures.

8.6.3
ANALYSIS

The analysis of the reactor transient for the 1000 MWe Pool-type LMFBR following a guillotine pipe break in one of the four primary pump outlet pipes was divided into several parts. First, the effects of post-scram pump-speed were considered. Next, the effect of initial core pressure drop was evaluated (75 and 100 psi plenum-to-plenum pressure drops were examined). Then the sensitivity of the results to changes in the inlets to the core inlet plenum were evaluated for the 75 psi pressure drop core.

The results of the analysis of the first two items are summarized in Table 6-1. In Table 6-1 the maximum hot channel cladding and sodium outlet temperatures calculated with DEMO-POOL are listed. The sodium temperatures are higher than those listed for the cladding because DEMO-POOL does not evaluate cladding temperatures at the core outlet but at locations 1/10, 3/10, 1/2, 7/10 and 9/10 of the distance between the top and bottom of the core. Therefore, the maximum hot channel cladding temperature should be considered to be somewhat above the hot channel sodium outlet temperature even though the tables show otherwise. The criterion for acceptability of this event for the CRBRP and the FFTF (at least initially) is to have maximum sodium and cladding temperatures below 1600°F. Examination of Table 6-1 indicates that the 1600°F criterion is met for the 75 psi pressure drop core without post-scram sodium pump-trip. It is nearly met for the 100 psi pressure drop core also without post-scram sodium pump-trip.

The reactor transient for the first case listed in Table 6-1 is shown in Figures 6-1 to 6-5. The transients for the other cases show similar behavior. A protection system trip based on the drop in core inlet plenum pressure was initiated 0.2 seconds after the pipe break. The protection system was also capable of tripping the sodium pumps if desired. Figure 6-1 shows the increase in sodium flow through the pumps caused by the core inlet plenum pressure reduction. The subsequent decrease in pump flow rates is caused by the pump trip to half speed. Figure 6-2 shows the core coolant flow reduction caused by the pipe break followed by a further reduction due to the pump trip. The resulting core-average coolant outlet temperature transient is shown in Figure 6-3. The calculated sodium outlet temperature transient for the average powered, peak powered and hot channel fuel assemblies is shown in Figure 6-4. The corresponding cladding temperature transients are shown in Figure 6-5. These are based on a 75 psi core pressure drop and a pump trip to half speed following the scram.

The effect of possible core inlet-plenum inlet-nozzle modifications that could provide more margin for meeting the criterion for acceptability for this event was examined for the 75 psi pressure drop core with pump trip to half speed. The results are listed in Table 6-2. The present core inlet plenum has rounded inlet nozzles which would have entrance losses of 0.205 velocity heads with an additional 1.00 velocity heads necessary for establishing the flow or a total drop of 1.205 velocity heads. This is the same as used to generate the data listed in Table 6-1. The hydraulic losses at the plenum inlet can be increased in a number of ways. Square corners on the inlet nozzles would increase the pressure drop for reverse flow to 1.5 velocity heads without significantly increasing the losses for forward flow. Table 6-2 shows that hot channel maximum temperatures are reduced by approximately 34°F as a result of a such a modification. The use of inlet baffles could raise the reverse flow pressure drop from plenum to break in the range of 1.8 to 2.0 velocity heads or higher. Table 6-2 shows that the 1600°F criterion can be met with such modifications.

## 8.6.4 CONCLUSIONS

The present analysis scopes the primary pipe break (DEG) for the Phase A pool design. Calculations using CRBRP hot channel factors and the CRBRP criterion for acceptability indicate acceptable consequences or nearly acceptable consequences assuming no post-scram pump trip (or a sufficiently delayed pump trip). The analysis results also show the event with a post-scram pump trip are borderline or not acceptable. A more detailed analysis using hot channel factors and a

Table 6-1

MAXIMUM TEMPERATURES FOLLOWING A DEG PRIMARY PIPE BREAK AT THE CORE INLET PLENUM OF THE PHASE A PLANT

| Post Scram Pump Speed (%) | Core $\Delta P$ (psi) | Maximum Hot Channel Temperature Sodium (°F) | Maximum Hot Channel Temperature Cladding (°F) |
|---|---|---|---|
| 50 | 75 | 1664 | 1643 |
| 100 | 75 | 1582 | 1571 |
| 50 | 100 | 1727 | 1699 |
| 100 | 100 | 1609 | 1597 |

Table 6-2

MAXIMUM TEMPERATURES FOLLOWING A DEG PRIMARY PIPE BREAK AT THE CORE INLET PLENUM OF THE PHASE A PLANT WITH A 75 PSI PRESSURE DROP CORE VERSUS HYDRAULIC LOSS ASSOCIATED WITH THE BREAK*

| Total Hydraulic Losses (Velocity Heads) | Maximum Hot Channel Temperature Sodium (°F) | Maximum Hot Channel Temperature Cladding (°F) |
|---|---|---|
| 1.205 | 1664 | 1643 |
| 1.5 | 1630 | 1611 |
| 1.8 | 1603 | 1587 |
| 2.0 | 1589 | 1573 |

*Also assumes the sodium pumps are tripped to half speed following the scram initiation.

criterion for the Phase A core could possibly show the borderline cases are also acceptable. Should such analyses show the results are not acceptable, some minor changes can be made to increase the reverse flow pressure drop between the core inlet plenum and the break. Table 6-2 shows that minor changes are able to potentially provide a margin for obtaining acceptability even if hot channel factors and criteria do not improve.

## V-8.7

## SINGLE PRIMARY PUMP FAILURE AFTER SCRAM

### 8.7.1 INTRODUCTION

The event under consideration is a single primary pump failure (such as a pony motor failure) immediately after a reactor scram. The affected pump is assumed to coast down and stop while the other pumps coast down to the appropriate post-scram pump speed. Some of the core coolant from the operating pumps is diverted from the core and flows backwards through the affected pump. The present 1000 MWe Pool-Type LMFBR design does not contain primary check valves. This causes a potential undercooling situation for the core.

### 8.7.2 BASIS

Since the usual intent of the analysis is the determination of whether or not the core is adequately cooled, several assumptions were made to conservatively maximize core power and minimize core flow during the calculation. The assumptions are as follows:

1. Maximum decay heat (the CRBRP decay power[3] fraction for the average fuel assembly including the positive uncertainties of 25% of fission product decay power and 10% of U-239 and Np-239 decay power).

2. Conservatively fast sodium pump coast down (pump speed half-times of 5 and 6 seconds, respectively, for the primary and intermediate sodium pumps).

3. CRBRP DEMO Rev. 3 hot channel factors[4] for the core fuel assemblies.

| | | |
|---|---|---|
| Radial nuclear factor (assembly) | FNRA | = 1.351 |
| Radial nuclear factor (fuel rod), | FNRP | = 1.003 |
| Flow maldistribution factor, | FMD | = 1.15 |
| Flow orificing factor, | FOR | = 1.10 |
| Heat flux factor, | FQ | = 1.1613 |
| Fuel conductivity factor, | FFUEL | = 1.10 |
| Gap conductivity factor, | FGAP | = 1.3745 |
| Clad conductivity factor, | FCLAD | = 1.514 |
| Film conductivity factor, | FFILM | = 1.575 |
| Channel enthalpy rise factor, | FDH | = 1.298 |

4. Minimum locked rotor hydraulic resistance for the affected pump (175 ft. at rated sodium flow).

5. Maximum core pressure drop (100 psi).

The CRBRP decay heat analysis is believed to conservatively apply to the present analysis. The pump coastdown characteristics were chosen based on current ANL E-spec data for the large component development program. The CRBRP hot channel factors were used because no complete set of 1000 MWe Pool-Type LMFBR hot channel factors is available and because the CRBRP values appear to be conservative. The minimum locked rotor hydraulic resistance for the affected pump and the maximum core pressure drop result in the maximum bypass of core coolant from the operating pumps. This results in the highest calculated core temperatures.

8.7.3
ANALYSIS

The analysis of the reactor transient for the 1000 MWe Pool-Type LMFBR following a single primary pump failure immediately after a scram involved the evaluation of two cases. The first case assumed a normal post-scram pump speed of 50 percent. The second case assumed post-scram pony motor operation to be at 7 percent speed. In both cases the core (plenum to plenum) pressure drop at full flow was assumed to be 100 psi.

Figures 7-1 to 7-5 show the reactor transient with 50 percent post-scram pump speed. Figure 7-1 shows the operating pumps increase flow from the normal 50 percent value to approximately 65 percent due to the reduced lower plenum backpressure. Curve 3 demonstrates this behavior. The bypass flow through the affected pump is slightly less than 40 percent of its rated forward flow. Figure 7-2 shows the resulting core coolant and primary IHX sodium mass flow rates. These curves indicate the core coolant flow rate drops to 39 percent of rated which is quite adequate for post-scram cooling. Adequate cooling is also demonstrated in Figures 7-4 and 7-5 which show the core cladding and coolant outlet temperatures drop to less than 700°F shortly after the scram. It should be noted that there are no sodium temperature changes at any of the primary pumps due to the core coolant bypass.

Figures 7-6 to 7-10 show the event with a post-scram pony motor speed of 7 percent. In this case the core coolant flow rate (Figure 7-7) drops to slightly below 7 percent. Figures 7-9 and 7-10 show the core sodium exit and cladding temperatures in the average powered, peak powered and hot channel assemblies. These curves indicate that the core temperatures do not exceed normal full power operating temperatures. Therefore, the consequences of this event are most likely acceptable.

## 8.7.4 CONCLUSIONS

The results of calculations for this event with post-scram pump speeds of 50 and 7 percent show that post-scram core temperatures do not exceed full power operating temperatures. Since the results are based on calculations without primary check valves, the single primary pump failure event after a scram does not establish a need for primary check valves. The results for this event are most likely acceptable without primary check valves. Other operating conditions, however, might require primary check valves such as part power operation with 3 of the 4 primary pumps in service.

## REFERENCES


1. EPRI NP-646, Pool-Type LMFBR Plant, 1000 MWe Phase A Design, April, 1978.

2. EPRI NP-646, Pool Type LMFBR Plant 1000 MWe Phase A Design, Part II: Heat Transport Systems, Section 5: Plant Thermal Transient Model, April, 1978.

3. C.A. McGinnis, et al., "CRBRP Decay Power Analysis", WARD -D-0090, January, 1976.

4. "LMFBR Demonstration Plant Simulation Model (DEMO)", WARD-D-0005, Rev. 3, April 15, 1975.

FIGURE 3-1

POOL REACTOR SCRAM FROM 100 PERCENT POWER (TWO-ZONE MIXING * 0.5)
RUN DATED 03/28/78
NUMBER DEPGE07

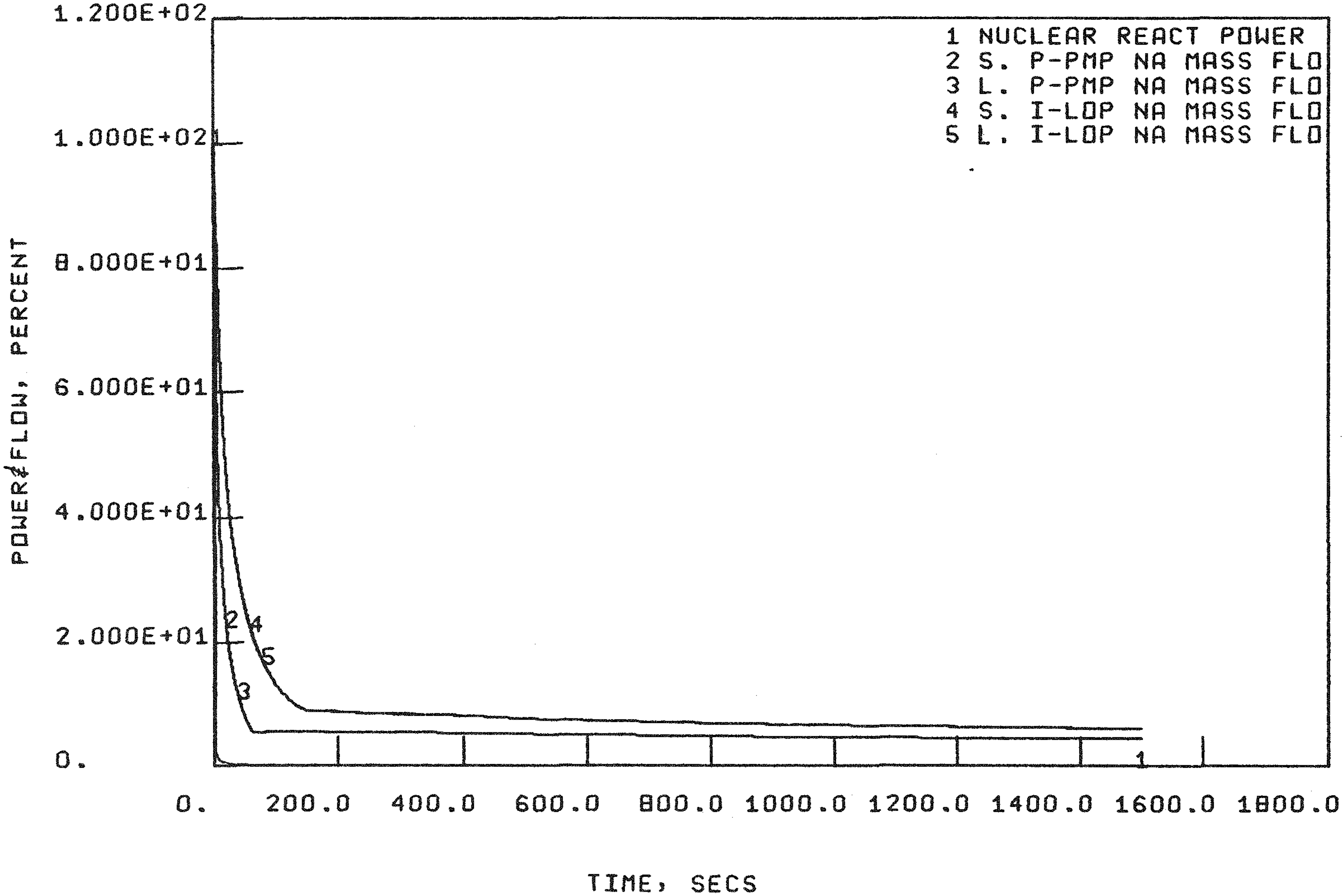


FIGURE 3-2
POOL REACTOR SCRAM FROM 100 PERCENT POWER (TWO-ZONE MIXING * 0.5)
RUN DATED 03/28/78
NUMBER DEPGE07

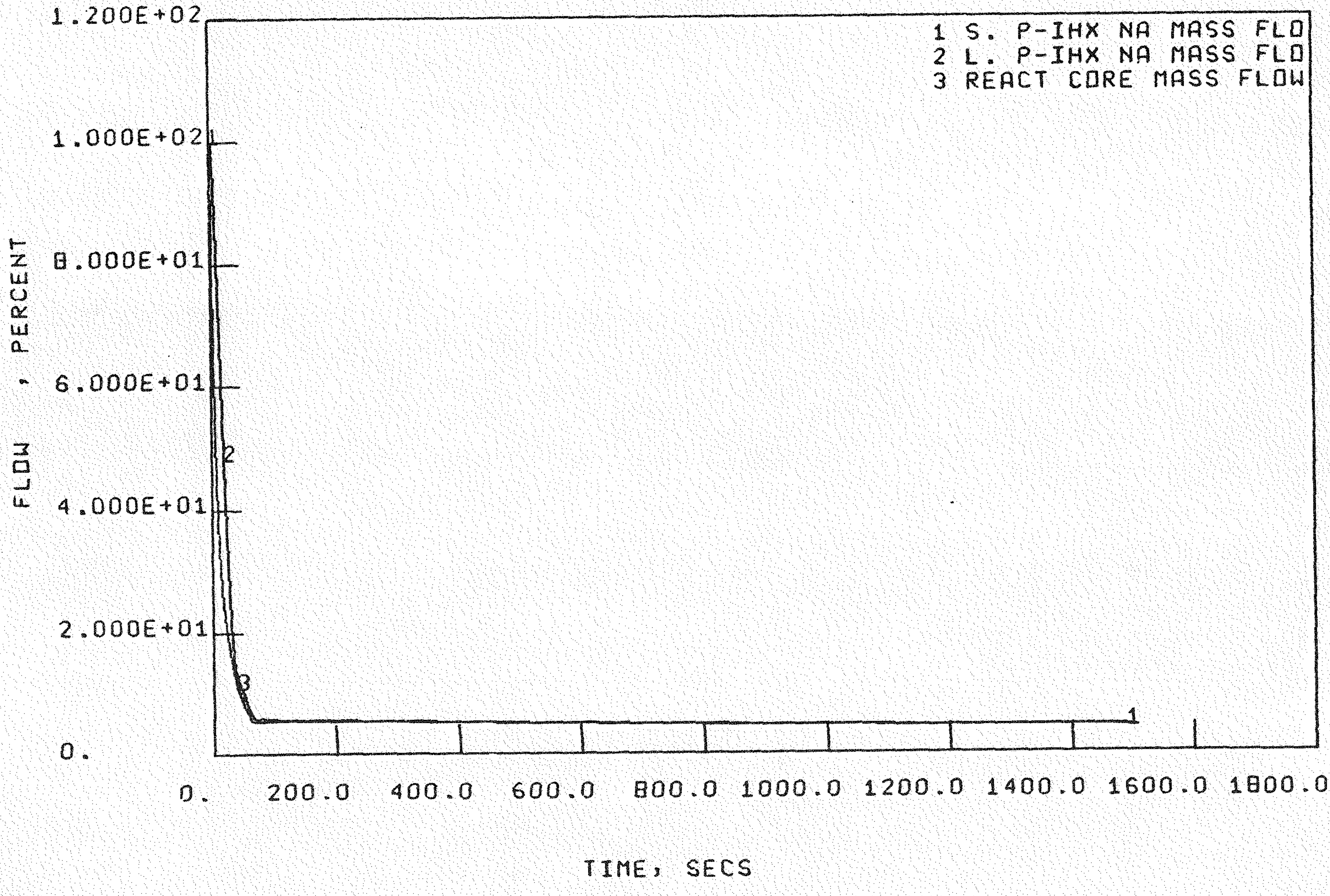


FIGURE 3-3

POOL REACTOR SCRAM FROM 100 PERCENT POWER (TWO-ZONE MIXING * 0.5)
RUN DATED 03/28/78
NUMBER DEPGE07

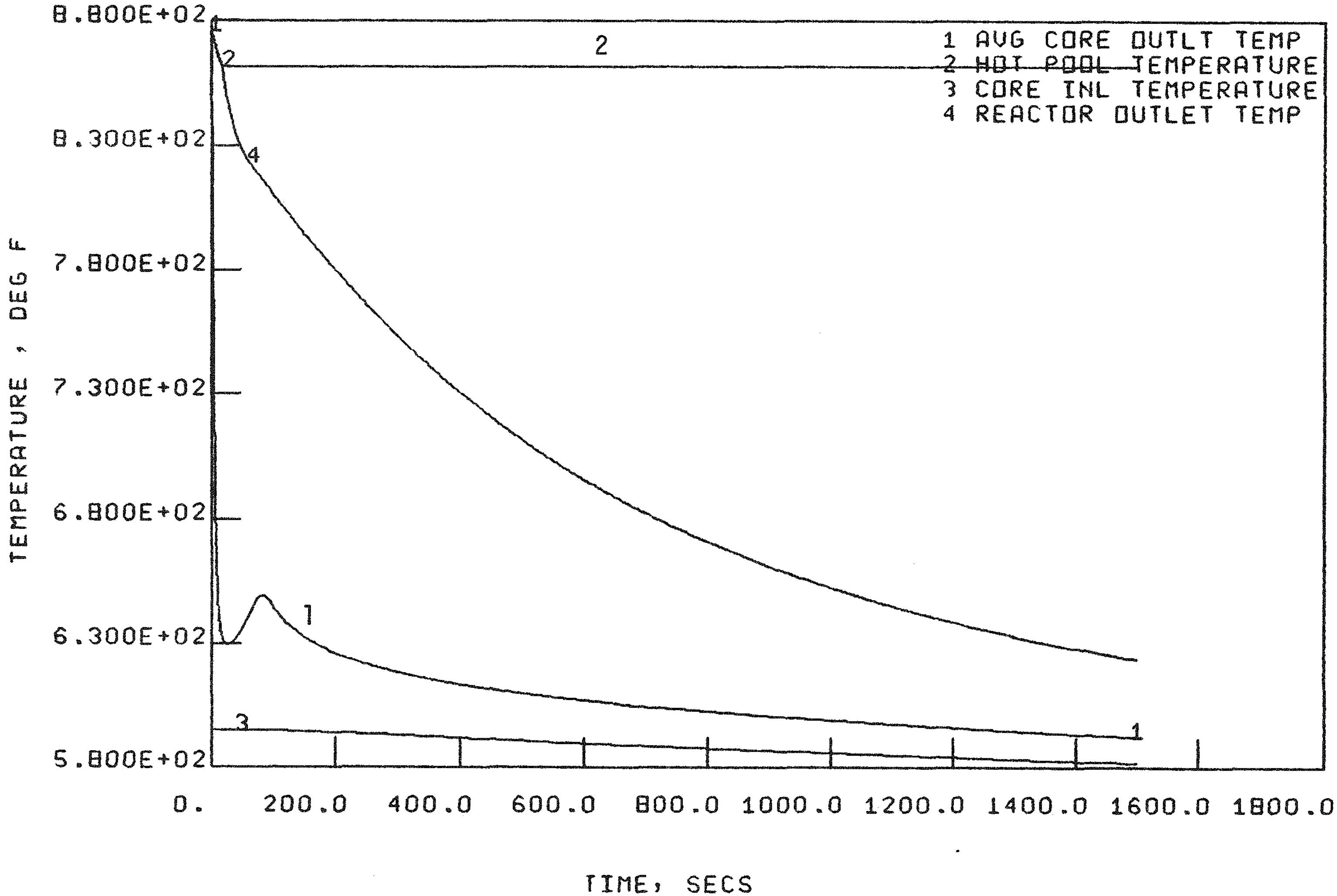


FIGURE 3-4

POOL REACTOR SCRAM FROM 100 PERCENT POWER (TWO-ZONE MIXING * 0.5)
RUN DATED 03/28/78
NUMBER DEPGE07

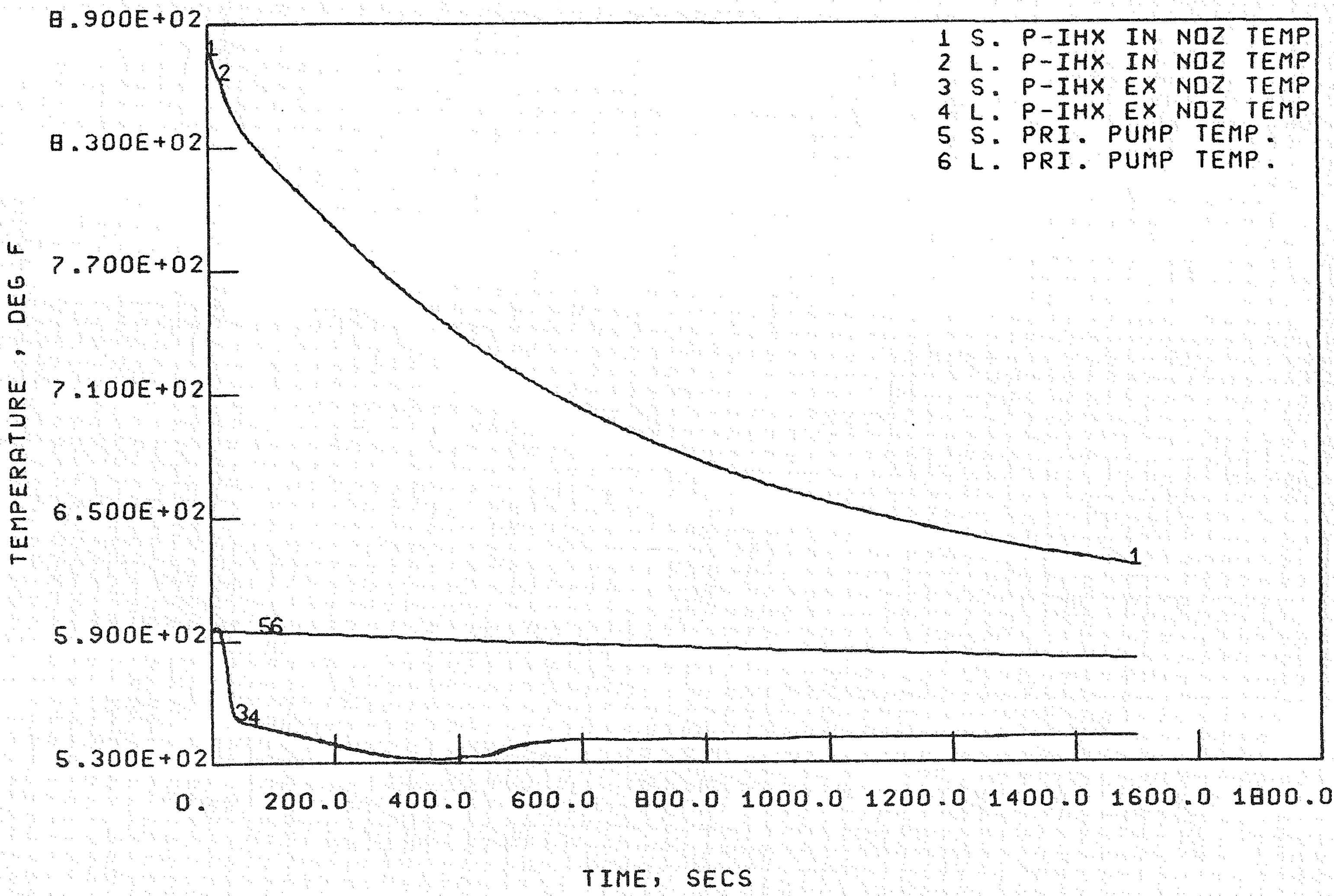


FIGURE 3-5
POOL REACTOR SCRAM FROM 100 PERCENT POWER (TWO-ZONE MIXING * 0.5)
RUN DATED 03/28/78
NUMBER DEPGE07

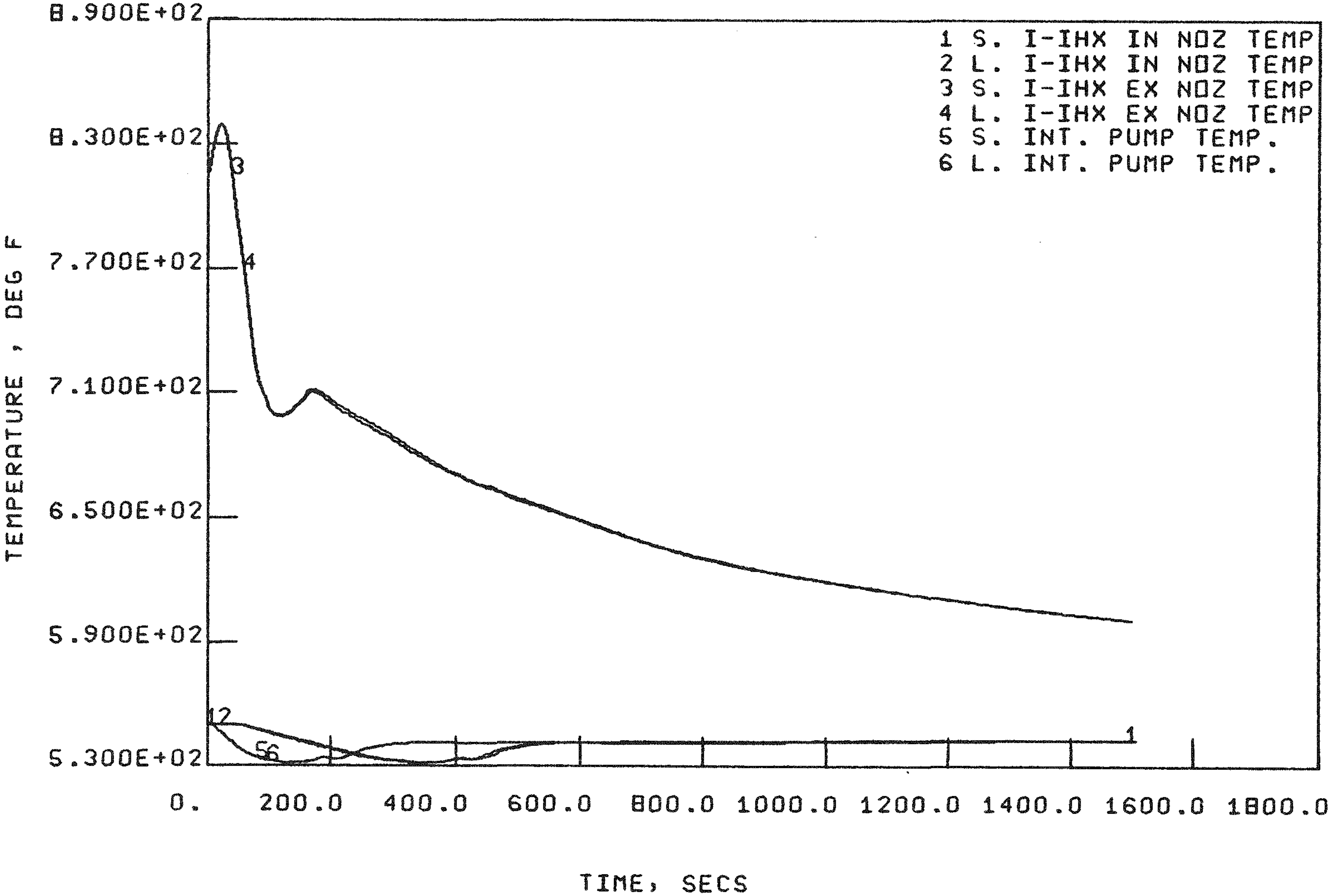


FIGURE 3-6

POOL REACTOR SCRAM FROM 100 PERCENT POWER (34 SEC PUMP TRIP DELAY)

RUN DATED 03/28/78

NUMBER DEPGE06

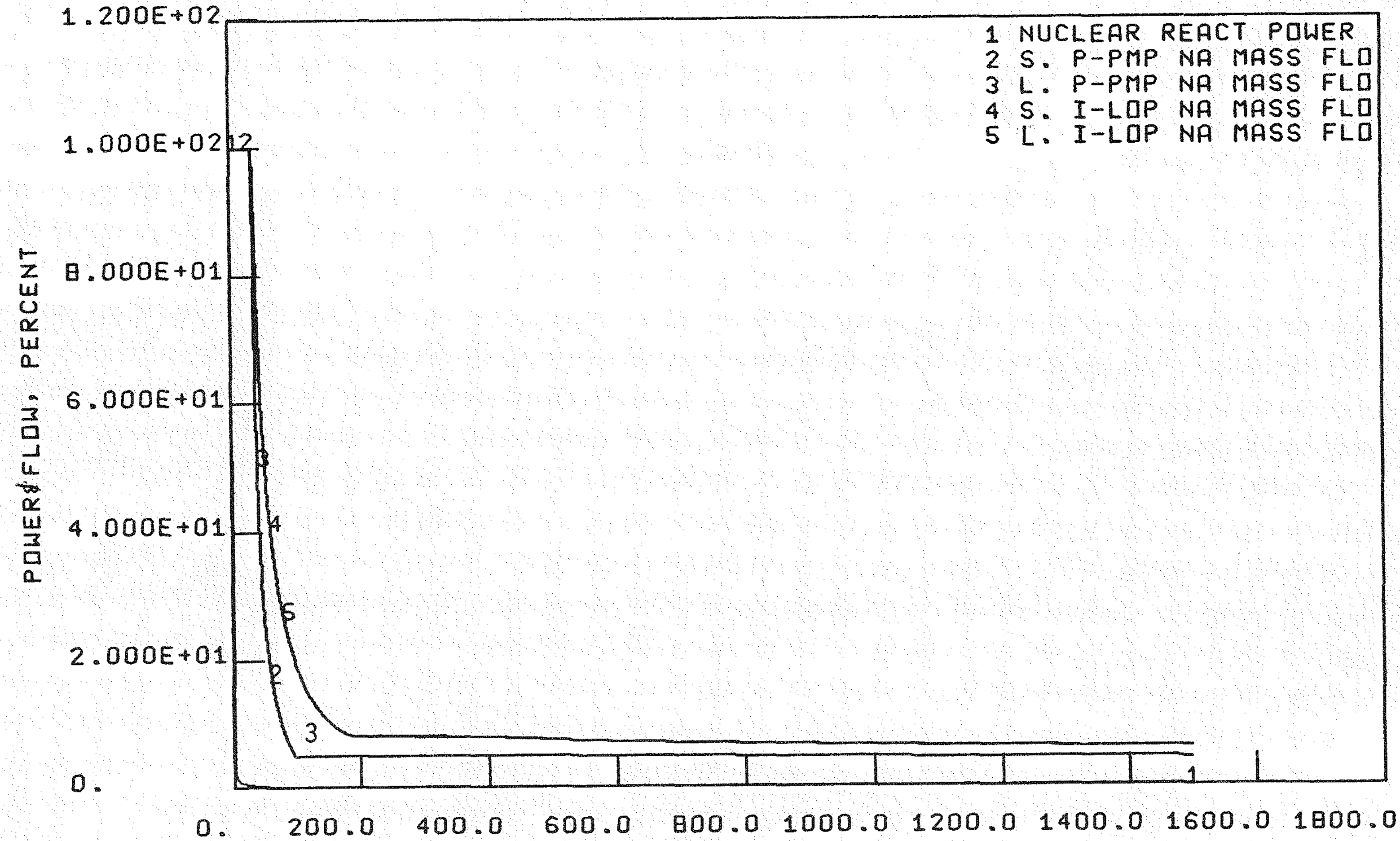


FIGURE 3-7

POOL REACTOR SCRAM FROM 100 PERCENT POWER (34 SEC PUMP TRIP DELAY)
RUN DATED 03/28/78
NUMBER DEPGE06

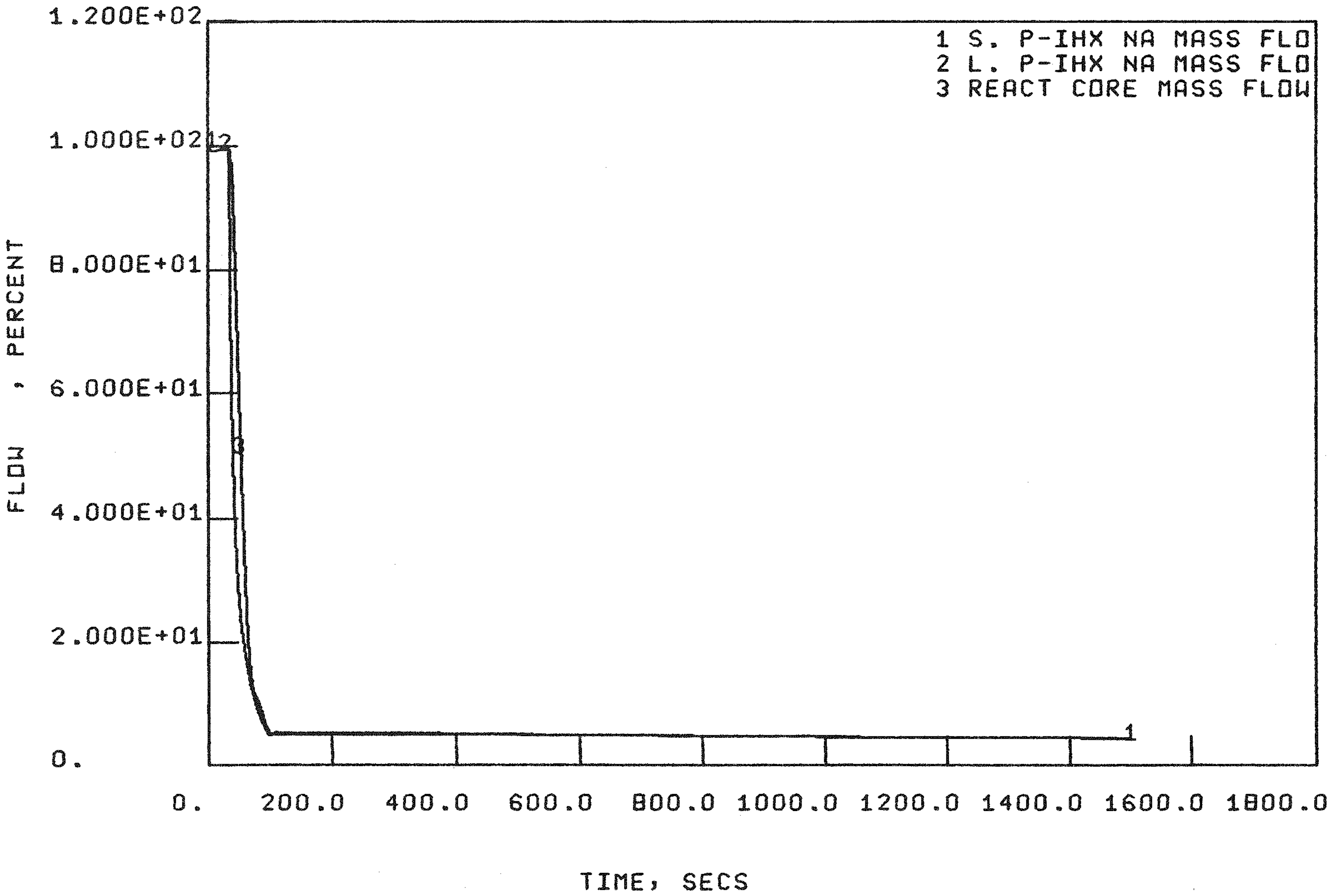


FIGURE 3-8

POOL REACTOR SCRAM FROM 100 PERCENT POWER (34 SEC PUMP TRIP DELAY)
RUN DATED 03/28/78
NUMBER DEPGE06

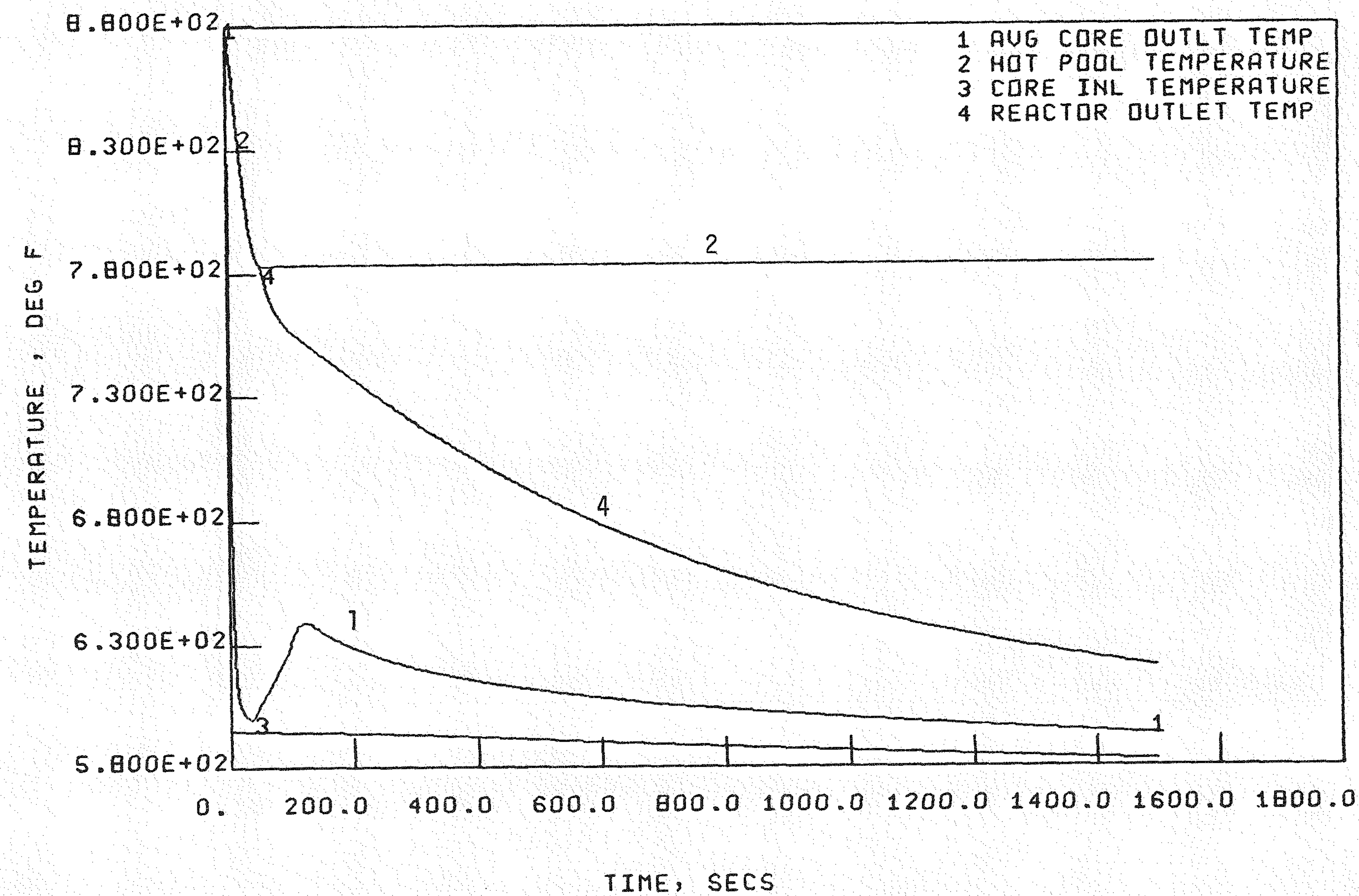


FIGURE 3-9

POOL REACTOR SCRAM FROM 100 PERCENT POWER (34 SEC PUMP TRIP DELAY)
RUN DATED 03/28/78
NUMBER DEPGE06

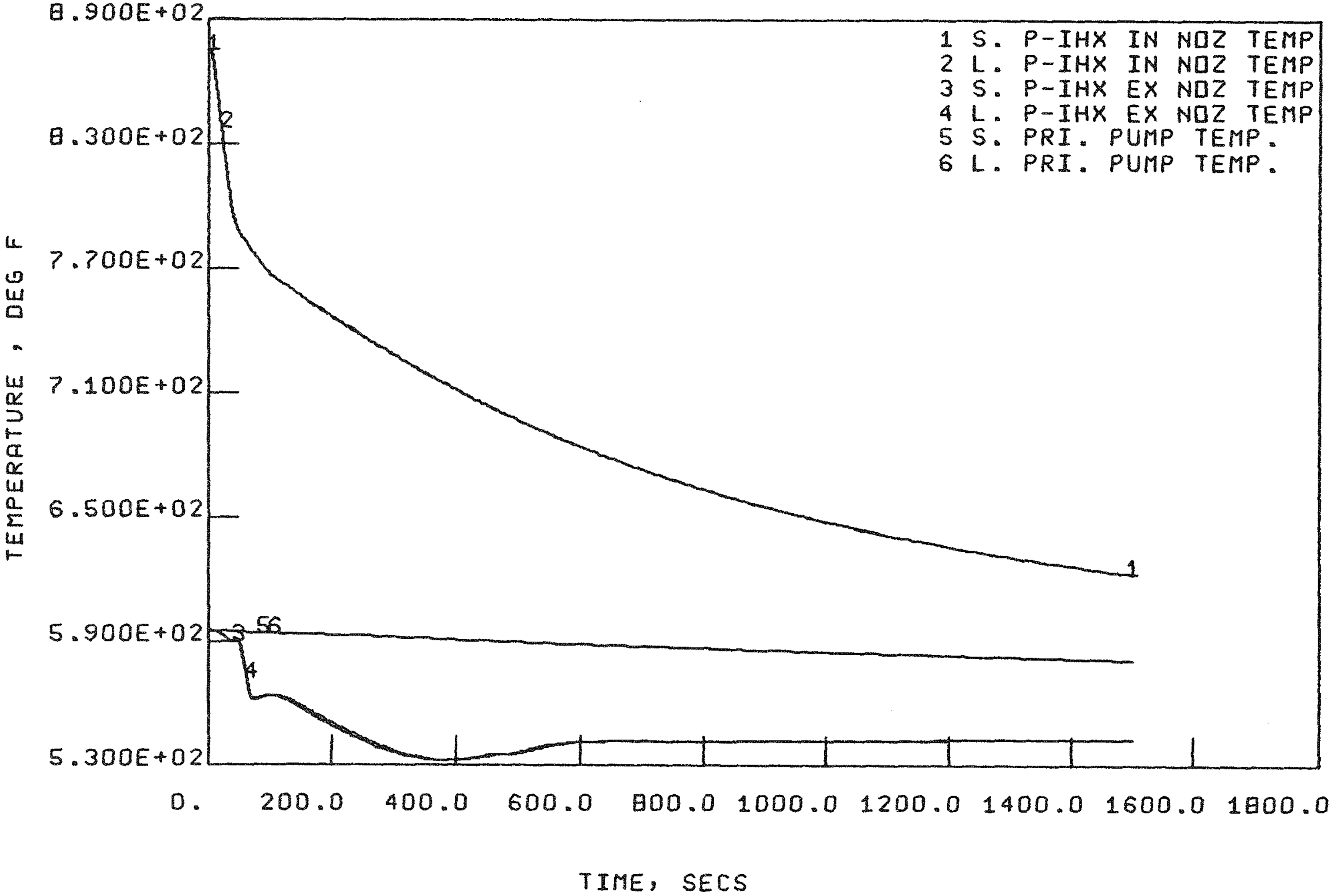


FIGURE 3-10
POOL REACTOR SCRAM FROM 100 PERCENT POWER (34 SEC PUMP TRIP DELAY)
RUN DATED 03/28/78
NUMBER DEPGE06

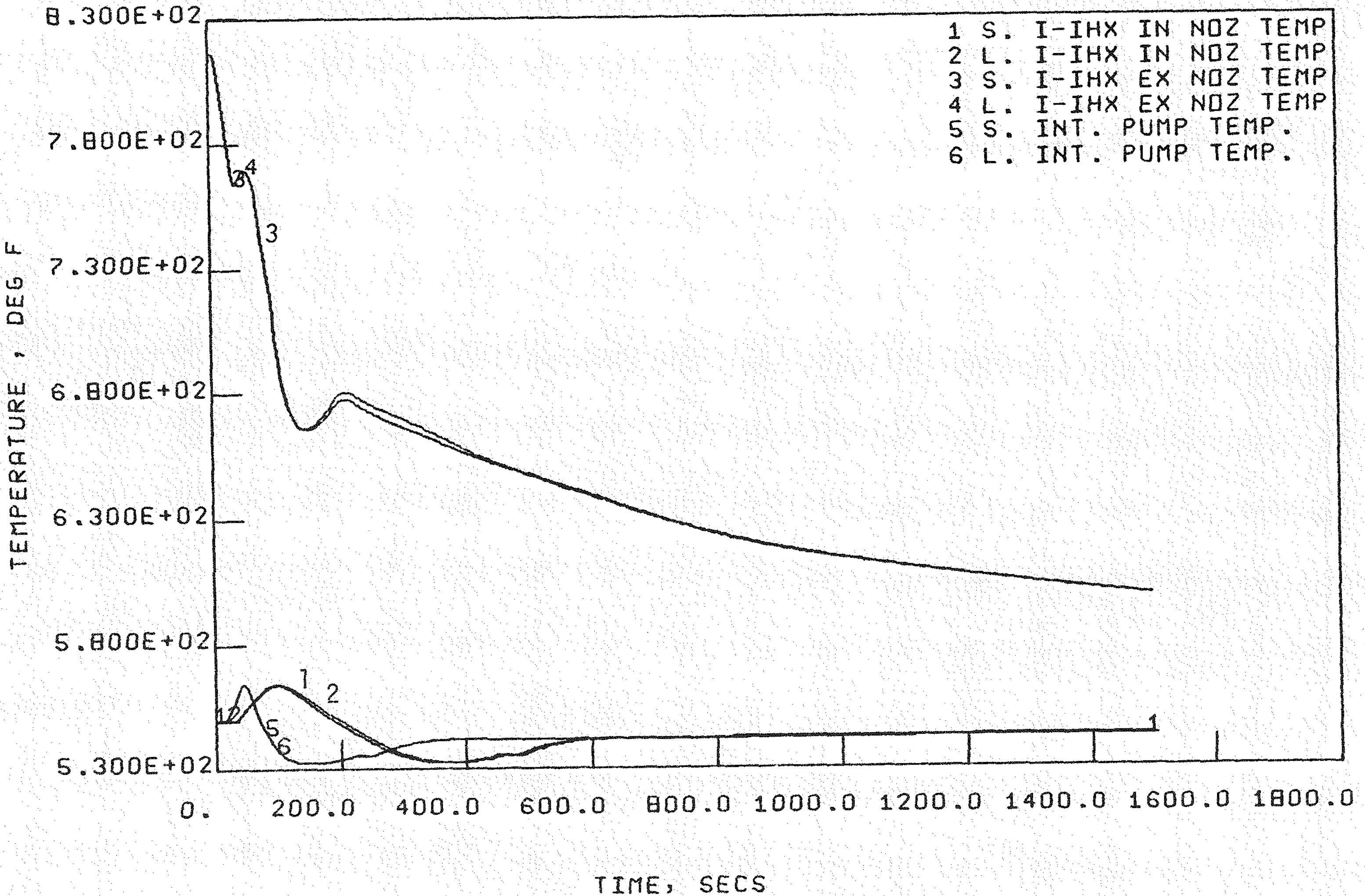


FIGURE 3-11
POOL REACTOR SCRAM FROM 100 PERCENT POWER (78 SEC PUMP TRIP DELAY)
RUN DATED 03/28/78
NUMBER DEP6E05

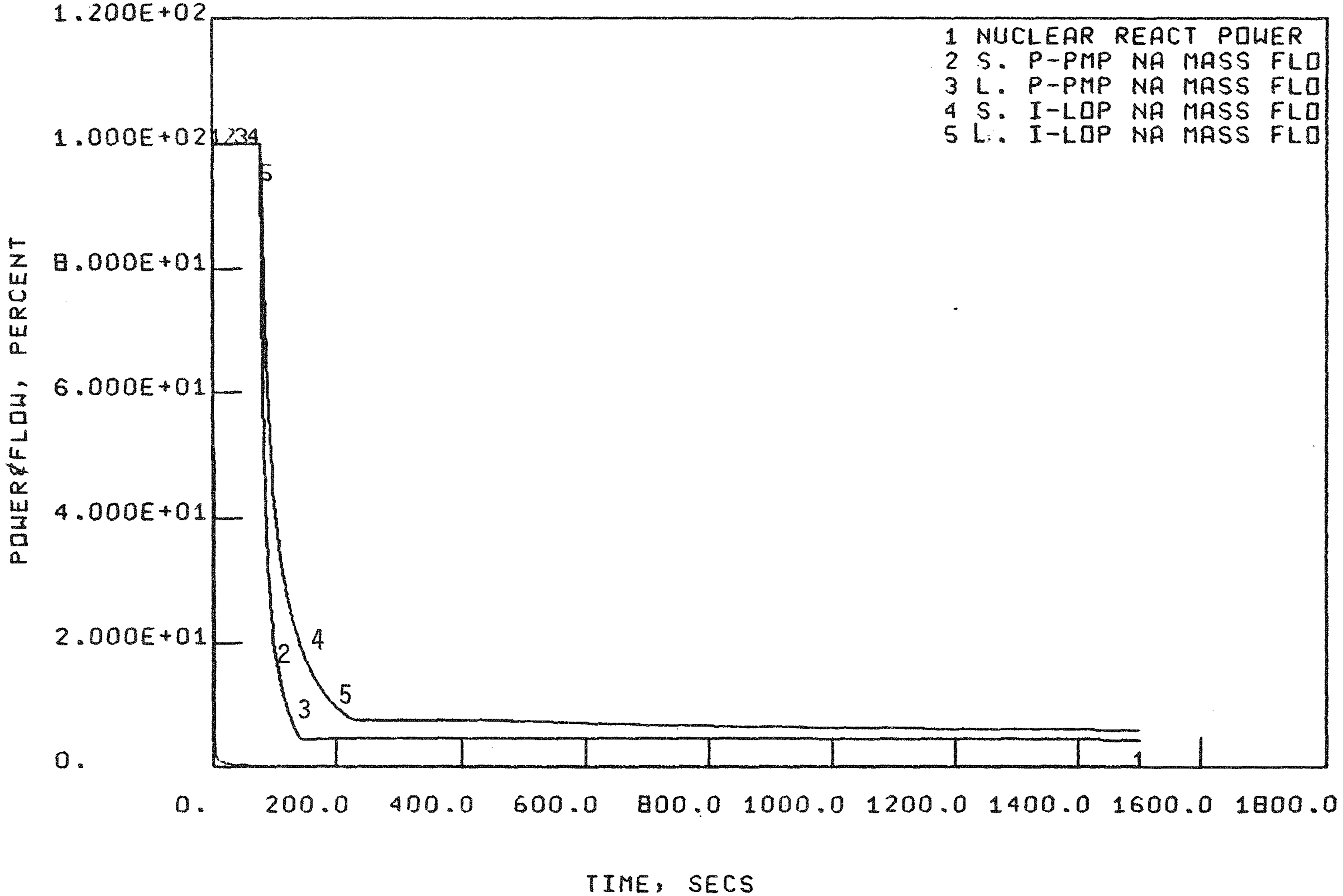


FIGURE 3-12
POOL REACTOR SCRAM FROM 100 PERCENT POWER (78 SEC PUMP TRIP DELAY)
RUN DATED 03/28/78
NUMBER DEPGE05

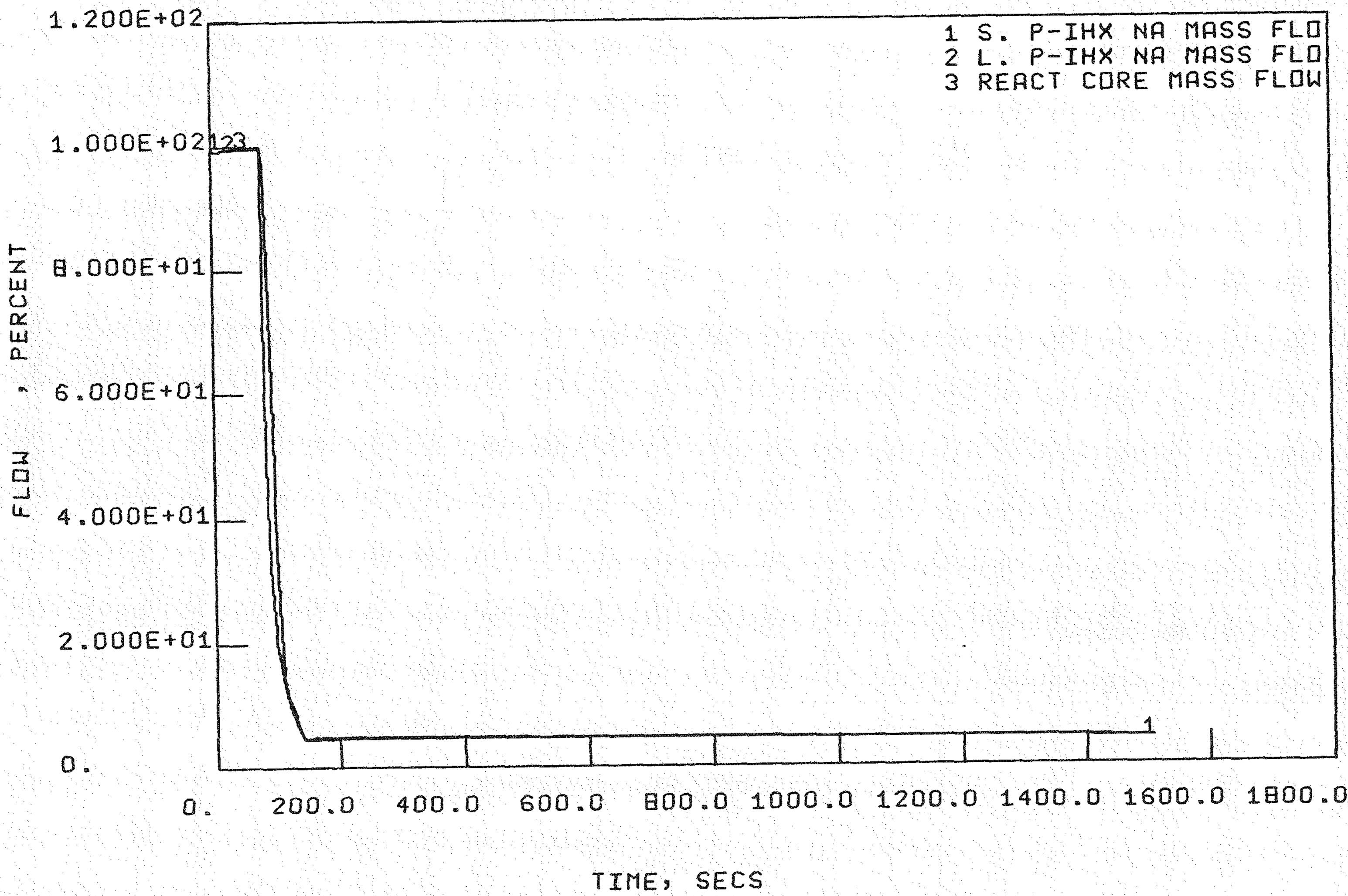


FIGURE 3-13
POOL REACTOR SCRAM FROM 100 PERCENT POWER (78 SEC PUMP TRIP DELAY)
RUN DATED 03/28/78
NUMBER DEPGE05

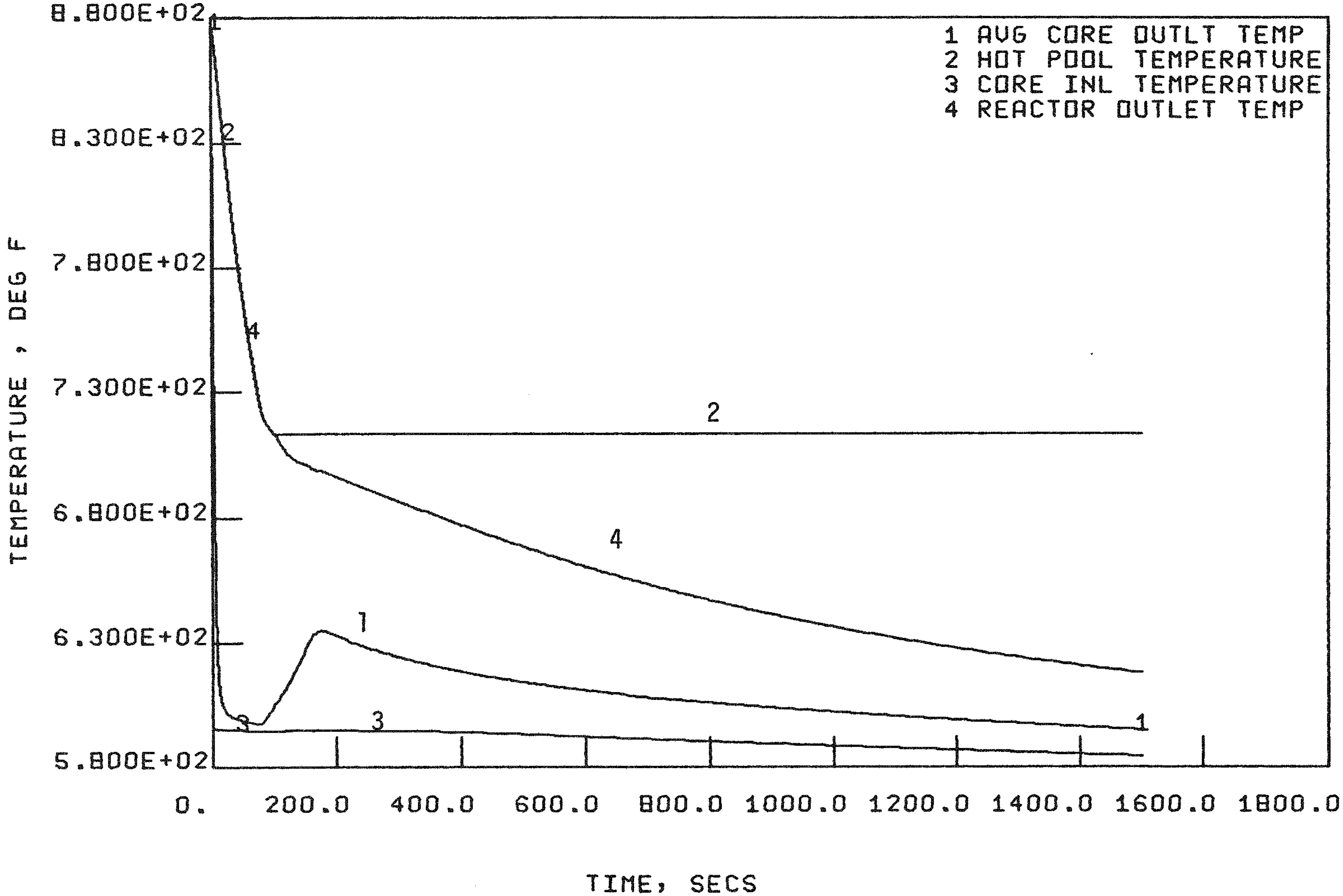


FIGURE 3-14
POOL REACTOR SCRAM FROM 100 PERCENT POWER (78 SEC PUMP TRIP DELAY)
RUN DATED 03/28/78
NUMBER DEPGEOS

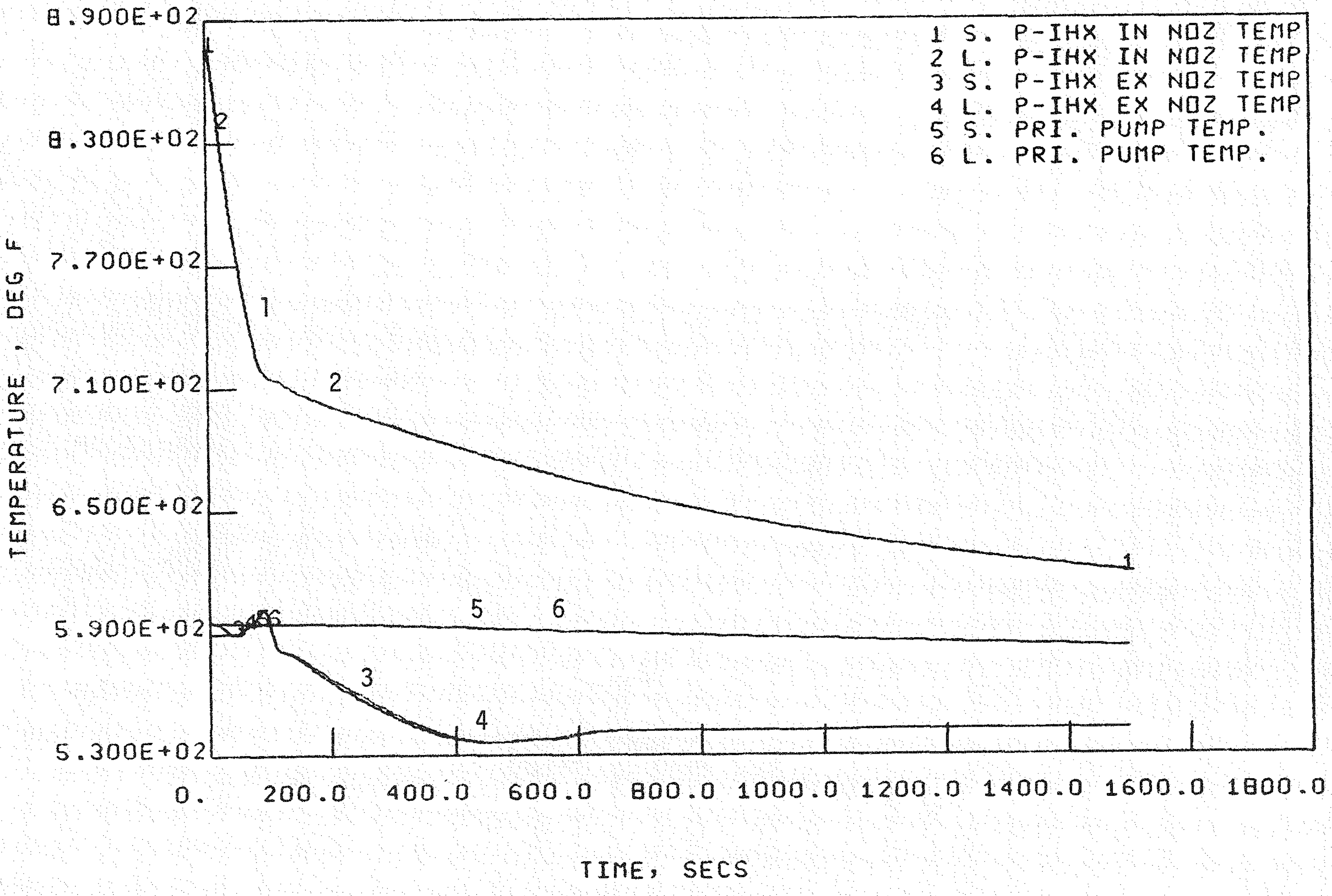
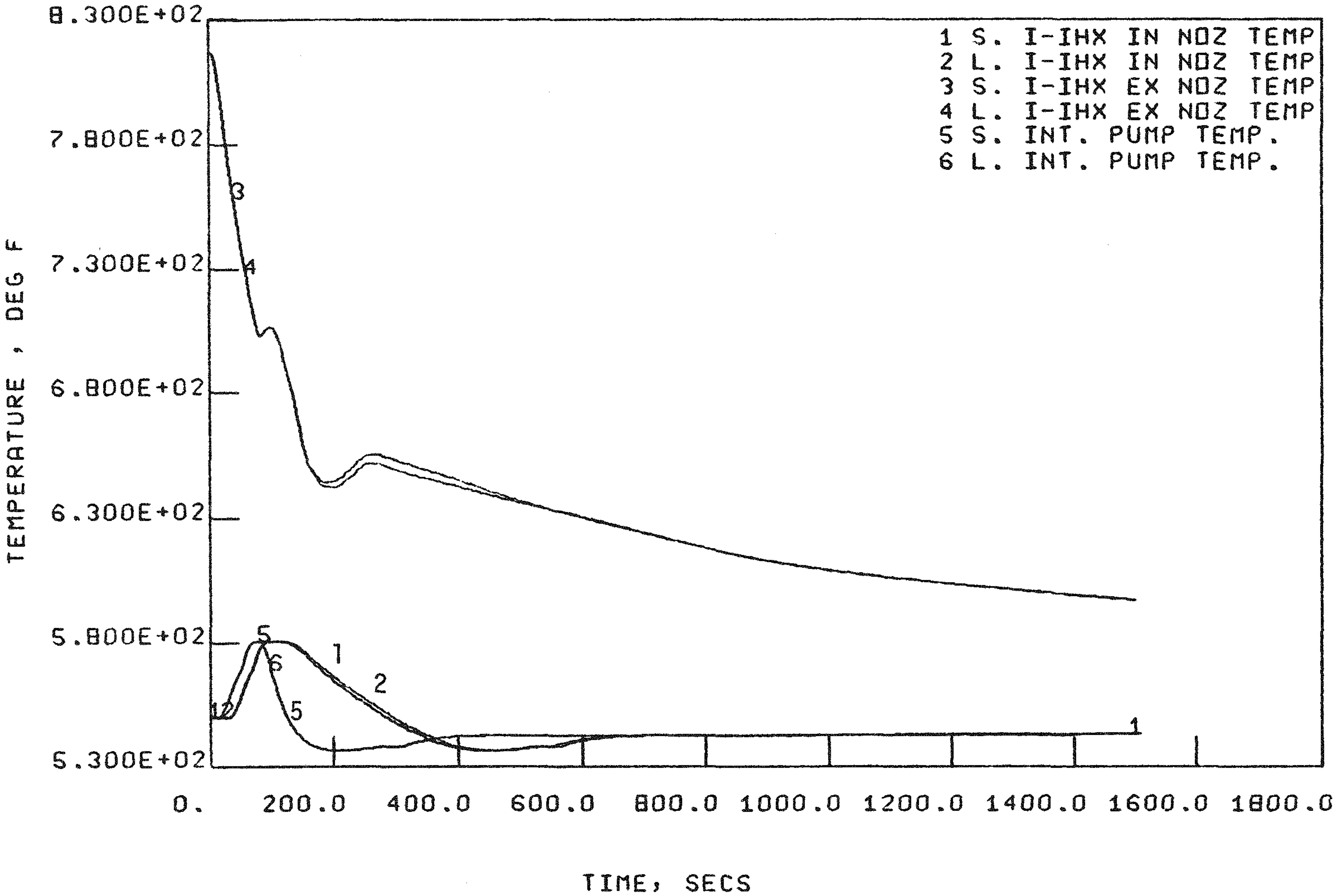


FIGURE 3-15

POOL REACTOR SCRAM FROM 100 PERCENT POWER (78 SEC PUMP TRIP DELAY)
RUN DATED 03/28/78
NUMBER DEPGE05




V-8-45

FIGURE 3-16

POOL REACTOR TRIP WITHOUT PUMP TRIP
RUN DATED 11/16/77
NUMBER DEPGEOO

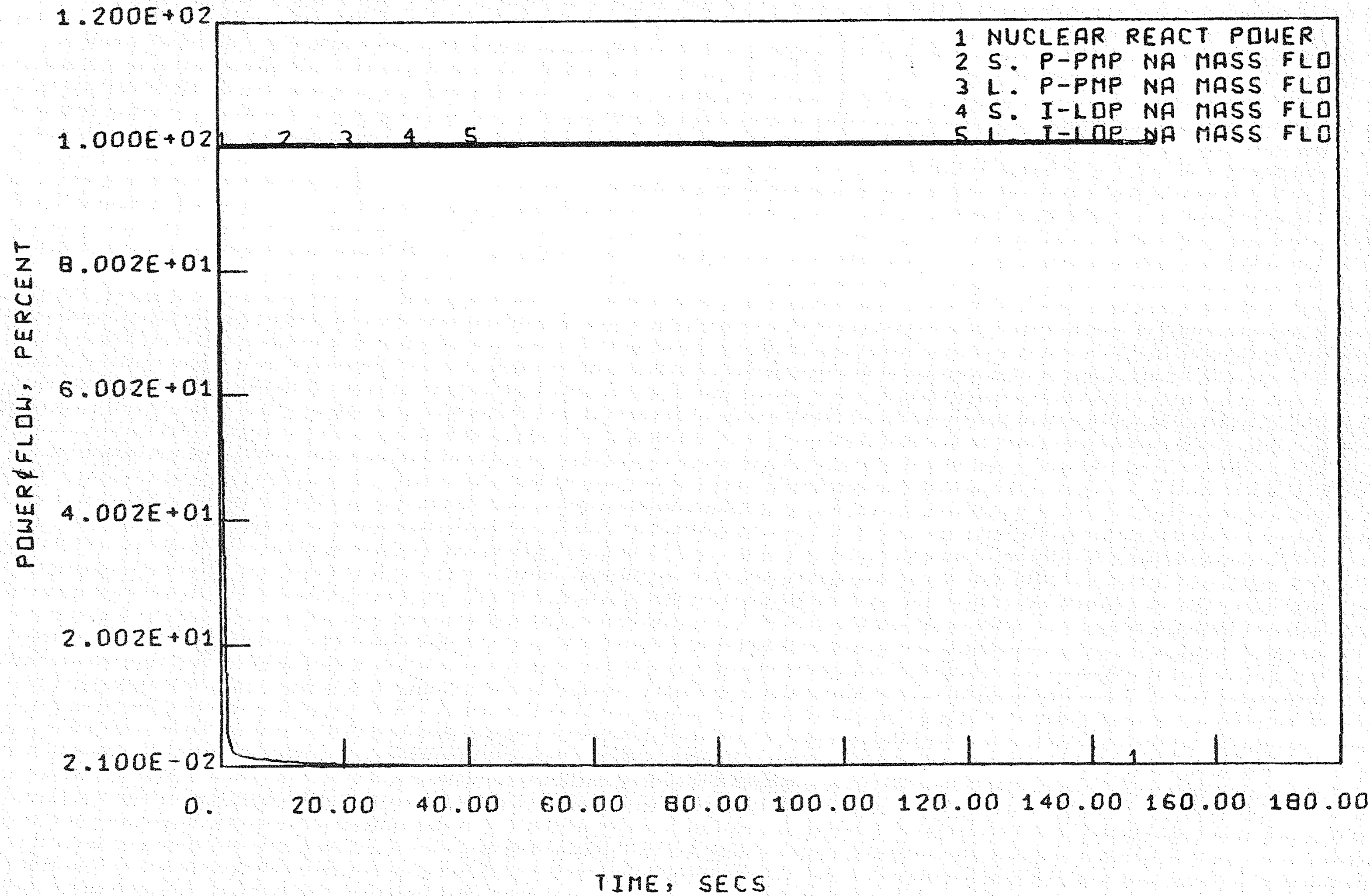


FIGURE 3-17

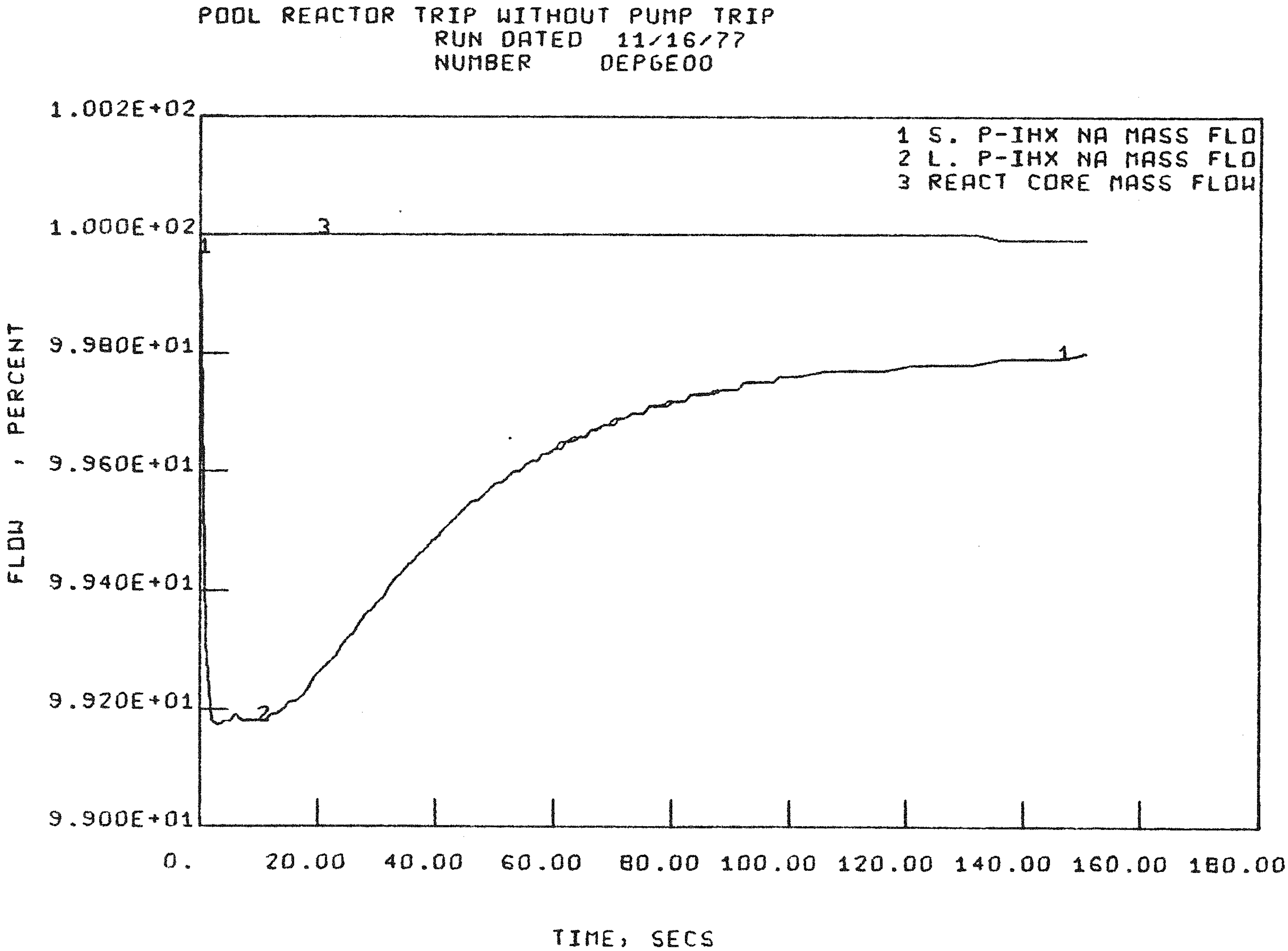

POOL REACTOR TRIP WITHOUT PUMP TRIP
RUN DATED 11/16/77
NUMBER DEPGEOO
1 S. P-IHX NA MASS FLO
2 L. P-IHX NA MASS FLO
3 REACT CORE MASS FLOW
FLOW , PERCENT
1.002E+02
1.000E+02
9.980E+01
9.960E+01
9.940E+01
9.920E+01
9.900E+01
0.
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
TIME, SECS

FIGURE 3-18

POOL REACTOR TRIP WITHOUT PUMP TRIP
RUN DATED 11/16/77
NUMBER DEPGEOD

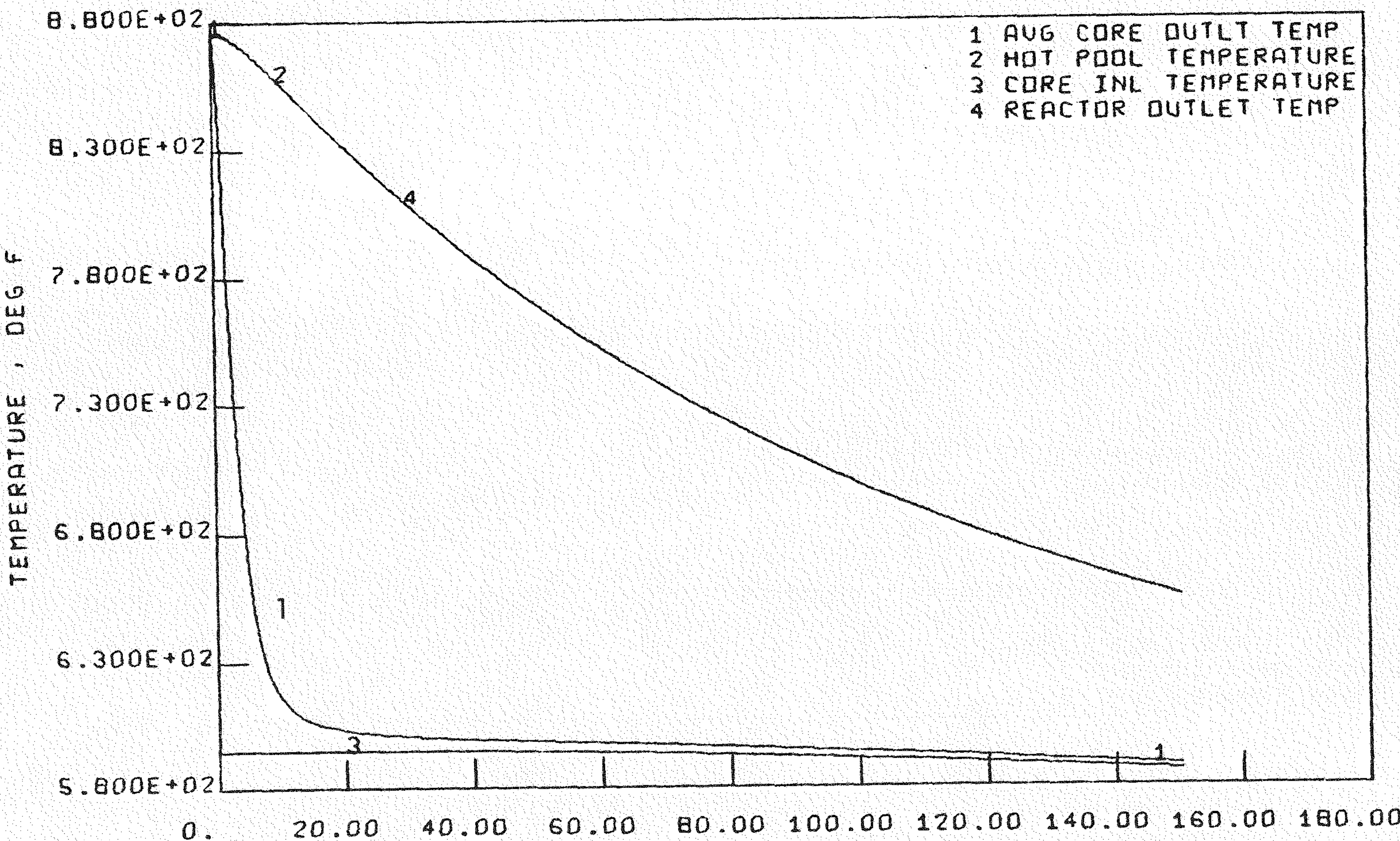


FIGURE 3-19

POOL REACTOR TRIP WITHOUT PUMP TRIP
RUN DATED 11/16/77
NUMBER DEPGEOO

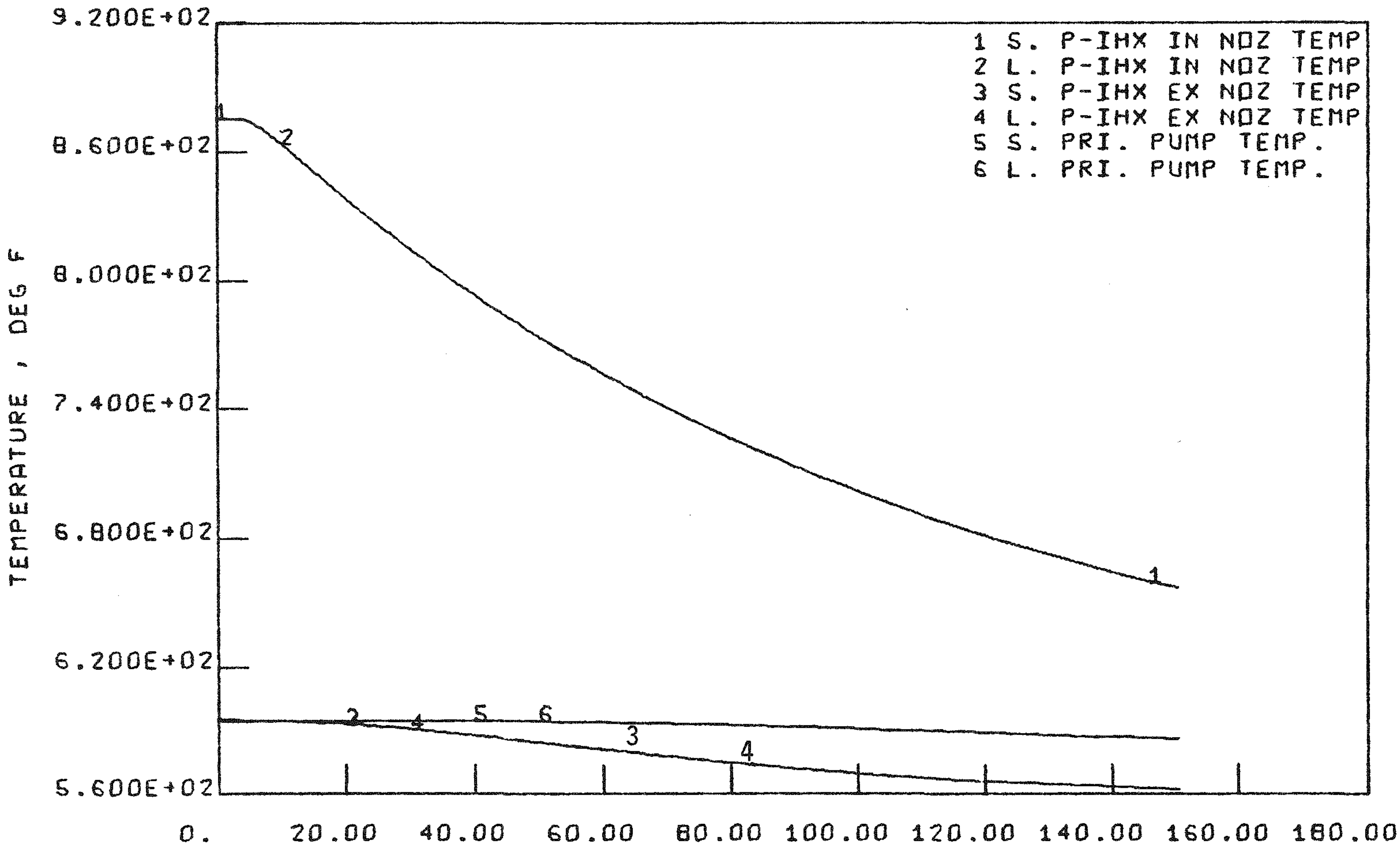


FIGURE 3-20

POOL REACTOR TRIP WITHOUT PUMP TRIP
RUN DATED 11/16/77
NUMBER DEPGEOO

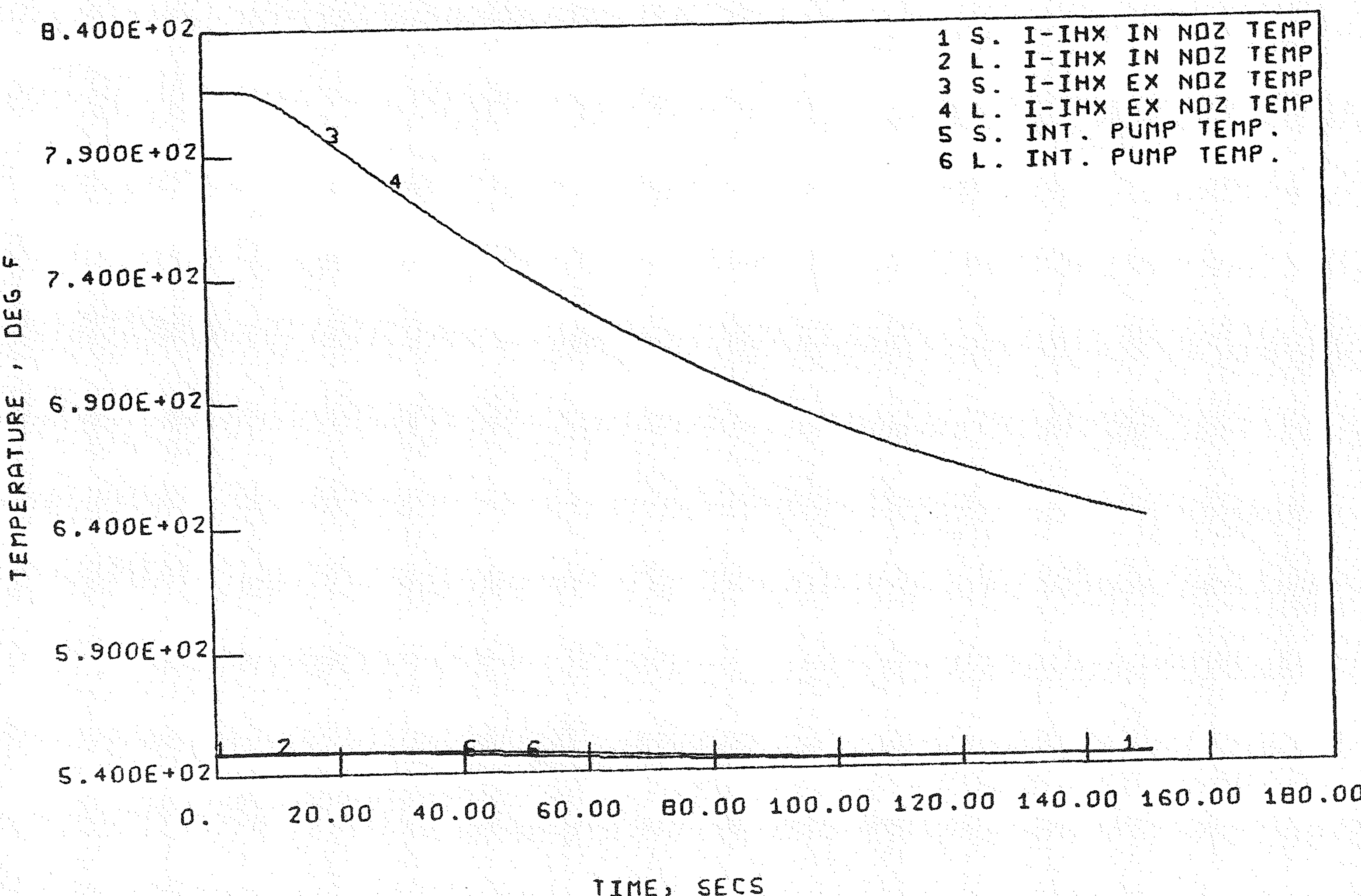


FIGURE 3-21

POOL REACTOR SCRAM FROM 100 PERCENT POWER (WITH PUMP TRIP TO HALF SPEED)
RUN DATED 03/30/78
NUMBER DEPGE09

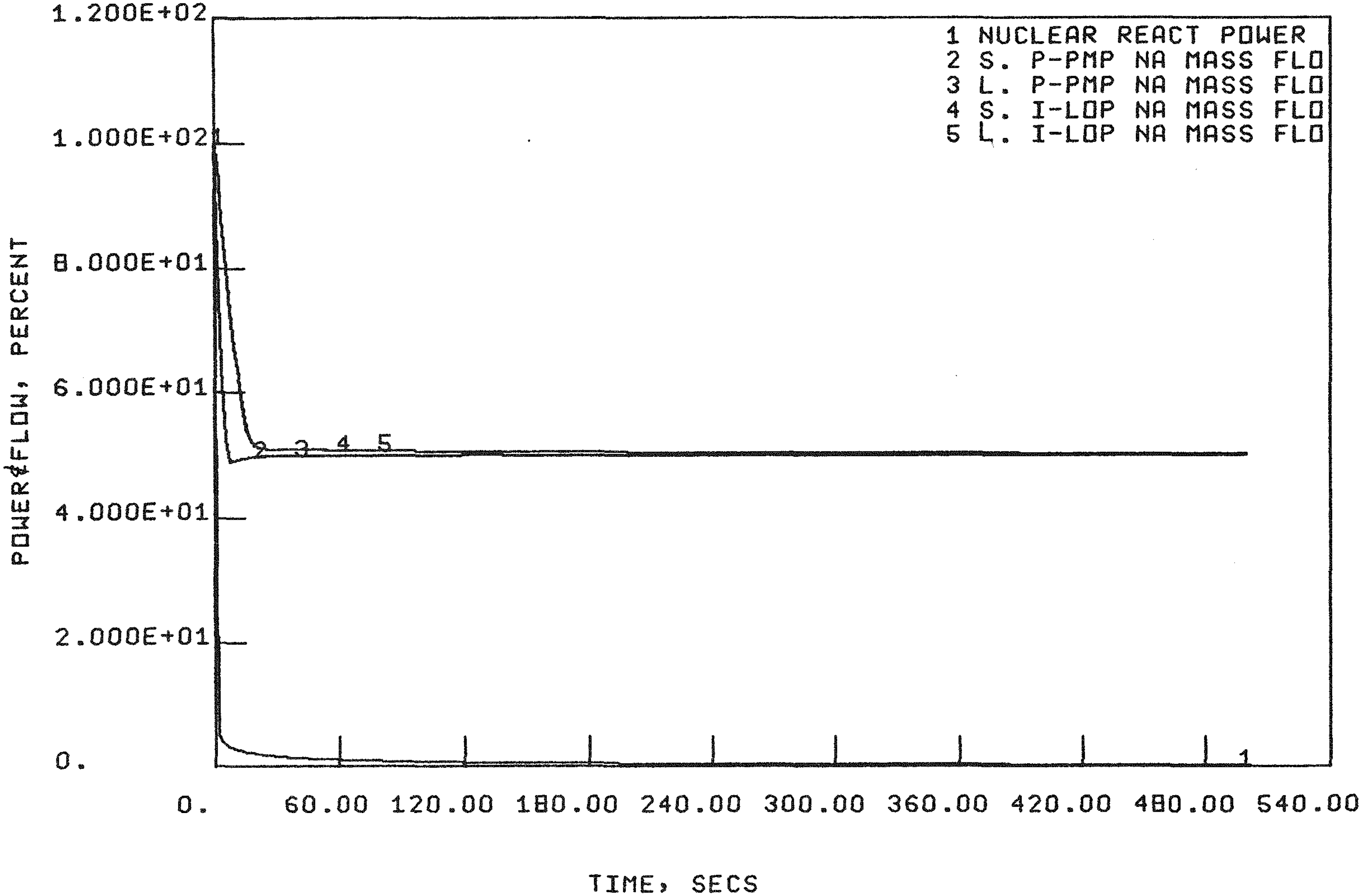


FIGURE 3-22
POOL REACTOR SCRAM FROM 100 PERCENT POWER (WITH PUMP TRIP TO HALF SPEED)
RUN DATED 03/30/78
NUMBER DEPGE09

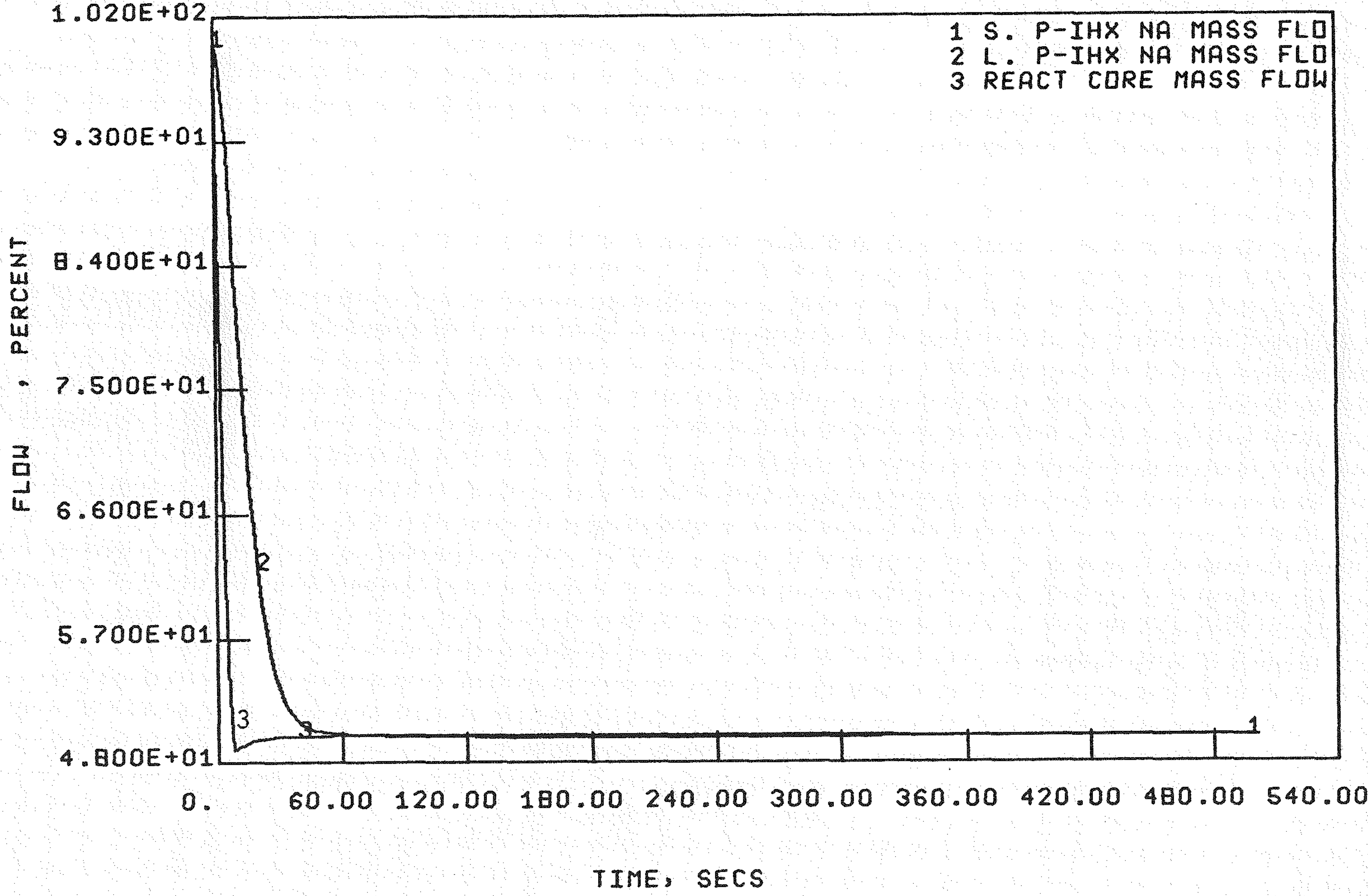


FIGURE 3-23

POOL REACTOR SCRAM FROM 100 PERCENT POWER (WITH PUMP TRIP TO HALF SPEED)
RUN DATED 03/30/78
NUMBER DEPGE09

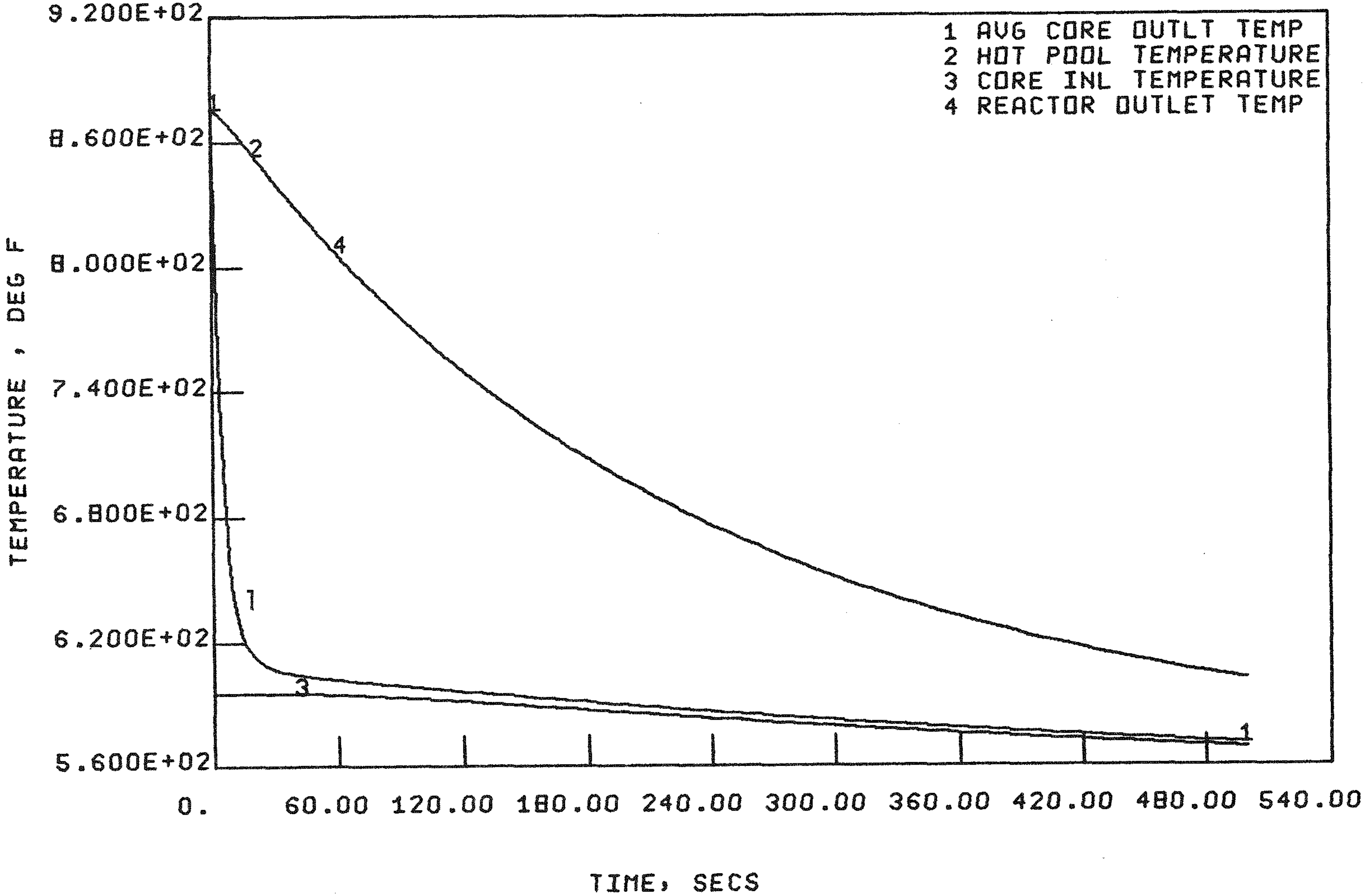


FIGURE 3-24

POOL REACTOR SCRAM FROM 100 PERCENT POWER (WITH PUMP TRIP TO HALF SPEED)
RUN DATED 03/30/78
NUMBER DEPGE09

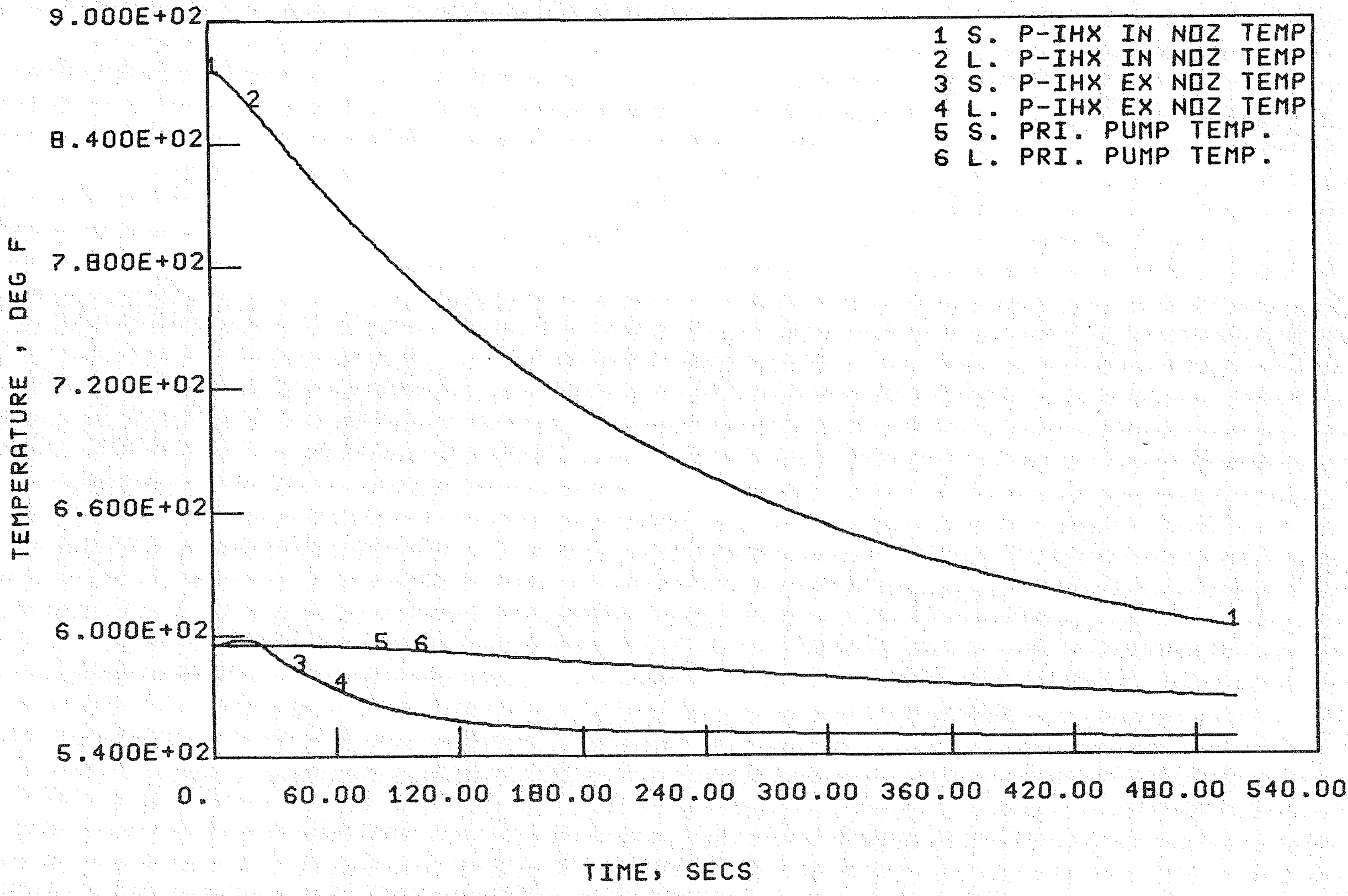


FIGURE 3-25

POOL REACTOR SCRAM FROM 100 PERCENT POWER (WITH PUMP TRIP TO HALF SPEED)
RUN DATED 03/30/78
NUMBER DEPGE09

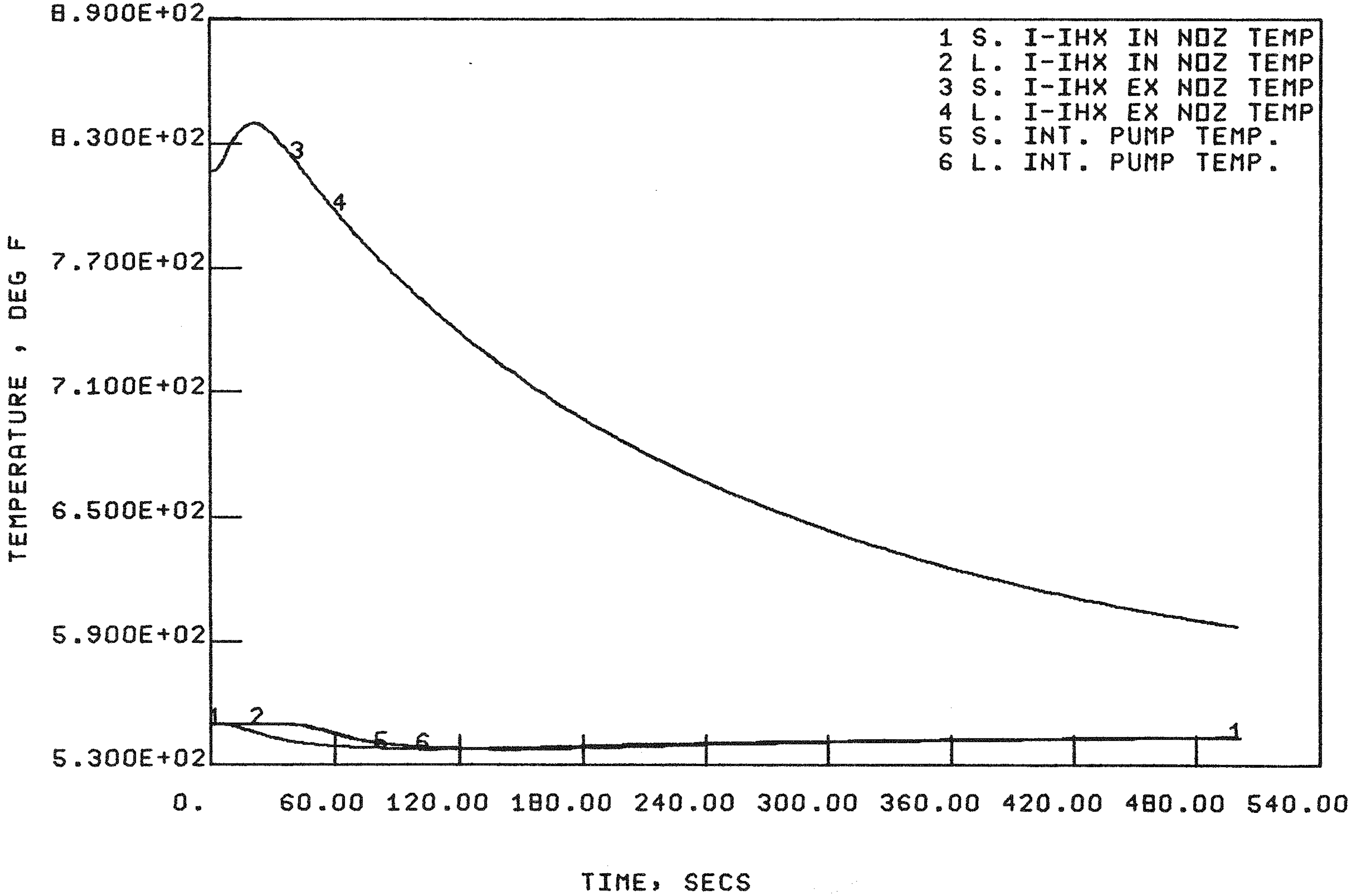


FIGURE 3-26

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND NO PUMP TRIP
RUN DATED 04/03/78
NUMBER DEP6E02

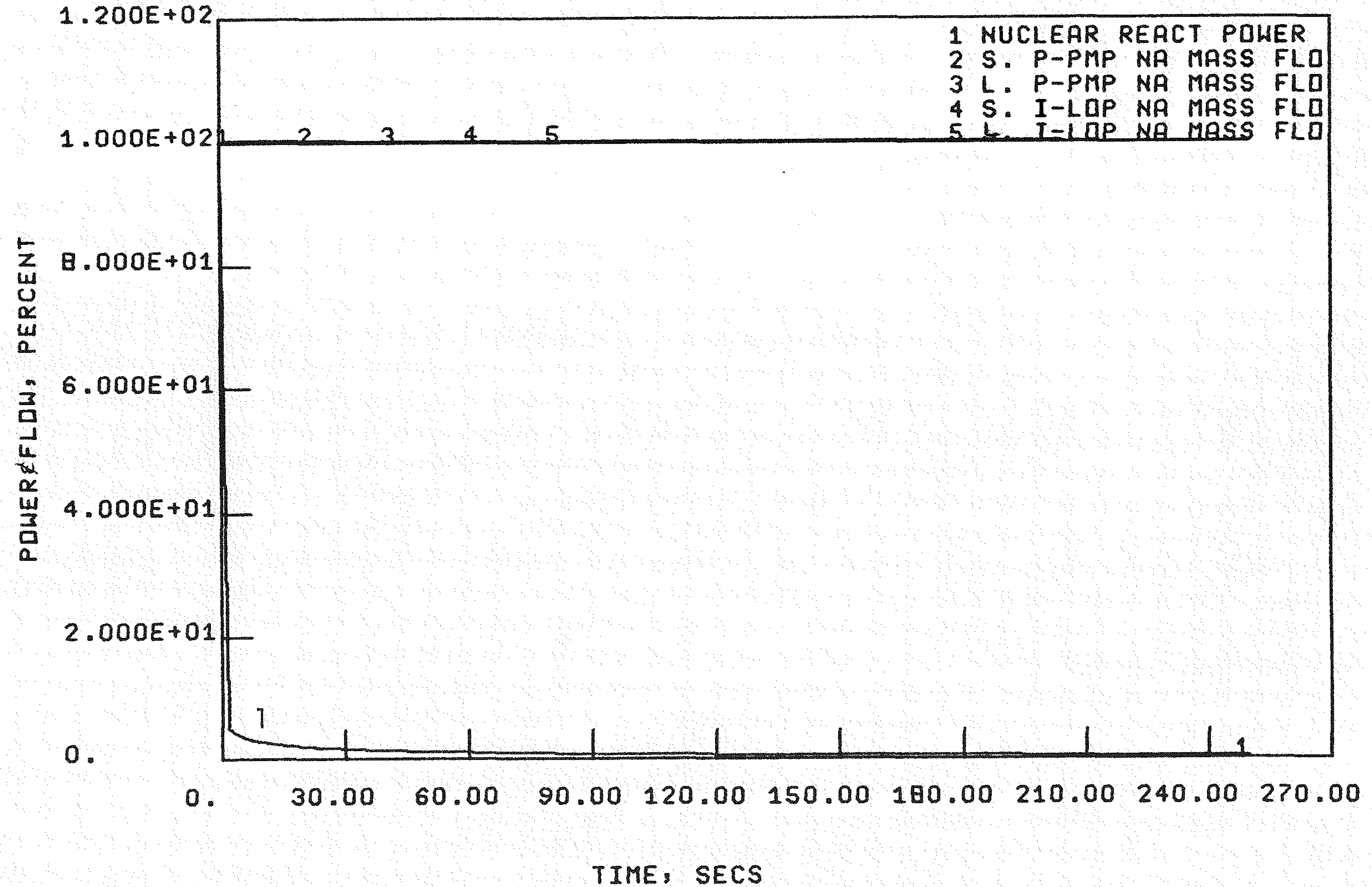


FIGURE 3-27
POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND NO PUMP TRIP
RUN DATED 04/03/78
NUMBER DEPGE02

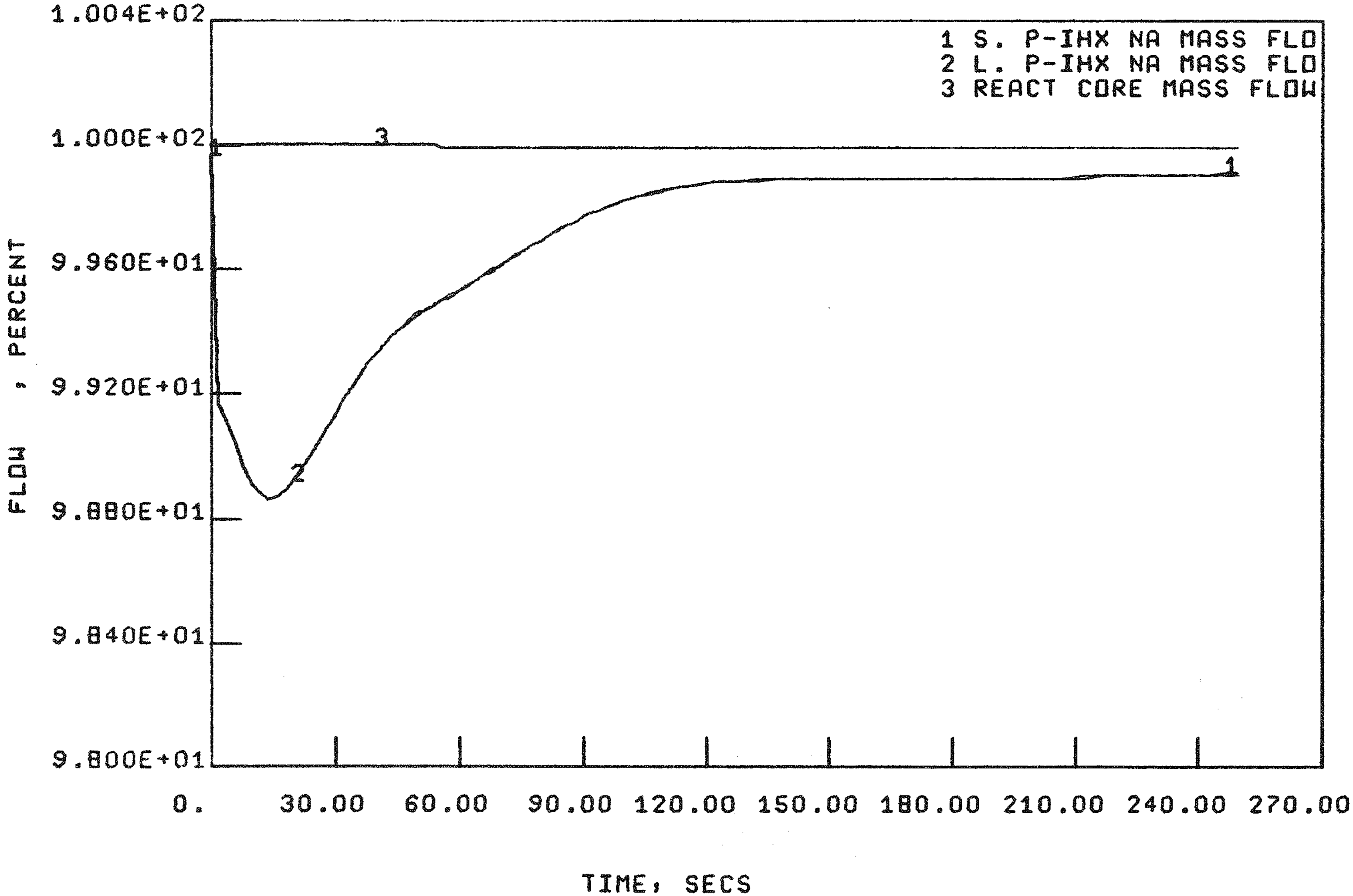


FIGURE 3-28

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND NO PUMP TRIP
RUN DATED 04/03/78
NUMBER DEPGE02

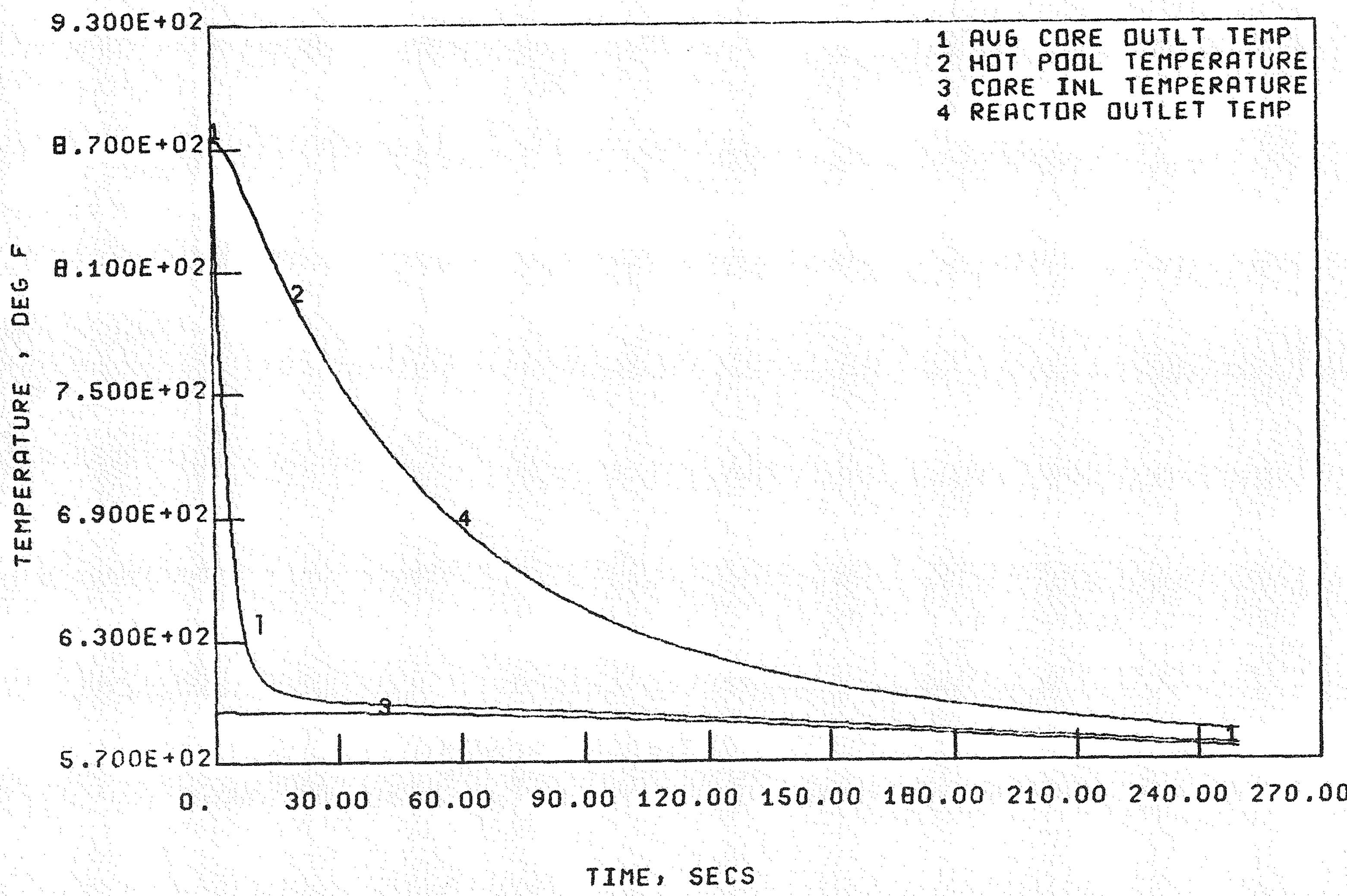


FIGURE 3-29

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND NO PUMP TRIP
RUN DATED 04/03/78
NUMBER DEP6E02

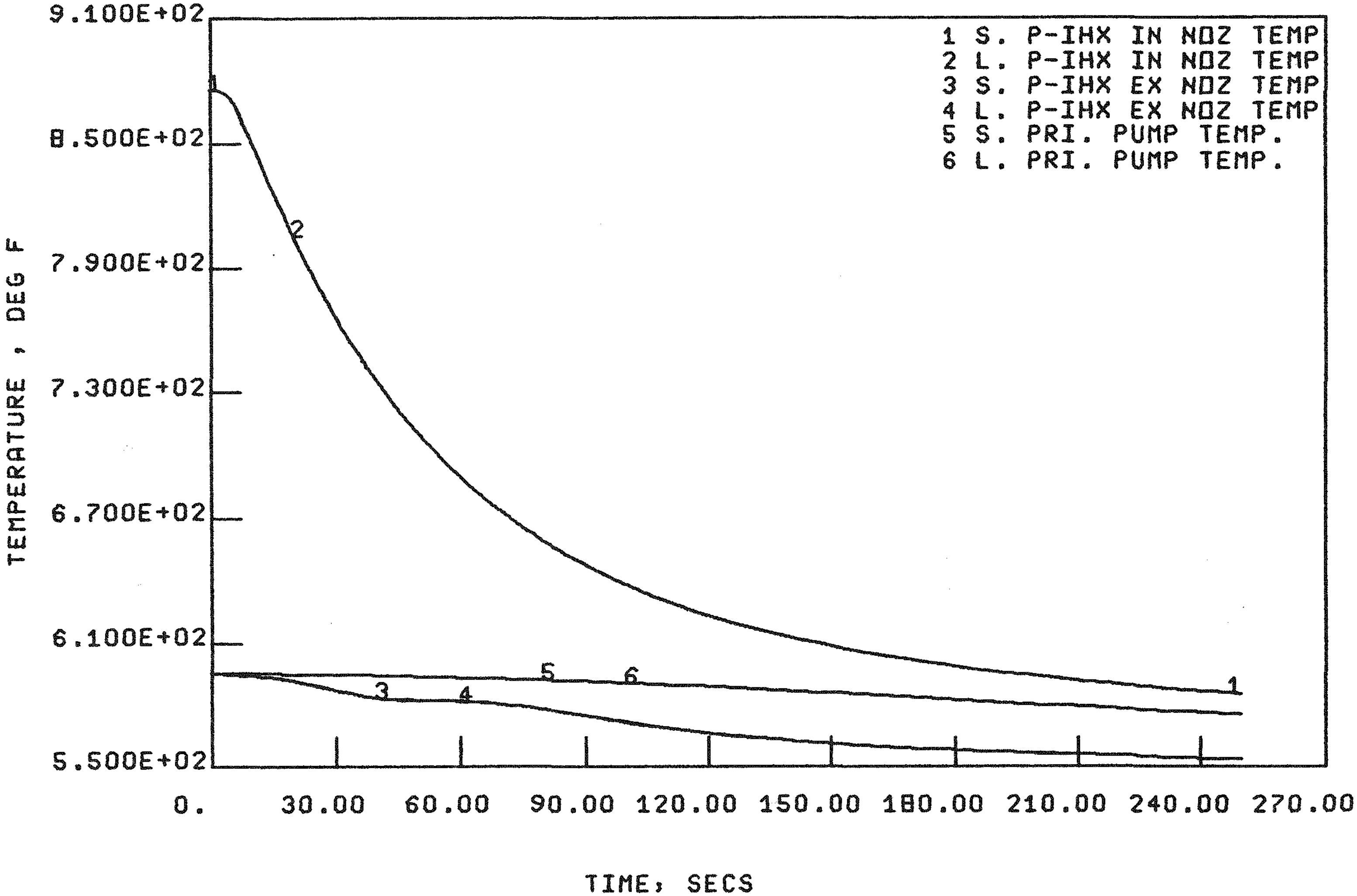


FIGURE 3-30

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND NO PUMP TRIP

RUN DATED 04/03/78

NUMBER DEPGE02

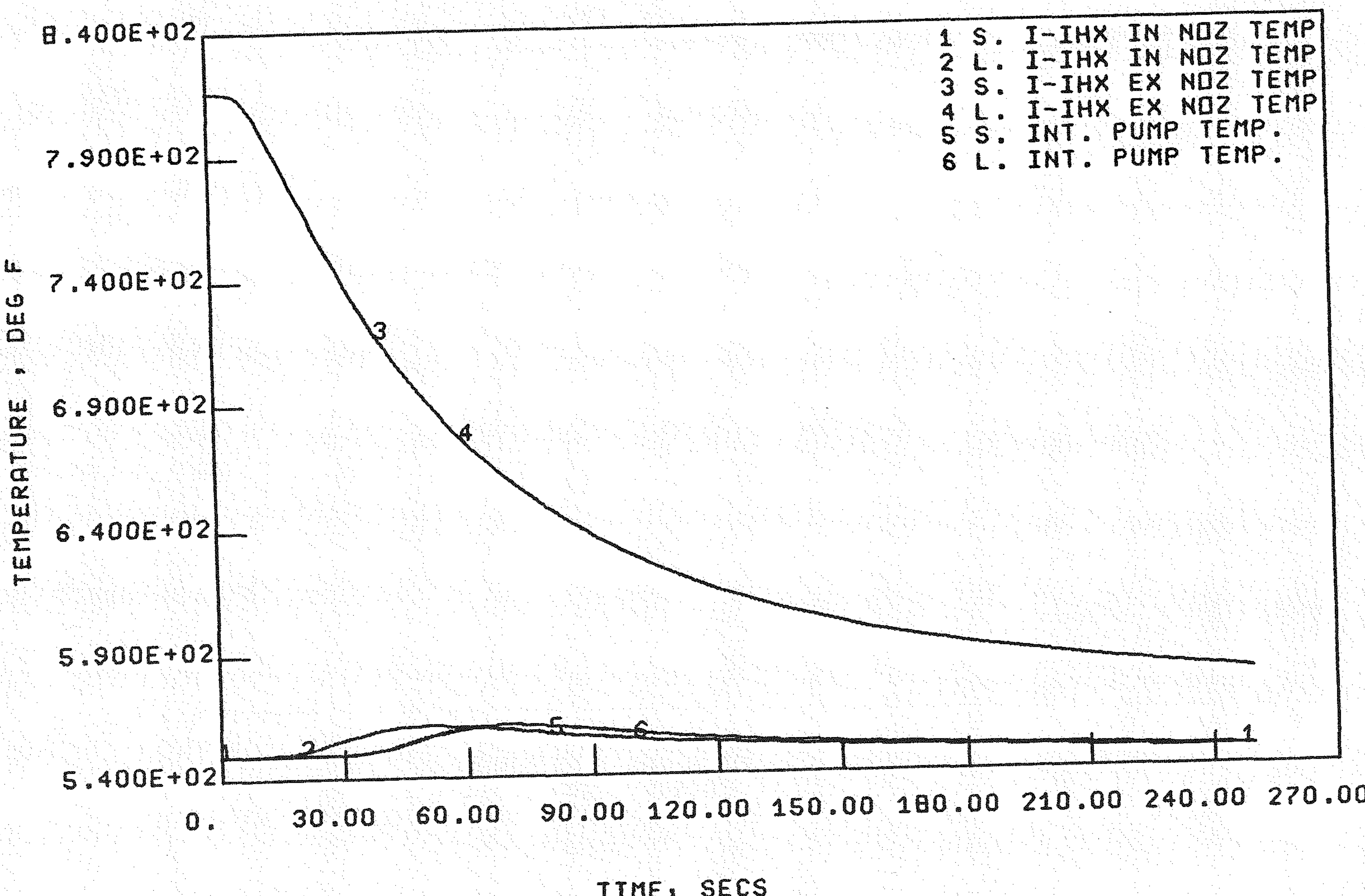


FIGURE 3-31

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO HALF SPEED
RUN DATED 04/03/78
NUMBER DEP6E00

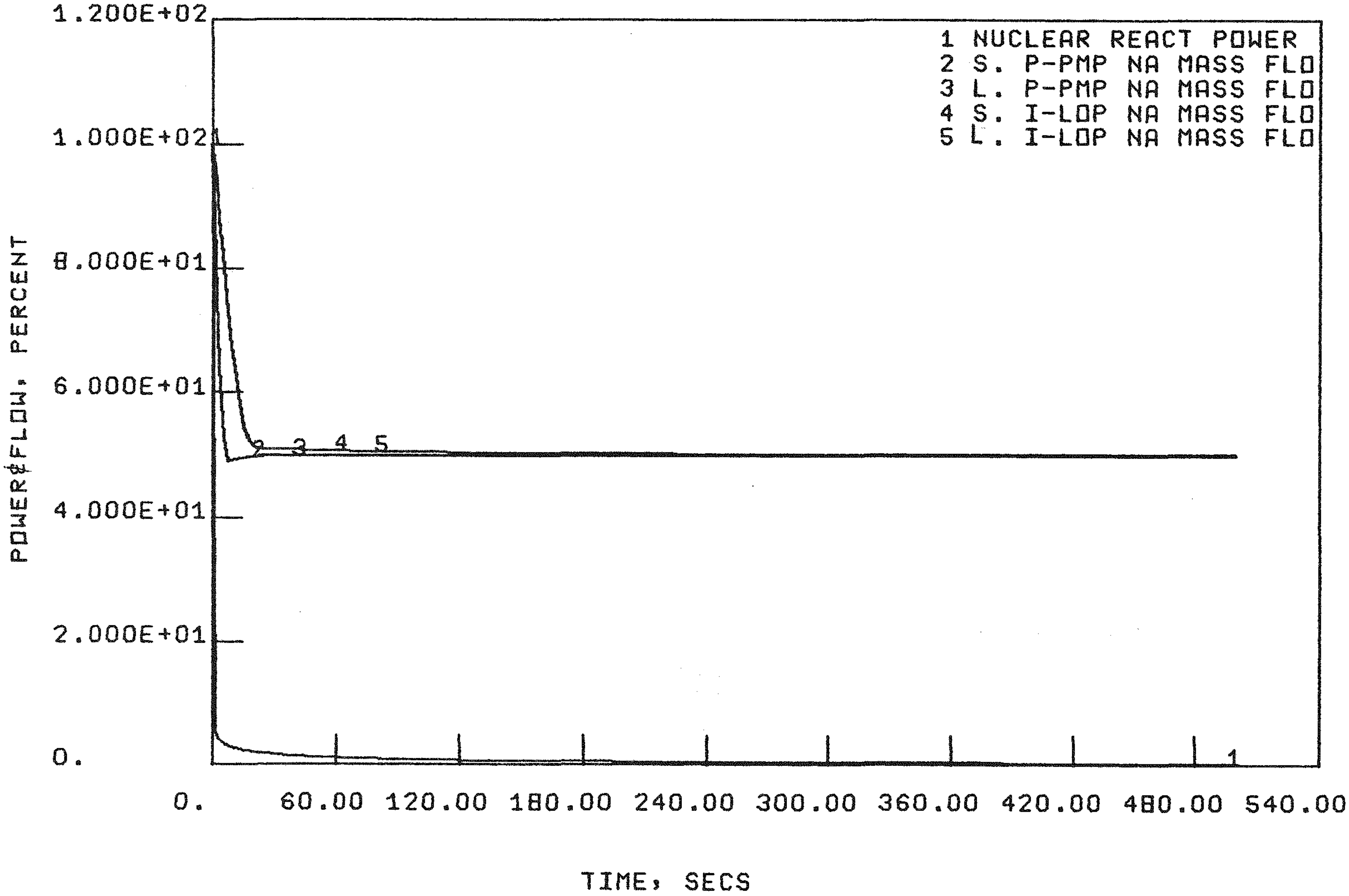


FIGURE 3-32

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO HALF SPEED
RUN DATED 04/03/78
NUMBER DEPGEOO

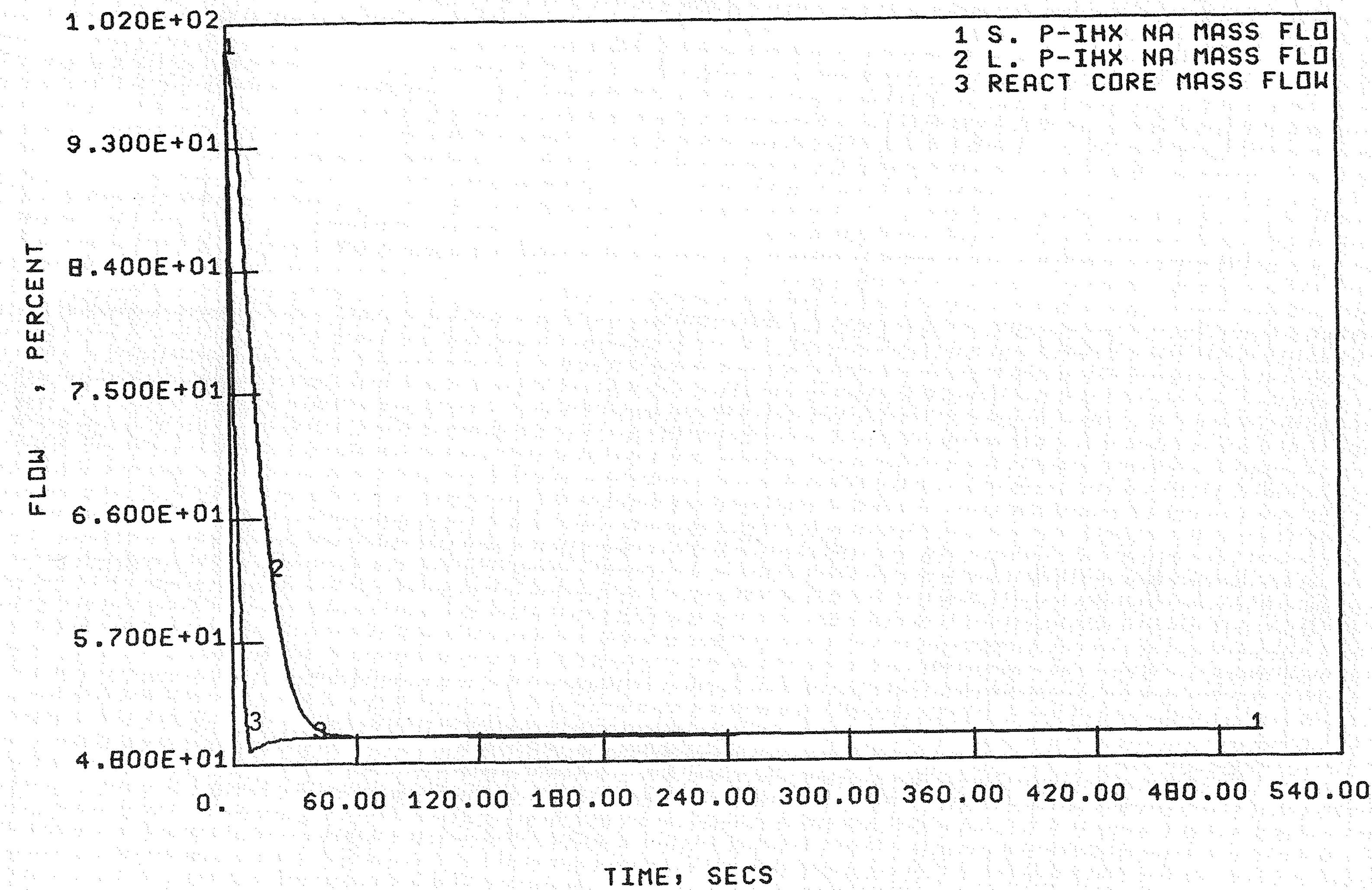


FIGURE 3-33

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO HALF SPEED
RUN DATED 04/03/78
NUMBER DEPGEOO

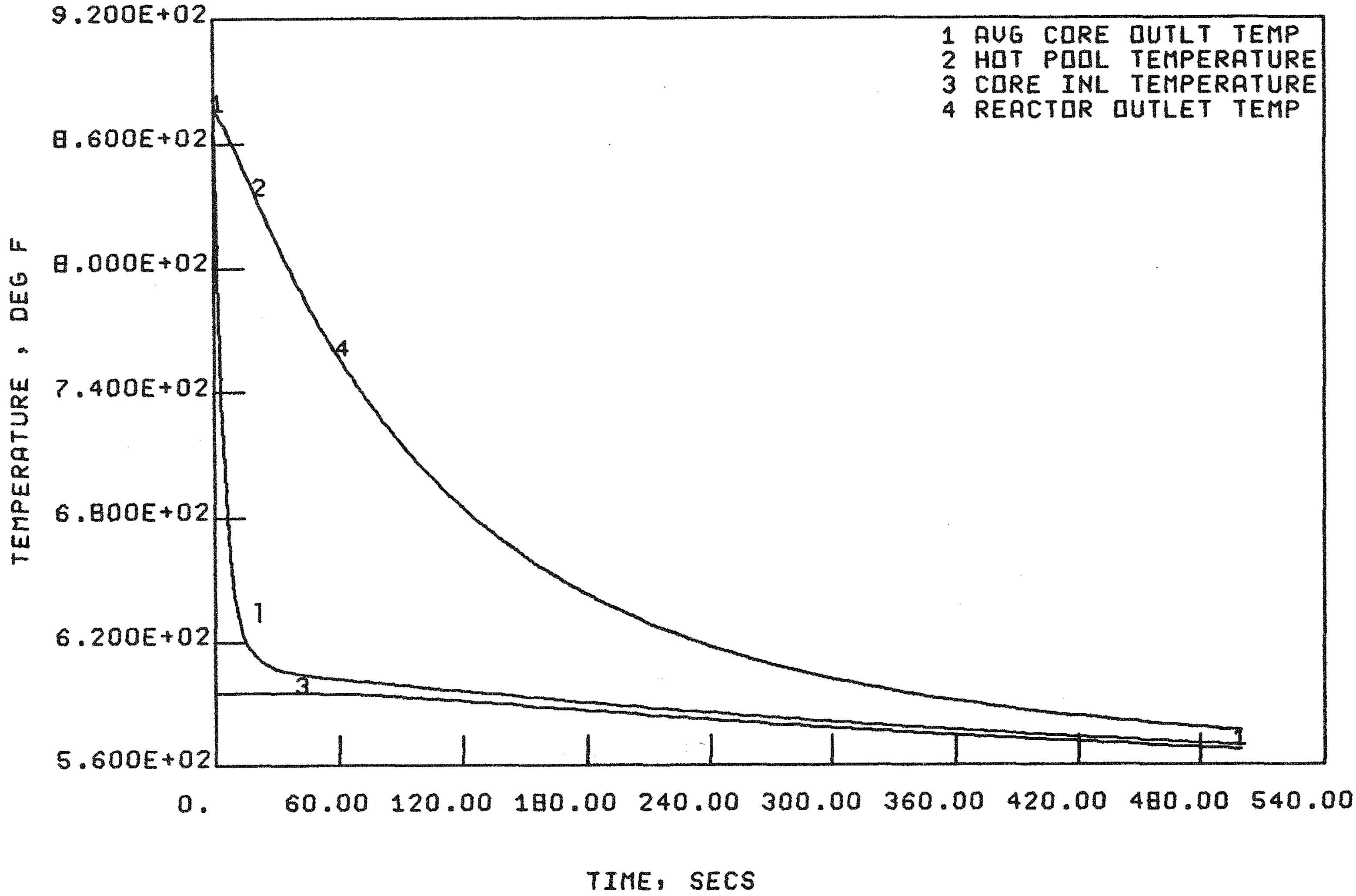


FIGURE 3-34
POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO HALF SPEED
RUN DATED 04/03/78
NUMBER DEPGE00

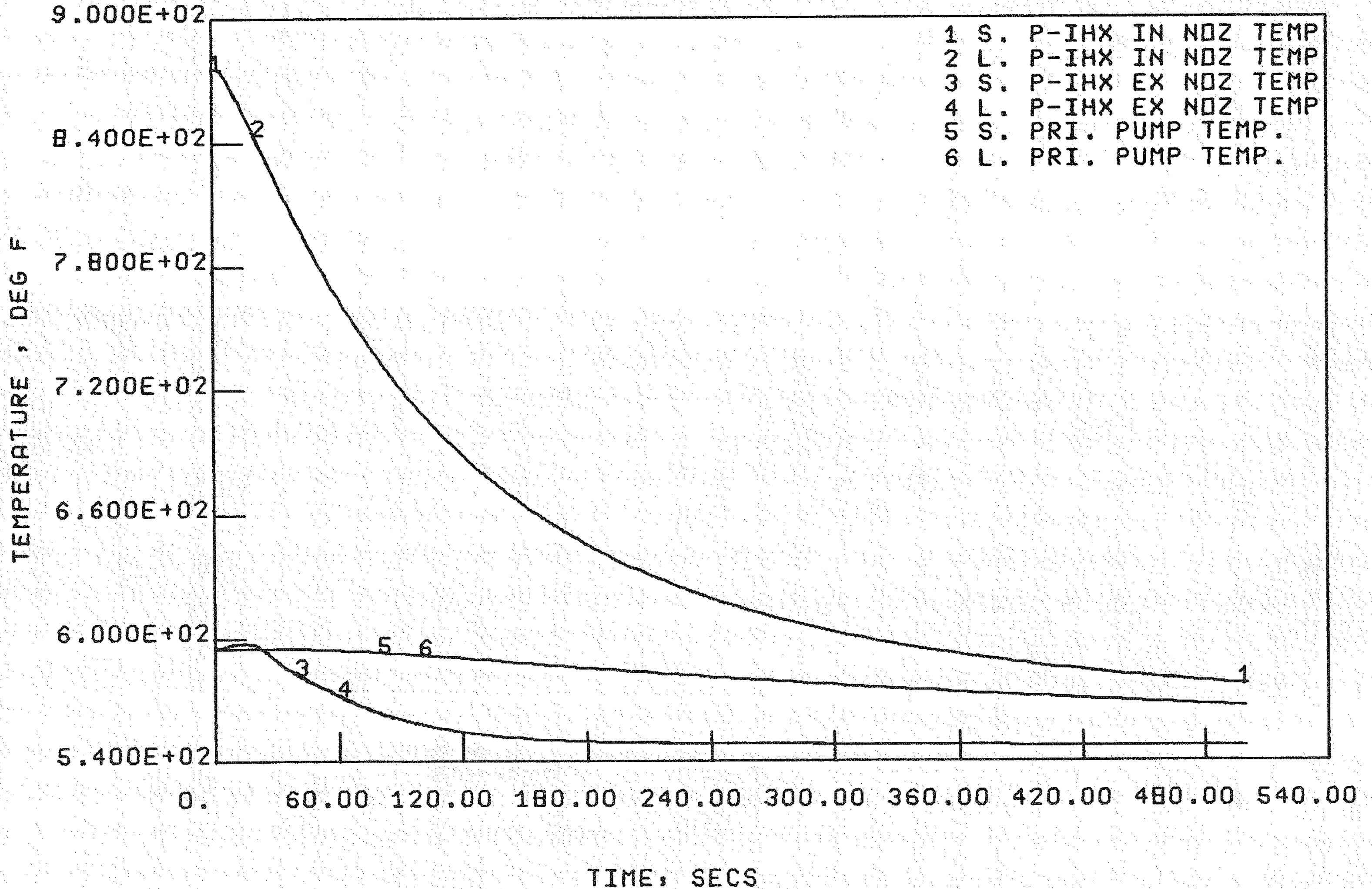


FIGURE 3-35

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO HALF SPEED
RUN DATED 04/03/78
NUMBER DEPGEOO

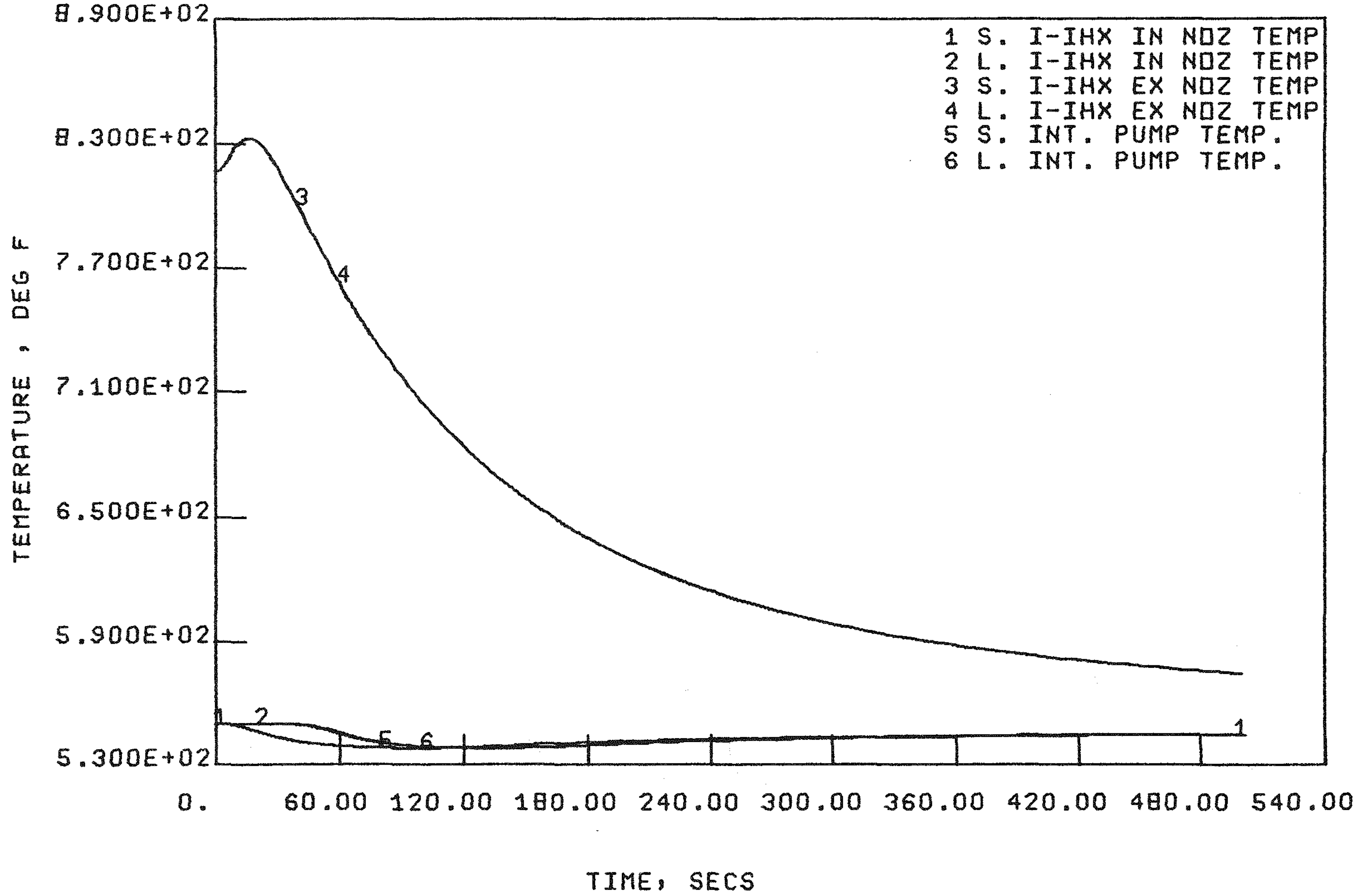


FIGURE 3-36

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO QUARTER SPD

RUN DATED 04/03/78

NUMBER DEPGE01

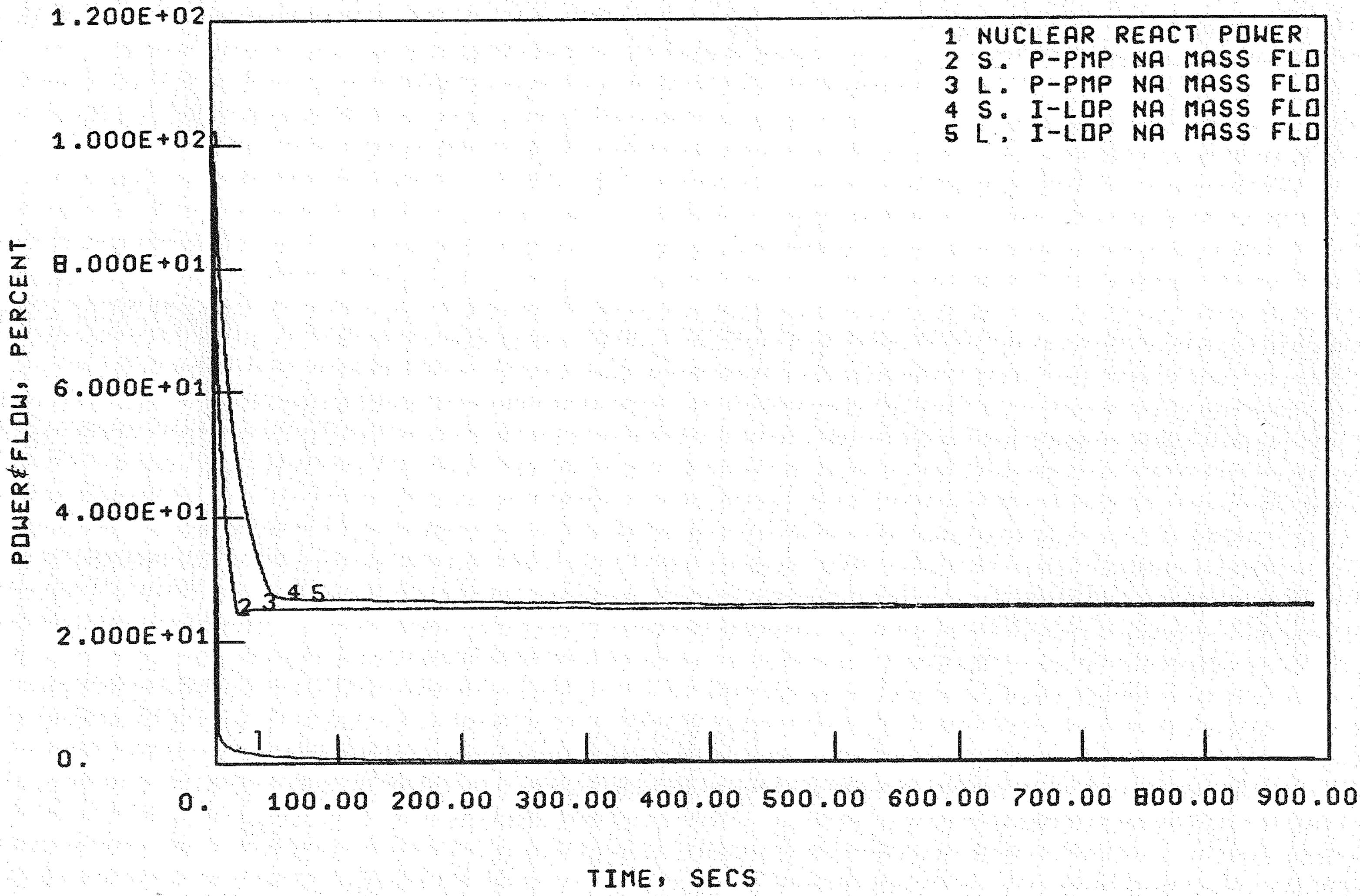


FIGURE 3-37

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO QUARTER SPD
RUN DATED 04/03/78
NUMBER DEFGE01

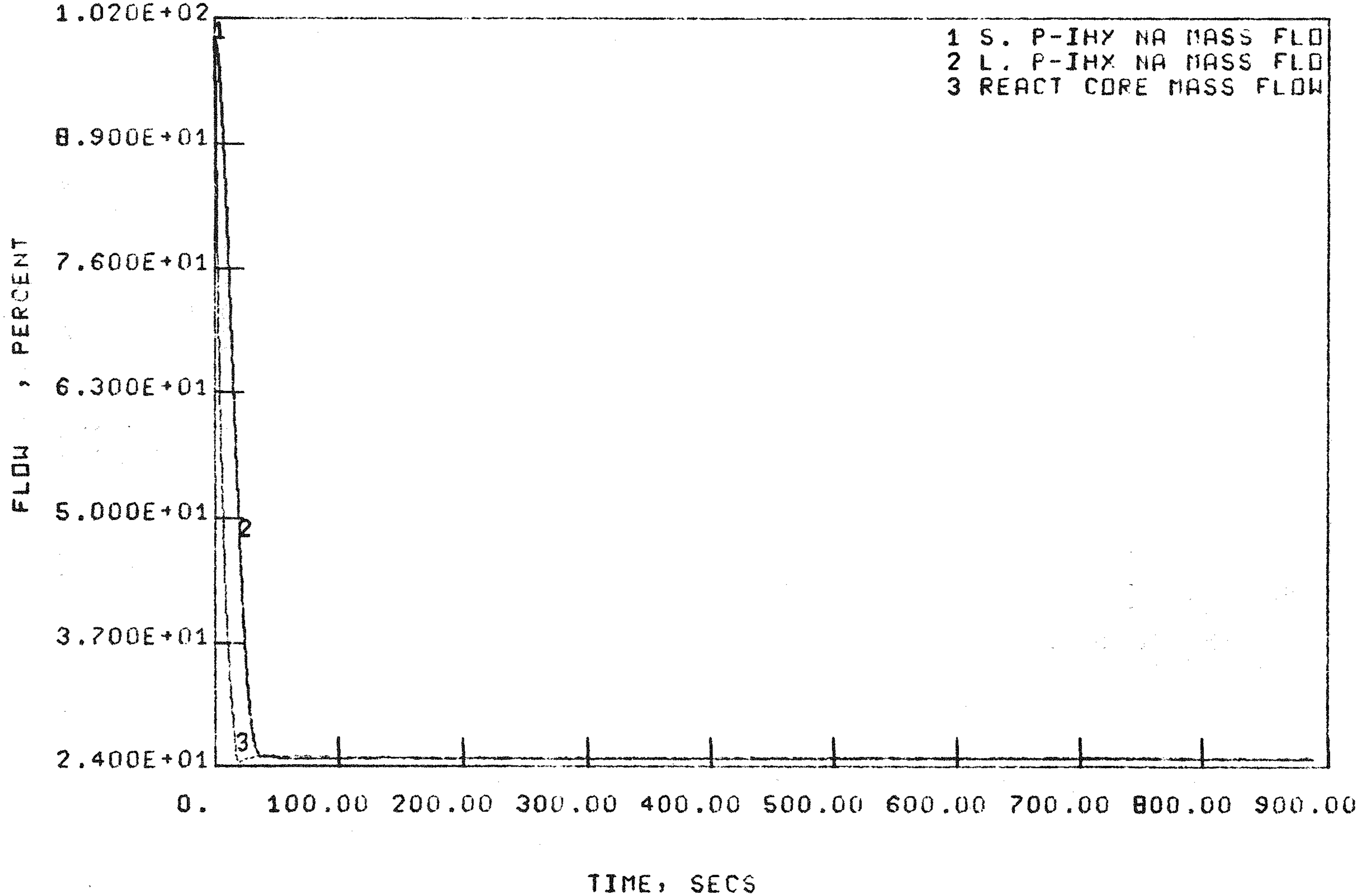


FIGURE 3-38

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO QUARTER SPD
RUN DATED 04/03/78
NUMBER DEPGE01

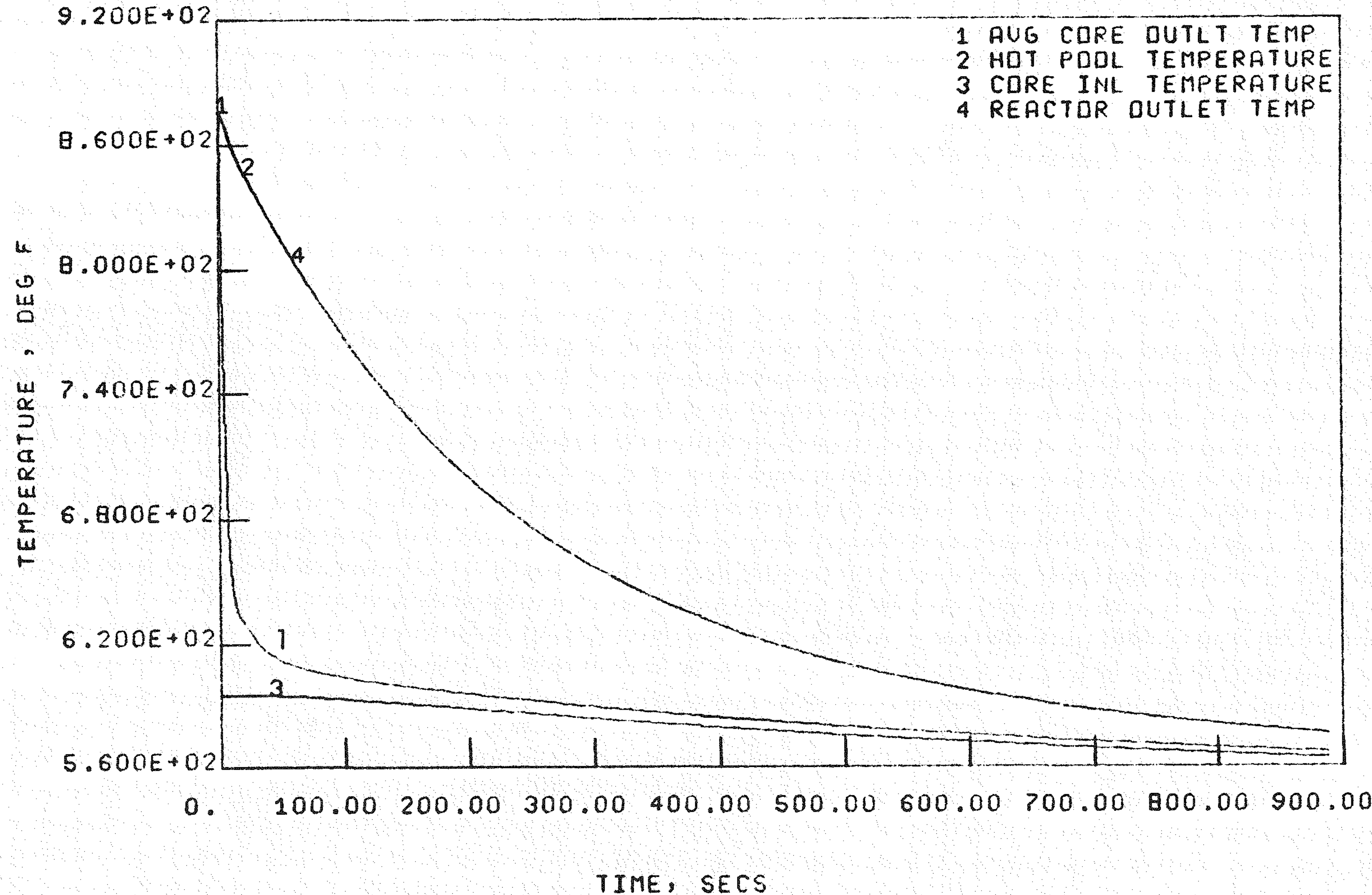


FIGURE 3-39

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO QUARTER SPD
RUN DATED 04/03/78
NUMBER DEPGE01

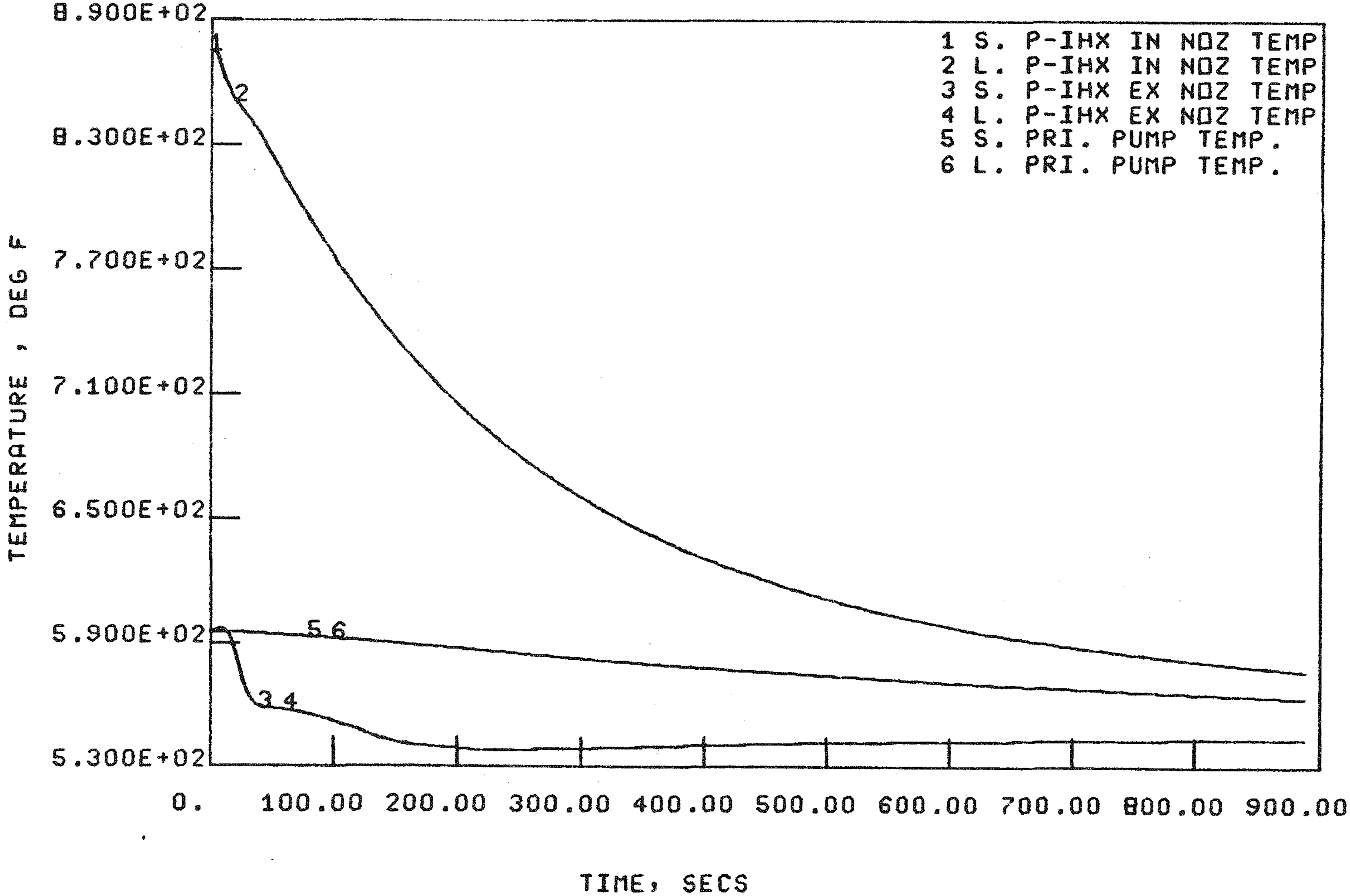


FIGURE 3-40

POOL REACTOR SCRAM WITH 50 PERCENT MIXING AND PUMP TRIP TO QUARTER SPD
RUN DATED 04/03/78
NUMBER DEPGE01

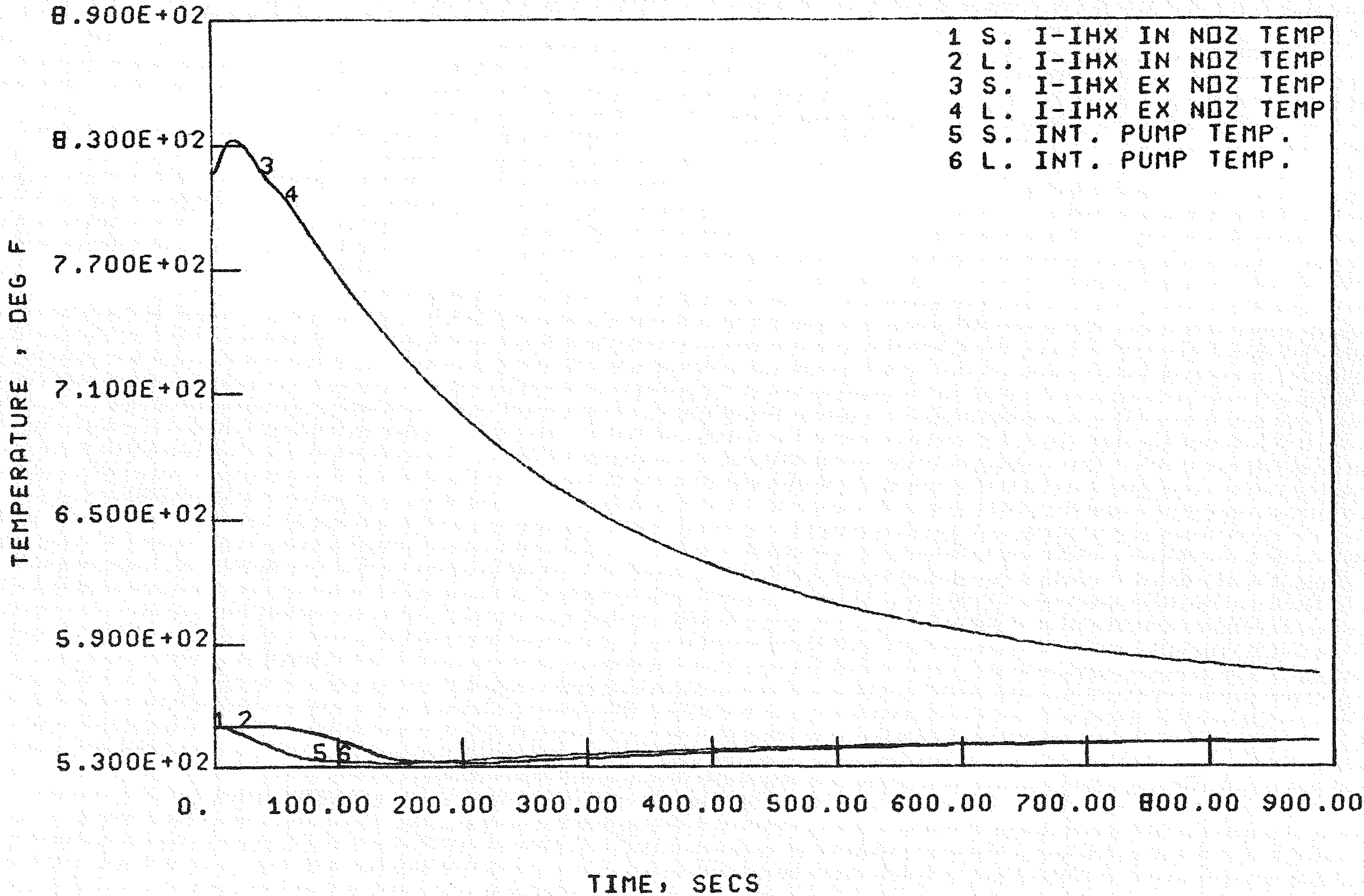


FIGURE 4-1
POOL REACTOR SINGLE INTERMEDIATE PUMP LOSS OF POWER WITHOUT SCRAM
RUN DATED 05/02/78
NUMBER DEPGE03

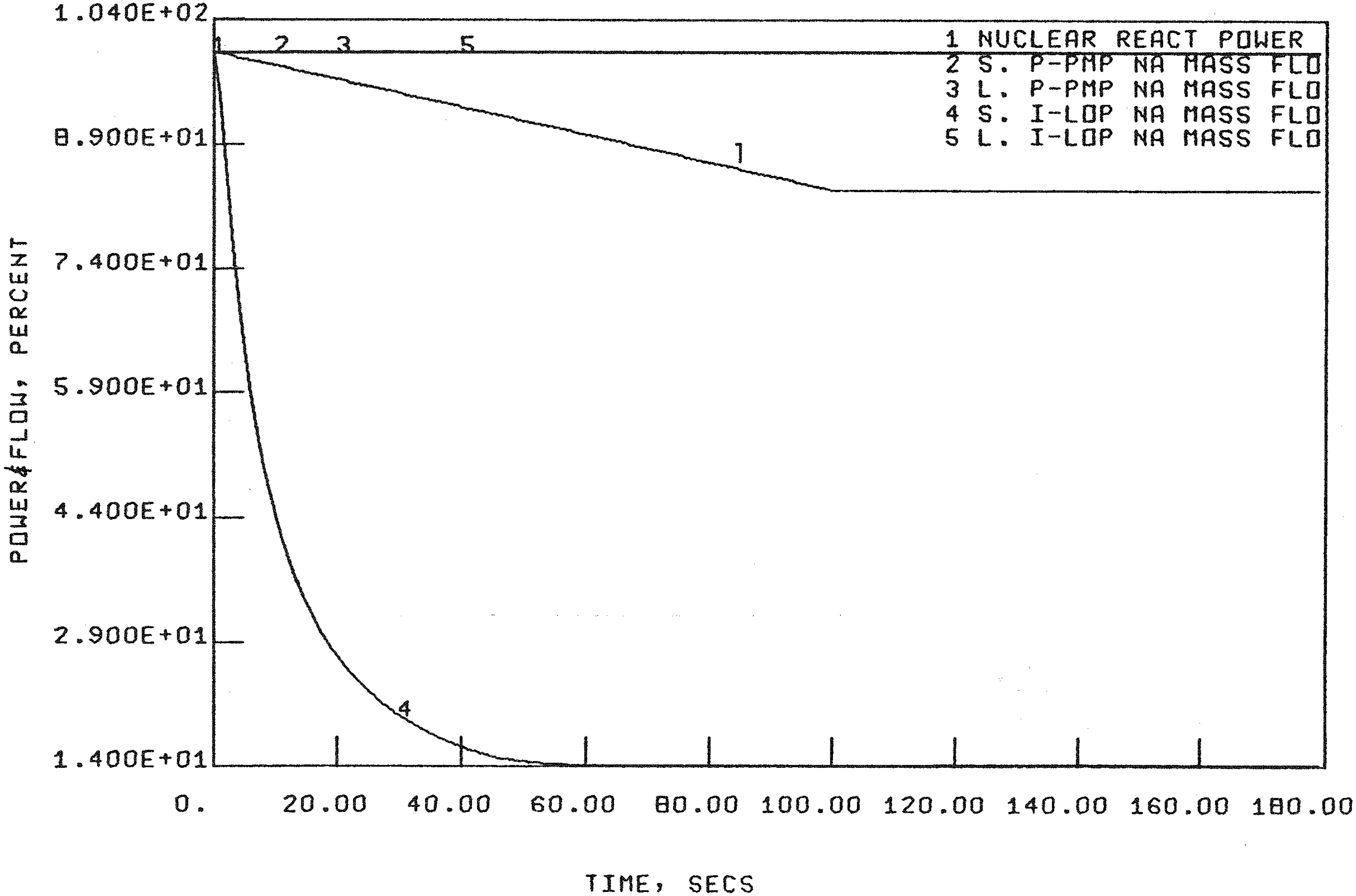


FIGURE 4-2

POOL REACTOR SINGLE INTERMEDIATE PUMP LOSS OF POWER WITHOUT SCRAM

RUN DATED 05/02/78

NUMBER DEPGE03

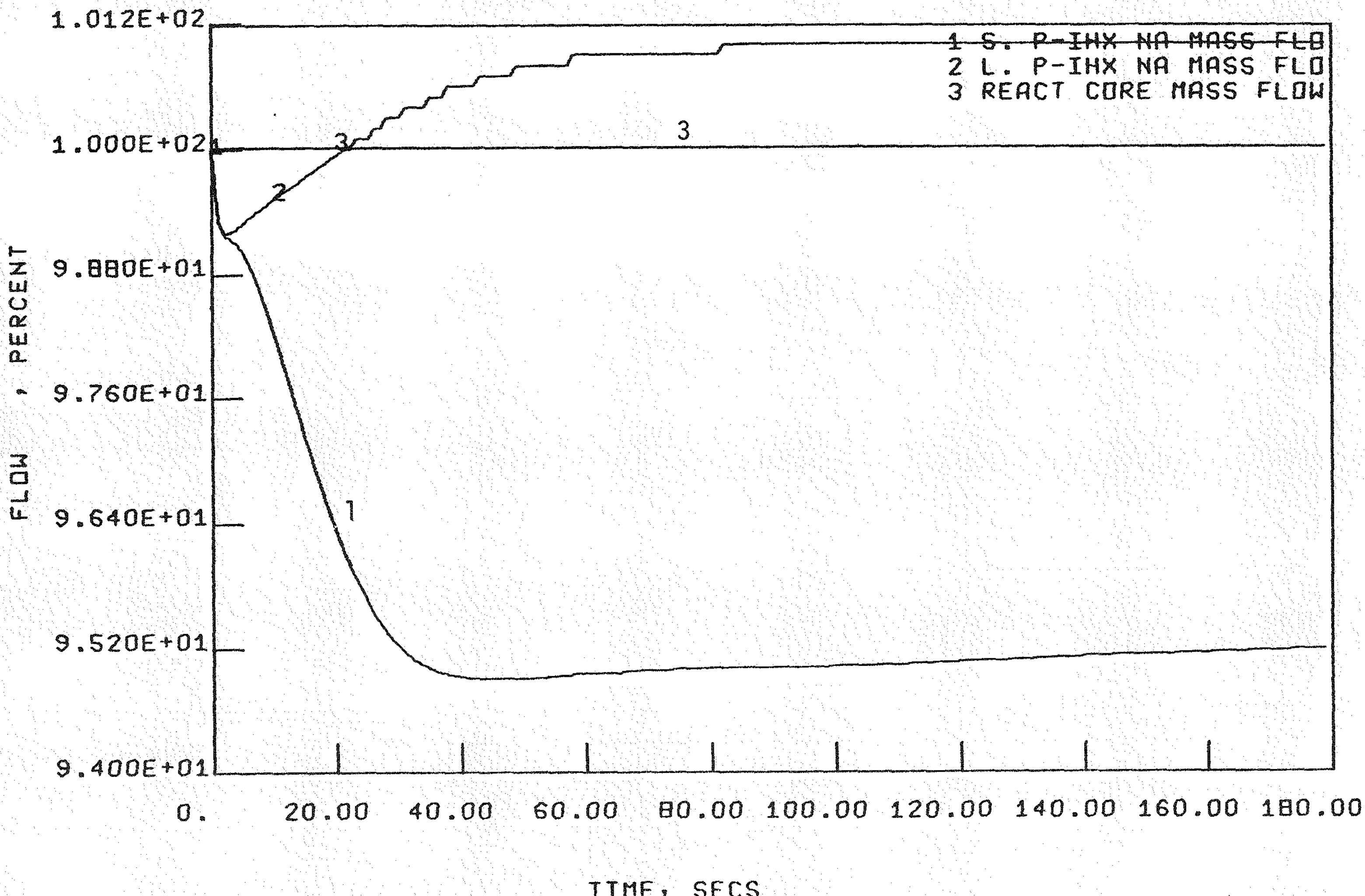


FIGURE 4-3

POOL REACTOR SINGLE INTERMEDIATE PUMP LOSS OF POWER WITHOUT SCRAM
RUN DATED 05/02/78
NUMBER DEPGE03

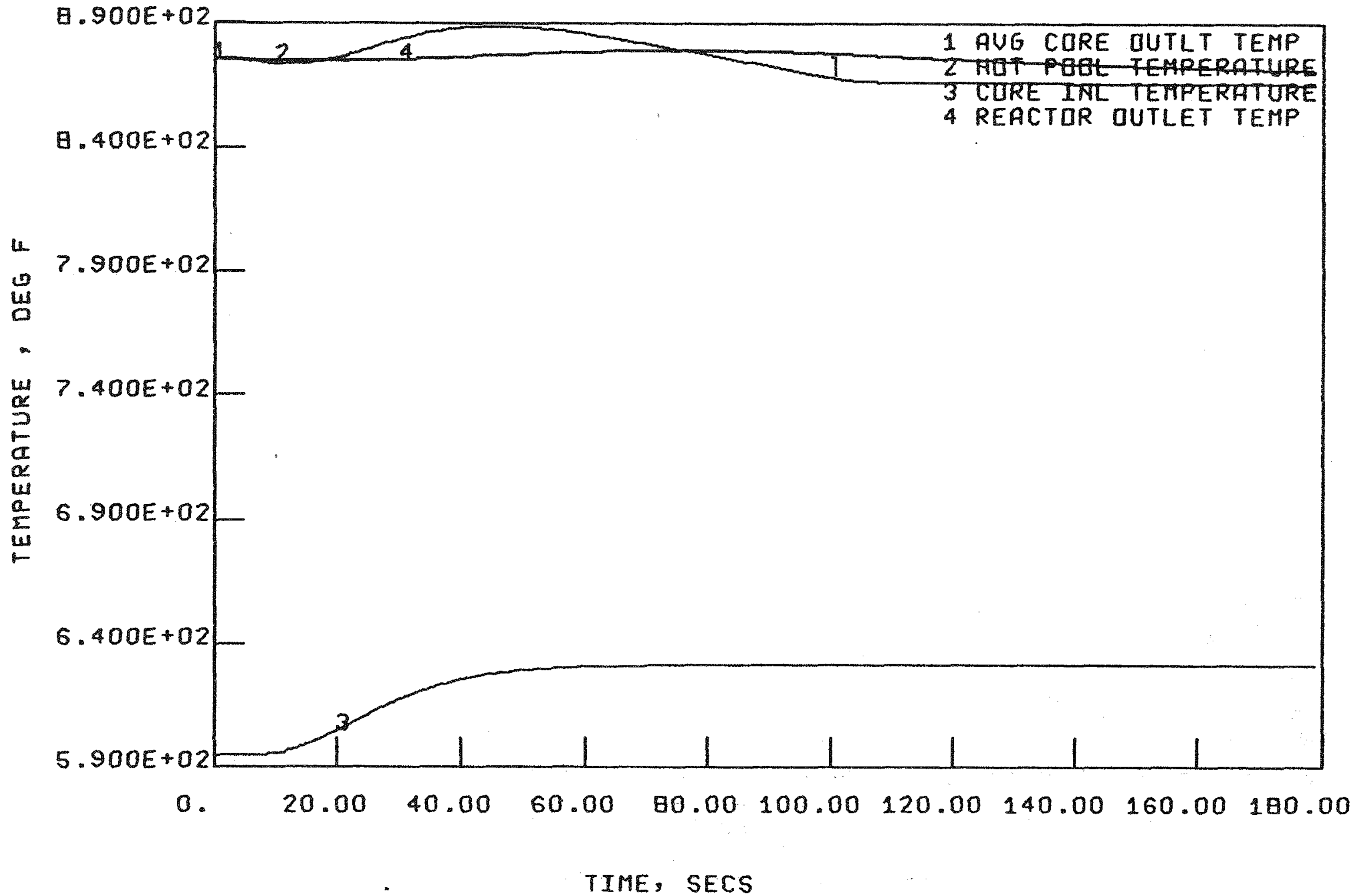


FIGURE 4-4

POOL REACTOR SINGLE INTERMEDIATE PUMP LOSS OF POWER WITHOUT SCRAM
RUN DATED 05/02/78
NUMBER DEPGE03

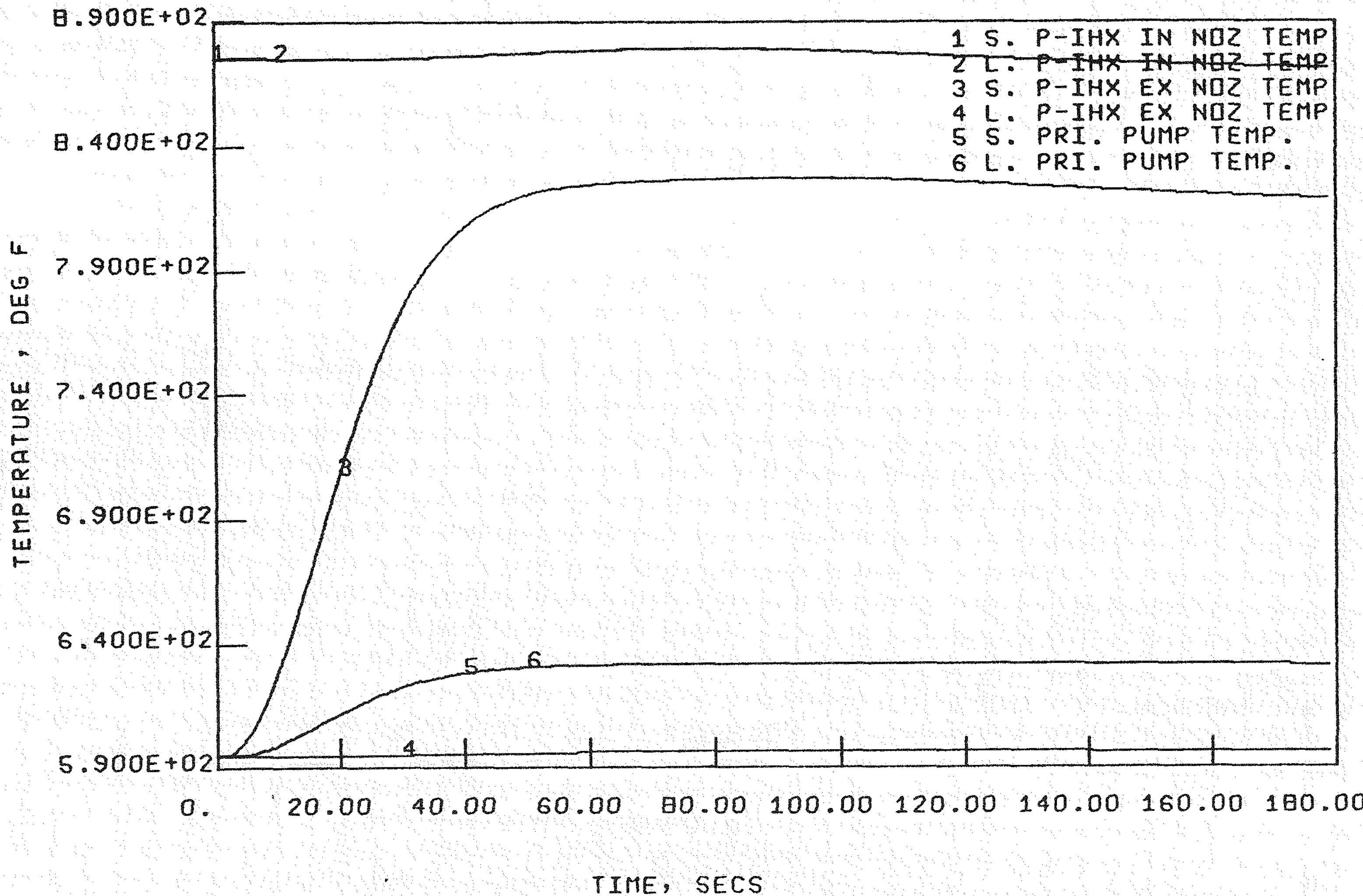


FIGURE 4-5

POOL REACTOR SINGLE INTERMEDIATE PUMP LOSS OF POWER WITHOUT SCRAM

RUN DATED 05/02/78

NUMBER DEPGE03

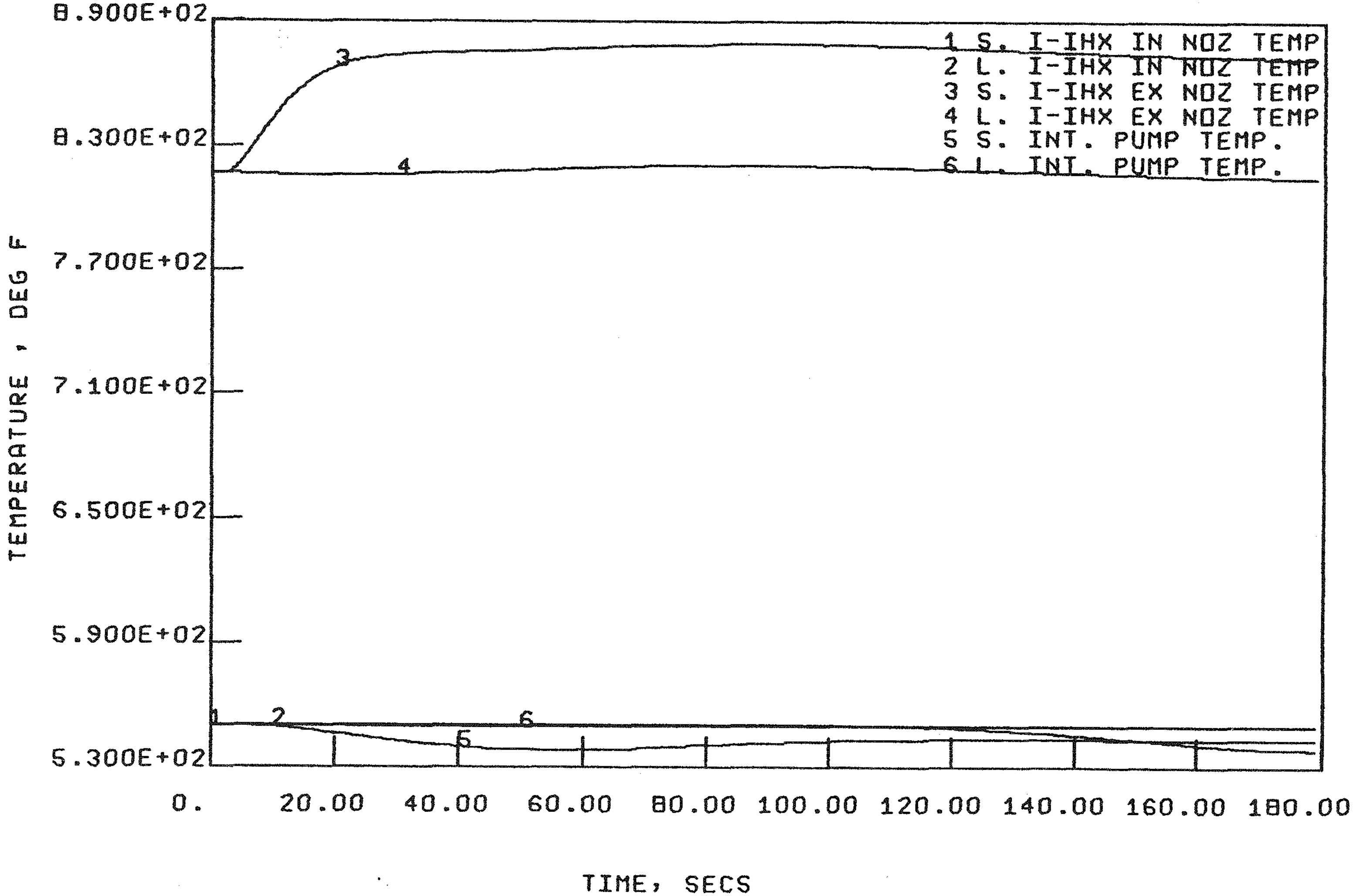


FIGURE 4-6

IHTS PUMP PWR LOSS WITH SCRAM AND PMP TRIP TO HALF SPD (MAX DECAY HT)
RUN DATED 05/11/78
NUMBER DEPGE01

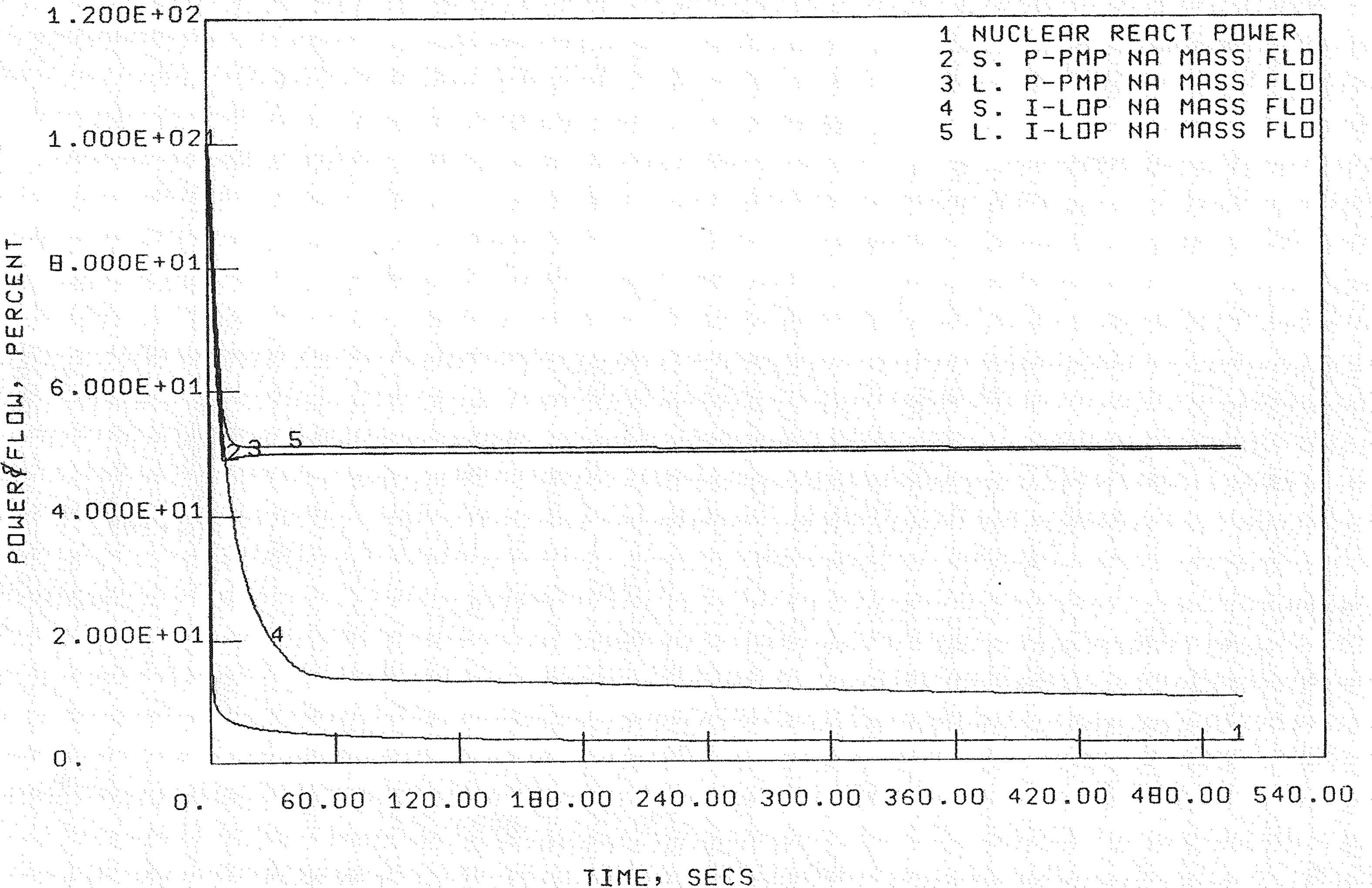


FIGURE 4-7

IHTS PUMP PWR LOSS WITH SCRAM AND PMP TRIP TO HALF SPD (MAX DECAY HT)

RUN DATED 05/11/78

NUMBER DEPGE01

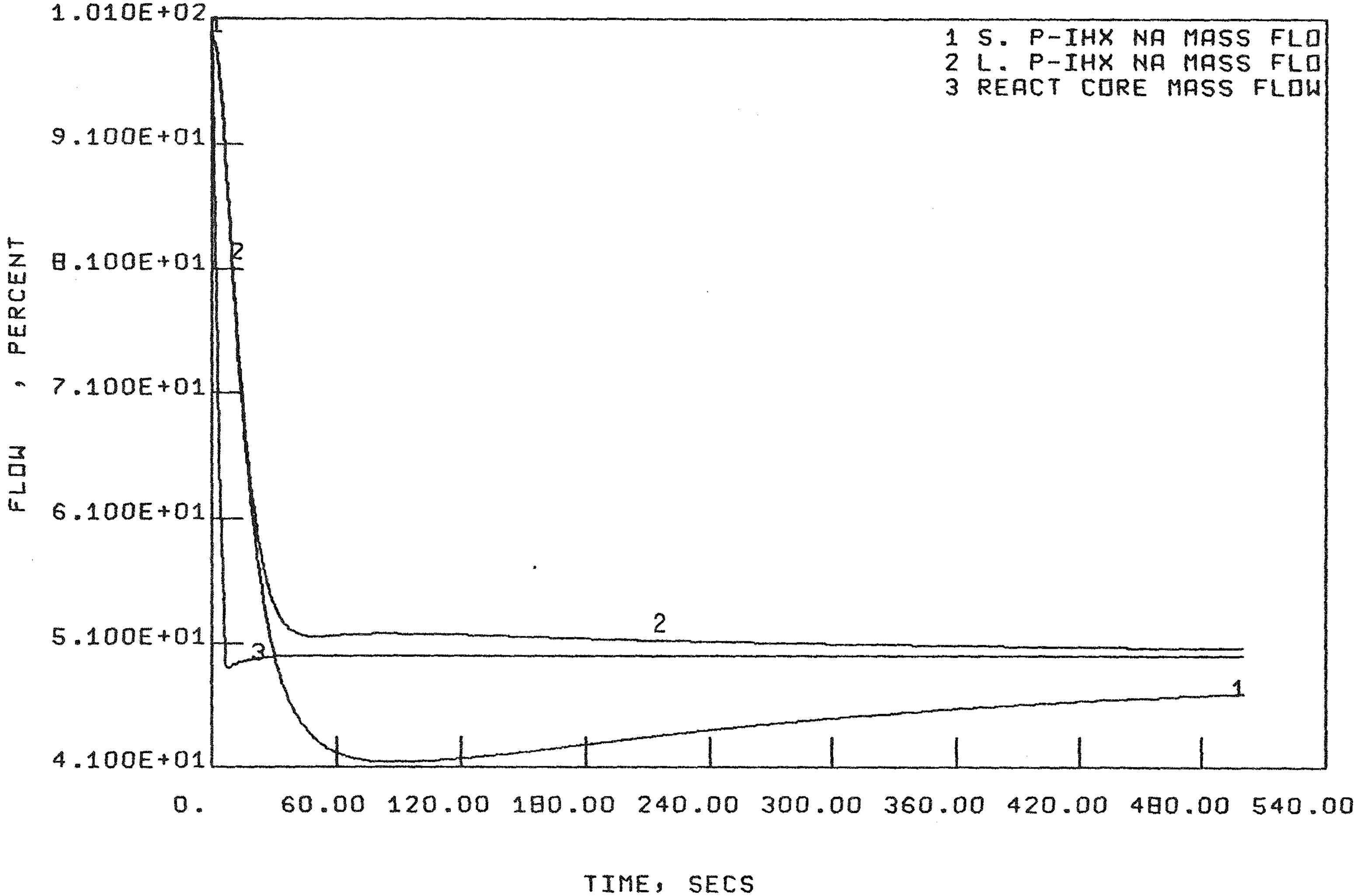


FIGURE 4-8
IHTS PUMP PWR LOSS WITH SCRAM AND PMP TRIP TO HALF SPD (MAX DECAY HT)
RUN DATED 05/11/78
NUMBER DEPGE01

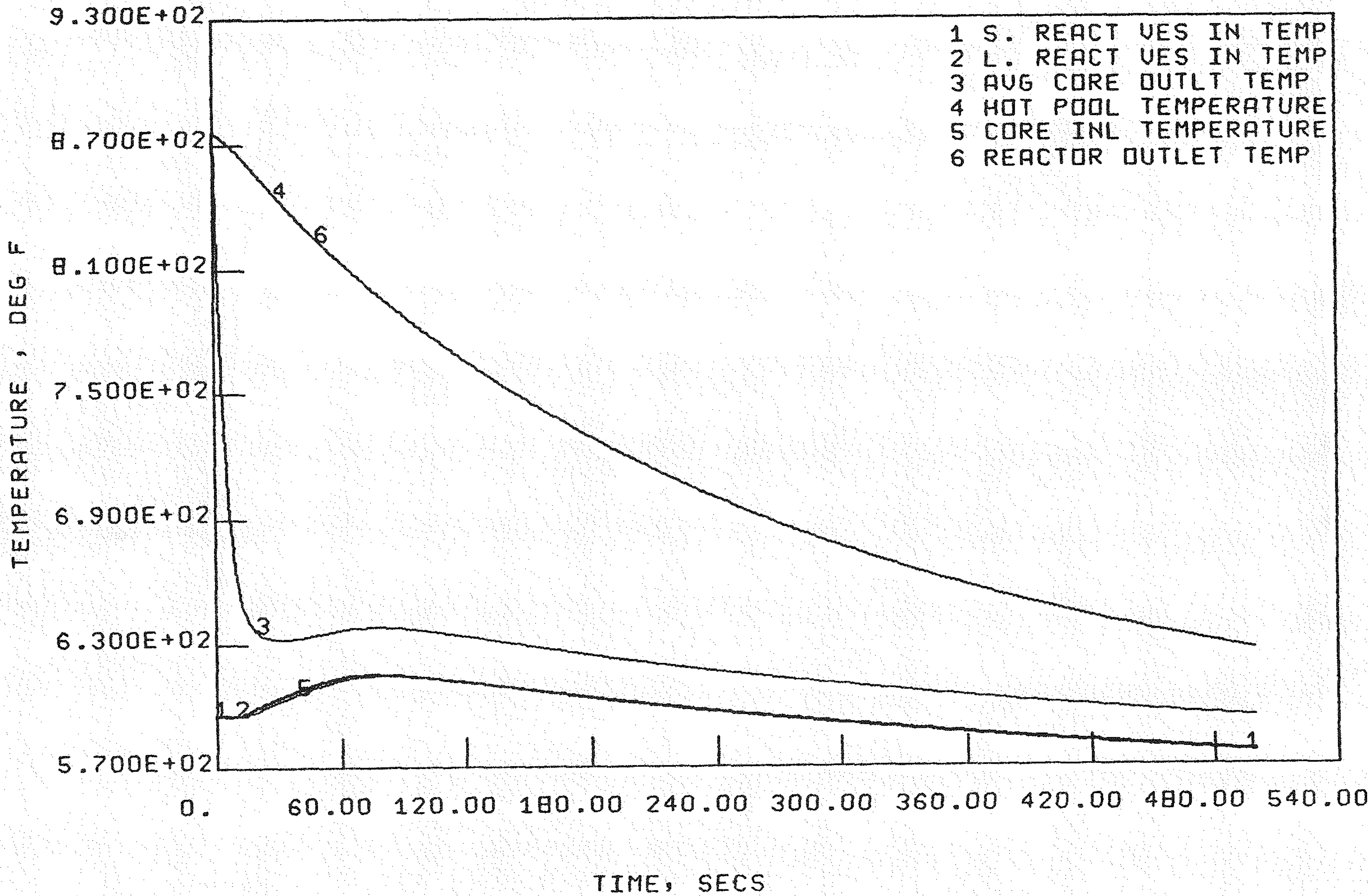


FIGURE 4-9

IHTS PUMP PWR LOSS WITH SCRAM AND PMP TRIP TO HALF SPD (MAX DECAY HT)
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NUMBER DEPGE01

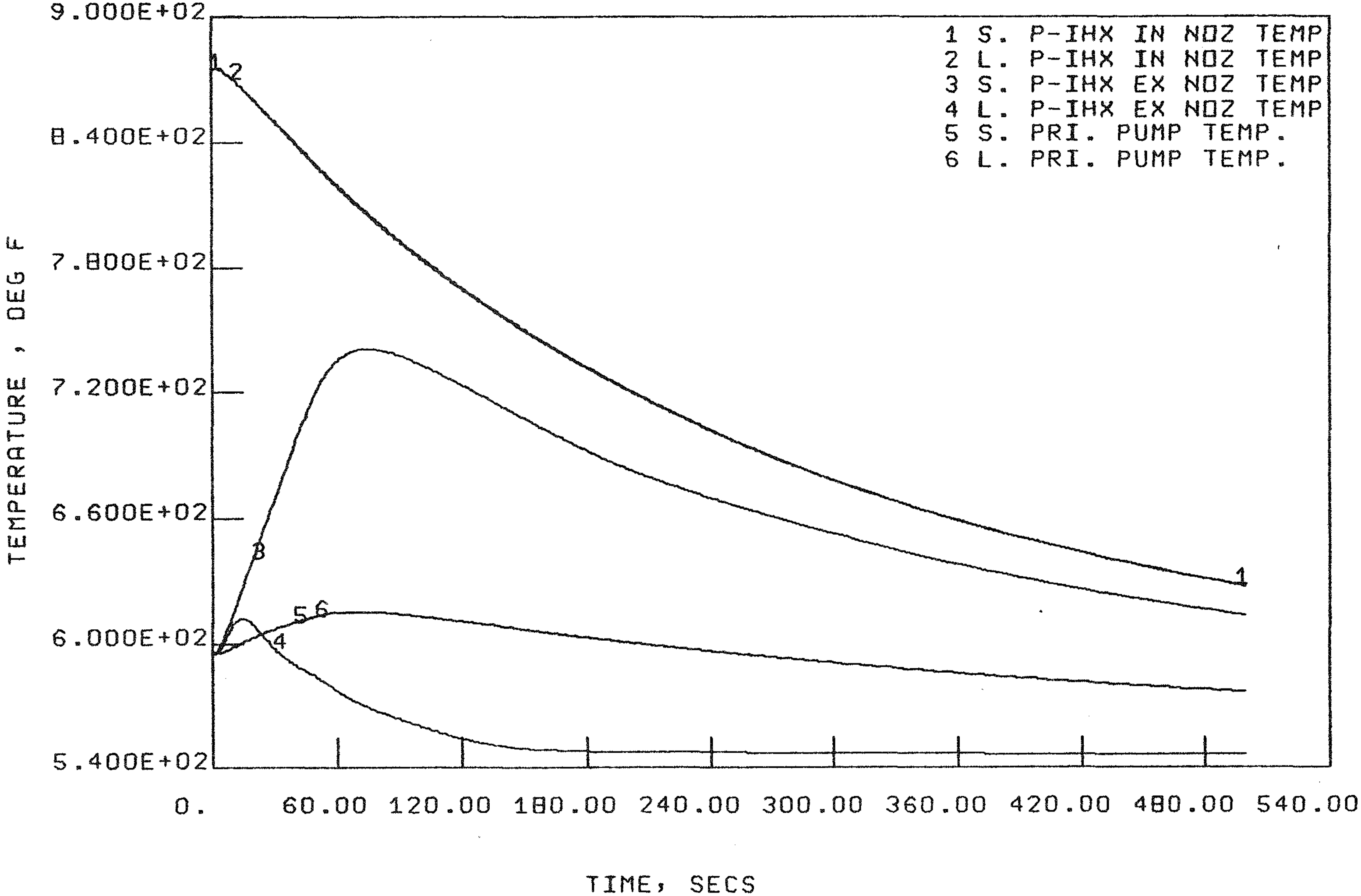

FIGURE 4-10

IHTS PUMP PWR LOSS WITH SCRAM AND PMP TRIP TO HALF SPD (MAX DECAY HT)

RUN DATED 05/11/78

NUMBER DEPGE01

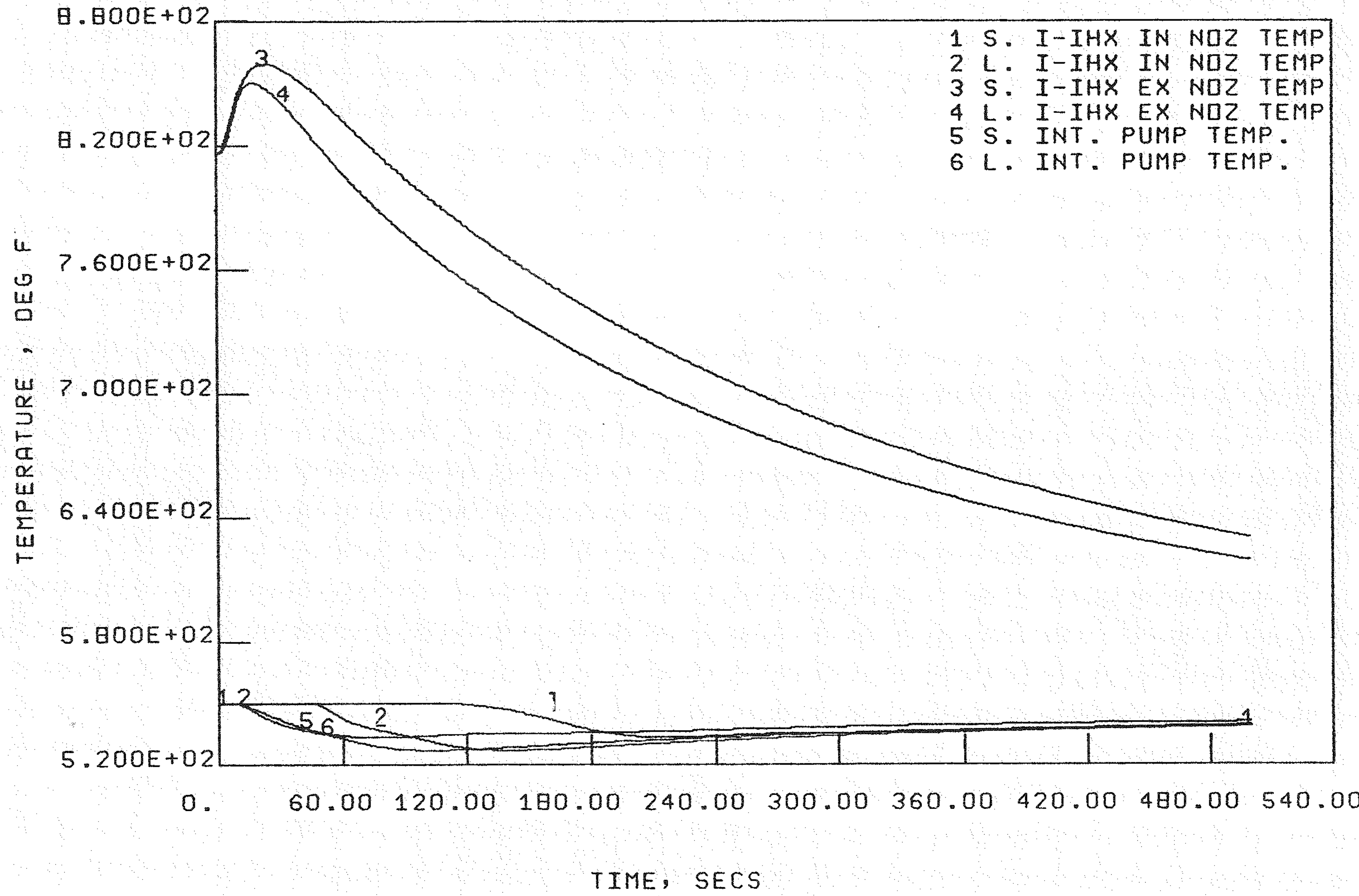

FIGURE 4-11
POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 34 SEC PUMP TRIP DELAY
RUN DATED 04/19/78
NUMBER DEPGE04

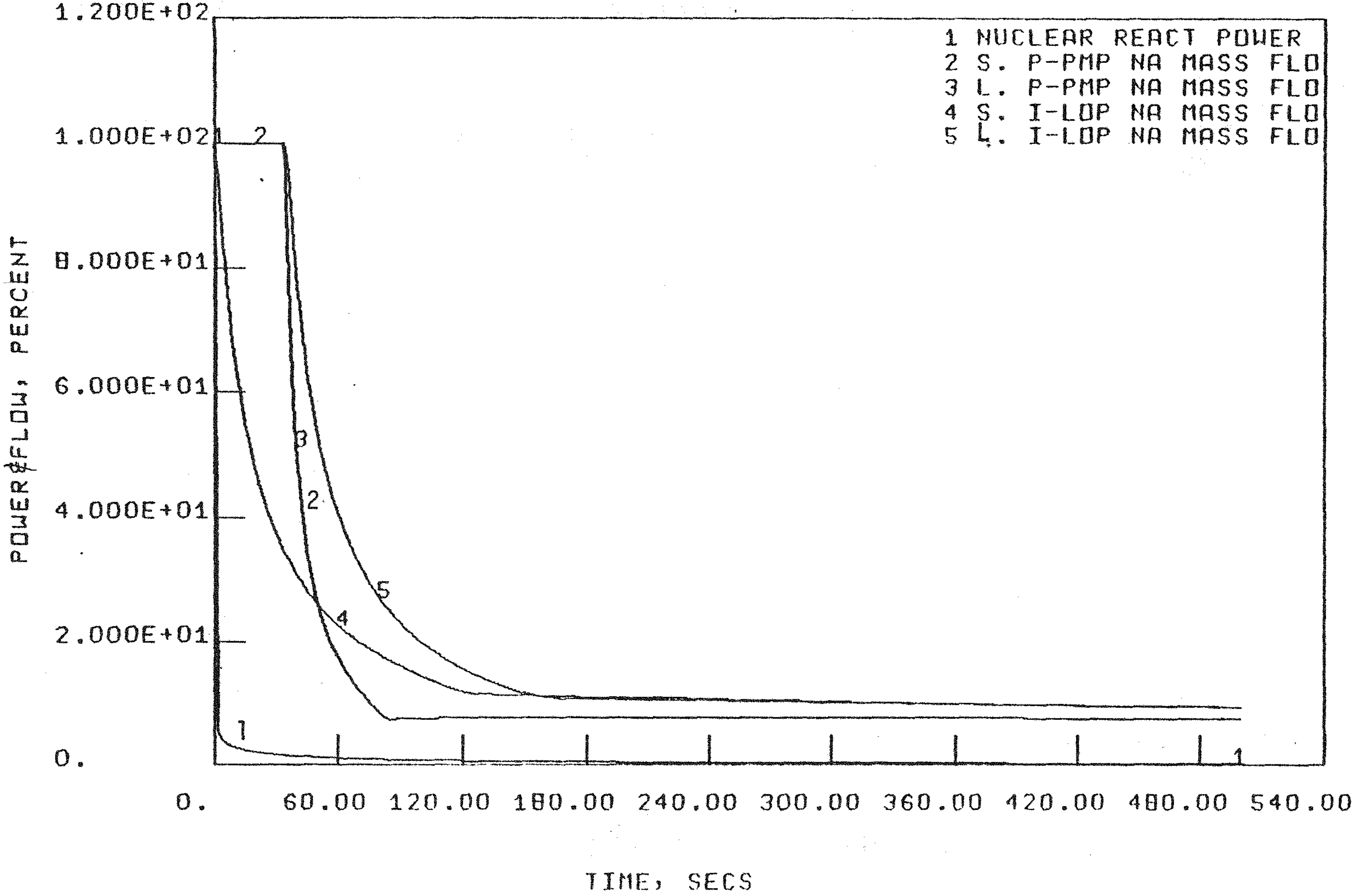

FIGURE 4-12
POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 34 SEC PUMP TRIP DELAY
RUN DATED 04/19/78
NUMBER DEPGE04

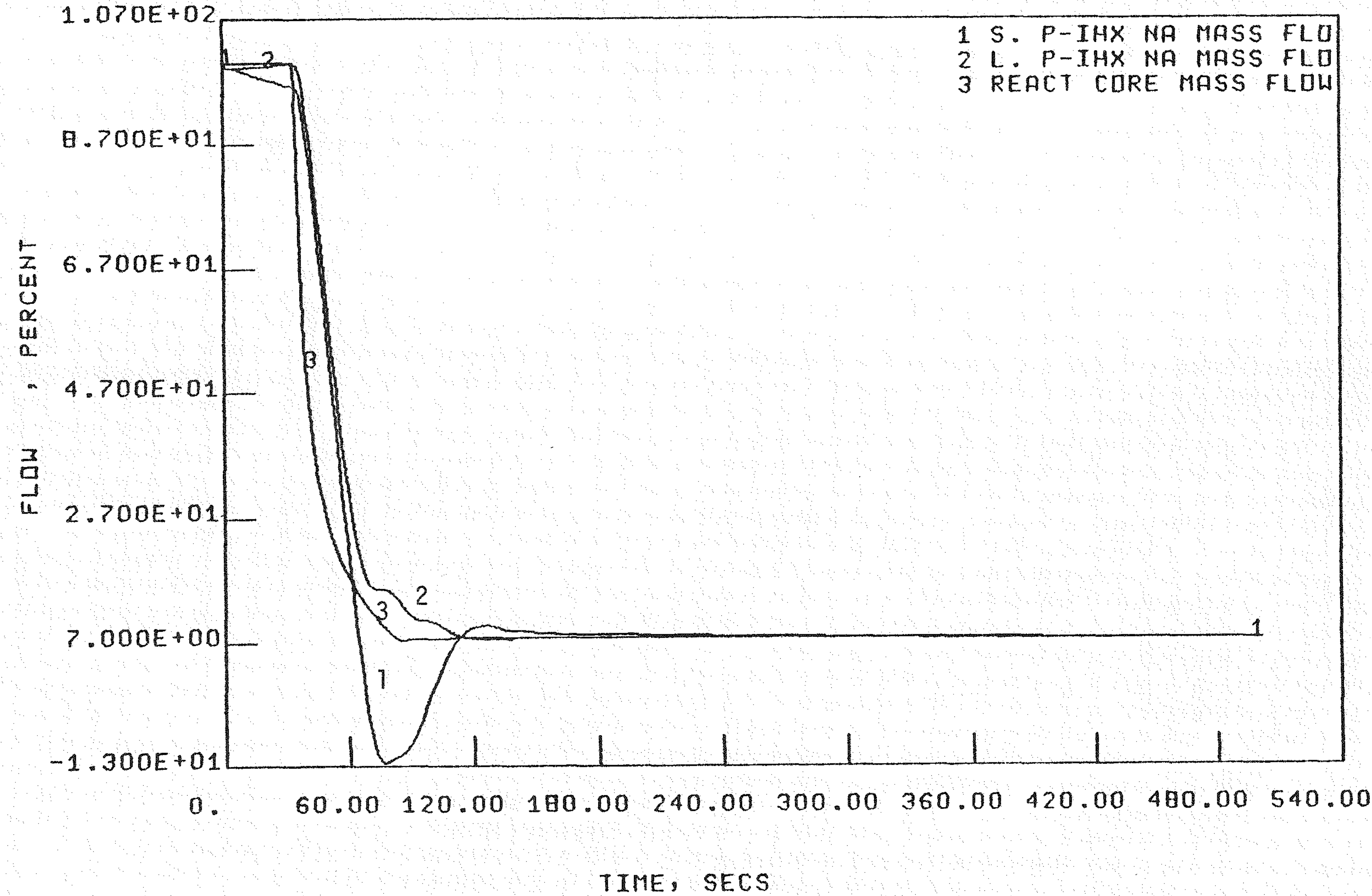

FIGURE 4-13

POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 34 SEC PUMP TRIP DELAY
RUN DATED 04/19/78
NUMBER DEPGE04

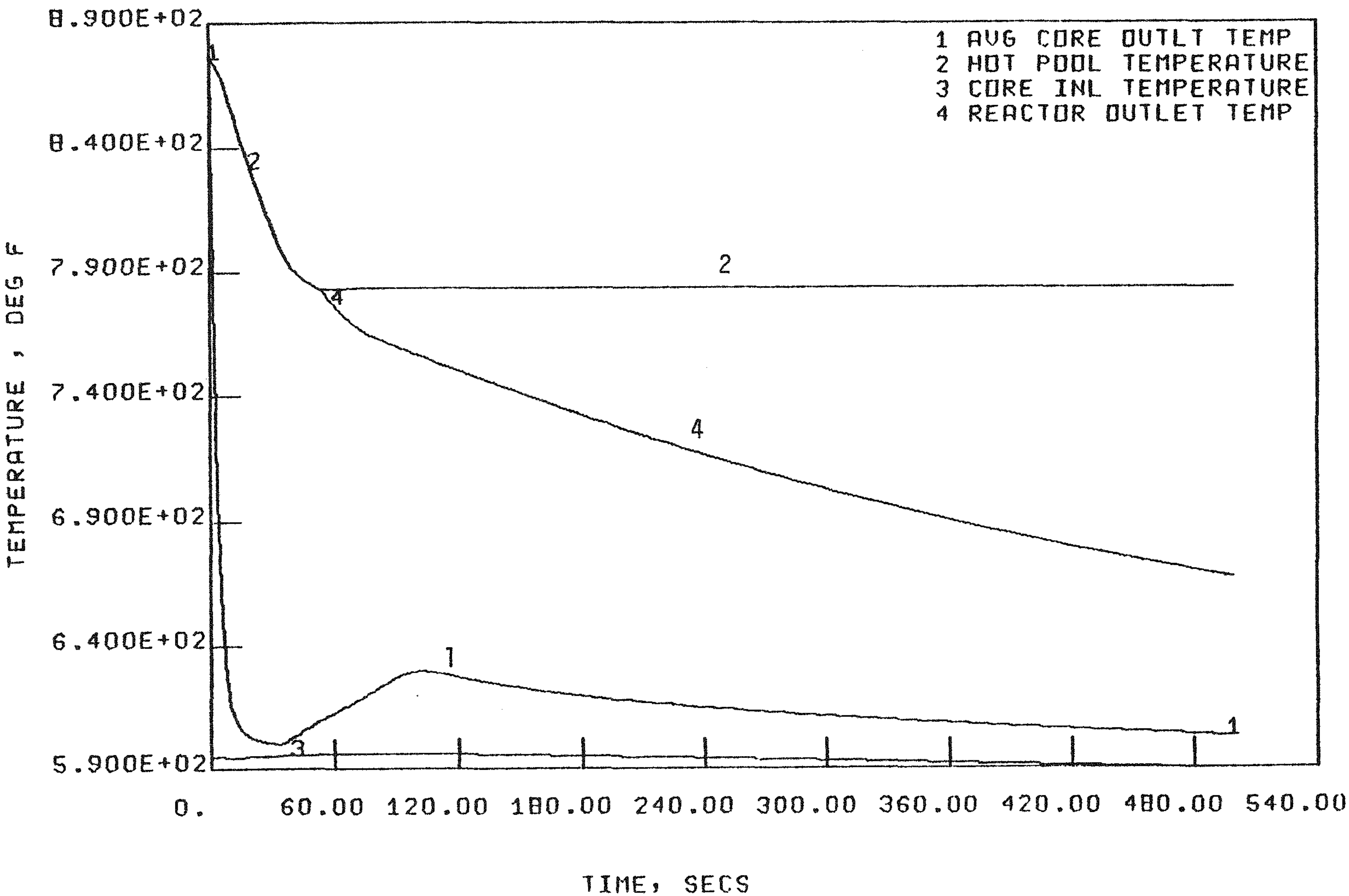

FIGURE 4-14

POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 34 SEC PUMP TRIP DELAY
RUN DATED 04/19/78
NUMBER DEP6E04

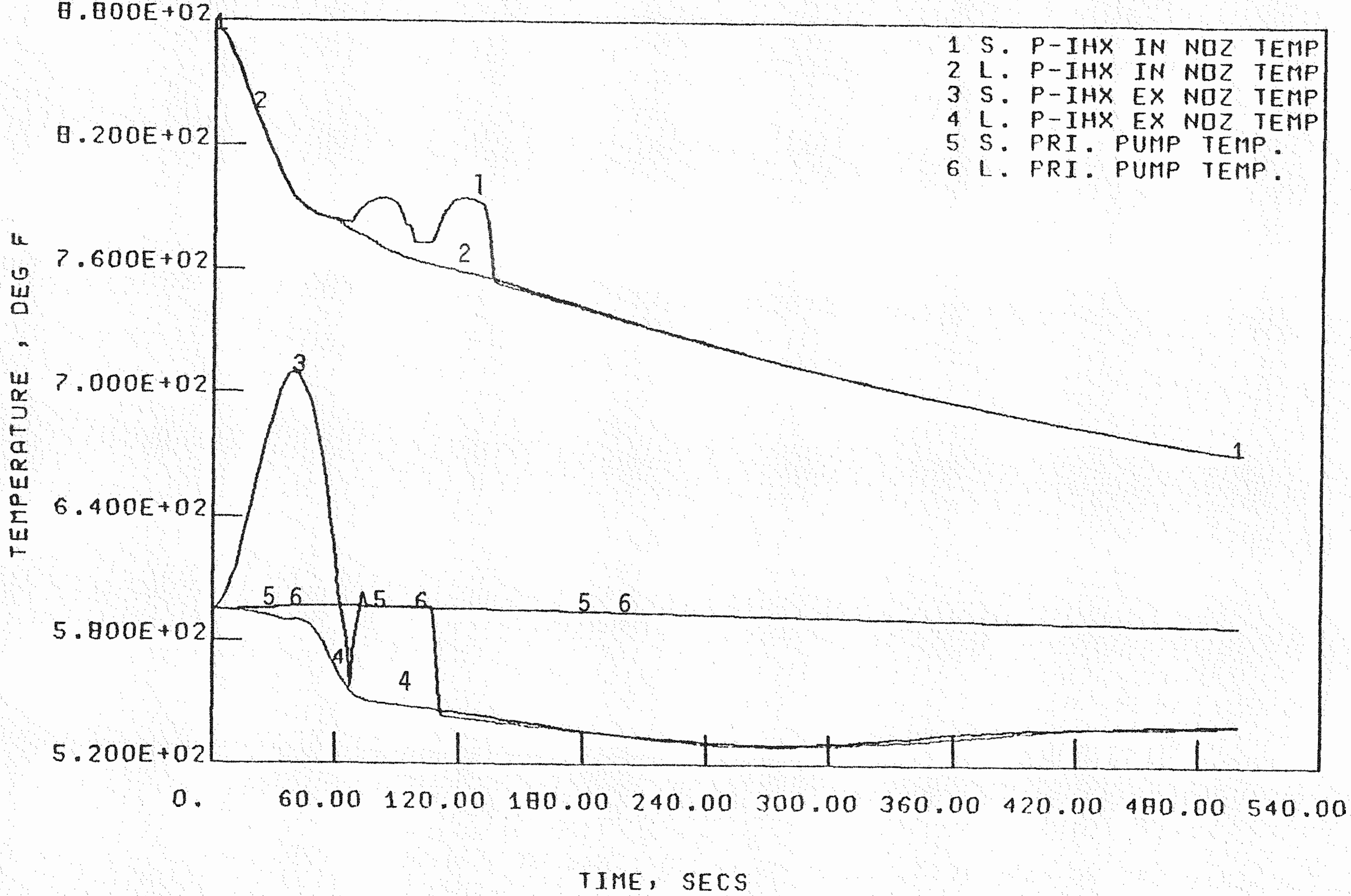

FIGURE 4-15
POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 34 SEC PUMP TRIP DELAY
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NUMBER DEPGE04

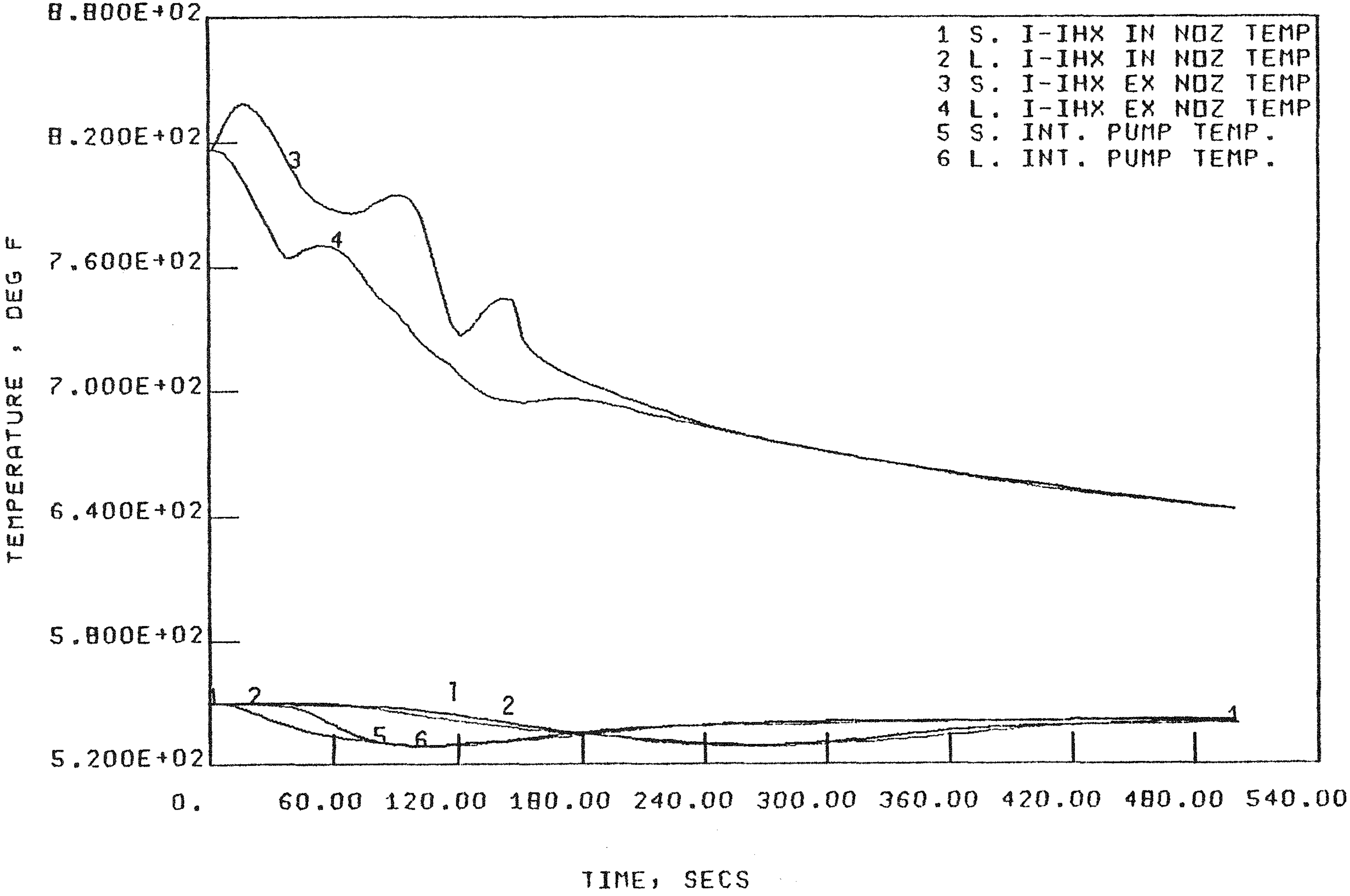

FIGURE 4-16

POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 78 SEC PUMP TRIP DELAY
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NUMBER DEP6E03

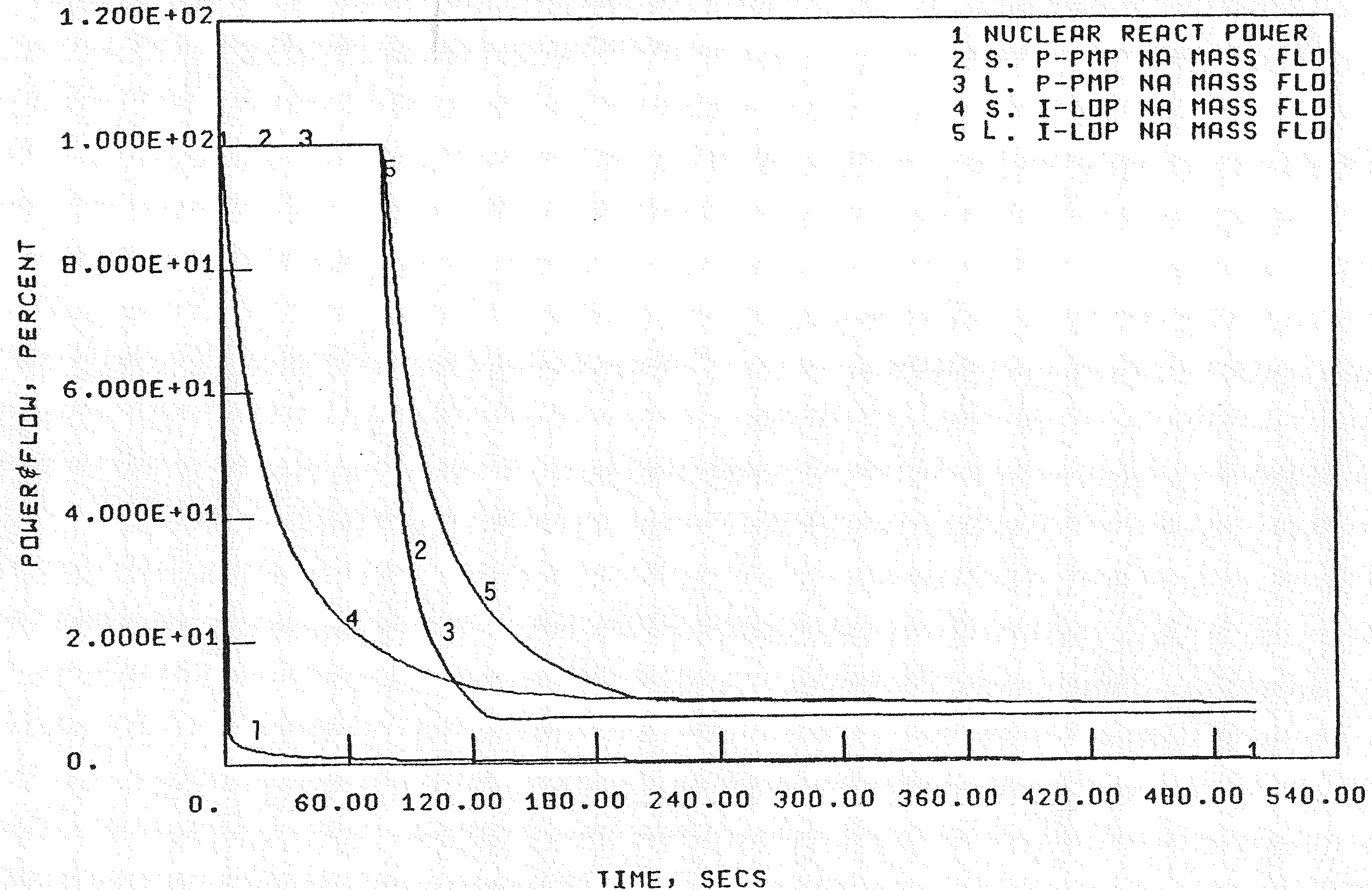

FIGURE 4-17

POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 78 SEC PUMP TRIP DELAY
RUN DATED 04/19/78
NUMBER DEPGE03

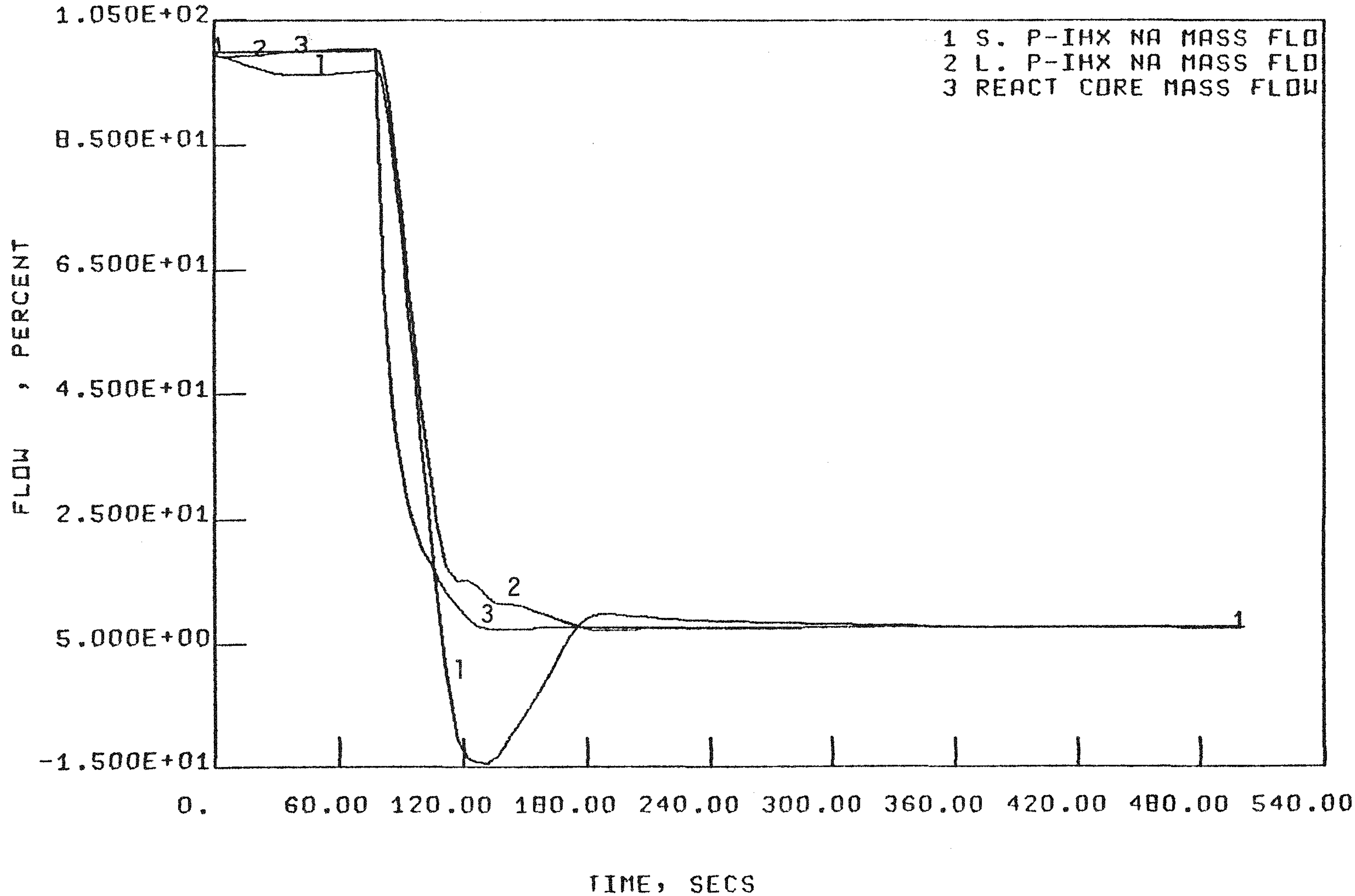

FIGURE 4-18

POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 78 SEC PUMP TRIP DELAY
RUN DATED 04/19/78
NUMBER DEPGE03

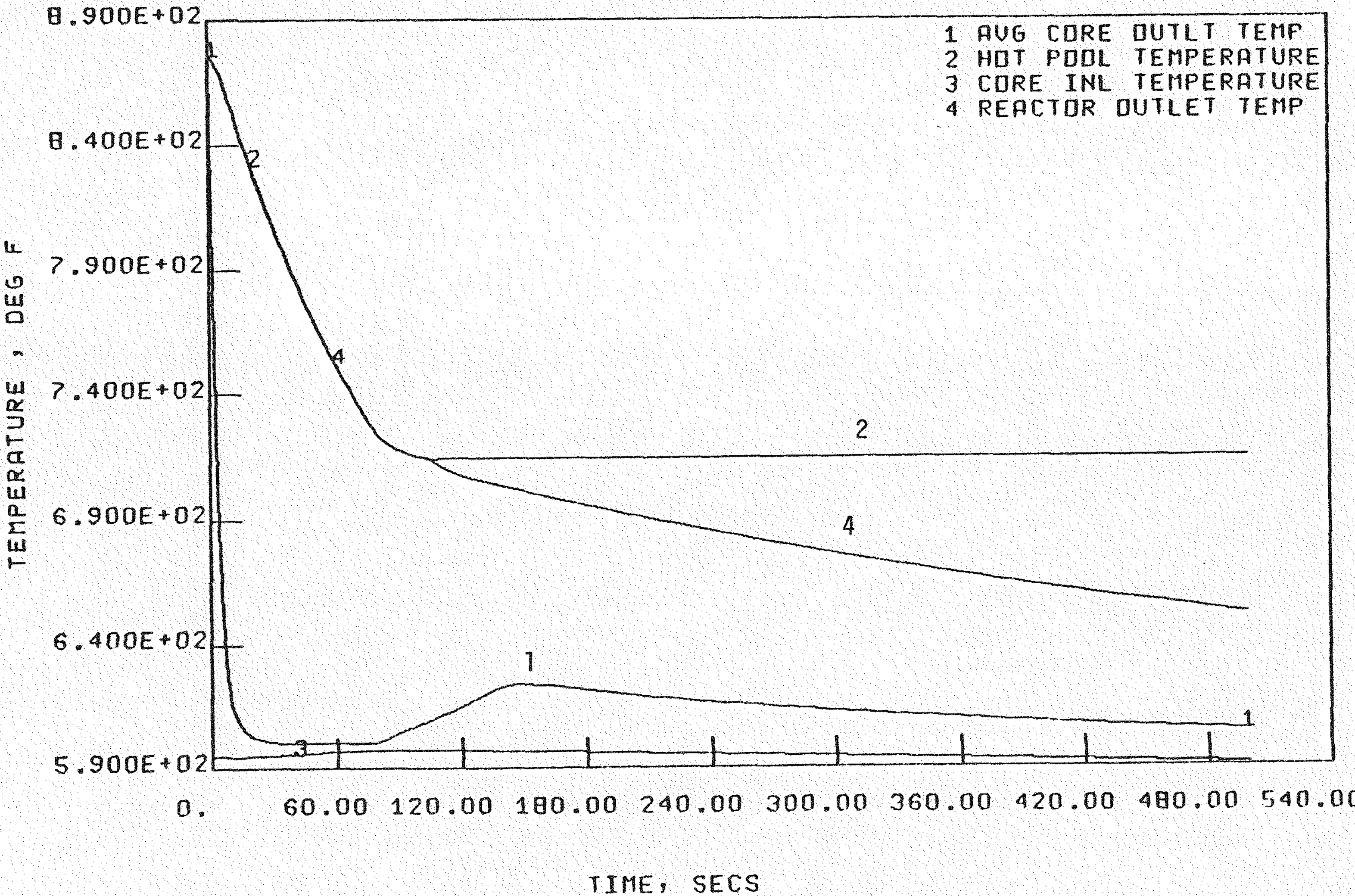

FIGURE 4-19

POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 78 SEC PUMP TRIP DELAY
RUN DATED 04/19/78
NUMBER DEPGE03

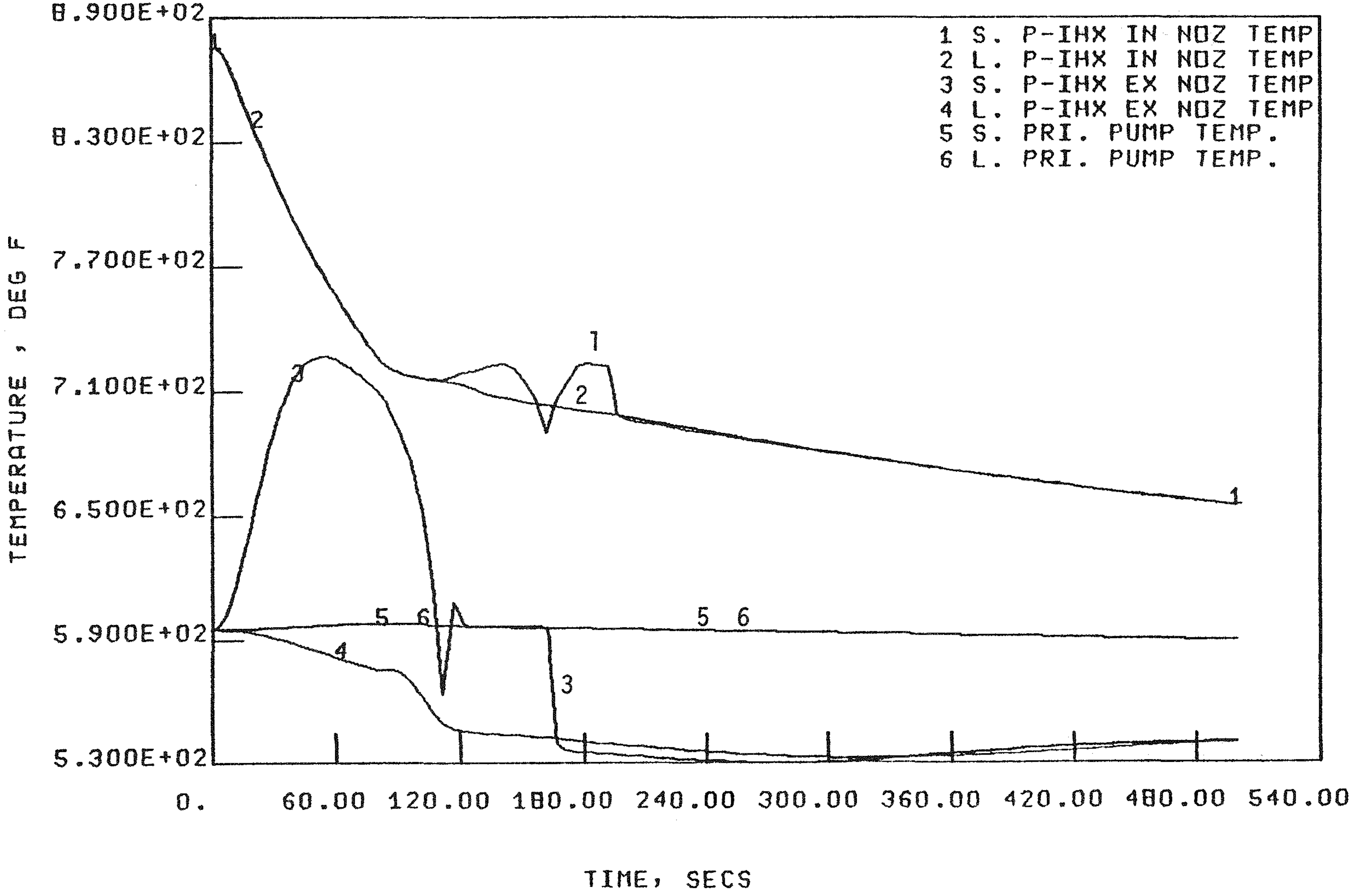

FIGURE 4-20
POOL LOSS OF POWER TO ONE IHTS PUMP WITH SCRAM AND 78 SEC PUMP TRIP DELAY
RUN DATED 04/19/78
NUMBER DEPGE03

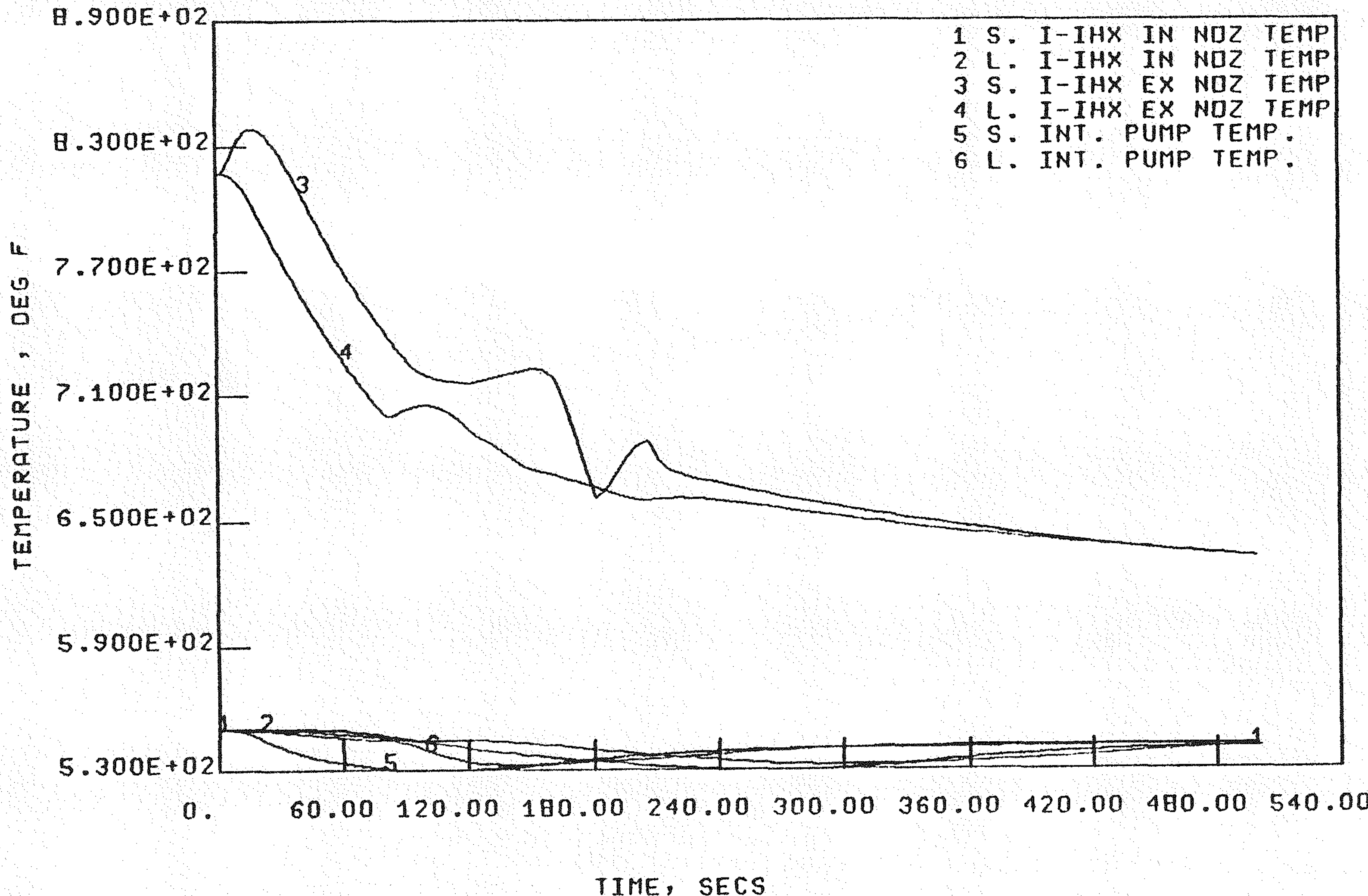

FIGURE 5-1
POOL REACTOR SCRAM WITH TRANSITION TO NATURAL CONVECTION (MAX DECAY HT)
RUN DATED 05/25/78
NUMBER DEPGE03

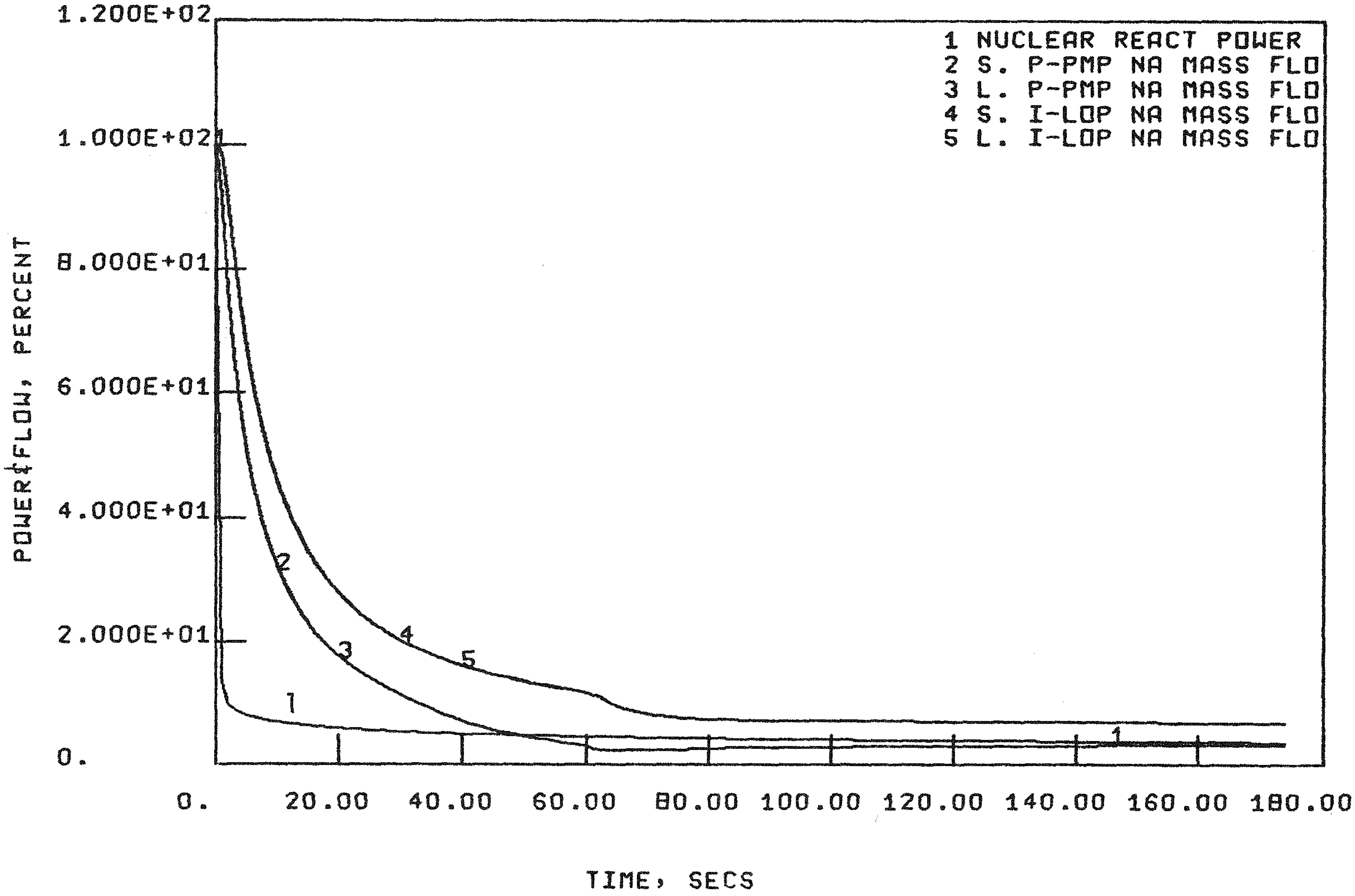

FIGURE 5-2
POOL REACTOR SCRAM WITH TRANSITION TO NATURAL CONVECTION (MAX DECAY HT)
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NUMBER DEPGE03

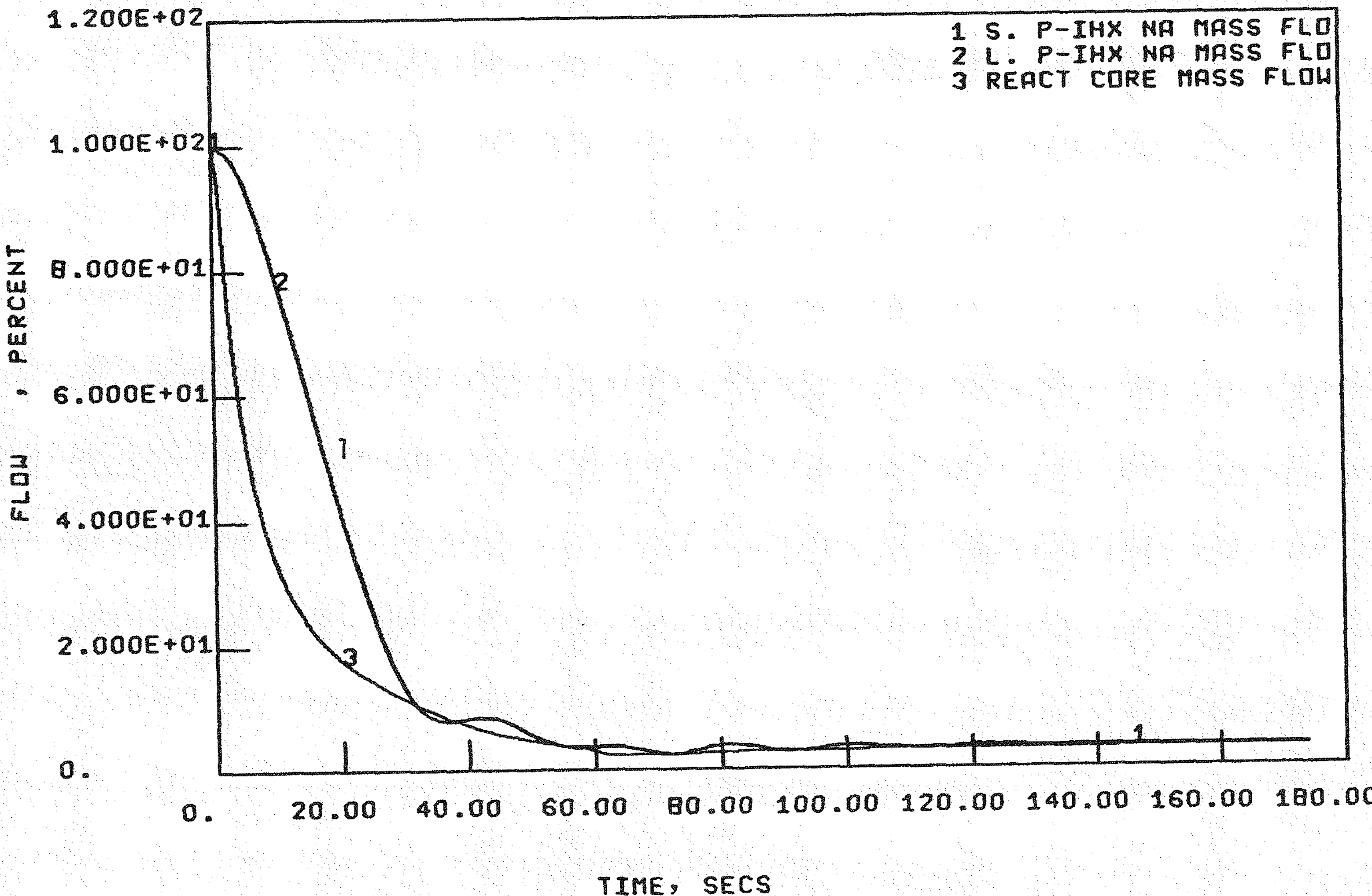

FIGURE 5-3
POOL REACTOR SCRAM WITH TRANSITION TO NATURAL CONVECTION (MAX DECAY HT)
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NUMBER DEPGE03

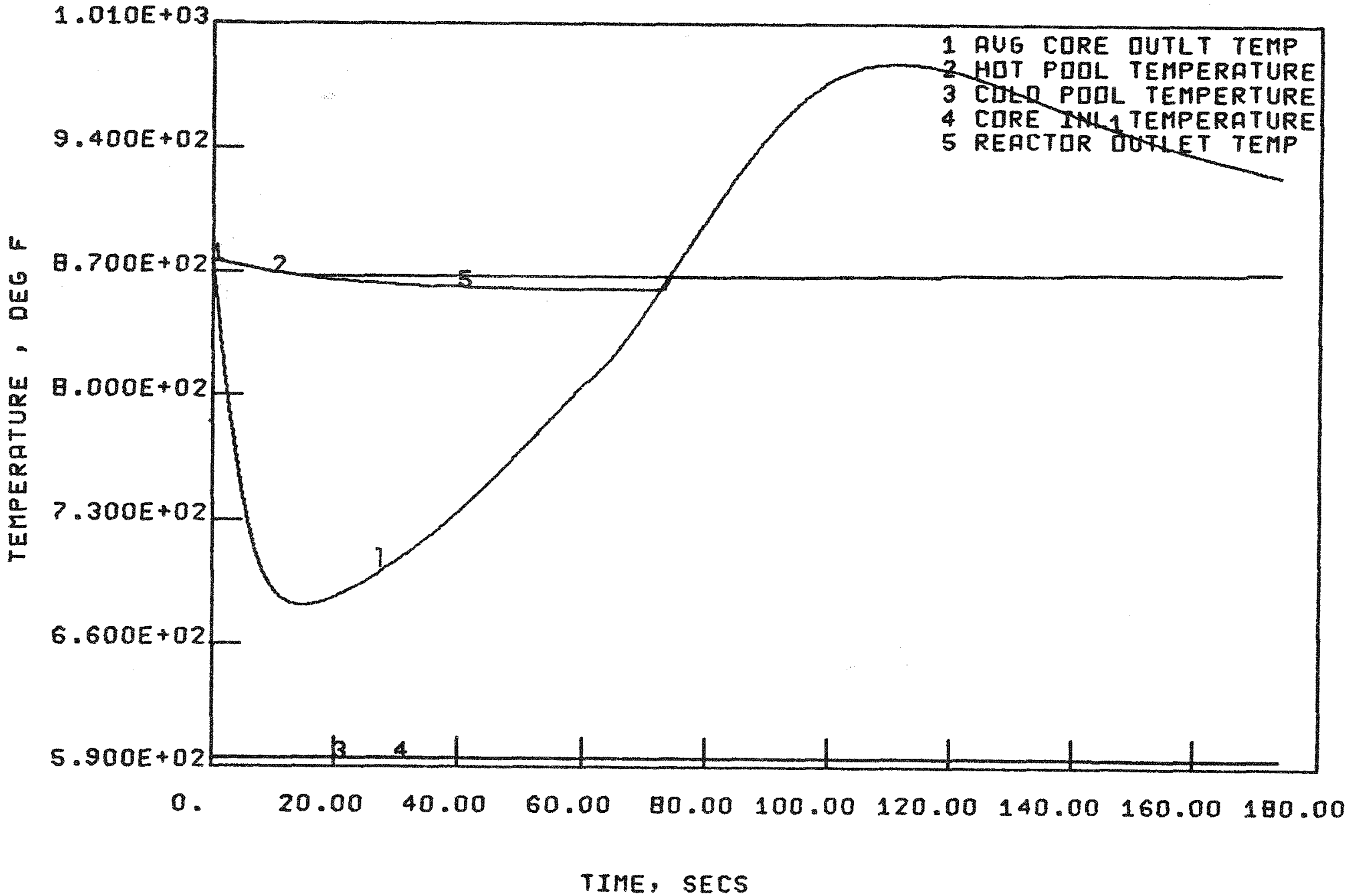


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FIGURE 5-4
POOL REACTOR SCRAM WITH TRANSITION TO NATURAL CONVECTION (MAX DECAY HT)
RUN DATED 05/25/78
NUMBER DEPGE03

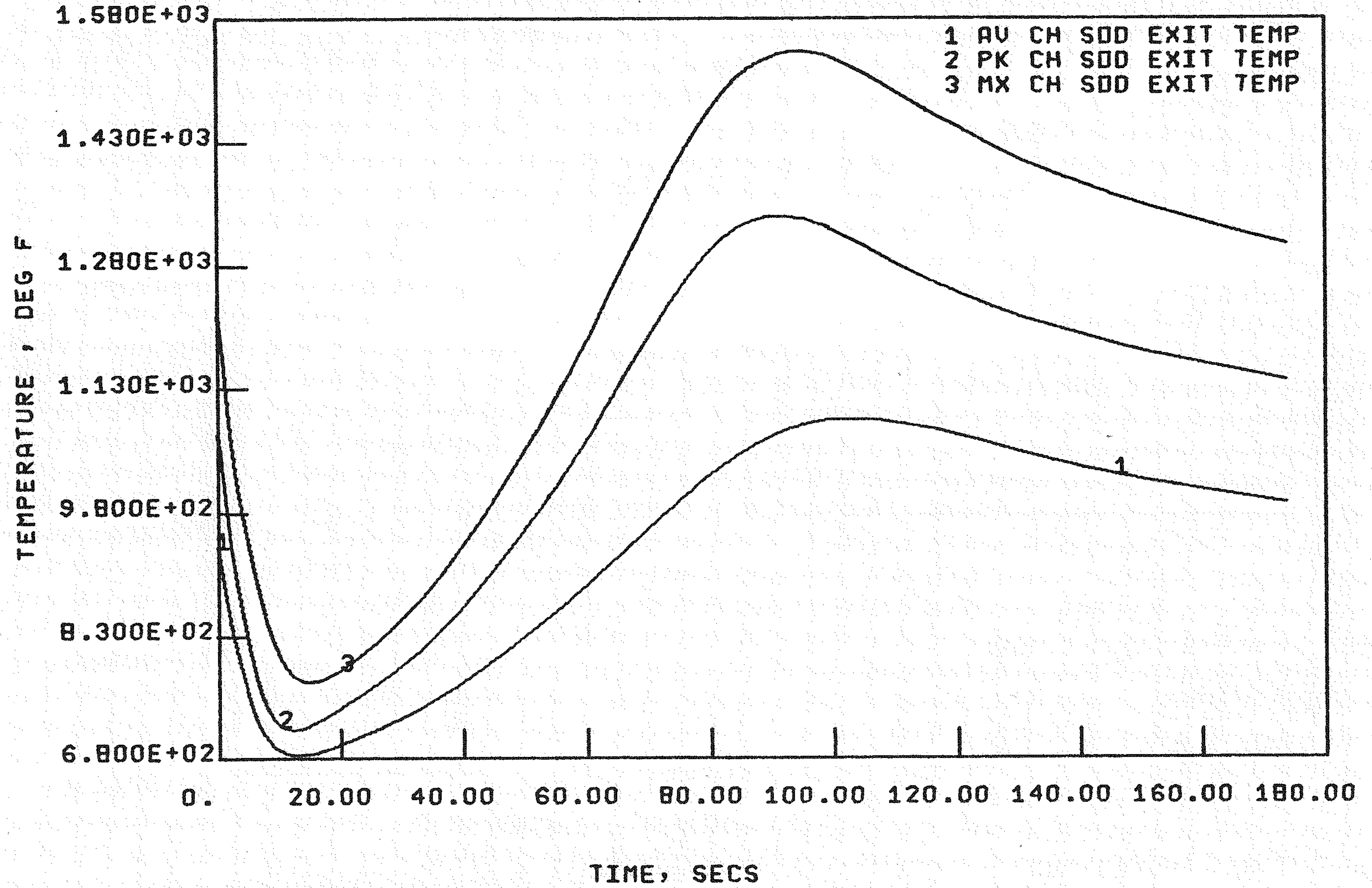

FIGURE 5-5

POOL REACTOR SCRAM WITH TRANSITION TO NATURAL CONVECTION (MAX DECAY HT)
RUN DATED 05/25/78
NUMBER DEPGE03

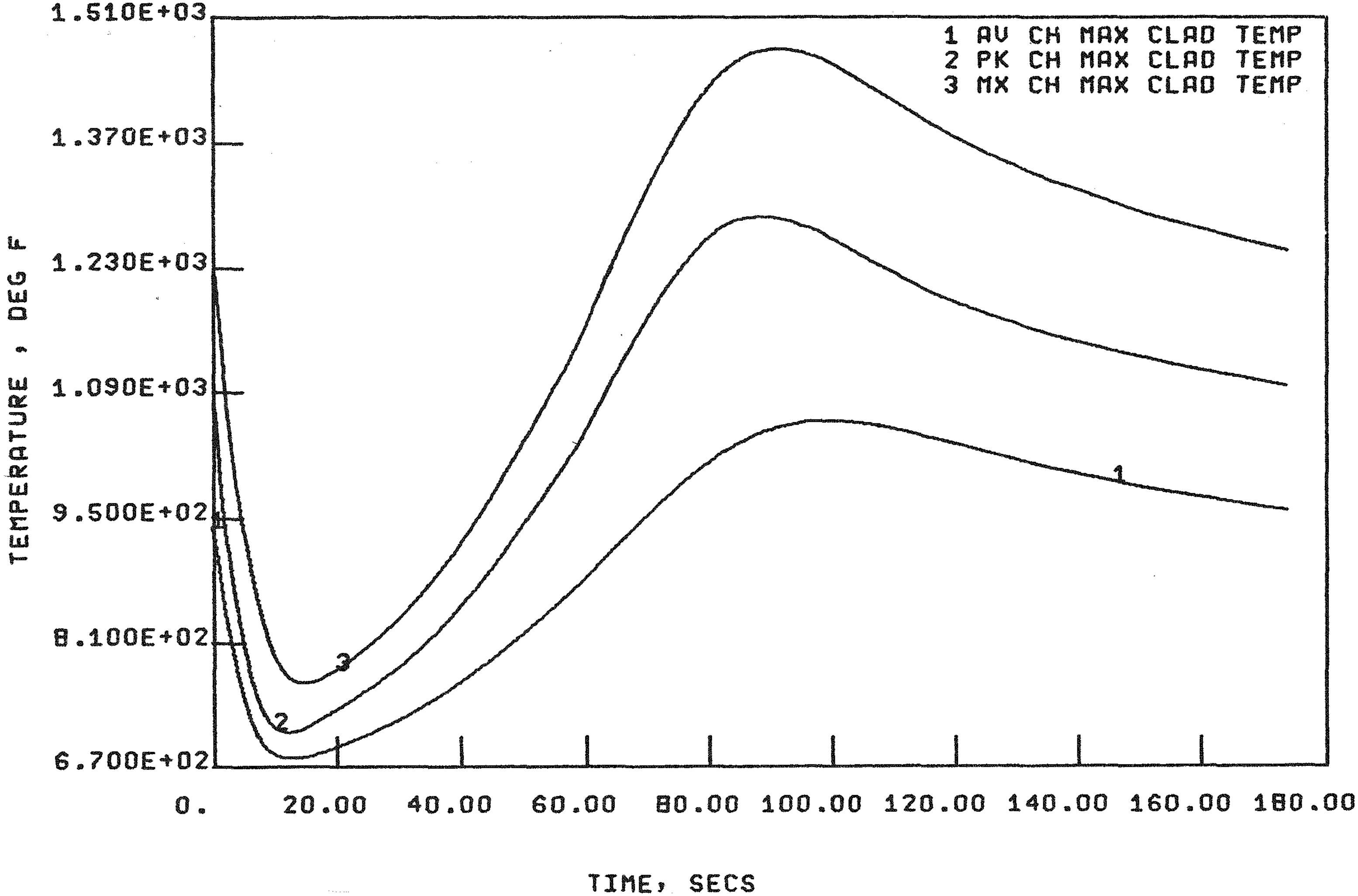

FIGURE 5-6

POOL REACTOR SCRAM WITH TRANSITION TO NATURAL CONVECTION (MAX DECAY HT)
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NUMBER DEPGE03

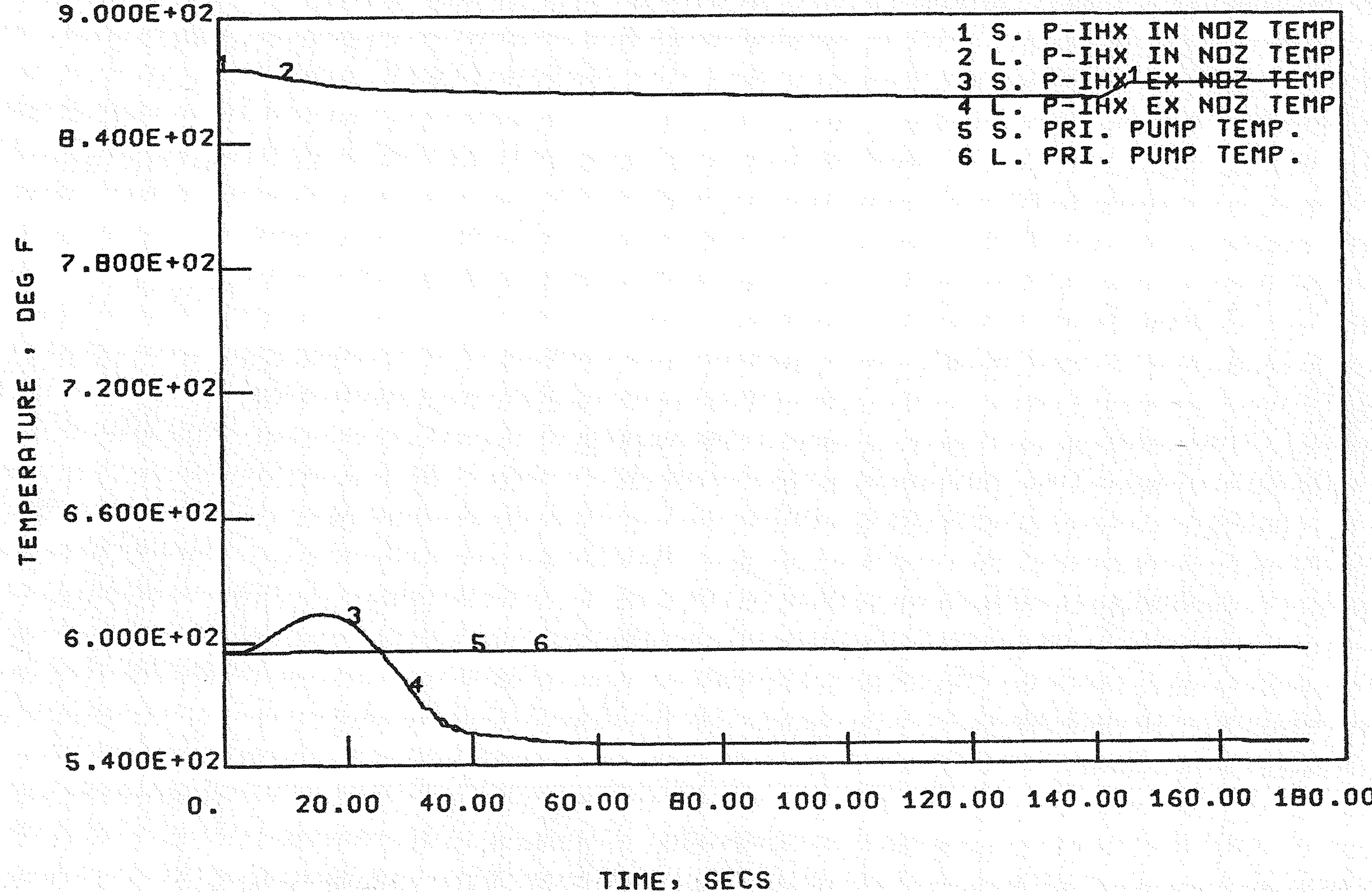

FIGURE 5-7
POOL REACTOR SCRAM WITH TRANSITION TO NATURAL CONVECTION (MAX DECAY HT)
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NUMBER DEPGE03

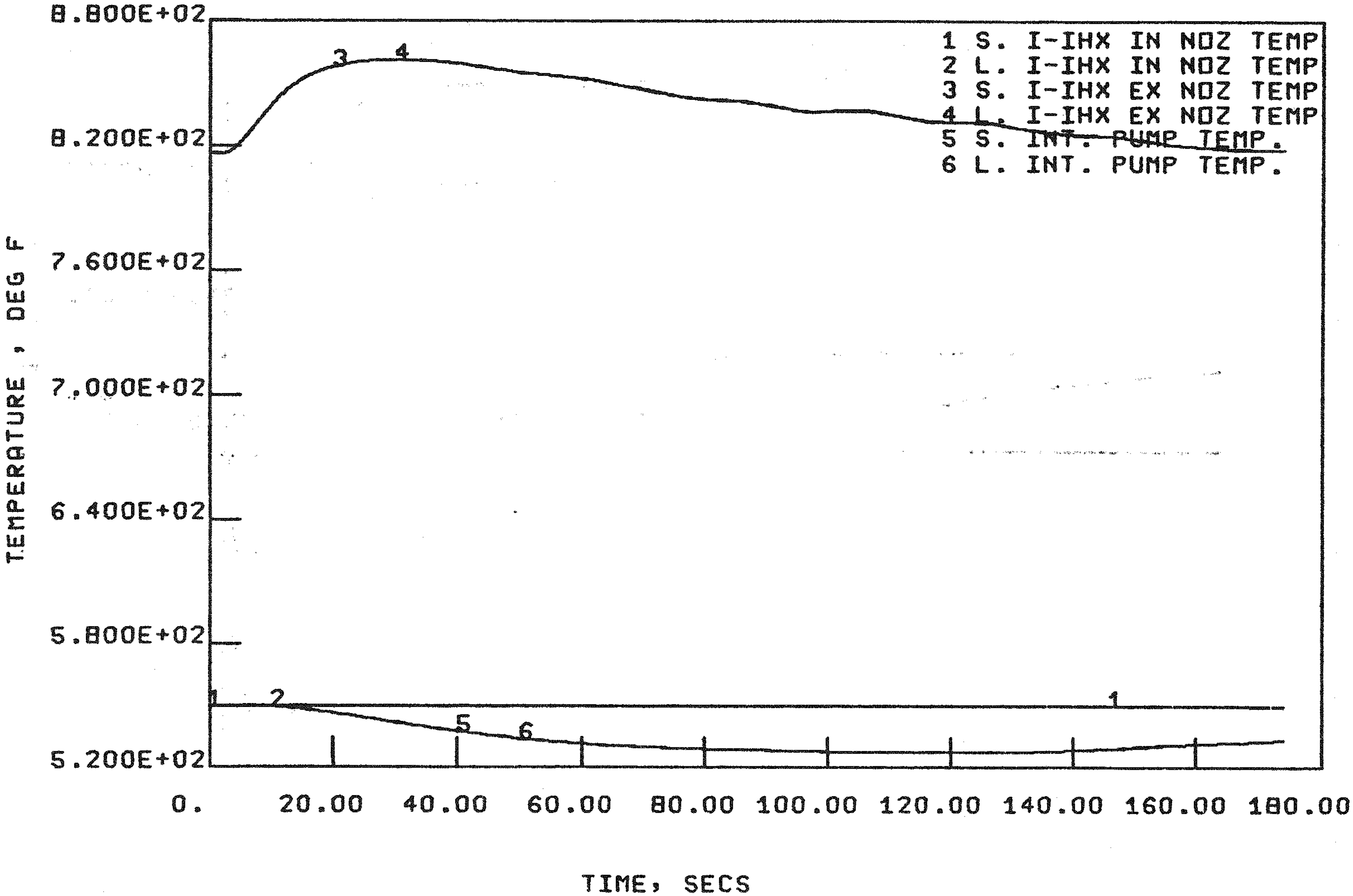

FIGURE 6-1
POOL REACTOR PIPE RUPTURE WITH SCRAM AND PUMP TRIP TO HALF SPEED
RUN DATED 06/08/78
NUMBER DEPGE03

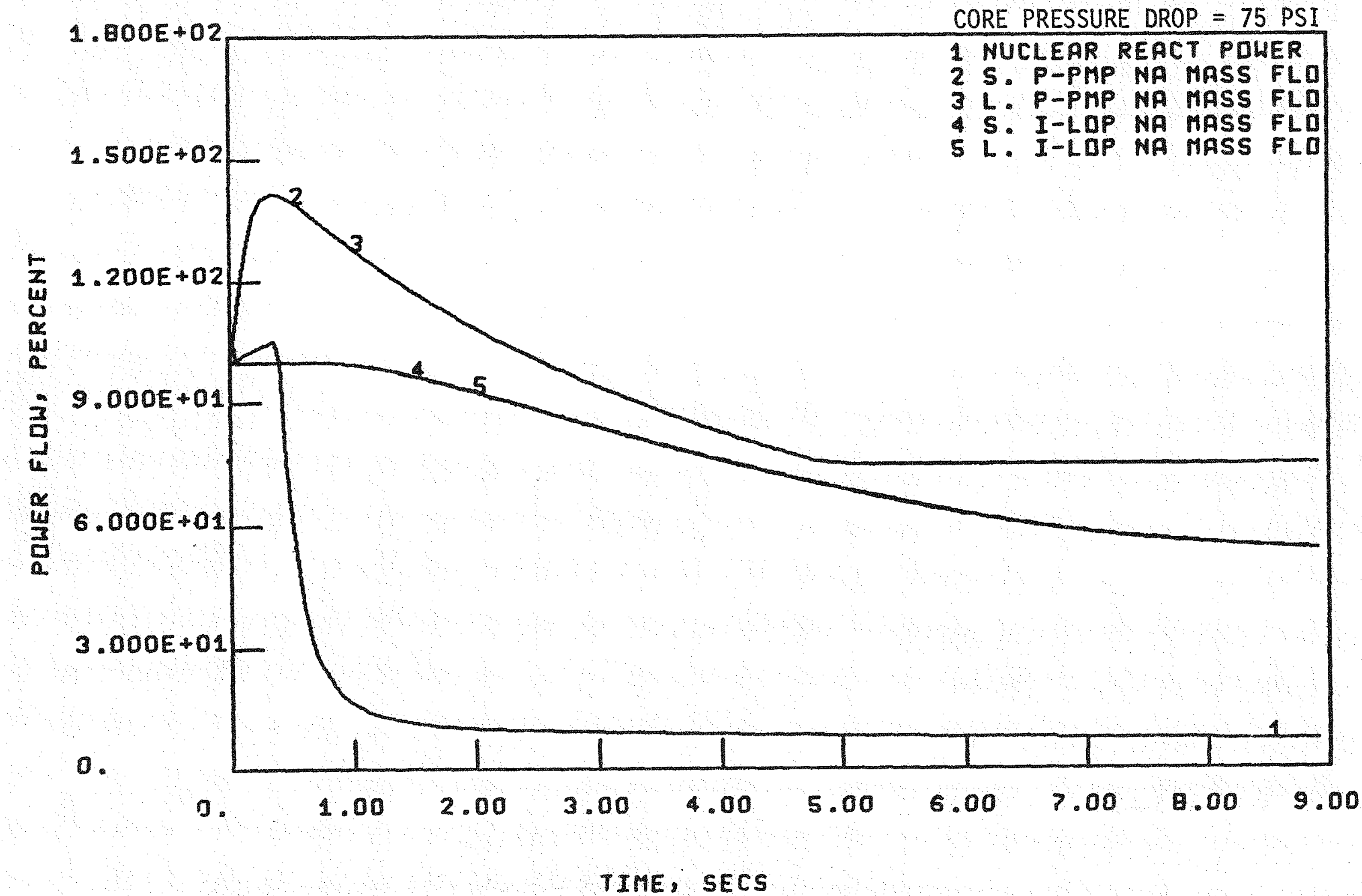

FIGURE 6-2

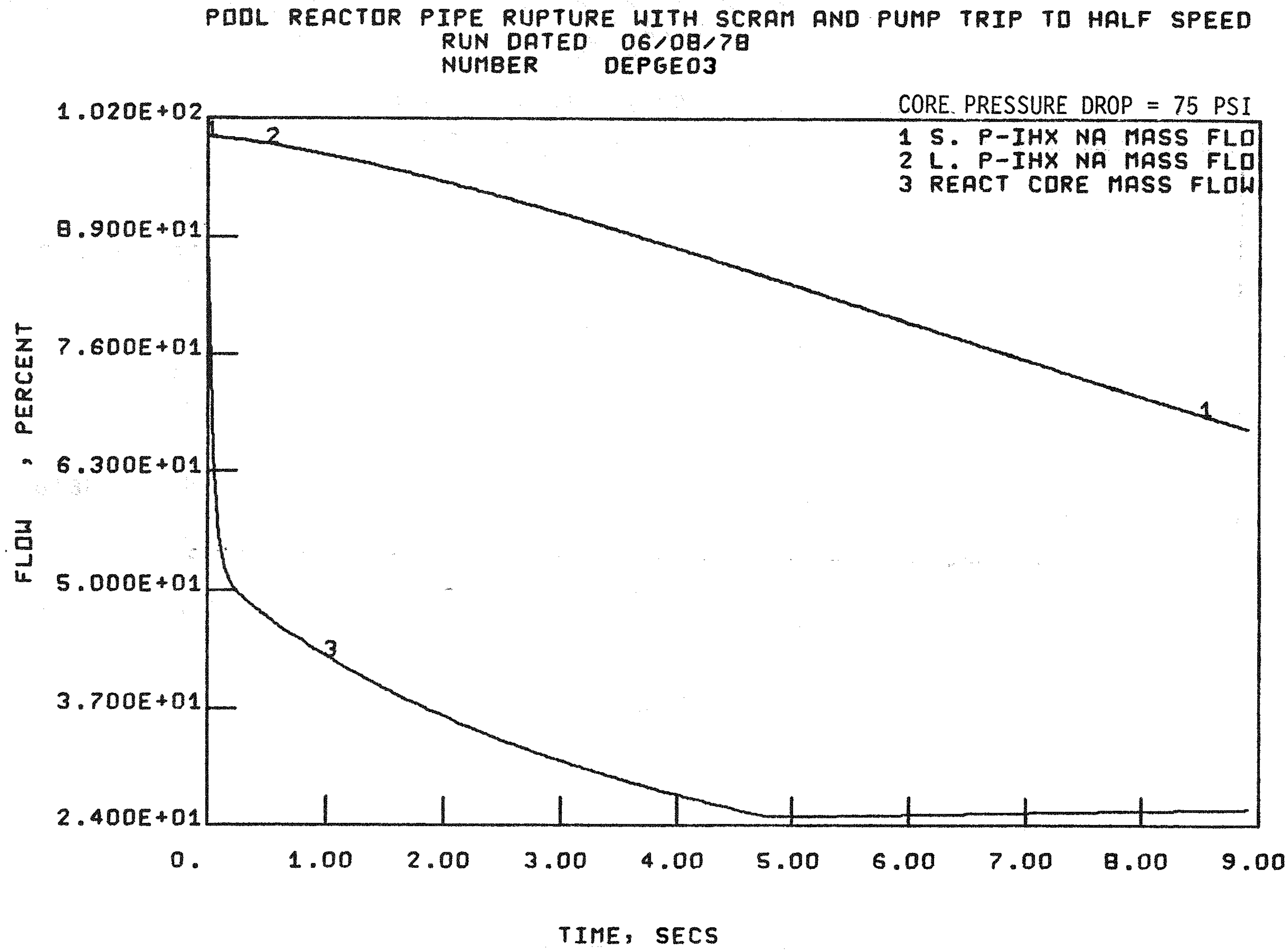
POOL REACTOR PIPE RUPTURE WITH SCRAM AND PUMP TRIP TO HALF SPEED
RUN DATED 06/08/78
NUMBER DEPGE03
CORE PRESSURE DROP = 75 PSI
1 S. P-IHX NA MASS FLO
2 L. P-IHX NA MASS FLO
3 REACT CORE MASS FLOW
1.020E+02
8.900E+01
7.600E+01
6.300E+01
5.000E+01
3.700E+01
2.400E+01
FLOW , PERCENT
0.
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
TIME, SECS
1
2
3

FIGURE 6-3
POOL REACTOR PIPE RUPTURE WITH SCRAM AND PUMP TRIP TO HALF SPEED
RUN DATED 06/08/78
NUMBER DEPGE03

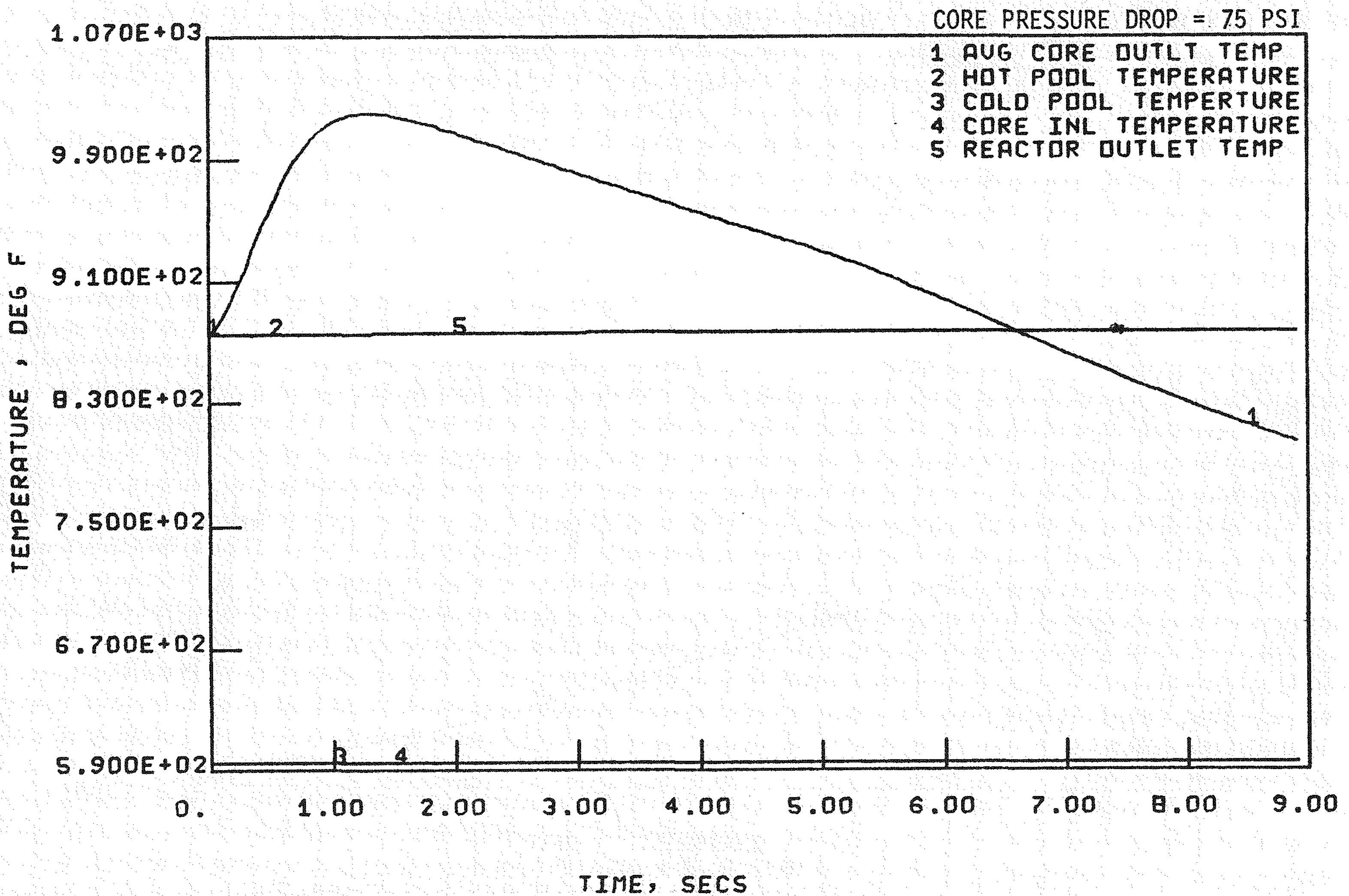

FIGURE 6-4

POOL REACTOR PIPE RUPTURE WITH SCRAM AND PUMP TRIP TO HALF SPEED
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NUMBER DEPGE03

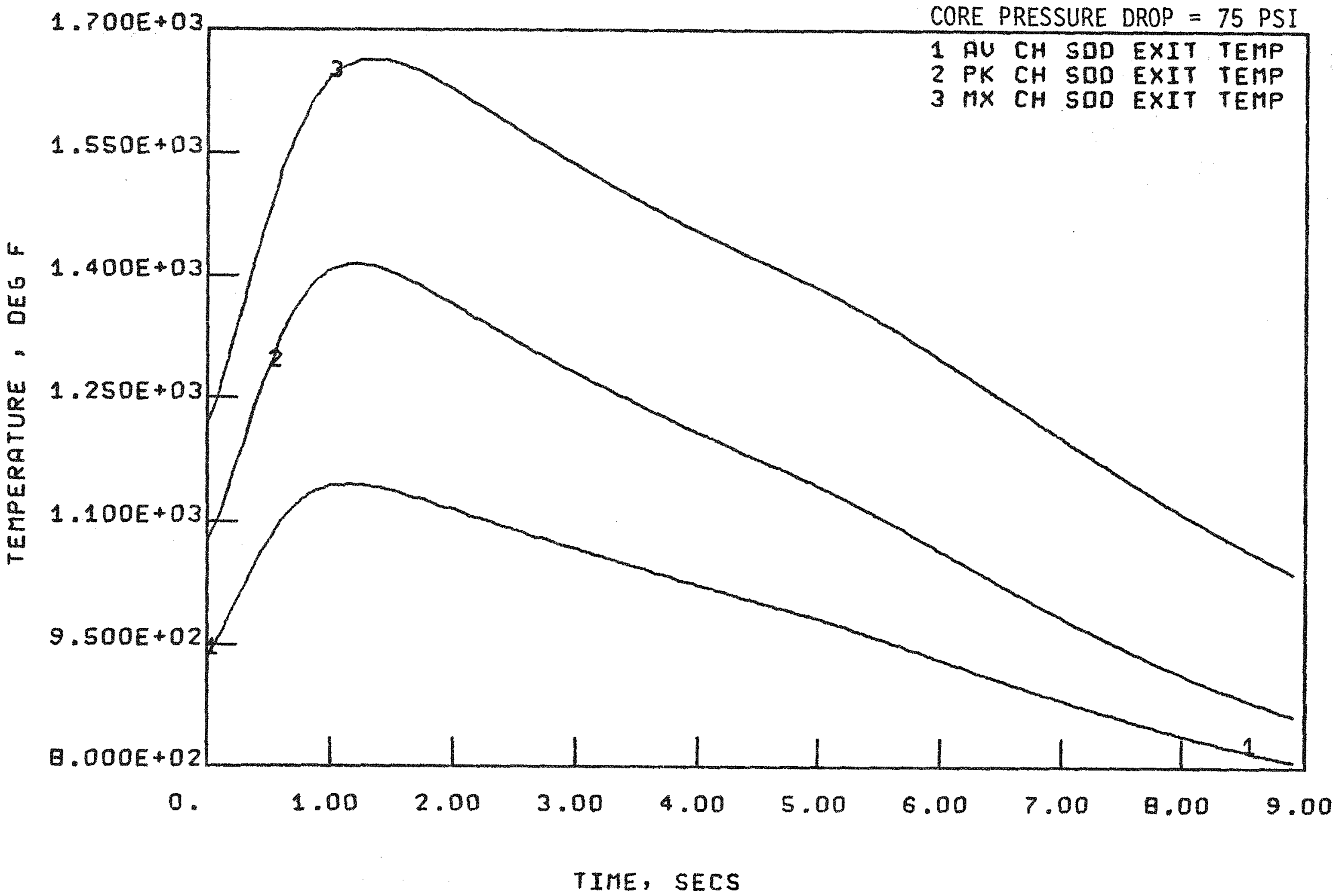

FIGURE 6-5

POOL REACTOR PIPE RUPTURE WITH SCRAM AND PUMP TRIP TO HALF SPEED

RUN DATED 06/08/78

NUMBER DEPGE03

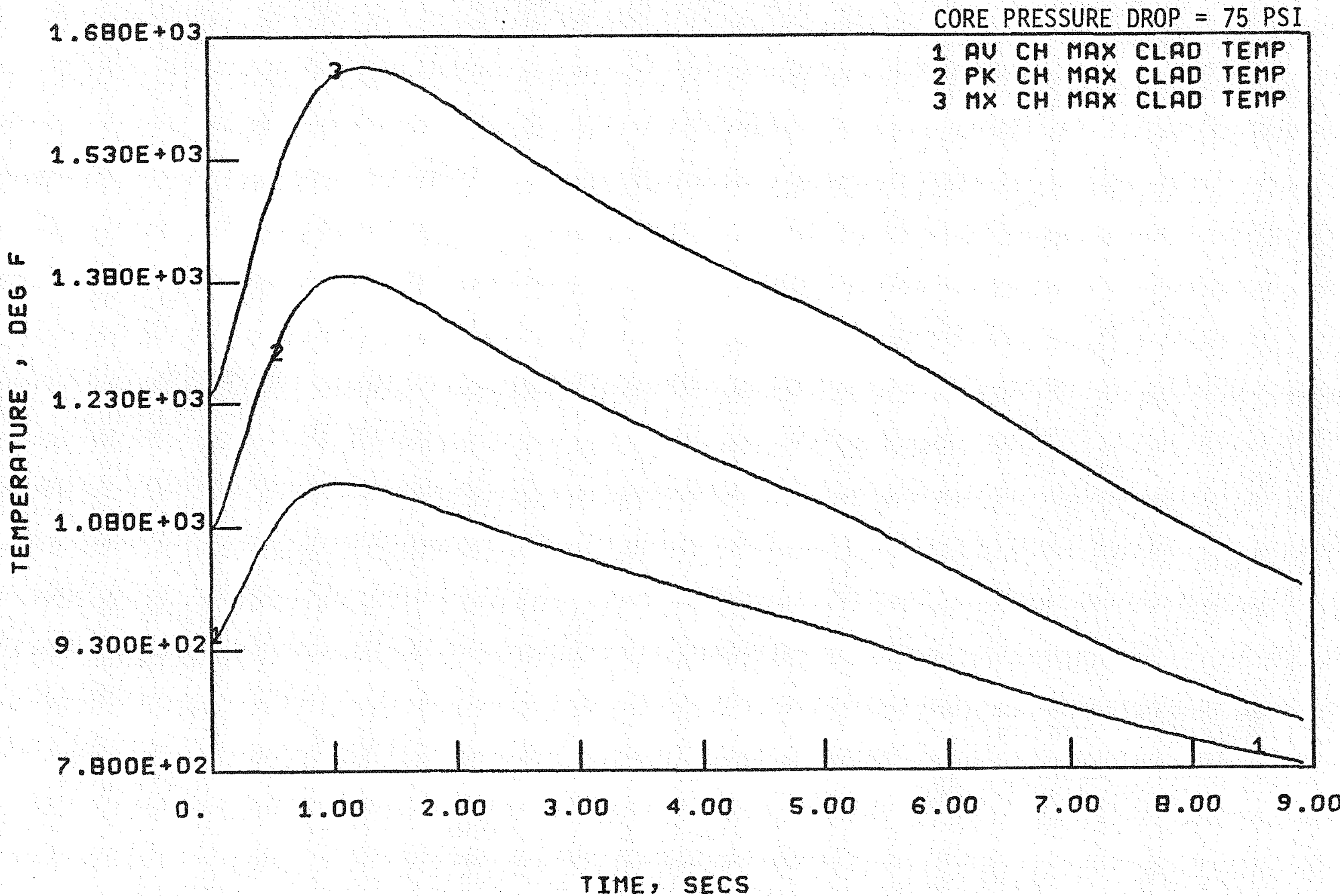

FIGURE 7-1
POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM
RUN DATED 06/19/78
NUMBER DEPGE00

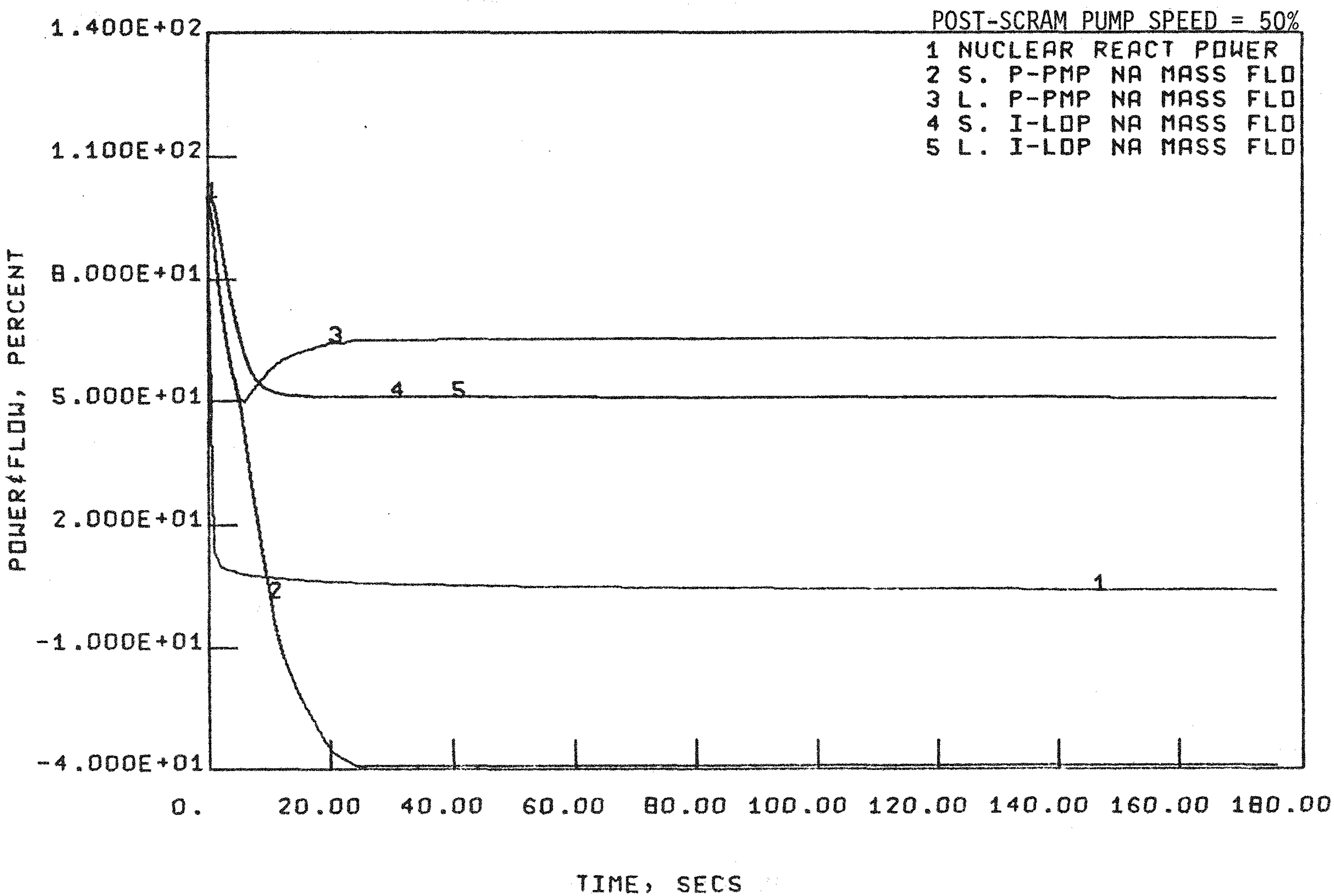

FIGURE 7-2

POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM

RUN DATED 06/19/78

NUMBER DEPGEOO

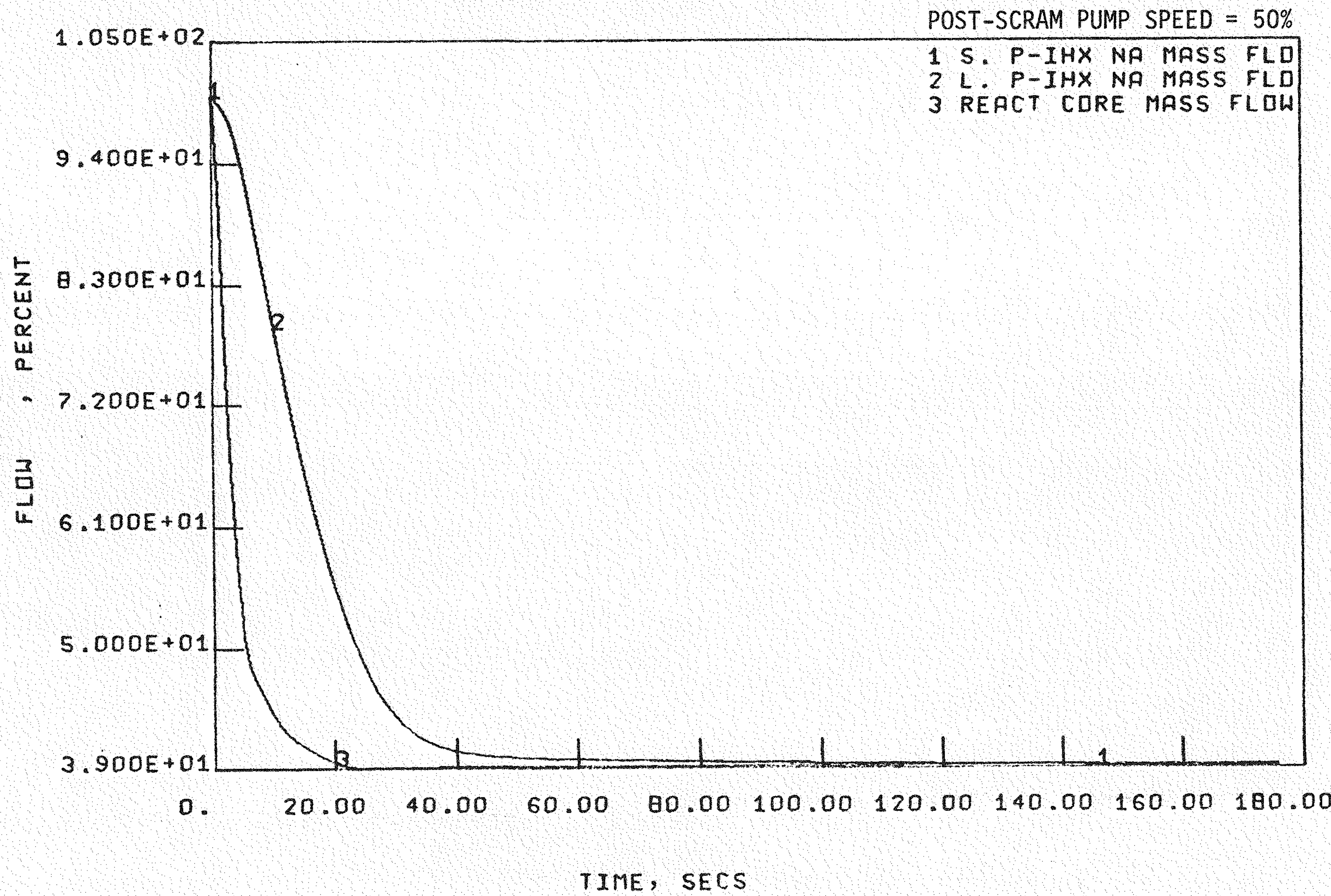

FIGURE 7-3
POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM
RUN DATED 06/19/78
NUMBER DEPGE00

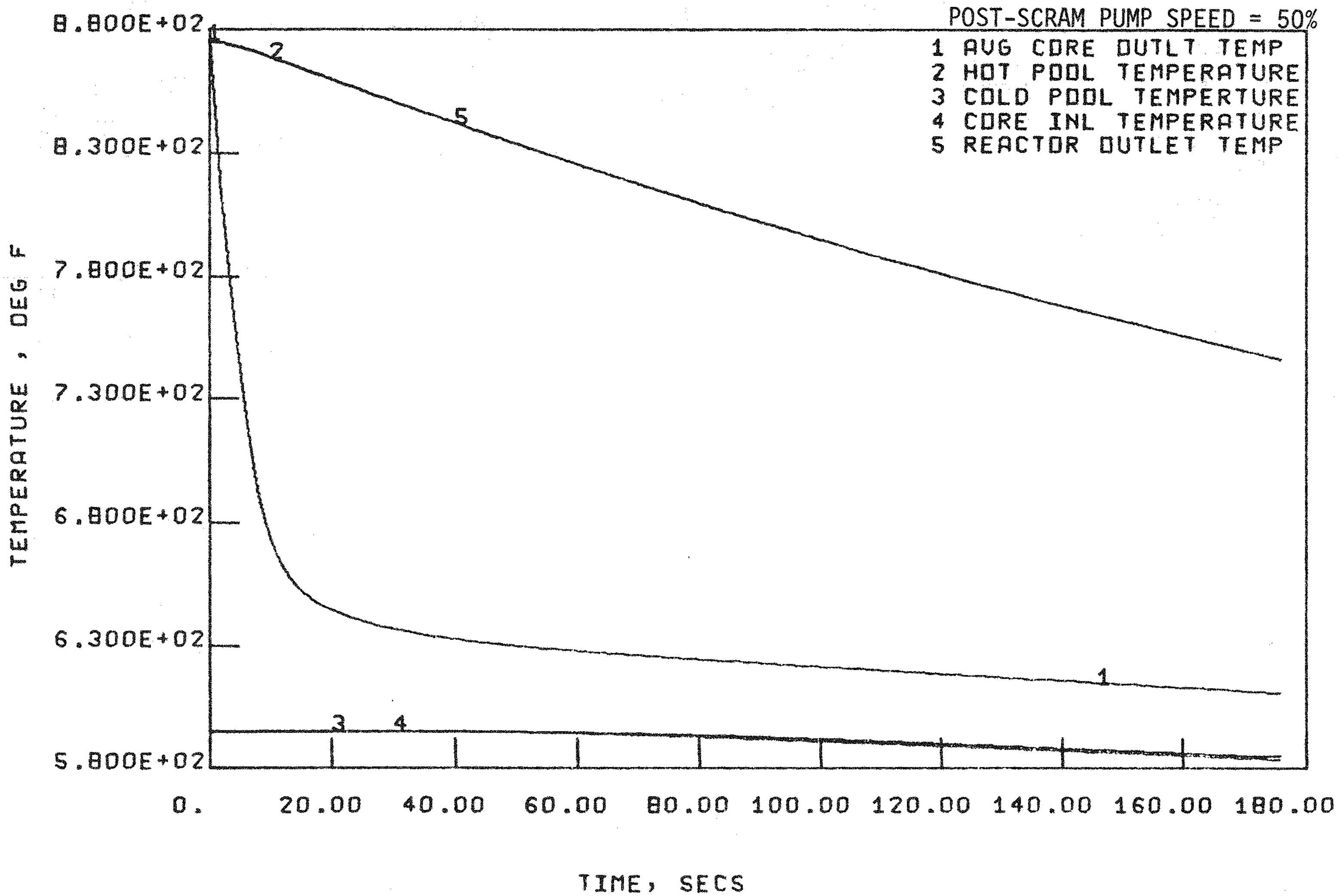

FIGURE 7-4

POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM

RUN DATED 06/19/78

NUMBER DEPGE00

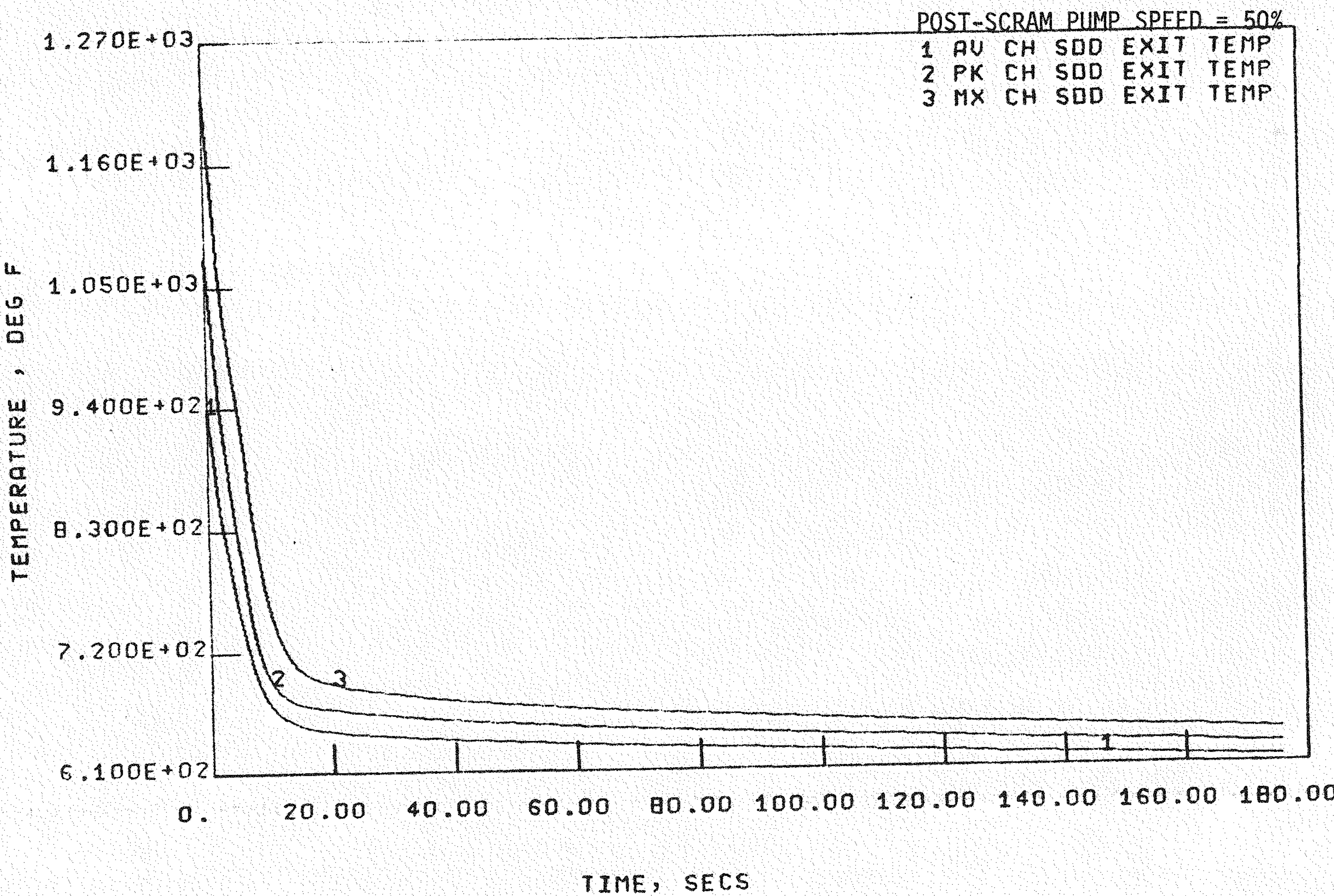

FIGURE 7-5

POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM
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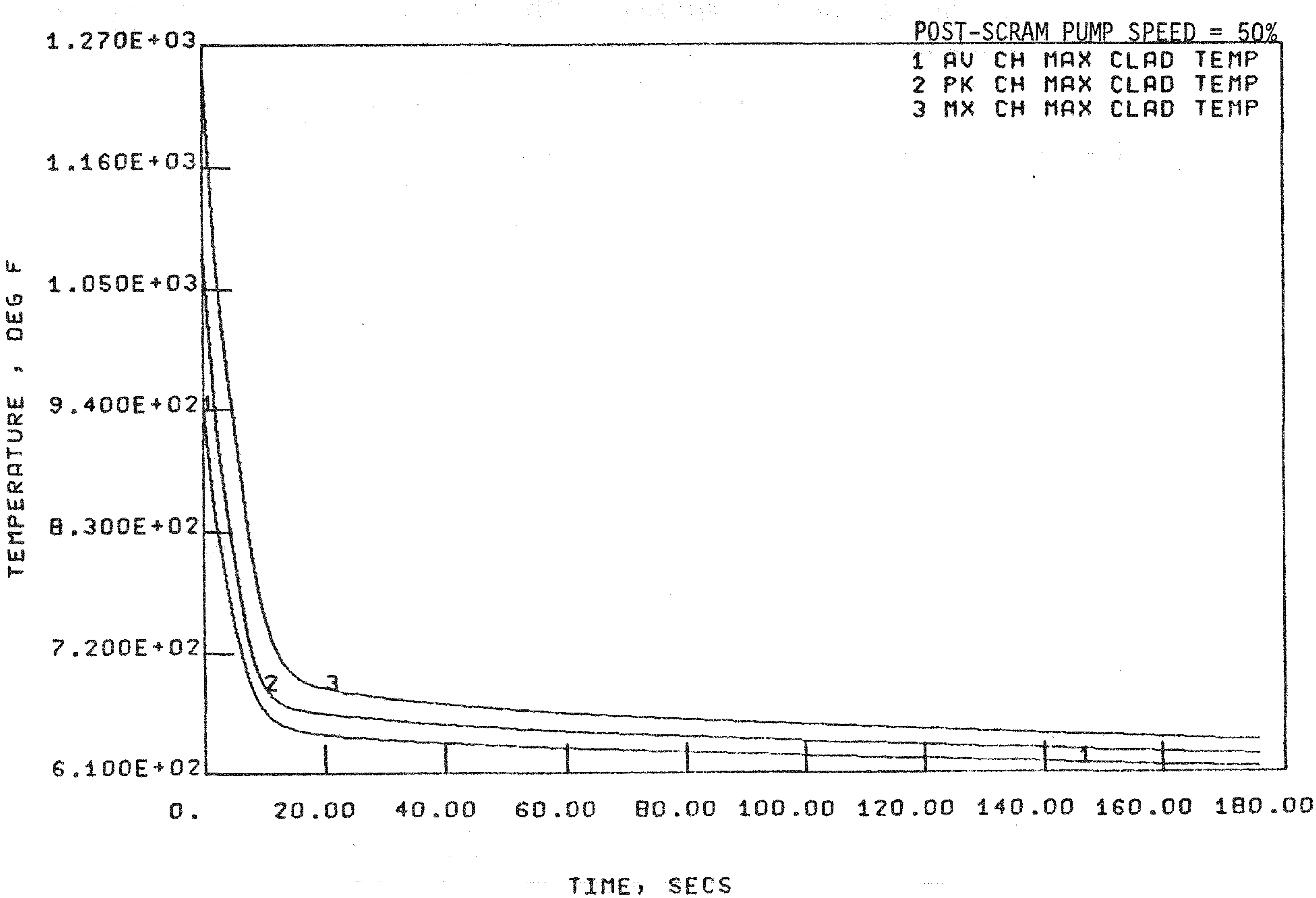

FIGURE 7-6
POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM
RUN DATED 06/19/78
NUMBER DEPGE01

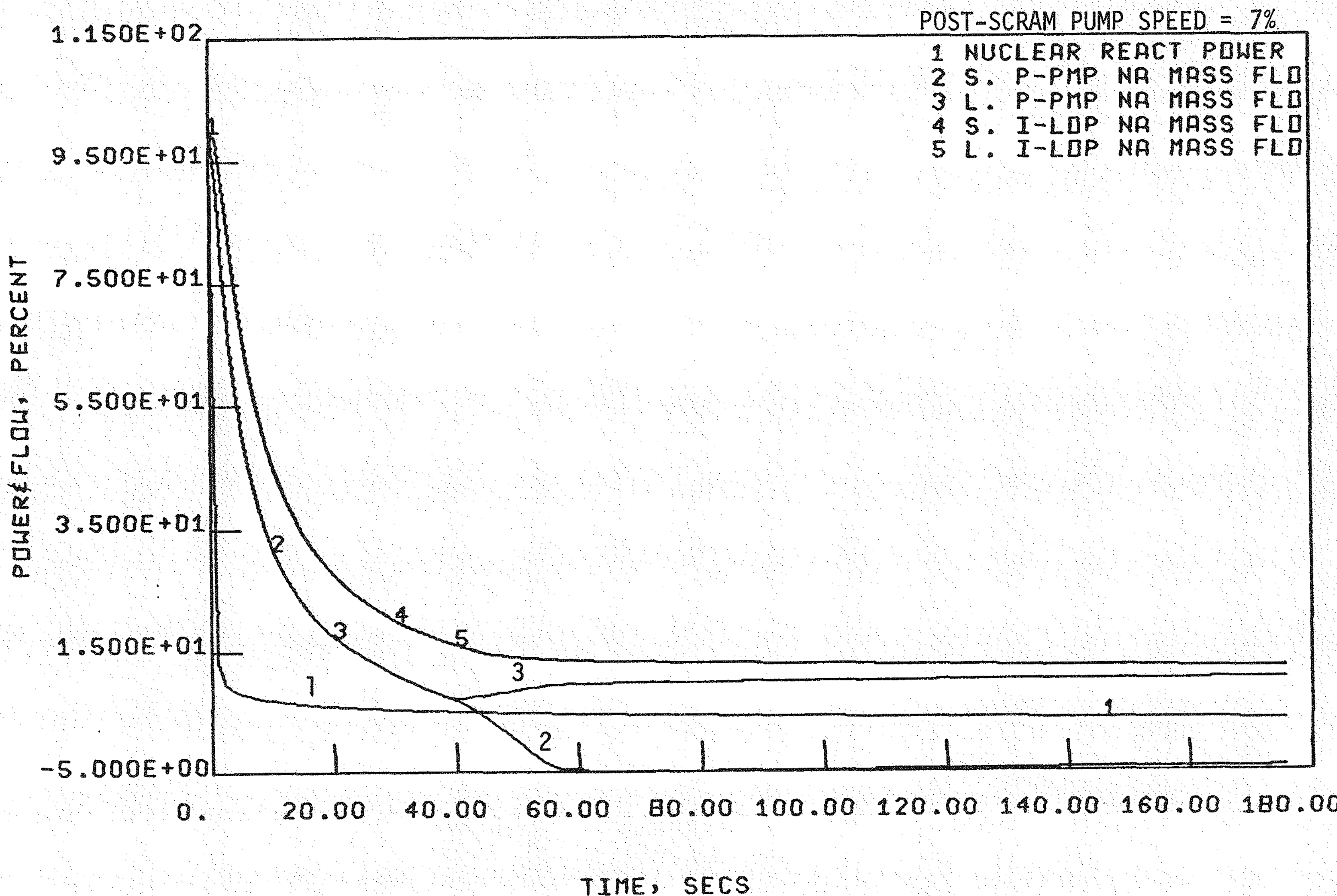

FIGURE 7-7
POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM
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NUMBER DEPGE01

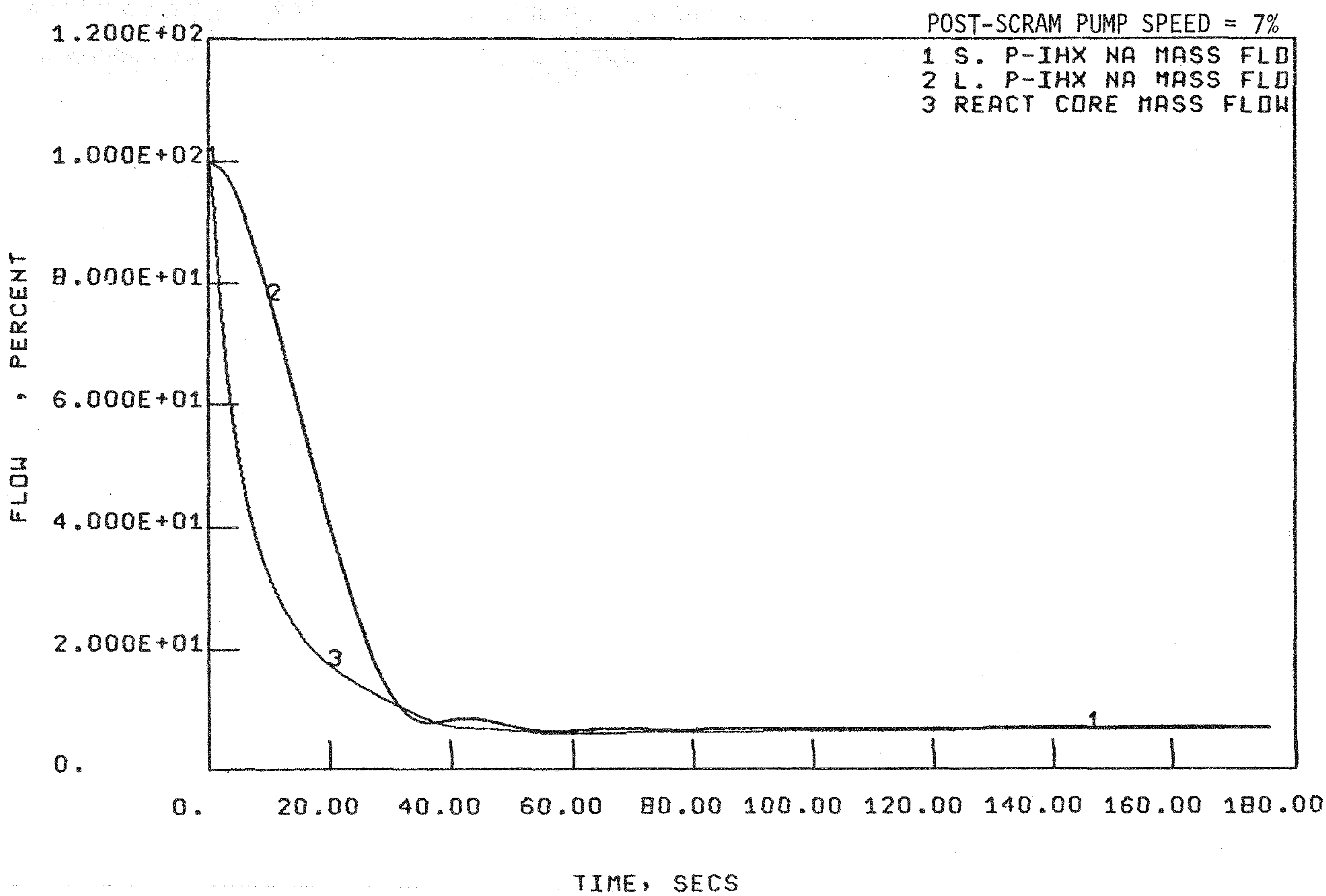


FIGURE 7-8
POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM
RUN DATED 06/19/78
NUMBER DEPGE01

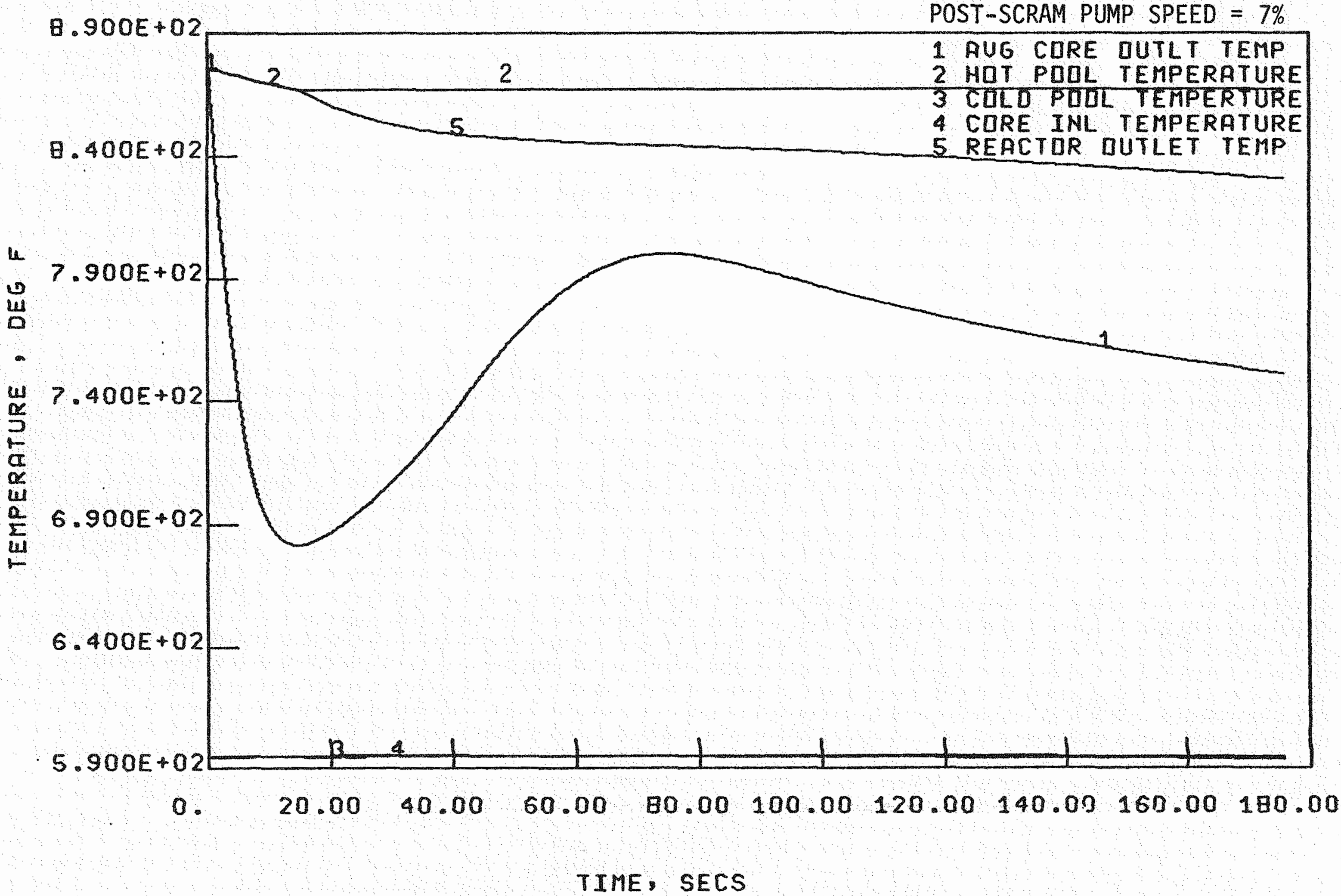


FIGURE 7-9

POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM
RUN DATED 06/19/78
NUMBER DEP6E01

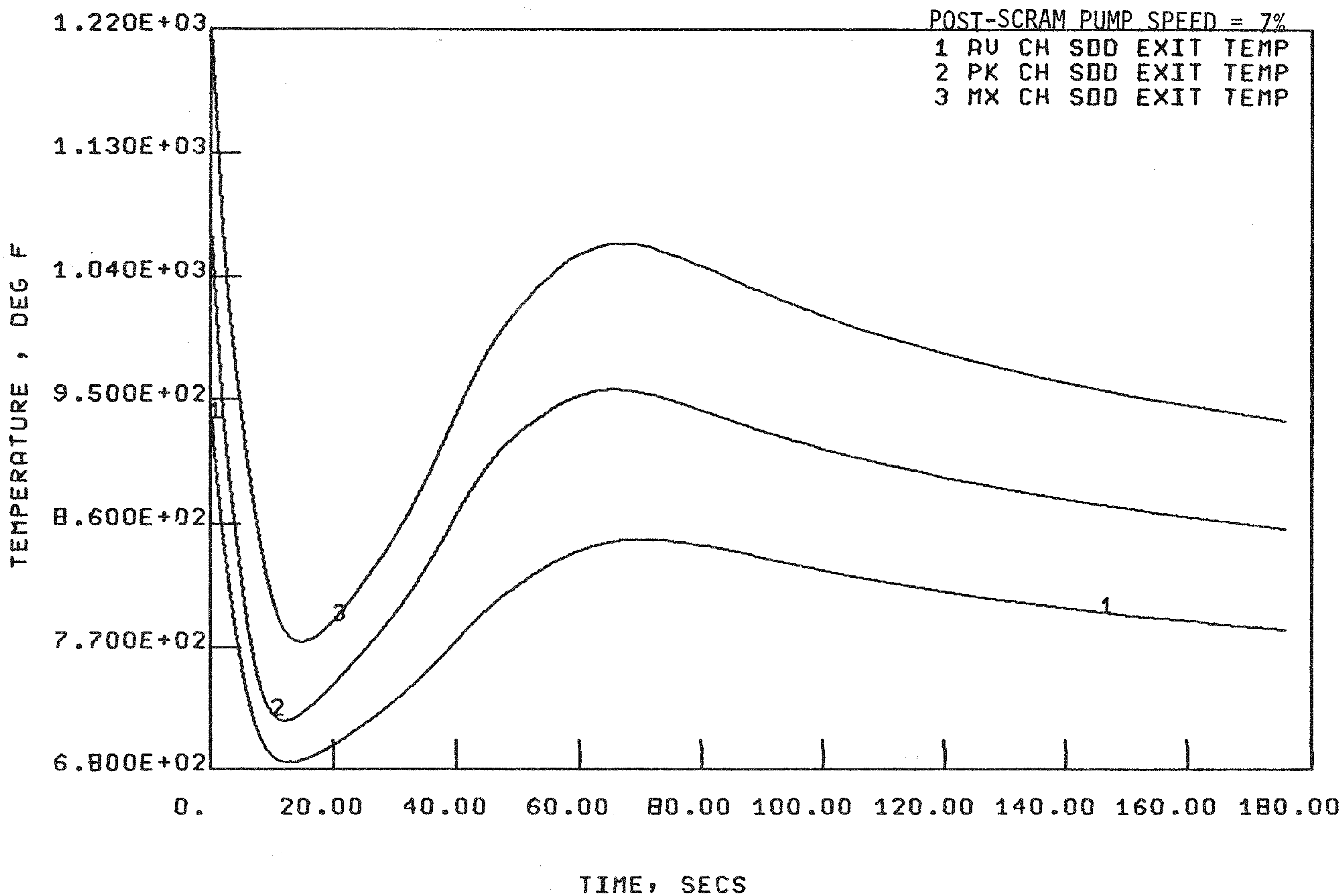
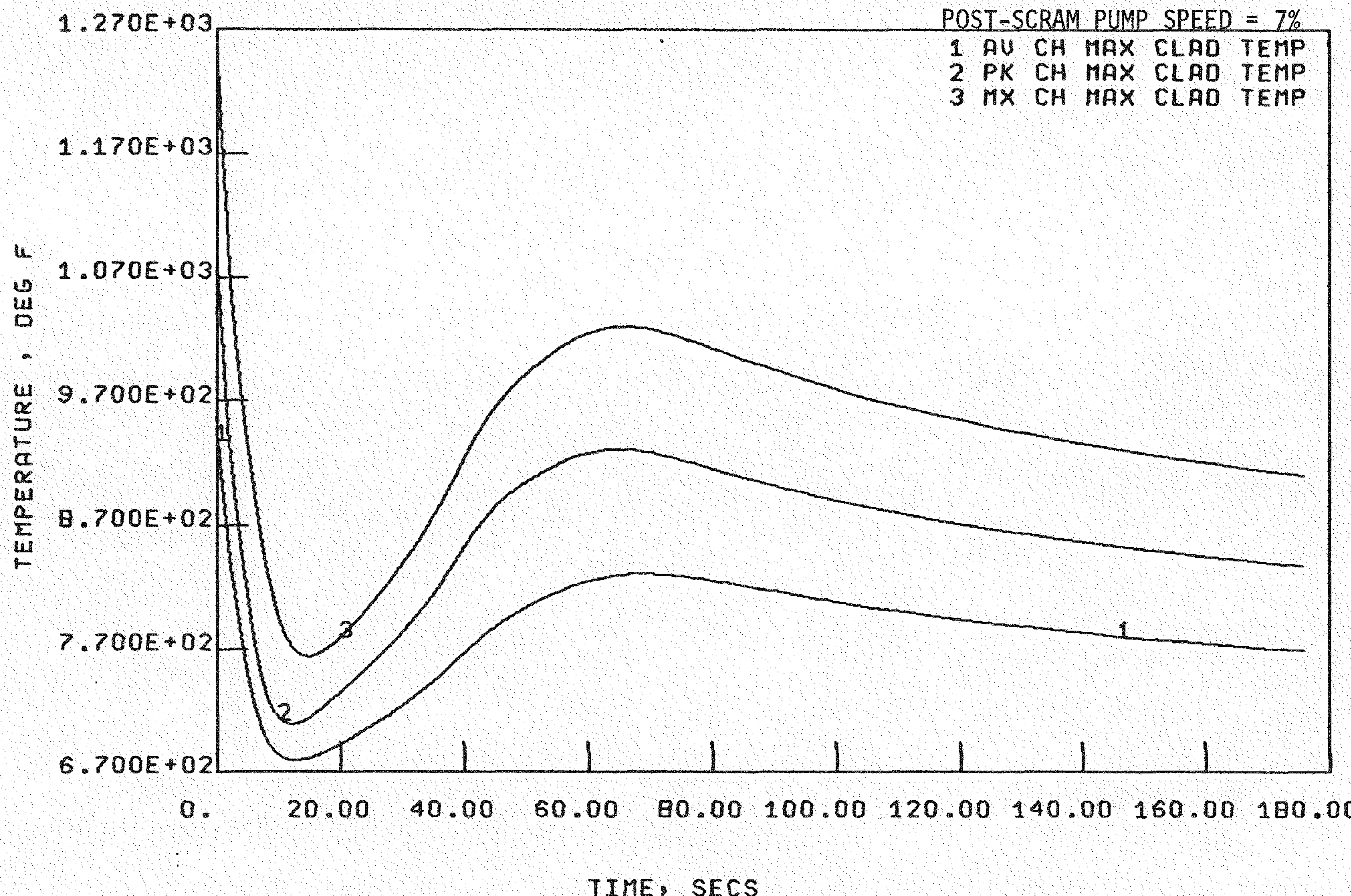


FIGURE 7-10
POOL REACTOR SINGLE PRIMARY PUMP PONY MOTOR FAILURE AFTER SCRAM
RUN DATED 06/19/78
NUMBER DEPGE01



PART V: HEAT TRANSPORT SYSTEM COMPONENTS

SECTION 9: REACTOR OUTLET PLENUM THERMAL HYDRAULICS

CONTENTS



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FIGURES

FIGURES (CONTINUED)

V-9.1

# INTRODUCTION AND SUMMARY

## 9.1.1

## INTRODUCTION

This memo considers the thermal hydraulics of the sodium in the outlet plenum of a pool reactor.

The outlet plenum includes the upper internal structure, UIS, the main components such as IHXs and pumps and the sodium which enters the region from the top of the core and leaves it at the IHX inlets.

The UIS has the potential of providing a means to control the core exit flow during both steady state and transient situations. During periods of steady state operation this structure may be used to effect mixing of core effluent such that the sodium reaching the IHX inlets or other outlet plenum components is near isothermal. During periods in which the core effluent is rapidly changing in temperature (scram transients) the UIS may be the only outlet plenum component available to mitigate the transient incurred by the IHX.

Substantial effort has been devoted to obtain background information on the subject. This information is reported here in some length. In the analysis that follows, however, we focus on the mixing phenomenon. This analysis performed with the VARR-II code is of a preliminary nature and by no means conclusive.

## 9.1.2
## SUMMARY

In the reactor outlet plenum the thermal hydraulic considerations include thermal striping, gas entrainment, flow induced vibration, instrumentation location and mixing. The experimental data available for a loop design may be only partially applicable to the larger (high aspect ratio) pool reactor. Analytical tools have been applied only to the mixing problem. This problem is the determination of the flow/temperature distribution in both the steady state and in a scram transient in which cold sodium is discharged into the hot pool. The sodium temperatures at the IHX inlet location are of particular interest. Among the various computer codes developed for mixing studies the two readily available are the VARR II (2-D) and COMMIX-1 (3-D).

A preliminary analysis of the current pool geometry, using the VARR II code, indicates that for the present configuration, buoyancy driven currents cause more mixing than the isothermal flow pattern. It shows a high temperature-rate-of-change (12°F/sec) at the IHX inlet location even if the pumps are tripped to the 50% flow rate. Bearing in mind the VARR II 2-D limitation and numberical deficiencies, this result must be investagated further using improved VARR II models as well as the COMMIX-1 code. Specifically the effect of the modeling of the IHXs on the results should be investagated as well as the effect of nodalization.

In view of the code limitations and the uncertainties involved in interpretating the results, the study emphasizes the need for experimental work. Even a limited experimental program may render enough information to evaluate the computer code results. Additionally, experimental tests are required to obtain data on other thermal hydraulic aspects which can not be treated analytical at the present time; specifically, free surface effects and thermal striping.

## V-9.2

## CONCLUSIONS AND RECOMMENDATIONS

The VARR II code analysis has raised the question of the effect of IHX modeling on the resulting IHX inlet temperature. This issue must be investigated further, specifically in order to substantiate the following two conclusions:

1. For the geometry studied, tripping the pumps to the 50% flow rate results in as high temperature rate of change as in the constant flow case. This rate, about 12°F/sec, is the result of sodium flowing directly from the top of the chimneys to the IHX inlets without significant mixing.

2. Temperature differences up to 100°F may exist among the sodium streams entering the IHX during a scram.

Additional conclusions and recommendations are:

3. The preliminary VARR II analysis suggests that for the configurations studied, buoyancy driven currents cause more mixing than the isothermal flow pattern. Reducing the flow to 50% of the rated flow may not result in a significant change of the flow pattern due to buoyancy effects. However substantial mixing occurs in the case of pump trip to pony motor speed, in which the cold sodium exiting the chimneys near the top of the plenum flows down and creates a large circulation. In this case the temperature rate of change at the IHX location is less than 0.8°F/sec.

4. The two-volume mixing model in the DEMO-POOL code is adequate to predict IHX inlet temperature for pump trip transients. VARR II predicts steeper temperature changes however, for the constant flow and the "50% flow" cases.

5. The main deficiency of the VARR II code is that it can handle only two dimensional (including cylindrical) geometries. This limitation leads to an inadequate geometrical representation of the flow near the IHXs. The resulting IHX inlet temperature transient may change significantly depending on the computer geometrical model. This problem must be investigated further using the VARR II code. In addition, it is recommended that the COMMIX-1, 3-D code used to evaluate this limitation.

6. Other VARR II uncertainties should be assessed such as the effect of nodalization on the results.

7. The present upper internal structure, UIS, may cause unsatisfactory mixing for post scram high flow rate cases. Future investigations should include the study of the mixing effectiveness of other geometrical configurations.

8. Experimental data for a pool geometry are not available in the USA. The data obtained in the UK are only partially applicable to our pool design. Additionally the foregoing conclusions point out the large uncertainty in the code calculations. Thus initiation of an experimental program is strongly recommended. Even a limited scope program may render sufficient information for us to be able to evaluate the computer code results.

9. Experimental tests are required to obtain data on other thermal hydraulic aspects, especially regarding free surface disturbances during steady state operation and the thermal striping problem in the UIS.

# THERMAL HYDRAULICS CONSIDERATIONS

## 9.3.1
## STEADY STATE OPERATION

At steady state reactor operation the following thermohydraulic phenomena must be considered by the designer:

1. <u>Thermal Cycling (Striping)</u>
   Temperature fluctuations are caused by the mixing of different temperature sodium streams exiting the core. These fluctuations are particularly severe at core exit plane. Also, very low flow regimes in the plenum may result in local natural convection currents which cause temperature oscillations.

2. <u>Gas Entrainment</u>
   High sodium velocities near the free surface cause entrainment of cover gas into the primary sodium system.

3. <u>Flow Induced Vibration</u>
   Internal structures in high vortex shedding regions will be subjected to flow-induced vibration.

4. <u>Instrumentation Location</u>
   If installation of certain instrumentation just above the core assemblies is contemplated, the flow in this area must be fully characterized in order to be certain the instruments

## 9.3.2
## TRANSIENTS

The main transient to be considered is a reactor scram which may be followed by a main pump trip. In this event cold sodium is discharged into the hot outlet plenum sodium ($\Delta T \sim 280°$). Stratification and inadequate flow distribution may result in poor mixing and lead to a thermal shock at the IHX inlet and other locations in the hot plenum region.

## V-9.4

## STATE OF THE ART TECHNIQUES

The flow/temperature field in the outlet plenum is complex and difficult to predict. This problem has been attacked both analytically and experimentally. In the U.S. most of the effort in this area has been directed toward a loop reactor design. This information is only partially applicable to the larger (higher aspect ratio) plenum of a pool plant. Most of the experimental work is carried out with water or air. In general these experiments adequately simulate sodium flow and it is expected that in sodium, temperature gradients will be less steep than in tests in other fluids.

The foreign data available consists of work performed in the U.K. They have concentrated on small scale model tests of their pool reactors.

The following is a brief description of recent experimental work and available computer codes.

### 9.4.1
### EXPERIMENTAL WORK

Extensive tests were performed to model LMFBR reactor outlet plenna, specifically the FFTF and CRBRP configurations. Some of the FFTF model tests are reported in References 1, 2, 3 and CRBRP model tests are reported in References 4, 5, and 6. The main objective of these experiments was to determine the outlet nozzle temperatures in a down transient in which stratification occurred and to compare them with computer model predictions. The main finding was that indeed, the cold sodium stratifies and consequently the mixing is minimized and leads to steeper temperature gradients. Lorenz and Howard [7] investigated the density interface in the stratified plenum. They determined its rate of rise and observed considerable temperature osciallation at the interface. J. J. Lorenz et al.[4] compared sodium, water, brine solutions data obtained at B-CL and ANL for different scale models. They concluded that for most practical purposes hot and cold water can be used to simulate scram as long as the proper modified Froude number is used in the model test. In their studies they also demonstrated the importance of the chimneys above the core (CRBRP design) which increased the mixing from 20% to 80%.

Liquid velocities were measured in FFTF mockup at HEDL in which 3-D pitot probes were used to characterize the three dimensional velocity field[8]. Model tests to determine the steady state mixing in the outlet plenum were performed at ANL[9, 10]. In these experiments temperature oscillations were measured at the suppressor plate and at the shear web. Flow recirculation regions were observed within and surrounding the shear web.

In the area of mixing ANL also tested the thermal hydraulics of a mixing T. In the experiments the temperature amplitude and fluctuations were measured as well as overall mixer pressure loss. It was found that for relatively low Reynolds numbers ($<10^4$) the temperature difference between the two mixing streams had a significant effect on the hydraulics.

Experimental validation work of some of the computer codes has also been done at M.I.T. Using Laser Doppler Anemometry (LDA) Chen and Golay[11, 12] measured point values of velocity and temperature in small scale two dimensional models of an LMFBR outlet plenum. Their objective was to validate the turbulence models in VARR II and TEACH-T (see the following section). The agreement was quite poor. The main conclusion was that the turbulence of the flow has a significant effect on the flow and temperature distribution in the plenum. Therefore, it must be accounted for in the analytical models.

A substantial amount of experimental work has been performed in the U.K. Their water tests consist of flow visualization in which free surface and buoyancy effects can be seen with the aid of either dye or bubble injection. Since they leave the primary pump running on a scram, they are not so much concerned about the mixing in the outlet plenum. Most of the tests address the gas entrainment and the striping phenomena. They employ small model air rigs equipped with hot wire anemometry to investigate temperature and flow oscillations.

## 9.?.? ANALYTICAL WORK

Several 2-D and 3-D computer codes have been developed to analyze the thermo-hydraulics of the outlet plenum. The codes are still being developed and improved. Some experimental verification is available.

## VARR II[13]

VAR II is a versatile two dimensional transient code developed by SAI for WARD. In addition to the general thermal hydraulic equations it includes a two equation turbulence model. It is capable of handling a variety of initial and boundary conditions as well as internal structures. The program calculates the pressure, velocity and temperature fields. The code was written for a CDC-7600 computer. It was used successfully to model the CRBRP outlet plenum[14].

## TEACH-T

TEACH-T is a 2-D steady state code developed at the Imperial College of Science and Technology, London. Since the code solves only the steady state equations it is merely mentioned here.

## 3DTRAN[15]

3DTRAN is a 3-D proprietary code developed by Energy Incorporated (EI). Some of the characteristics of the program are:

(1) Fully three-dimensional, transient, compressible or incompressible flows of arbitrary fluids.

(2) Flow resistance (friction) and energy sources or sinks may be arbitrarily distributed within the flow field.

(3) General boundary and initial conditions can be specified.

## CHAM Code[16]

Concentration, Heat and Momentum (CHAM) company founded by D.B. Spalding developed a three-dimensional code for analyzing a wide spectrum of steady state and transient engineering problems. The code solves the complete conservation equations including turbulence and can handle a variety of boundary conditions and internal obstructions. It uses iterative solution procedures developed and used at Imperial College (London).

Practical problems to which the codes have been applied include: flow blockage in a core, outlet plenum flow with stratification and flow/temperature distribution in the inner pool of a pool reactor.

## FOCS

This is a 2-D code developed by CHAM for the British who use it for their analyses. It is currently being improved as well as validated experimentally.

COMMIX-1[17]

COMMIX-1 is a 3-D code developed by ANL (funded by NRC) and is operational on the IBM 370 computer. It is a rather expensive code and only very few flow problems have been solved with this tool (Ref. 18 and 19). At this time it is the only readily available three-dimensional code.

PNL-3D

A three dimensional code in its last stages of development is now being written by Pacific Northwest Lab. (funded by DOE). The capabilities of this code are similar to the COMMIX-1.

Currently no experimental work is being carried out to validate any one of these codes and none is planned for the immediate future. Experimental results have been compared with VARR II and FOCS calculations, but these comparisons are usually limited to temperatures at certain locations and by no means validate the codes. If anything they may only increase our confidence in the codes results.

V-9.5

# MIXING IN THE HOT POOL

## 9.5.1 STEADY STATE MIXING

The different temperature streams of sodium exiting the core can be mixed directly above the core outlet and the striping problem is then confined just to this region. A mixing chamber such as is employed in the CRBRP design fulfills this requirement.

Another method of controlling the striping phenomenon is to construct a low baffle just above the core and extend it radially to cover the main core region (not the radial blanket). This design forces the hot and cold streams out into the open pool in which turbulent action reduces the temperature difference to an acceptable level. This concept is used in the French design and the British are investigating it also. In a preliminary experimental model of their design (which includes the shield upstands) the British have found that a low baffle causes a large free surface disturbance. This design has great potential however, since no structure is subjected to large $\Delta T$ oscillations.

## 9.5.2 TRANSIENT MIXING

One of the possible advantages of the pool reactor is the large volume of hot pool sodium available for mixing- expecially when large flow rates are maintained during and after a scram.

On a scram with pump trip it has been shown experimentally that buoyancy effects take over and stratification occurs. In a model test[20] for a loop design it has been shown that if the outlet nozzle is below the chimney outlet it will "see." a gradual change in temperature rather than a step change. In this case most of the sodium volume below the chimney top is involved in the mixing. The implication for the pool design (assuming similar thermal hydraulics characteristics) is that the IHX inlet should be within the mixing zone and the mixing zone should include as large a volume of sodium as possible.

Because of the large pool area however, the flow pattern in the upper plenum may not be similar in nature to the flow in a loop reactor. Thus, there is a large uncertainty in applying results from the "loop" mixing tests to the "pool" situation. The current pool design features a large pool flow area. Even at 100% core flow a typical sodium velocity in the middle of the pool is less than 0.5 ft/sec. If cold sodium enters the plenum after a scram without pump trips, it will sink down due to buoyancy at the speed of about 5 ft/sec* dominating the flow field. Thus, regardless of pump flow rates, the flow and temperature distribution in a large pool may be dominated by buoyancy.

Generally, it is the objective of the component designer to maximize the mixing effect at the minimum flow rate to achieve the slowest temperature change. Such an optimum flow rate, if it exists, must be known if the plant is to be designed on this bases. (It should be noted that other considerations such as the thermal barrier design favor higher flow rates and will affect the final selection of flow rate).

All these considerations lead us to the following questions:

- What portion of the total pool volume "participates" in the mixing process?
- How does this mixing portion vary with the incoming flow rate?
- What is the UIS role in the mixing process?

The first question is directly related to finding which flow patterns exist in a large pool configuration. The second question addresses the effect of buoyancy on the mixing process at various core flow rates. The UIS may contain features with the sole purpose of discharging the core outlet flow at a high elevation in order to enhance mixing. The elimination of these features could simplify significantly the design of the above the core structure. Therefore, their effect on the mixing must be determined for each contemplated pool configuration.

At the present time the answers to the foregoing questions are unknown. The only means currently available to answer these questions is by experimental investigation.

*Equating potential energy to kinetic energy, the vertical velocity is

$$v = \sqrt{2\Delta P/P\ gL} \approx \sqrt{2\text{x}2/53\text{x}32.2\text{x}10} \approx 5 \text{ ft/sec}$$

## V-9.6

### PRELIMINARY VARR II ANALYSIS

A preliminary study has been performed with the aid of the 2-D code VARR II. The purpose of the analysis is to obtain a preliminary estimate of the general flow field and temperature distribution in the hot pool for a few selected transients. The results are expected to increase the level of understanding of the mixing process.

Figure 1 shows the VARR II model of the outlet plenum. The use of a 2-D code poses some difficulties in modeling the IHXs and pumps which are three dimensional geometries. The model consists of a 17 x 9 mesh; each cell is two feet wide. The inlet flow is uniform and isothermal. Figure 2 shows the steady state velocity field. A large circulation region exists in the middle of the pool. The IHX inlets draw flow about equally from the inner and the outer regions. The fluid velocity in the outer region is small.

Three scram transients are investigated in order to gain some understanding of the effect of the inlet flow on the mixing process. They are:

1. Scram with constant flow (no pump trip)
2. Scram with pump trip to 50% flow
3. Scram with pump trip to pony motor speed

The velocity fields in several stages of the first transient are shown in Figure 3. Figure 3a shows the effect of buoyancy on the flow pattern. Note that the velocity vectors in Figure 3 are plotted about 50% longer than in Figure 2. When compared to the isothermal case (Figure 2) the flow field, after 50 sec, shows an increase in the circulation rate and natural convection currents in the outer region. As the pool cools down and approaches the isothermal condition the natural convection currents disappear and the flow resembles once again the initial steady state distribution. The temperature fields are shown in Figure 4. Twenty seconds after scram the cold sodium has penetrated below the suppressor plate and down the IHXs (Fig. 4a). After

50 seconds, cold sodium has reached the outer region causing a large natural circulation. After 140 sec (Fig. 4e) most of the pool is well mixed, temperative difference are less than 20°F. Some hotter sodium accumulates at the top of the outer region.

The buoyancy effect is more pronounced in the second case where the inflow rate is reduced by a factor of two. Figure 5a shows the velocity field after 40 seconds. The circulation in the inner region has increased, but not for a long time. After 60 seconds (Fig. 5b) the outer region takes part in the mixing and two recirculative patterns form in the inner region. Figures 5c through 5e show a continuous change in the flow field, but the overall recirculation pattern remains in which sodium flows down near the UIS and up close to the vessel wall.

Representative temperature contours for this transient are plotted in Figures 6a through 6e. Figure 6a shows that the cold temperature front follows the main flow. After 60 seconds (Fig. 6b) cold sodium reaches the lower part of the outer region. The hot sodium which has not mixed is being pushed to the top of the pool (Fig. 6c - 6e).

The velocity vectors resulting from a scram with pump trips to pony motor speed are shown in the Figure 7 series. After 30 seconds (Fig. 7a) the initial flow pattern collapses as buoyancy driven currents begin to dominate the field. Figure 7b and 7c show a counter-clockwise circulation region between the UIS and the IHXs which is the result of the discharge of cold sodium at the top of the chimneys. After 70 sec (Fig. 7d) a significant amount of sodium has reached the outer region to stir up natural convection currents between the IHXs and the vessel wall. Figures 7e through 7h show the velocity vectors up to 400 seconds into the transient. Generally the sodium flows down the UIS outside liner and up the vessel wall, thus a general overall recirculation flow characterizes the plenum flow as long as cold sodium is being discharged at the top. The temperature fields for this transient are plotted in Figure 8. It can be seen that there is no significant stratification build up at the bottom of the pool. The cold sodium exiting at the top of the plenum causes substantial mixing action in the inner region. After about a minute the outer region becomes involved too in the mixing.

The IHX inlet temperature for the three transients are shown in Figure 9. The temperature rate of change for the "50% flow" is as severe ($\sim$ 12°F/sec) as for the constant flow case. The reason is that the flow pattern in the region between the IHX and the UIS remains about the same during the initial stage of the transient. The sodium flows along the suppressor plate and down the IHXs toward the inlets without any significant mixing. We should note here that IHXs are not modeled properly because of the 2-D code limitation. It is likely that more sodium in the outer region participates in the mixing than this model indicates. It is clear also that the present design will require some modification in order to optimize the mixing for high flow rate cases.

The curve for the third case shows a very moderate temperature rate of change (0.7°F/sec). This is due to the mixing caused by the natural convection currents.

The numercial technique in VARR II increases the actural temperature diffusion among cells. This mechanism tends to "smear" the temperature distribution and reduce the buoyancy effect. How this deficiency affects the results remains unclear. Additional uncertainties exist regarding the effect of nodalization on the results.

Figure 10 shows the IHX inlet temperature at two different locations; one toward the inner region ($T_1$) and one toward the outer region ($T_3$). The average inlet temperature is $T_2$. The curve $T_2$ is not always between curves $T_1$ and $T_3$ because of the fluid convection lag between $T_1$, $T_3$ locations and $T_2$ location. The difference between $T_1$ and $T_2$ may be up to 100°F during the transient. We should keep in mind that in reality the IHX inlet has an annular flow area and draws fluid from all directions. There is an indication however, that sodium streams with a wide range of temperatures will enter the IHX. In light of the 2-D code deficiency this analysis must be pursued further to evaluate the effects of the modeling techniques on the results.

V-9.7

## TWO VOLUME MIXING MODEL USED FOR THE TRANSIENT ANALYSIS

After surveying a large body of data including the PFR pool reactor and supported by analytical work it can be concluded that a substantial amount of the available sodium in the outlet plenum takes part in the mixing. The exception is when the flow is low and no chimney-like structure exists above the core. Thus in order to maintain sufficient flexibility in the design and in operating conditions it is recommended that a chimney device should be provided in the design. The discharge of cold sodium at a high elevation will ensure a substantial amount of mixing for the case where the pumps are tripped after scram.

For the present system transient analysis, a simplified mixing model is used which is incorporated in the overall system code POOL-DEMOS and is described in Reference 21. The model is based on the extensive experimental studies performed by ANL.[22] It has been validated over a wide range of parameters. It has not been tested, however, for pools with high aspect ratio (e.g. pool diameter $\approx$ 4 x pool height). The model assumes that all the volume under the upcoming sodium jet (or under the top of the chimneys) is involved in the mixing process. When this model is applied to the pool geometry we assume that mixing occurs in only 50% of that volume. While this assumption seems to be adequate for the third case (pump trip) it may be less conservative for the other cases. Figure 11 compares the IHX inlet temperature with the temperatures obtained assuming full mixing in a fraction of the pool volume. The initial temperature drop (calculated by VARR II) corresponds to a mixing volume fraction of less than 10%.

## V-9.8

## FUTURE WORK

Fluid mixing is only one aspect of the overall thermal hydraulics in the outlet plenum which has to be investigated further. Most of the phenomena discussed above are almost impossible to predict with the current analytical capabilities. Future work should be concentrated on experimental work supplemented with analytical prediction.

### 9.8.1
### EXPERIMENTAL WORK

Near term (2-3 years) experimental programs will have to be limited to small-scale water tests. These tests are relatively less expensive to set up and they render very useful information about the basic phenomena. These tests should meet the following requirements:

1. Pool with high aspect (4:1) ratio geometry.
2. Three-dimensional simulation - preferably 360° representation of the outlet plenum.
3. Flow visualization capabilities.
4. Free surface.
5. Variable inlet flow and temperature (or density) to study the mixing and buoyancy effects.
6. Geometrical flexibility, to study the effect of various geometrical configurations (such as chimney, baffles, IHX inlet location) on the mixing and the free surface.
7. Inlet temperature distribution to study temperature oscillations.

Long term (>3 years) experimental programs should include large-scale tests possibly using sodium. These tests will answer the questions about the validity of small scale test data and the adequacy of applying water data to sodium prototypical conditions.

## 9.8.2 ANALYTICAL WORK

Because of practical considerations and computer limitations there is a need for simplified (e.g. 2 volumes) as well as for more complex (2,3-D) models. All models require experimental validation and should be checked periodically with test data to ensure that possible modifications have not created significant distortions of the predicted flow and temperature fields.

Detailed flow and temperature distribution can be calculated from a multi-dimensional code. A 2-D (or axisymmetric) code is then recommended wherever possible, since it is substantially more economical to run than a 3-D code. A 2-D code such as VARR II can be used for parametric studies to optimize UIS design and pump operations. When a two-dimensional version of the three-dimensional codes is available it might be more advantageous to use it instead of VARR II.

In the immediate future the effect of nodalization and IHX representation should be investigated using VARR II. Additionally, geometry changes should be explored to achieve better mixing in the post scram high flow cases.

There are regions in the hot pool where the thermal hydraulics is definitely three-deminsional in nature. The COMMIX-1 code (or the PNL-3D when it becomes available) can be used for the 3-D analysis. Such a code should be used selectively as it is expensive to operate. It should be used to check the adequacy of the 2-D analysis.

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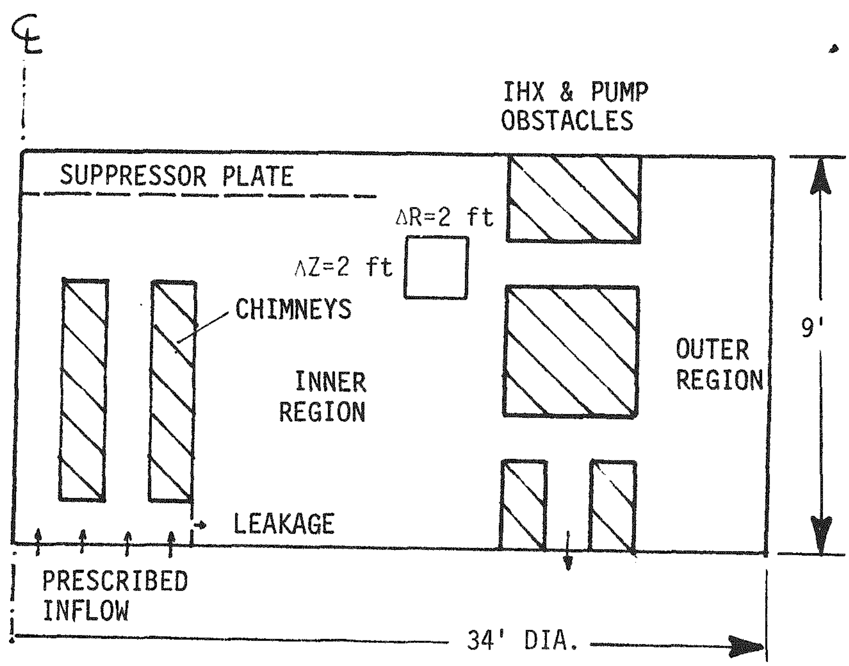
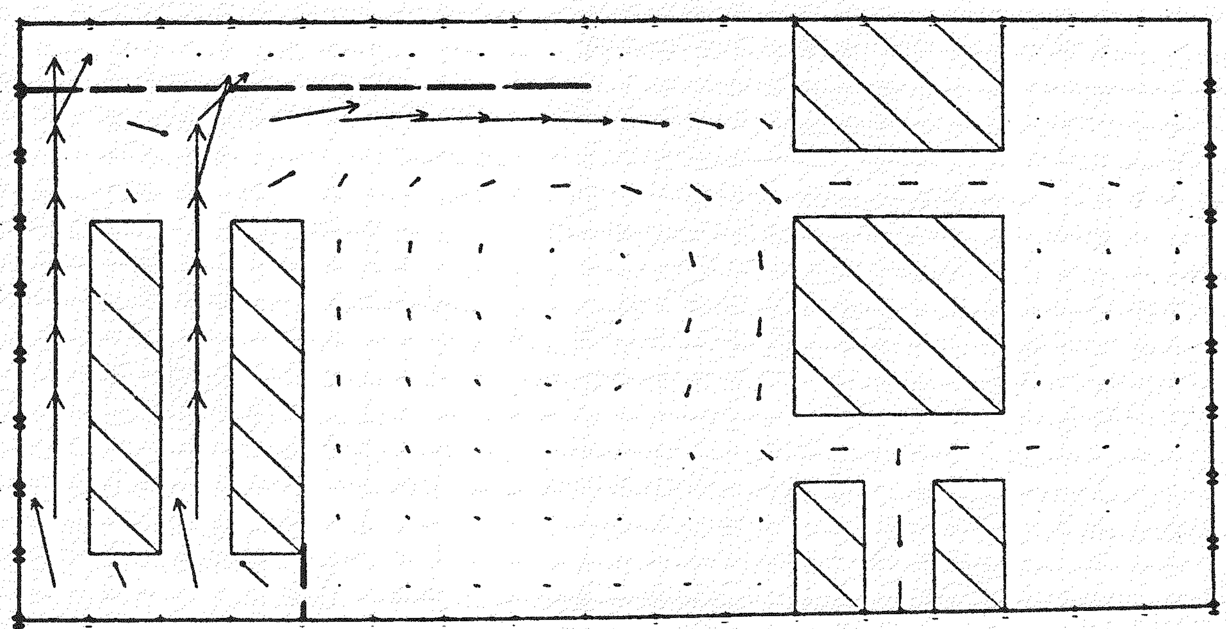
FIGURE 1 - VARR II MODEL OF OUTLET PLENUM



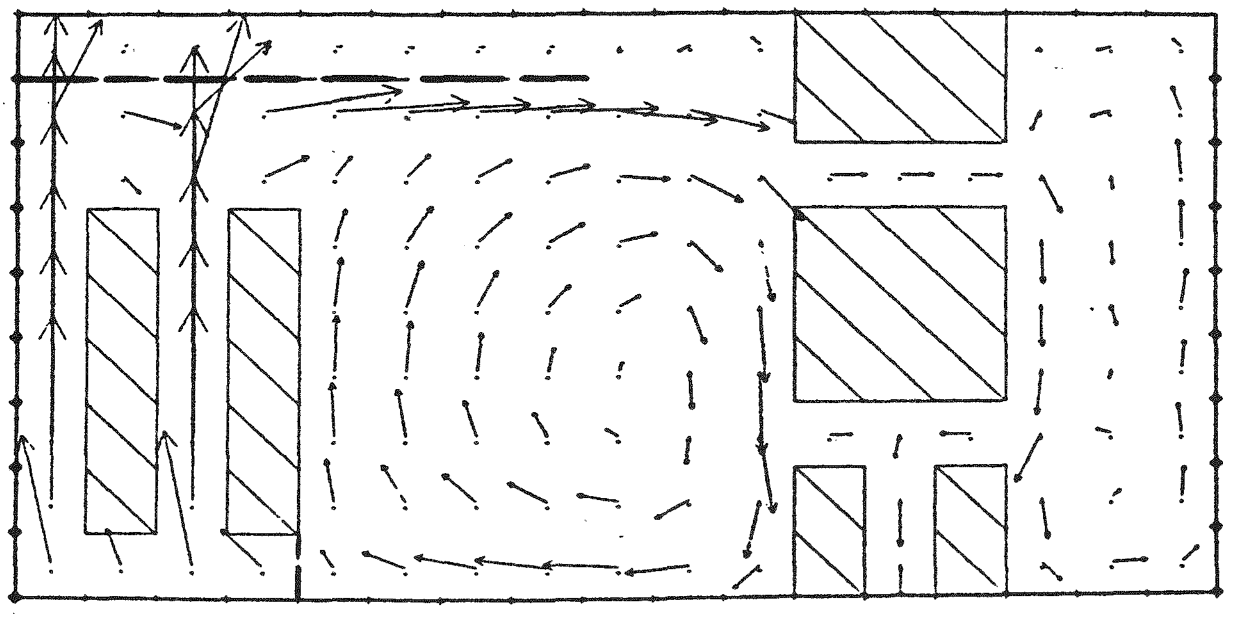


VARR II
05 JUL 78

TIME = 2.1949E-02 CYCLE = 12025

VELOCITY VECTORS
REFERENCE VELOCITY = 8.1136E+00

Figure 2 Steady State Velocity Field

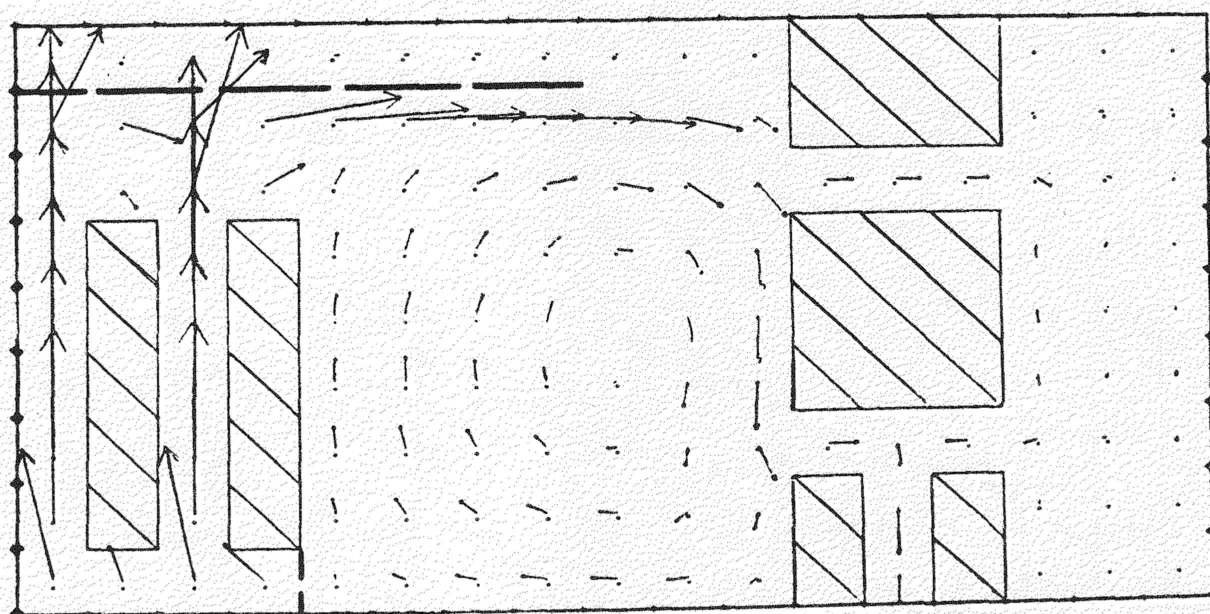


VARR II
26 JUN 78

TIME = 5.0024E+01 CYCLE = 13966

VELOCITY VECTORS
REFERENCE VELOCITY = 7.5874E+00

Figure 3a Velocity Field - Scram, Constant Flow - Time = 50 Seconds



VARR II

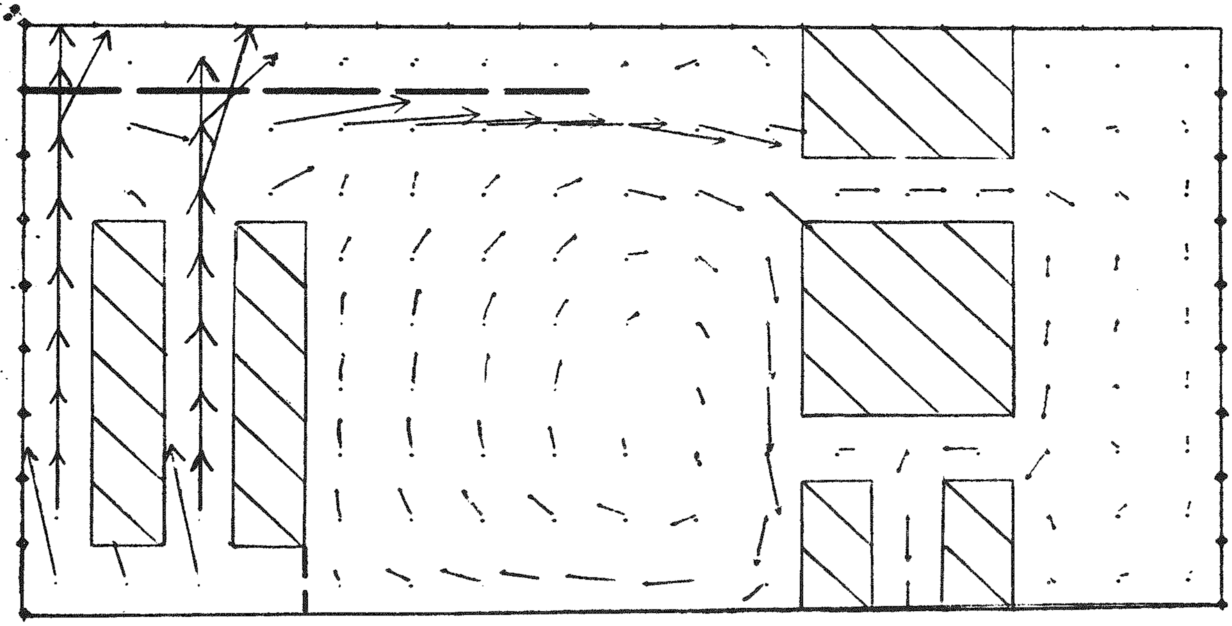
29 JUN 78

TIME = 8.0033E+01 CYCLE = 15100

VELOCITY VECTORS

REFERENCE VELOCITY = 7.5658E+00

Figure 3b Velocity Field - Scram, Constant Flow - Time = 80 Seconds



VARR II

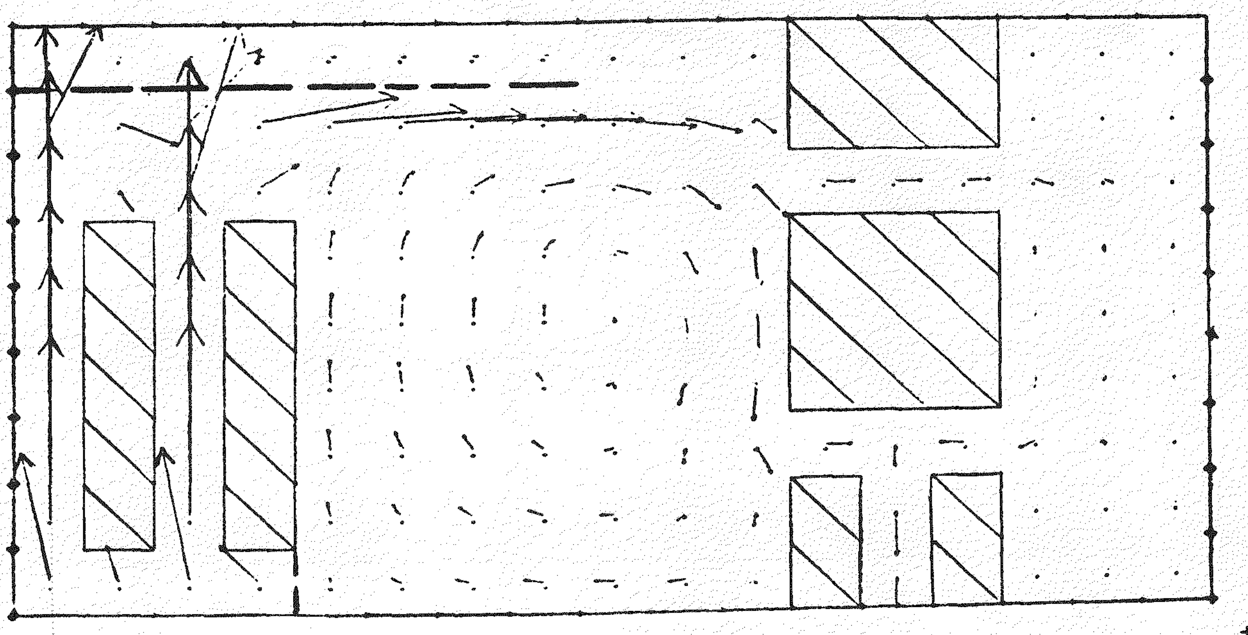
29 JUN 78

TIME = 1.1004E+02 CYCLE = 16251

VELOCITY VECTORS

REFERENCE VELOCITY = 7.5897E+00

Figure 3c Velocity Field - Scram, Constant Flow - Time = 110 Seconds



VARR II

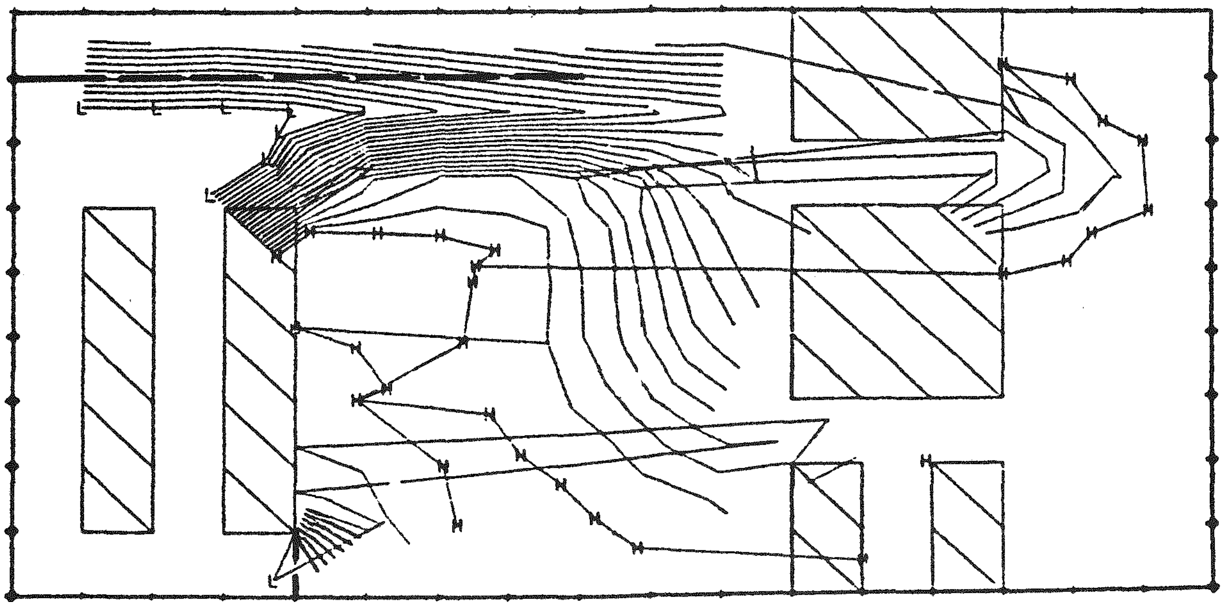
29 JUN 78

TIME = 1.5003E+02 CYCLE = 17769

VELOCITY VECTORS

REFERENCE VELOCITY = 7.6757E+00

Figure 3d Velocity Field - Scram, Constant Flow - Time = 150 Seconds



VARR II

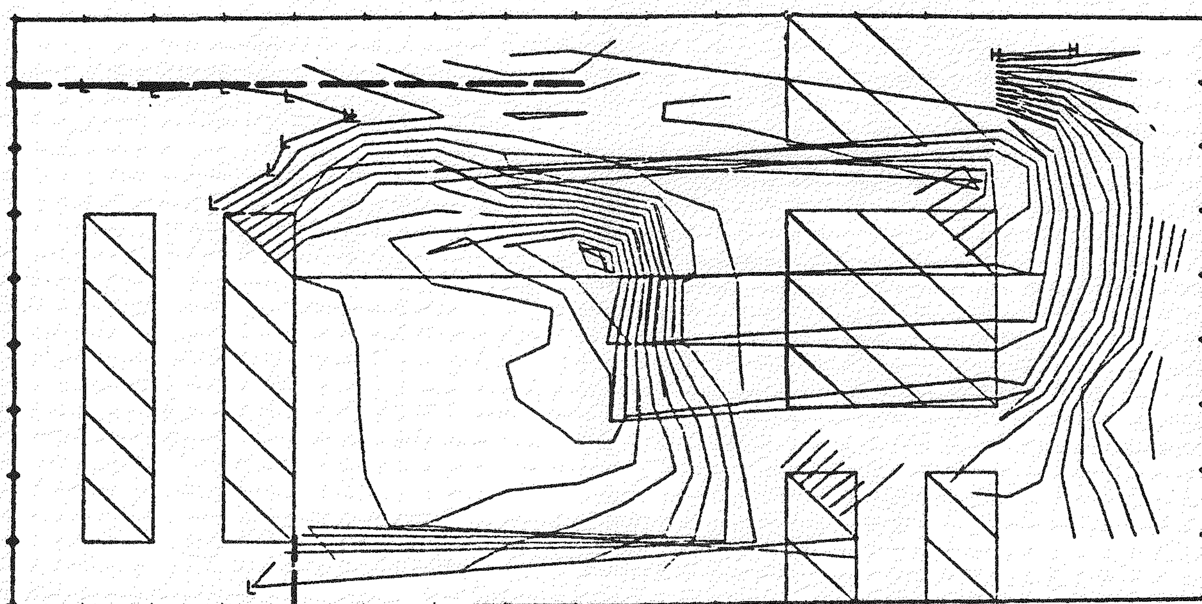
29 JUN 78

TIME = 2.0034E+01 CYCLE = 12803

TEMPERATURE CONTOURS

| | |
|---|---|
| QMAX 8.7750E+02 | QMIN 6.0083E+02 |
| Q(K)=QMN+K*DQ | DQ=1.3175E+01 |
| Q = 6.14002E+02 | Q = 6.27177E+02 |
| Q = 6.40352E+02 | Q = 6.53526E+02 |
| Q = 6.66701E+02 | Q = 6.79876E+02 |
| Q = 6.93050E+02 | Q = 7.06225E+02 |
| Q = 7.19400E+02 | Q = 7.32574E+02 |
| Q = 7.45749E+02 | Q = 7.58924E+02 |
| Q = 7.72098E+02 | Q = 7.85273E+02 |
| Q = 7.98448E+02 | Q = 8.11622E+02 |
| Q = 8.24797E+02 | Q = 8.37972E+02 |
| Q = 8.51146E+02 | Q = 8.64321E+02 |

Figure 4a Temperature Field - Scram, Constant Flow - Time = 20 Seconds



VARR II
26 JUN 78

TIME = 5.0024E+01 CYCLE = 13966

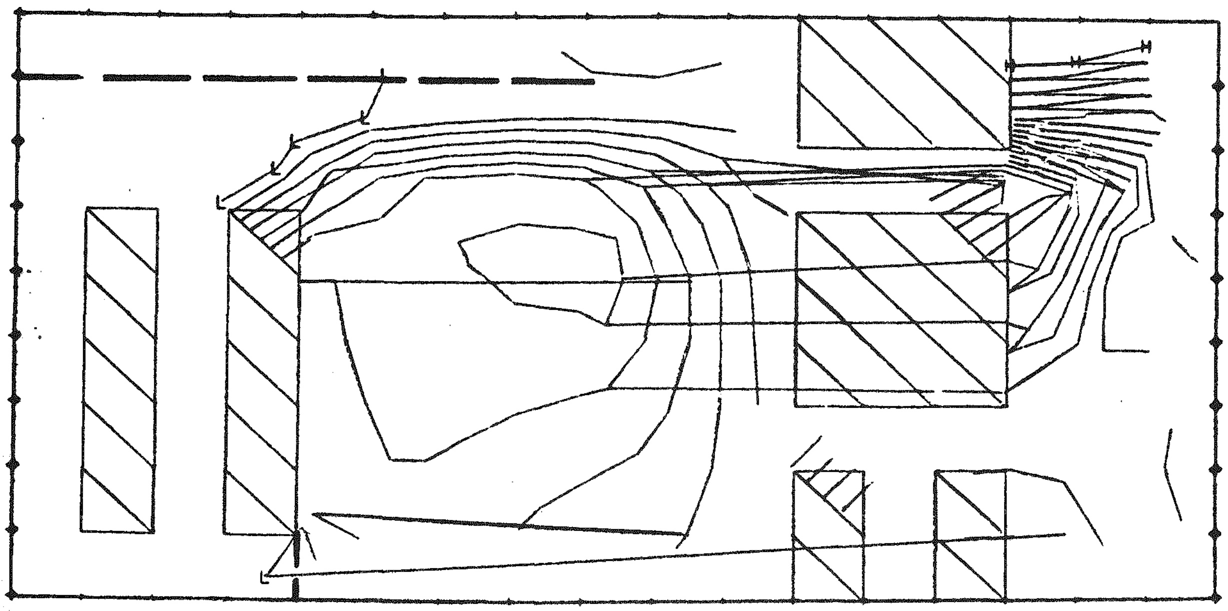
TEMPERATURE CONTOURS

QMAX 8.7991E+02 QMIN 5.9341E+02

Q(K)=QMN+K *DQ DQ = 1.3643E+01

| | |
|---|---|
| Q = 6.07052+02 | Q = 6.20695+02 |
| Q = 6.34337+02 | Q = 6.47980+02 |
| Q = 6.61623+02 | Q = 6.75266+02 |
| Q = 6.88909+02 | Q = 7.02551+02 |
| Q = 7.16194+02 | Q = 7.29837+02 |
| Q = 7.43480+02 | Q = 7.57123+02 |
| Q = 7.70765+02 | Q = 7.84408+02 |
| Q = 7.98051+02 | Q = 8.11694+02 |
| Q = 8.25337+02 | Q = 8.38979+02 |
| Q = 8.52622+02 | Q = 8.66265+02 |

Figure 4b Temperature Field - Scram, Constant Flow - Time = 50 Seconds



VARR II

29 JUN 78

TIME = 8.0033E+01 CYCLE = 15100

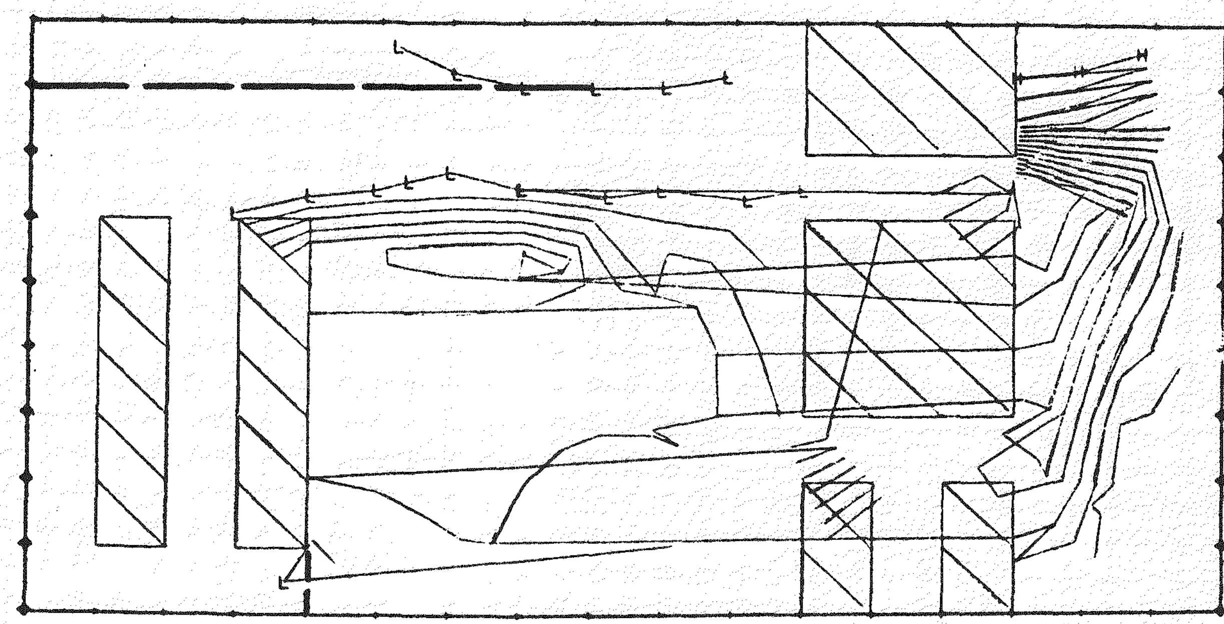
TEMPERATURE CONTOURS

QMAX 7.9492E+02 QMIN 5.9431E+02

Q(K)=QMN+K*00 DQ=9.5529E+00

| | |
|---|---|
| Q = 6.03863E+02 | Q = 6.13416E+02 |
| Q = 6.22969E+02 | Q = 6.32522E+02 |
| Q = 6.42075E+02 | Q = 6.51628E+02 |
| Q = 6.61180E+02 | Q = 6.70733E+02 |
| Q = 6.80286E+02 | Q = 6.89839E+02 |
| Q = 6.99392E+02 | Q = 7.08945E+02 |
| Q = 7.18497E+02 | Q = 7.28050E+02 |
| Q = 7.37603E+02 | Q = 7.47156E+02 |
| Q = 7.56709E+02 | Q = 7.66262E+02 |
| Q = 7.75815E+02 | Q = 7.85367E+02 |

Figure 4c Temperature Field - Scram, Constant Flow - Time = 80 Seconds



VARR II

29 JUN 78

TIME = 1.1004E+02 CYCLE = 16251

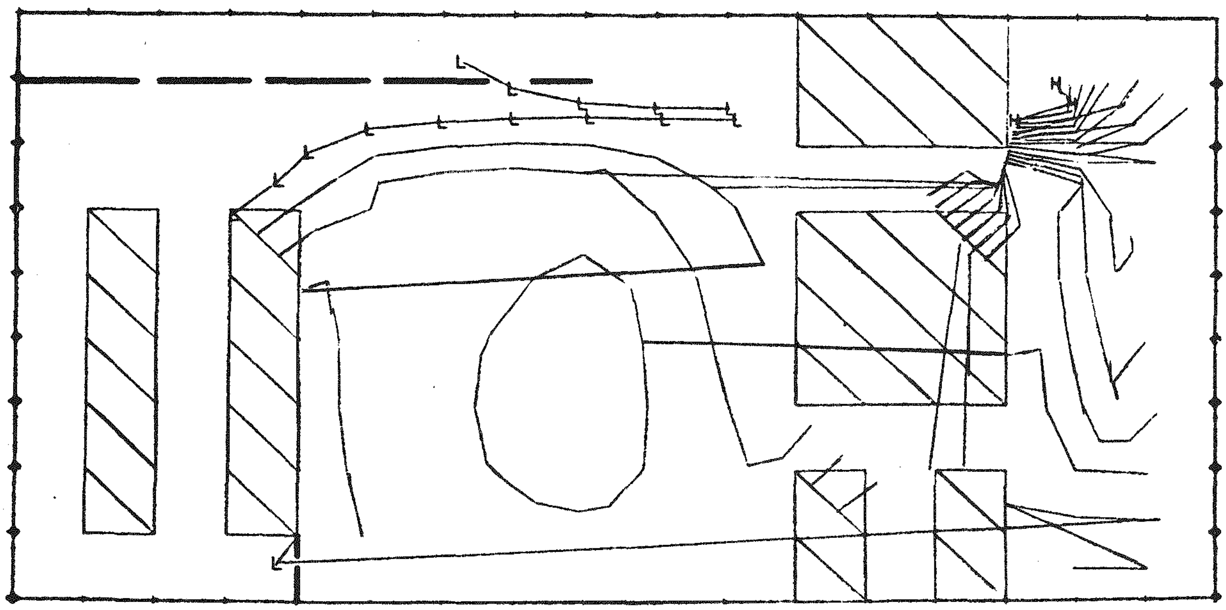
TEMPERATURE CONTOURS

QMAX 7.5912E+02 QMIN 5.9219E+02

Q(K)=QMN+K*DQ DQ = 7.9490E+00

| | |
|---|---|
| Q = 6.00141E+02 | Q = 6.08090E+02 |
| Q = 6.16039E+02 | Q = 6.23988E+02 |
| Q = 6.31937E+02 | Q = 6.39886E+02 |
| Q = 6.47835E+02 | Q = 6.55784E+02 |
| Q = 6.63733E+02 | Q = 6.71682E+02 |
| Q = 6.79631E+02 | Q = 6.87580E+02 |
| Q = 6.95529E+02 | Q = 7.03478E+02 |
| Q = 7.11427E+02 | Q = 7.19376E+02 |
| Q = 7.27325E+02 | Q = 7.35274E+02 |
| Q = 7.43223E+02 | Q = 7.51172E+02 |

Figure 4d Temperature Field - Scram, Constant Flow - Time = 110 Seconds



VARR II

29 JUN 78

TIME = 1.4003E+02  CYCLE = 17388

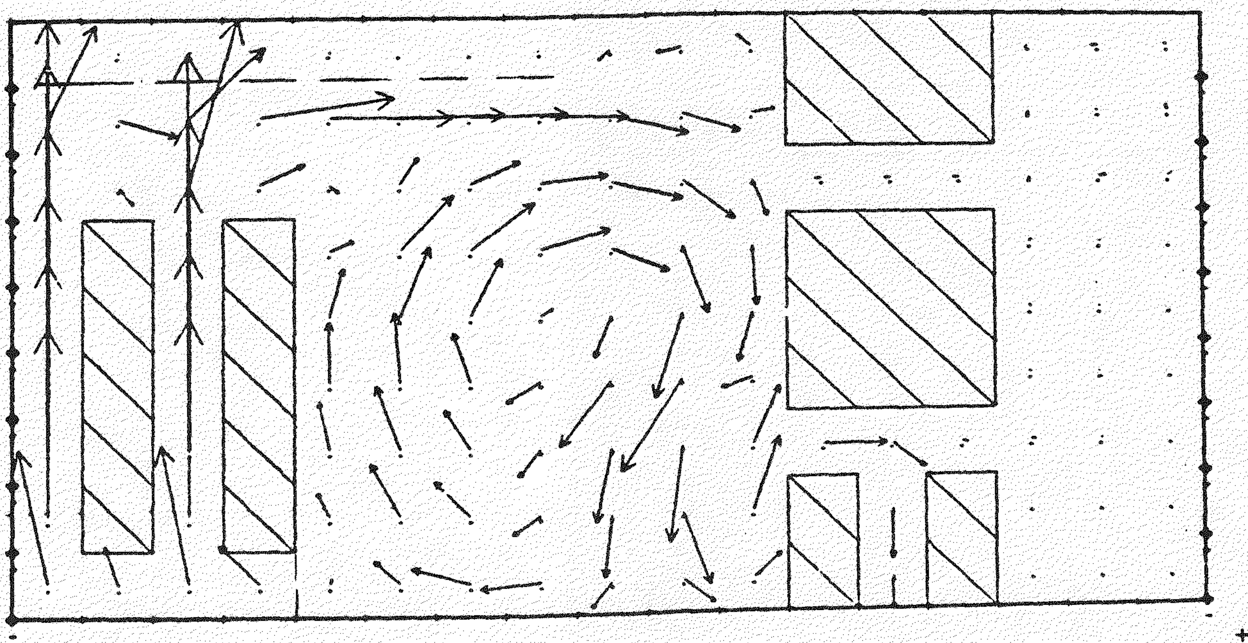
TEMPERATURE CONTOURS

QMAX 6.7829E+02  QMIN 5.8943E+02

Q(K)=QMN+K*DQ  DQ = 4.2314E+00

| | |
|---|---|
| Q = 5.93663E+02 | Q = 5.97895E+02 |
| Q = 6.02126E+02 | Q = 6.06358E+02 |
| Q = 6.10589E+02 | Q = 6.14821E+02 |
| Q = 6.19052E+02 | Q = 6.23283E+02 |
| Q = 6.27515E+02 | Q = 6.31746E+02 |
| Q = 6.35978E+02 | Q = 6.40209E+02 |
| Q = 6.44441E+02 | Q = 6.48672E+02 |
| Q = 6.52904E+02 | Q = 6.57135E+02 |
| Q = 6.61366E+02 | Q = 6.65598E+02 |
| Q = 6.69829E+02 | Q = 6.74061E+02 |

Figure 4e  Temperature Field - Scram, Constant Flor - Time = 140 Seconds



VARR II

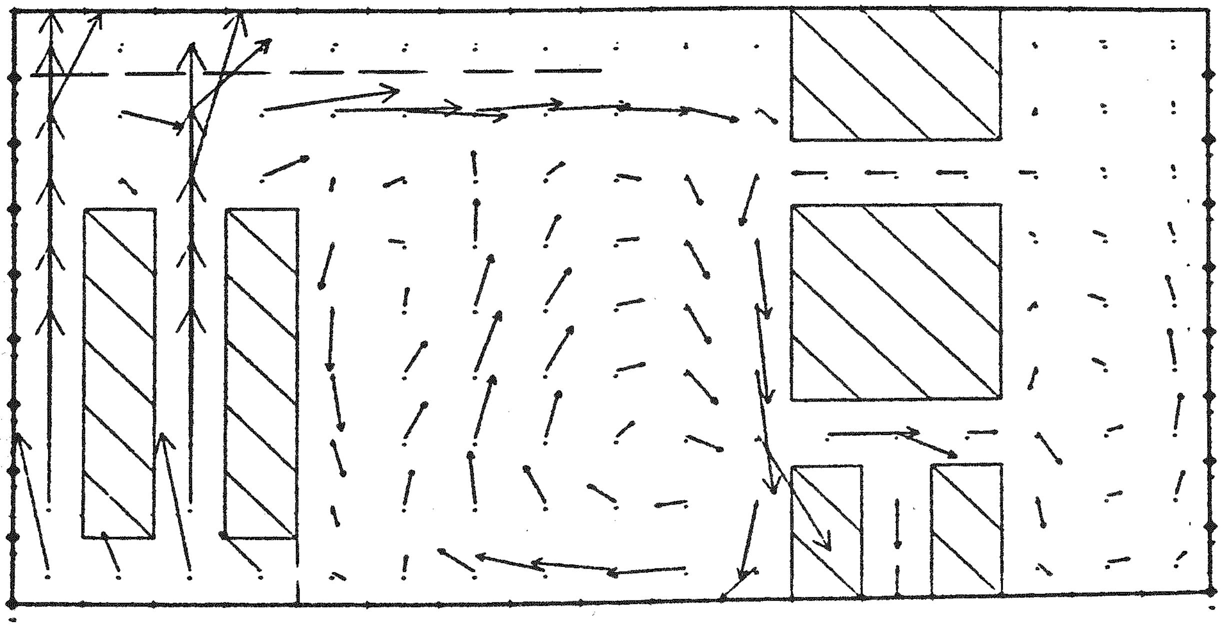
10 JUL 78

TIME = 4.0045E+01 CYCLE = 12865

VELOCITY VECTORS

REFERENCE VELOCITY = 3.7657E+00

Figure 5a Velocity Field - Scram, Pump Trip To 50% - Time = 40 Seconds



VARR II

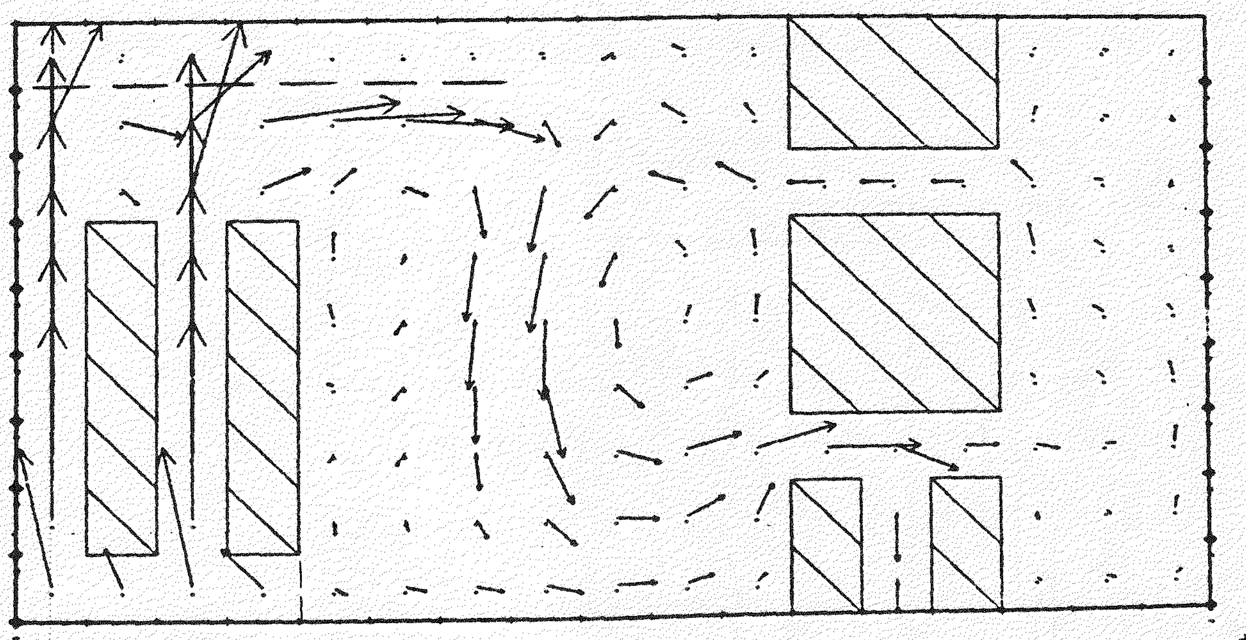
10 JUL 78

TIME = 6.0042E+01 CYCLE = 13241

VELOCITY VECTORS

REFERENCE VELOCITY = 3.7452E+00

Figure 5b Velocity Field - Scram, Pump Trip To 50% - Time = 60 Seconds



VARR II

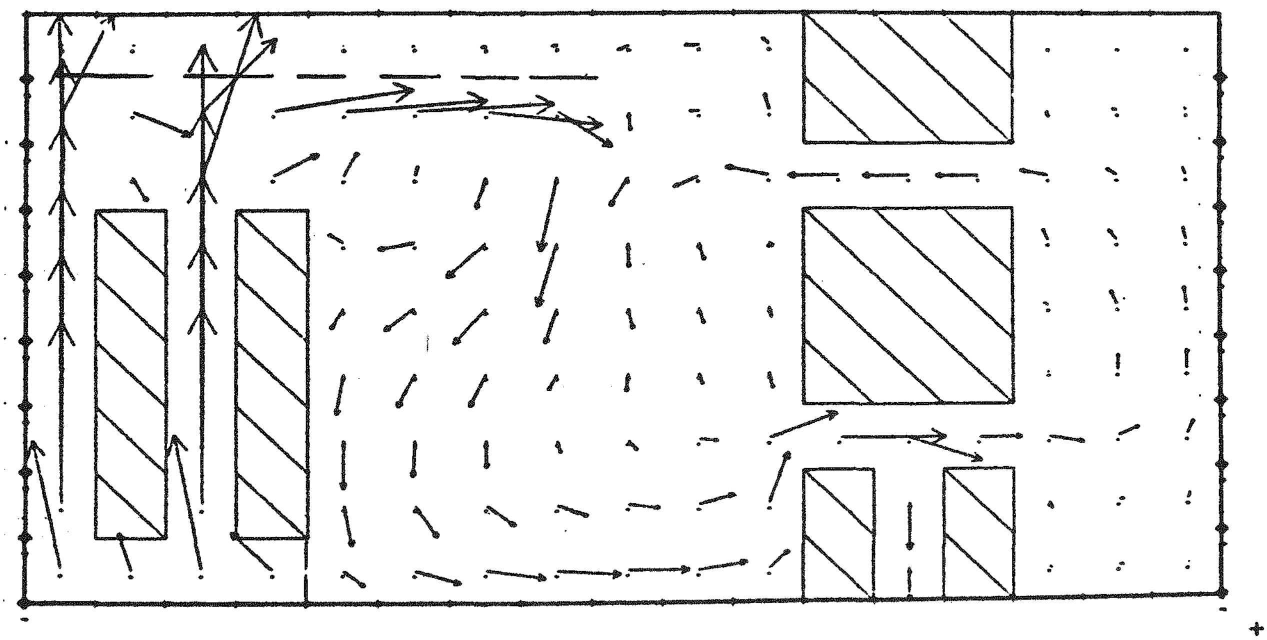
10 JUL 78

TIME = 9.0024E+01   CYCLE = 13804

VELOCITY VECTORS

REFERENCE VELOCITY = 3.7509E+00

Figure 5c   Velocity Field - Scram, Pump Trip To 50% - Time = 90 Seconds



VARR II

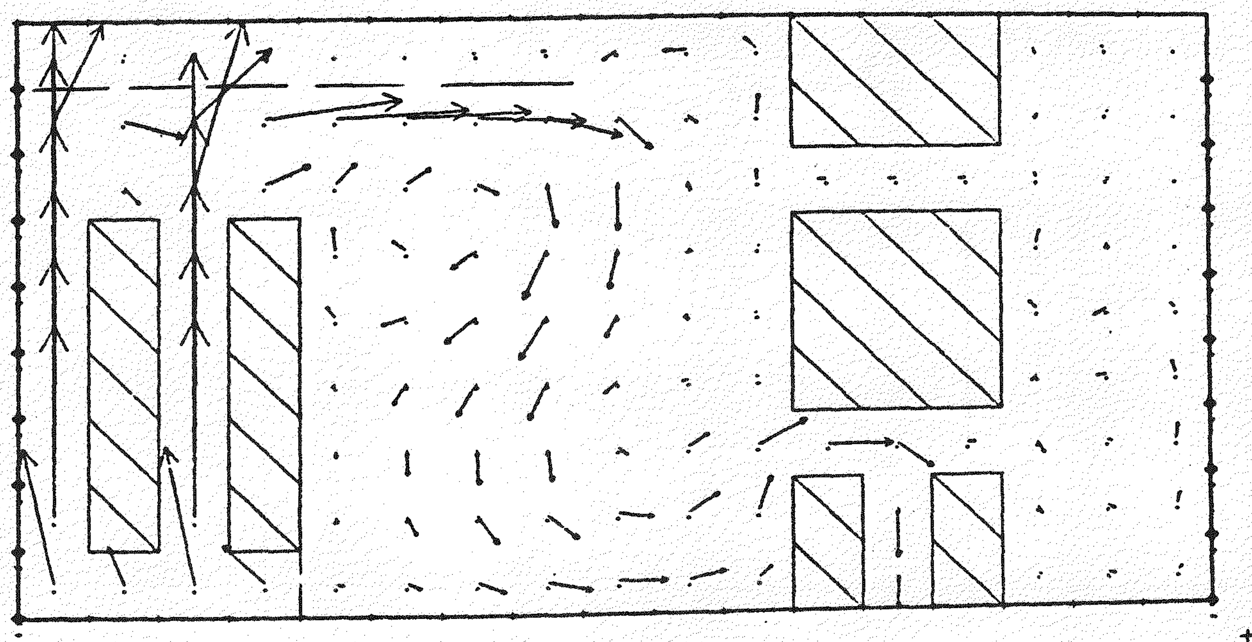
10 JUL 78

TIME = 1.5005E+02  CYCLE = 14940

VELOCITY VECTORS

REFERENCE VELOCITY = 3.7995E+00

Figure 5d  Velocity Field - Scram, Pump Trip To 50% - Time = 150 Seconds



VARR II

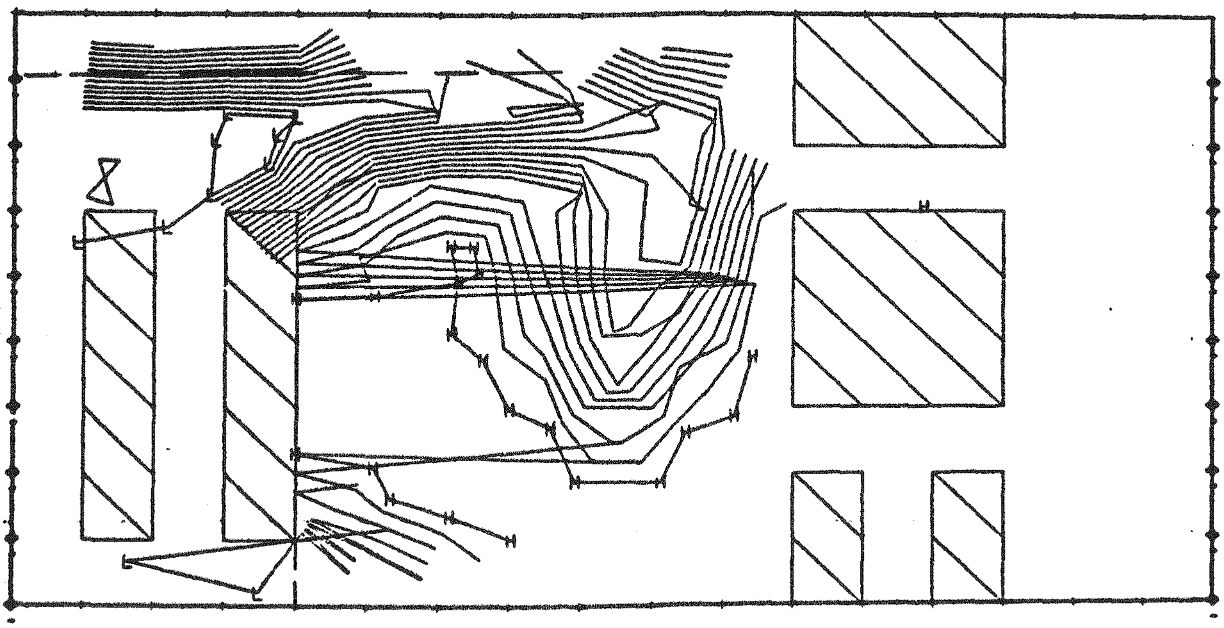
10 JUL 78

TIME = 2.0007E+02 CYCLE = 15886

VELOCITY VECTORS

REFERENCE VELOCITY = 3.7709E+00

Figure 5e Velocity Field - Scram, Pump Trip To 50% - Time = 200 Seconds



VARR II

10 JUL 78

TIME = 3.0043E+01  CYCLE = 12677

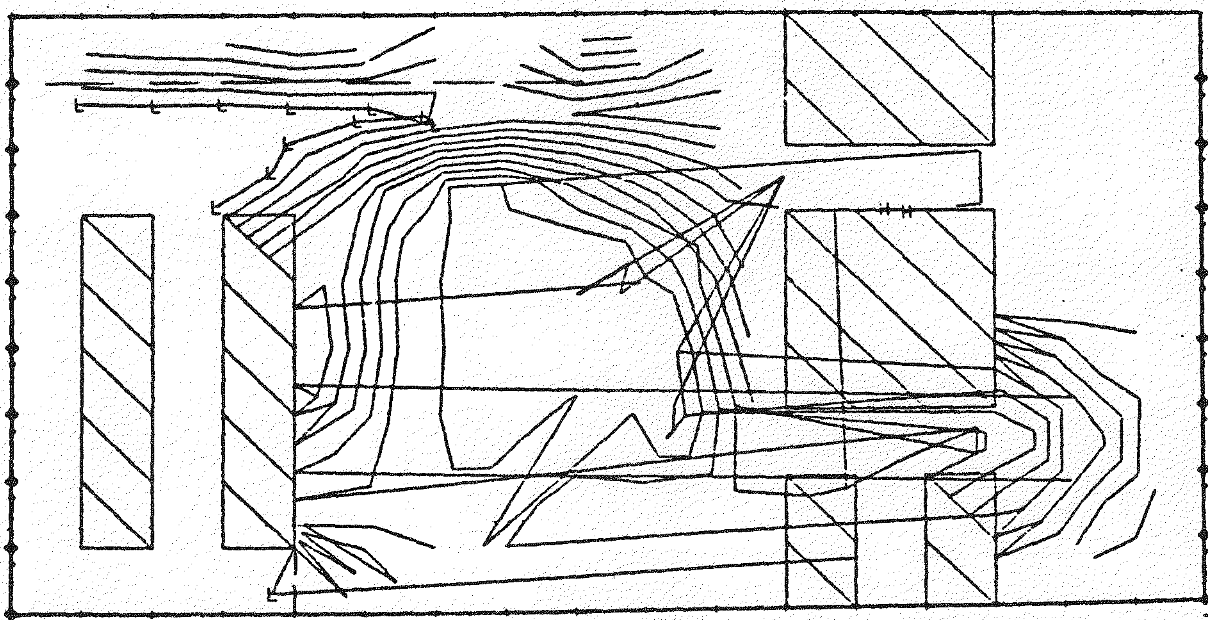
TEMPERATURE CONTOURS

QMAX 8.7676E+02  QMIN 5.9380E+02

Q(K)=QMN+k*DQ  DQ=1.3454E+01

Q = 6.07273E+02  Q = 6.20748E+02
Q = 6.34222E+02  Q = 6.47697E+02
Q = 6.61171E+02  Q = 6.74645E+02
Q = 6.88120E+02  Q = 7.01584E+02
Q = 7.15069E+02  Q = 7.28543E+02
Q = 7.42018E+02  Q = 7.55492E+02
Q = 7.68967E+02  Q = 7.82441E+02
Q = 7.95916E+02  Q = 8.09390E+02
Q = 8.22865E+02  Q = 8.36339E+02
Q = 8.49813E+02  Q = 8.63288E+02

Figure 6a  Temperature Field - Scram, Pump Trip To 50% - Time = 30 Seconds



VARR II

10 JUL 78

TIME = 6.0042E+01  CYCLE = 13241

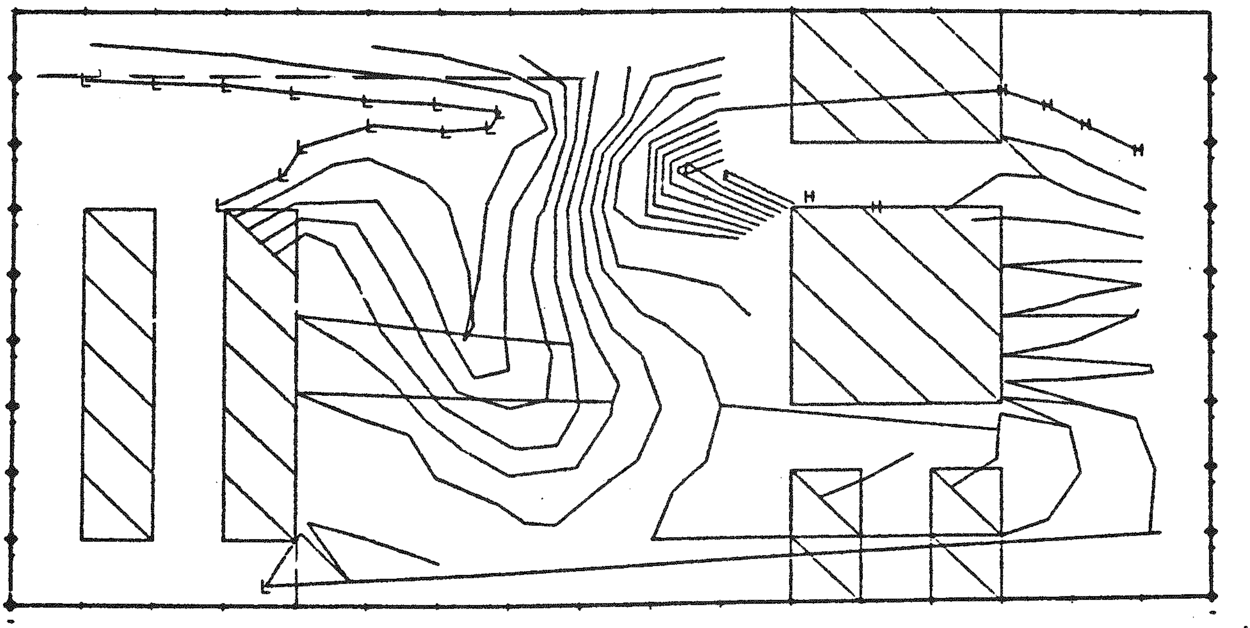
TEMPERATURE CONTOURS

QMAX 9.2994E+02  QMIN 5.933E+02

Q(K)=QMN+K*DQ  DQ = 1.5744E+01

| | |
|---|---|
| Q = 6.15070E+02 | Q = 6.30813E+02 |
| Q = 6.46557E+02 | Q = 6.62300E+02 |
| Q = 6.78044E+02 | Q = 6.93788E+02 |
| Q = 7.09531E+02 | Q = 7.25275E+02 |
| Q = 7.41018E+02 | Q = 7.56762E+02 |
| Q = 7.72505E+02 | Q = 7.88249E+02 |
| Q = 8.03992E+02 | Q = 8.19736E+02 |
| Q = 8.35480E+02 | Q = 8.51223E+02 |
| Q = 8.66967E+02 | Q = 8.82710E+02 |
| Q = 8.98454E+02 | Q = 9.14197E+02 |

Figure 6b  Temperature Field - Scram, Pump Trip To 50% - Time = 60 Seconds



VARR II

10 JUL 78

TIME = 9.0024E+01 CYCLE = 13804

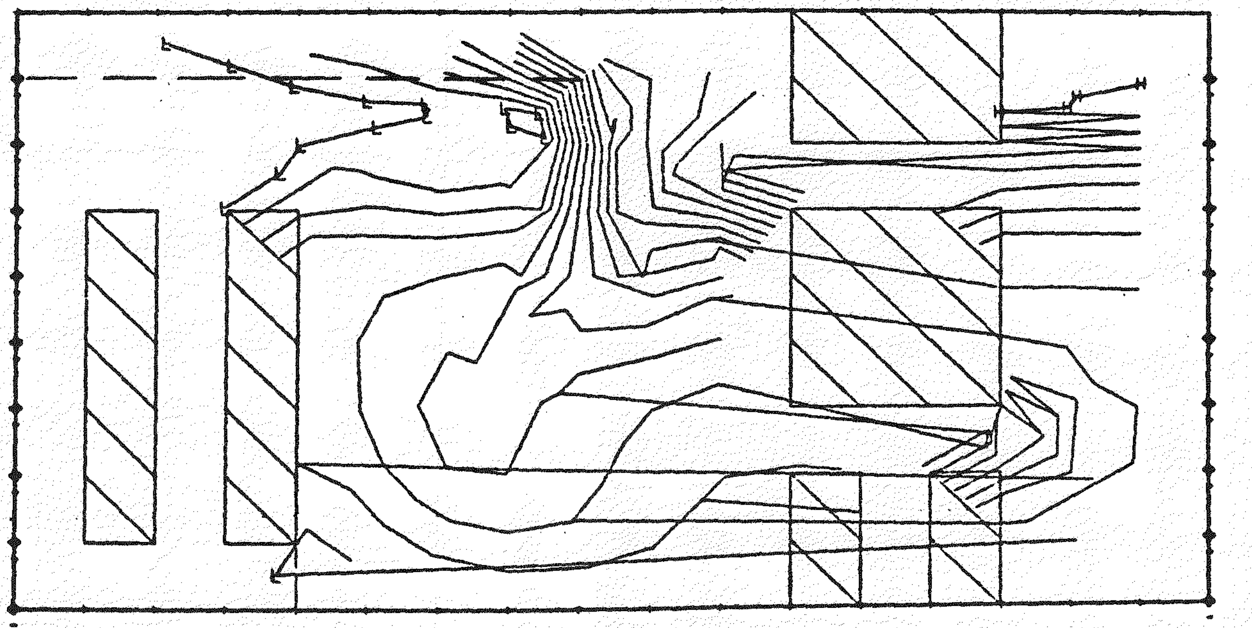
TEMPERATURE CONTOURS

QMAX 8.7285E+02 QMIN 5.9778E+02

Q(K)=QMN+K*DQ DQ = 1.3099E+01

| | |
|---|---|
| Q = 6.10877E+02 | Q = 6.23975E+02 |
| Q = 6.37074E+02 | Q = 6.50172E+02 |
| Q = 6.63271E+02 | Q = 6.76369E+02 |
| Q = 6.89468E+02 | Q = 7.02566E+02 |
| Q = 7.15665E+02 | Q = 7.28763E+02 |
| Q = 7.41862E+02 | Q = 7.54960E+02 |
| Q = 7.68059E+02 | Q = 7.81157E+02 |
| Q = 7.94256E+02 | Q = 8.07354E+02 |
| Q = 8.20453E+02 | Q = 8.33551E+02 |
| Q = 8.46650E+02 | Q = 8.59748E+02 |

Figure 6c Temperature Field - Scram, Pump Trip TO 50% - Time = 90 Seconds



VARR II

10 JUL 78

TIME = 1.5005E+02 CYCLE = 14940

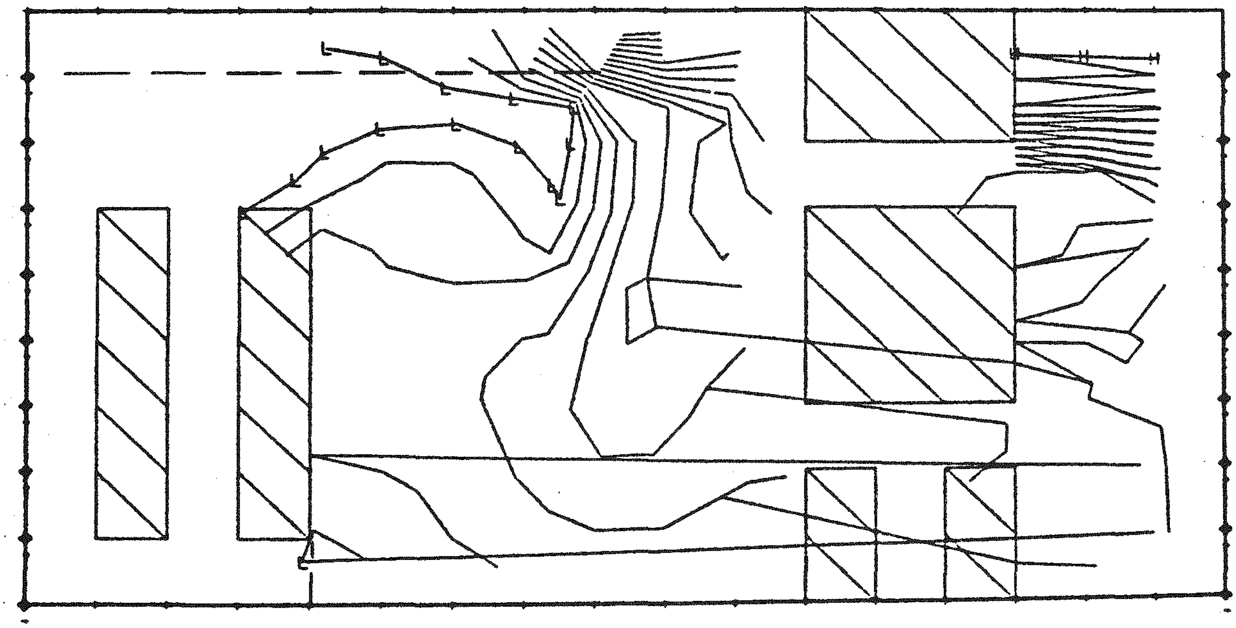
TEMPERATURE CONTOURS

QMAX 8.5172E+02 QMIN 5.9353E+02

Q(K)=QMN+K*DQ DQ = 1.2295E+01

| | |
|---|---|
| Q = 6.05820E+02 | Q = 6.18115E+02 |
| Q = 6.30410E+02 | Q = 6.42704E+02 |
| Q = 6.54999E+02 | Q = 6.67294E+02 |
| Q = 6.79589E+02 | Q = 6.91883E+02 |
| Q = 7.04178E+02 | Q = 7.16473E+02 |
| Q = 7.28768E+02 | Q = 7.41062E+02 |
| Q = 7.53357E+02 | Q = 7.65652E+02 |
| Q = 7.77947E+02 | Q = 7.90241E+02 |
| Q = 8.02536E+02 | Q = 8.14831E+02 |
| Q = 8.27126E+02 | Q = 8.39420E+02 |

Figure 6d Temperature Field - Scram, Pump Trip To 50% - Time - 150 Seconds



VARR II

10 JUL 78

TIME = 2.0007E+02 CYCLE = 15886

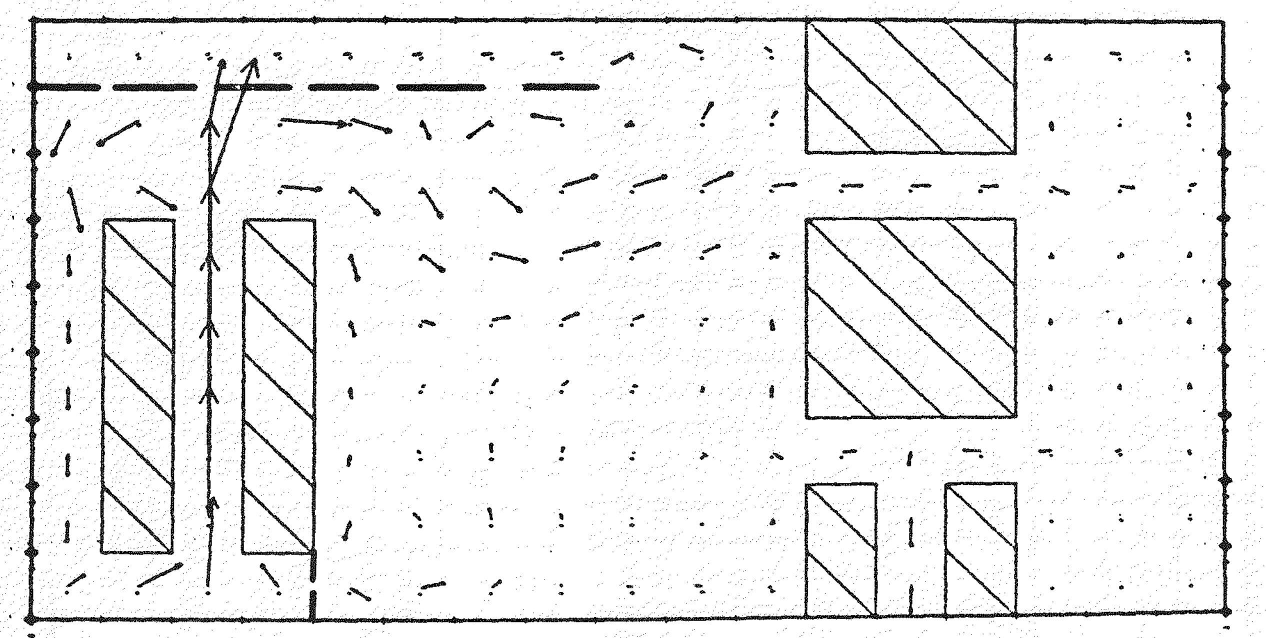
TEMPERATURE CONTOURS

QMAX 8.4607E+02 QMIN 5.8814E+02

Q(K)=QMN+K*DQ DQ = 1.2282E+01

| | |
|---|---|
| Q = 6.00424E+02 | Q = 6.12706E+02 |
| Q = 6.24988E+02 | Q = 6.37271E+02 |
| Q = 6.49553E+02 | Q = 6.61836E+02 |
| Q = 6.74118E+02 | Q = 6.86400E+02 |
| Q = 6.98683E+02 | Q = 7.10965E+02 |
| Q = 7.23248E+02 | Q = 7.35530E+02 |
| Q = 7.47812E+02 | Q = 7.60095E+02 |
| Q = 7.72377E+02 | Q = 7.84660E+02 |
| Q = 7.96942E+02 | Q = 8.09224E+02 |
| Q = 8.21507E+02 | Q = 8.33789E+02 |

Figure 6e Temperature Field - Scram, Pump Trip To 50% - Time = 200 Seconds



VARR II

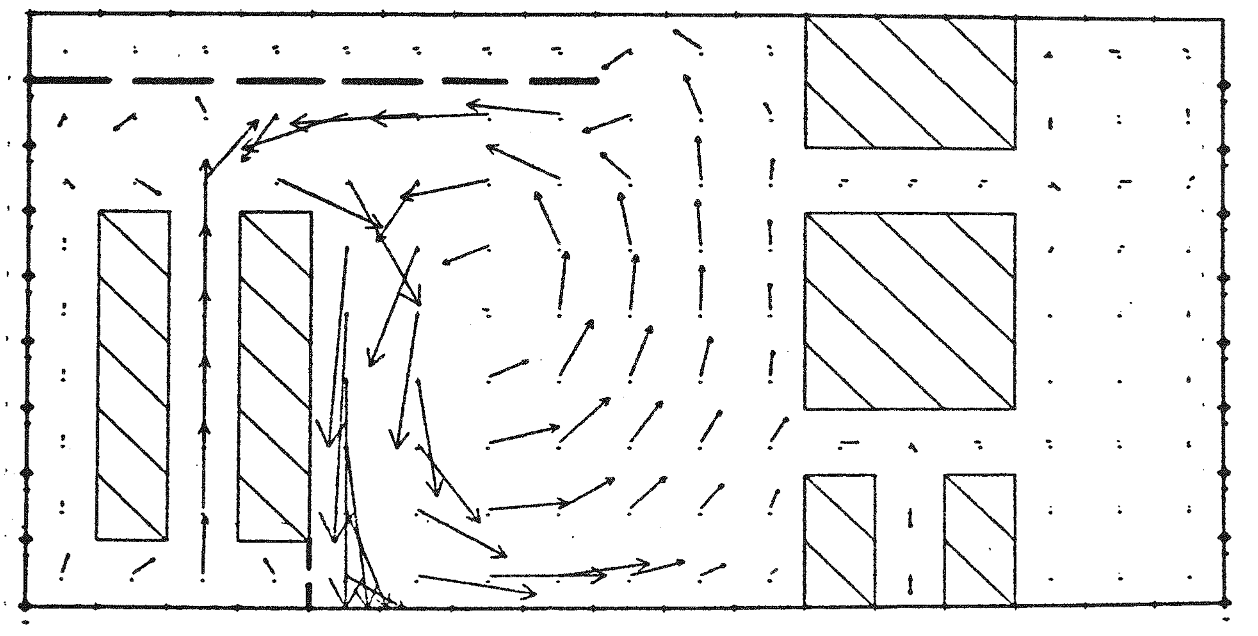
05 JUL 78

TIME = 3.0056E+01 CYCLE - 12481

VELOCITY VECTORS

REFERENCE VELOCITY = 1.3945E+00

Figure 7a Velocity Field - Scram, Pump Trip - Time = 30 Seconds



VARR II

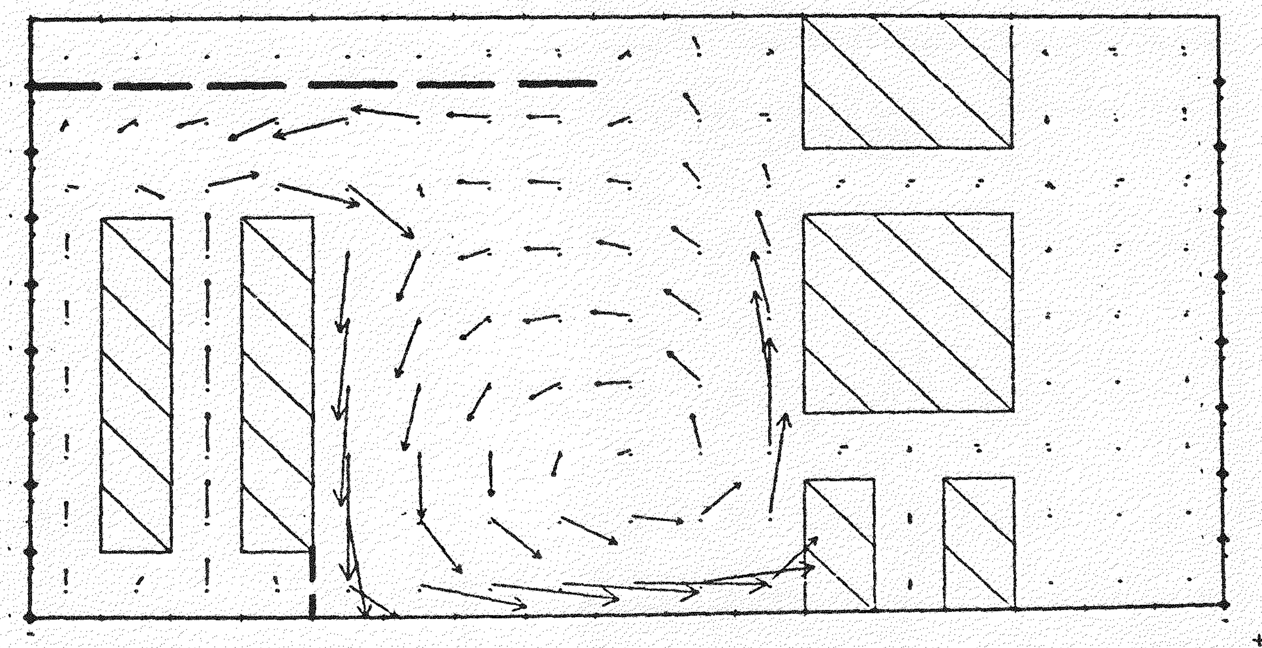
05 JUL 78

TIME = 4.0122E+01 CYCLE = 12542

VELOCITY VECTORS

REFERENCE VELOCITY = 1.4000E+00

Figure 7b Velocity Field - Scram, Pump Trip - Time = 40 Seconds



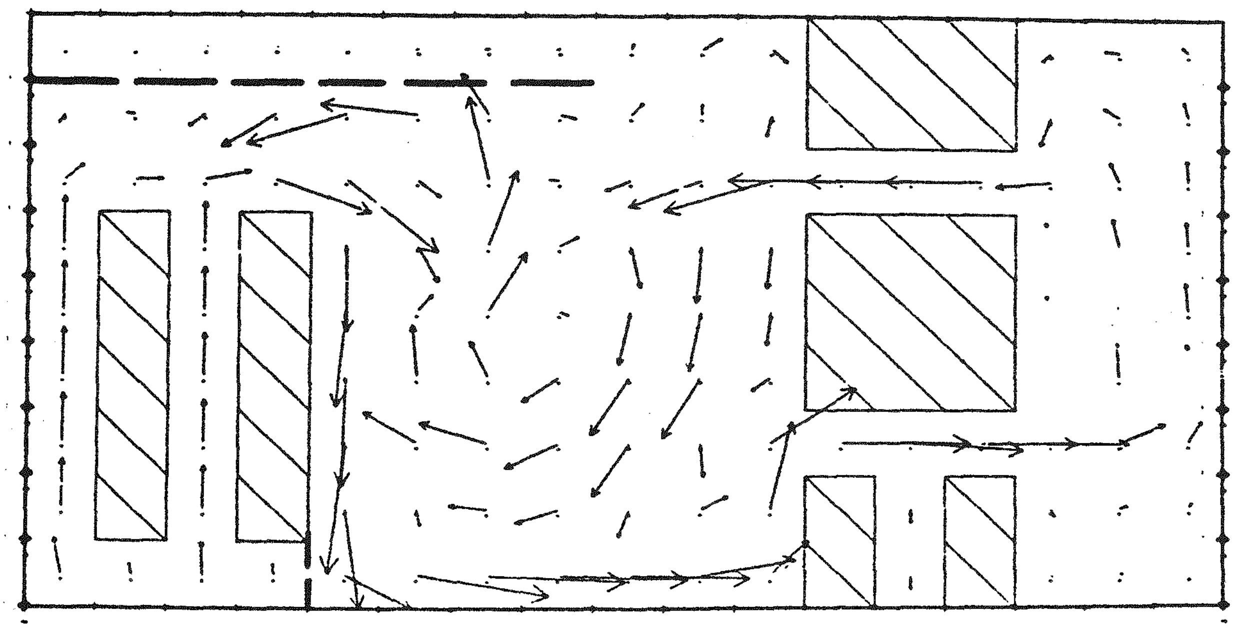
VARR II
05 JUL 78

TIME = 5.0051E+01  CYCLE = 12657

VELOCITY VECTORS

REFERENCE VELOCITY = 2.0279E+00

Figure 7c  Velocity Field - Scram, Pump Trip - Time = 50 Seconds



VARR II

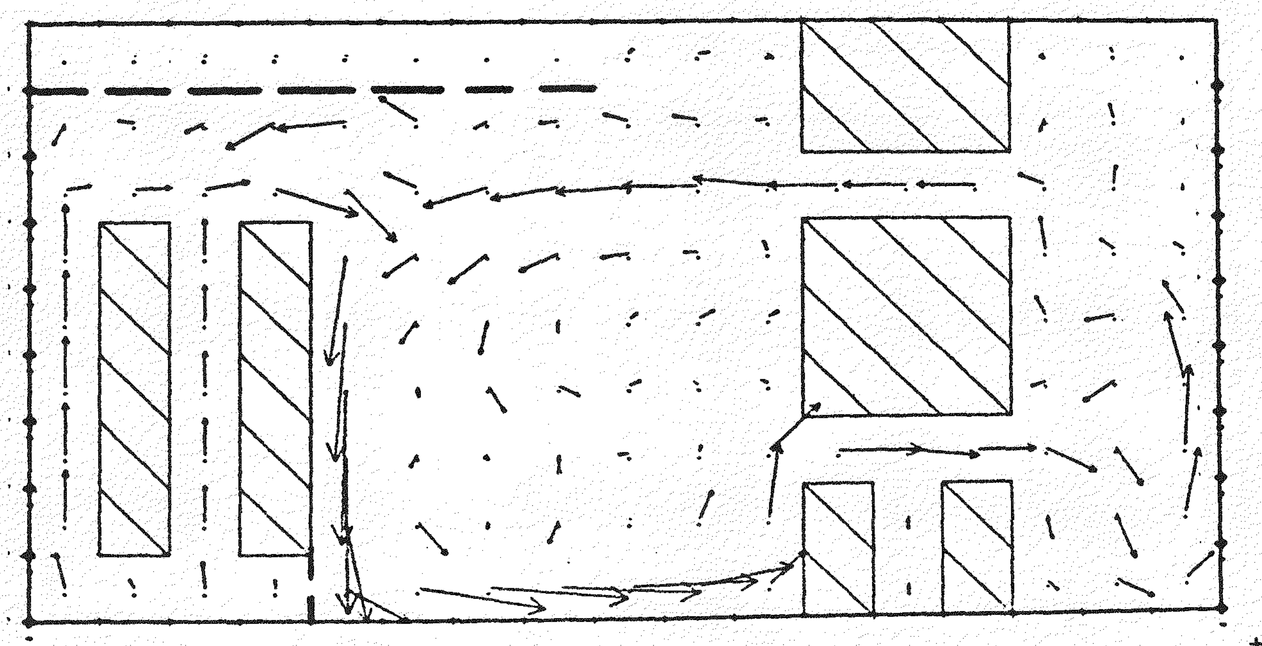
05 JUL 78

TIME = 7.0048E+01   CYCLE = 12796

VELOCITY VECTORS

REFERENCE VELOCITY = 9.7199E-01

Figure 7d   Velocity Field - Scram, Pump Trip - Time = 70 Seconds

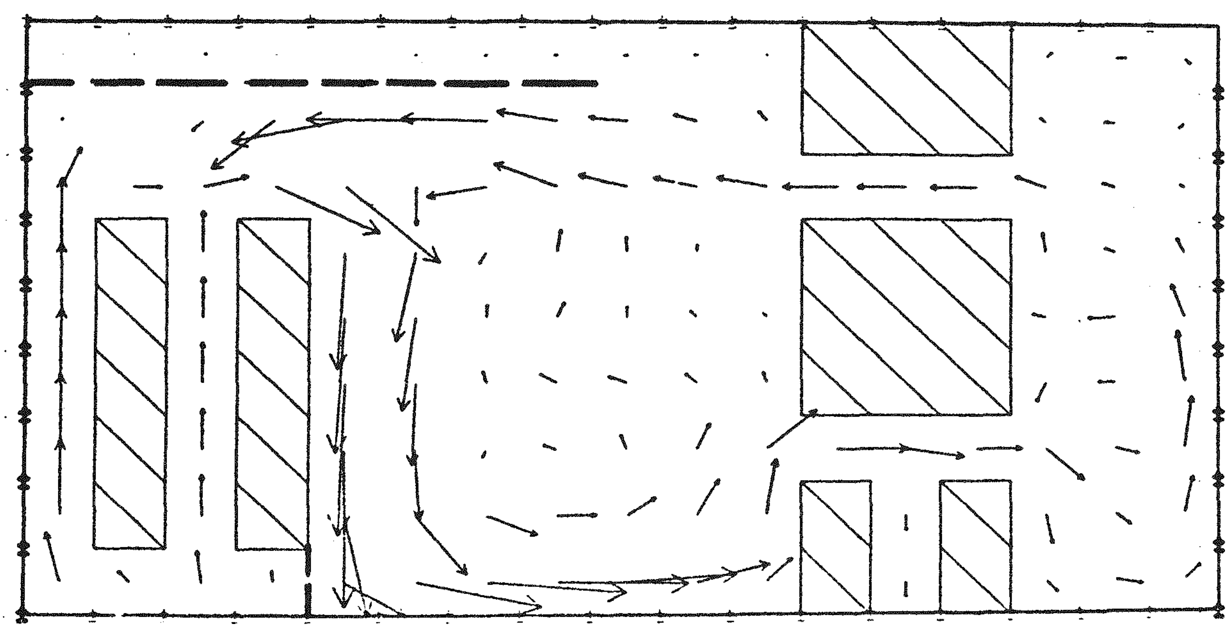


VARR II
05 JUL 78

TIME = 1.0004E+02 CYCLE = 12946

VELOCITY VECTORS
REFERENCE VELOCITY = 1.1442E+00

Figure 7e Velocity Field - Scram, Pump Trip -
Time = 100 Seconds



VARR II

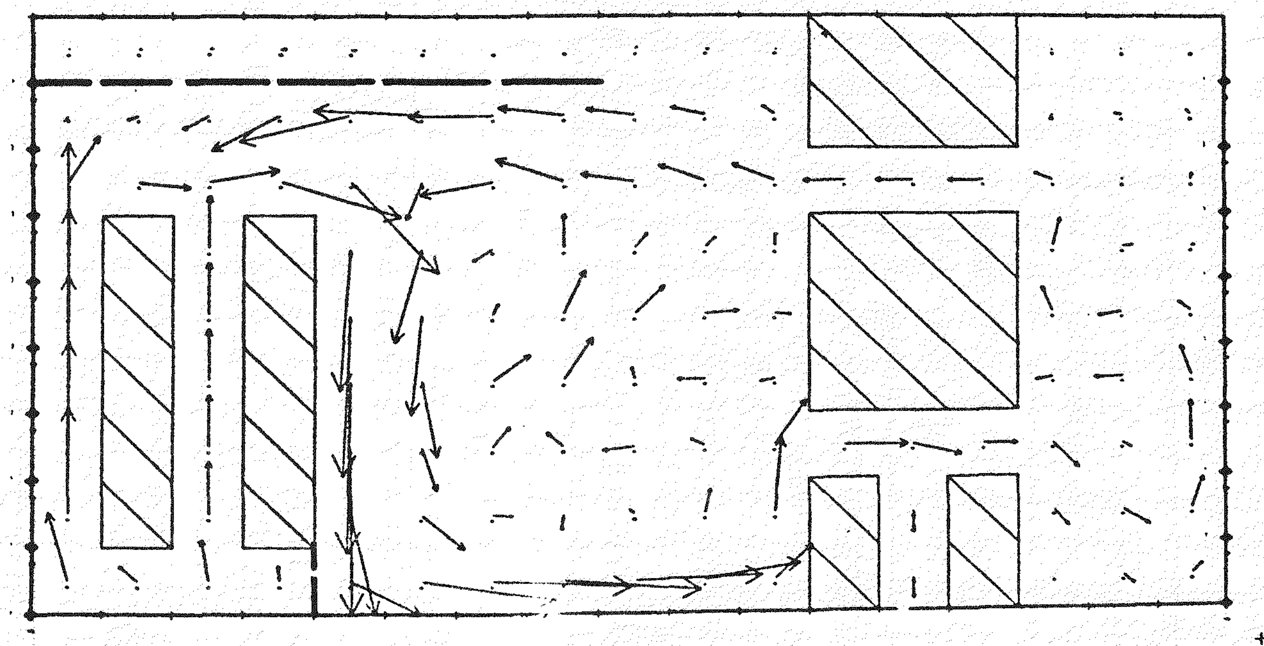
06 JUL 78

TIME = 2.0005E+02  CYCLE = 13472

VELOCITY VECTORS

REFERENCE VELOCITY = 9.4601E-01

Figure 7f  Velocity Field - Scram, Pump Trip - Time = 200 Seconds



VARR II

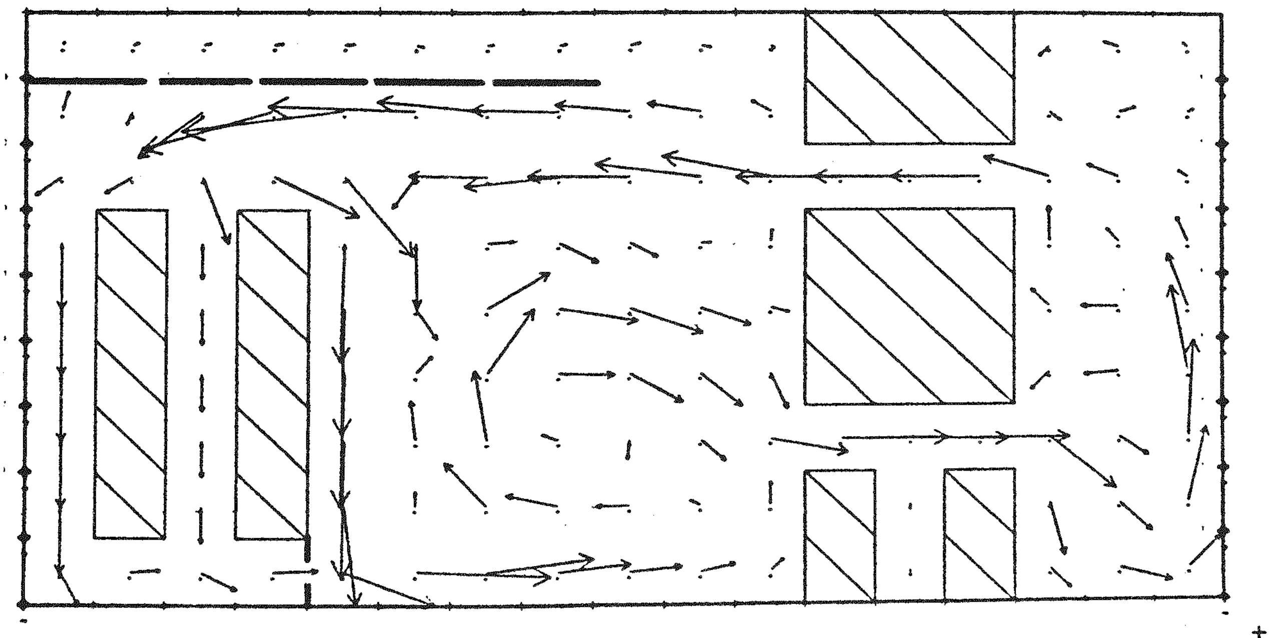
06 JUL 78

TIME = 3.0009E+02 CYCLE - 13931

VELOCITY VECTORS

REFERENCE VELOCITY = 7.1546E-01

Figure 7g Velocity Field - Scram, Pump Trip - Time = 300 Seconds



VARR II

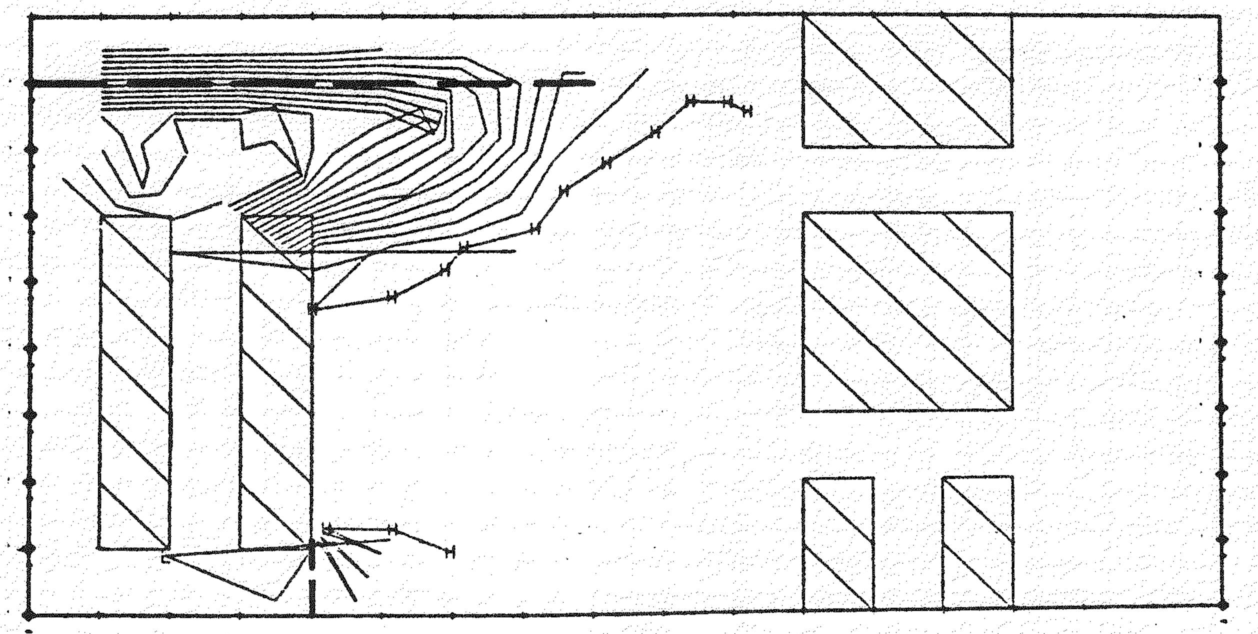
06 JUL 78

TIME = 4.0017E+02 CYCLE = 14288

VELOCITY VECTORS

REFERENCE VELOCITY = 2.4092E-01

Figure 7h Velocity Field - Scram, Pump Trip - Time = 400 Seconds



VARR II

05 JUL 78

TIME = 3.0056E+01   CYCLE = 12481

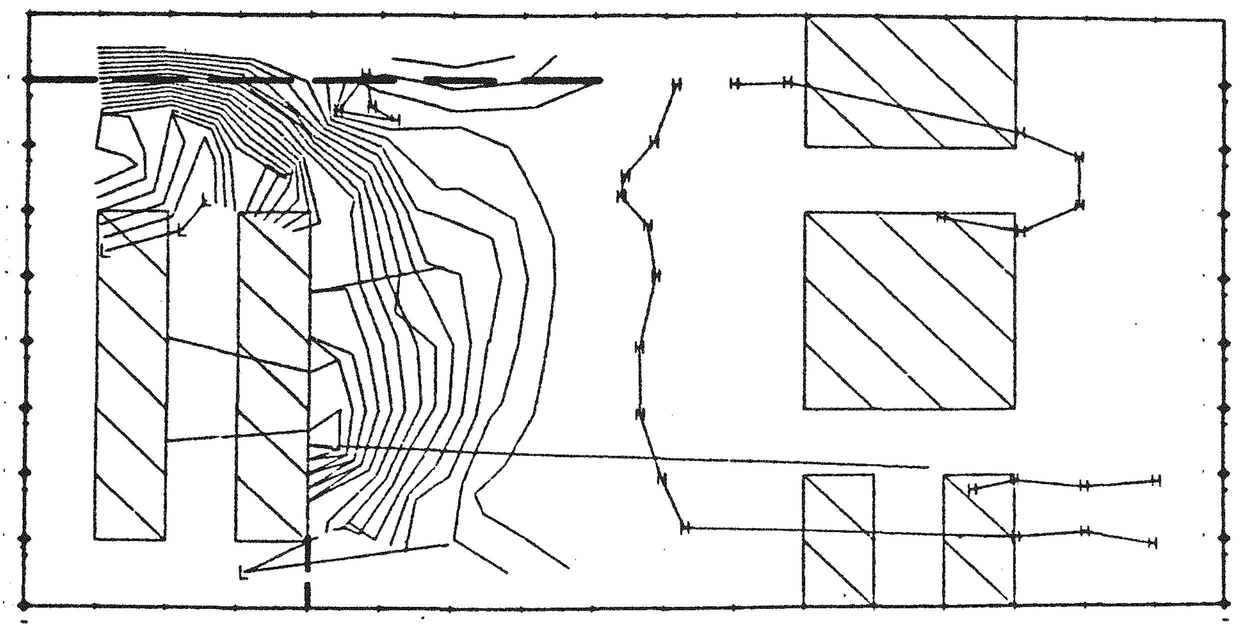
TEMPERATURE CONTOURS

QMAX 8.8099E+02   QMIN 6.1991E+02

Q(K)=QMN+K*DQ   DQ = 1.2432E+01

Q = 6.32340E+02   Q = 6.44773E+02
Q = 6.57205E+02   Q = 6.69637E+02
Q = 6.82070E+02   Q = 6.94502E+02
Q = 7.06934E+02   Q = 7.19367E+02
Q = 7.31799E+02   Q = 7.44231E+02
Q = 7.56664E+02   Q = 7.69096E+02
Q = 7.81529E+02   Q = 7.93961E+02
Q = 8.06393E+02   Q = 8.18826E+02
Q = 8.31258E+02   Q = 8.43690E+02
Q = 8.56123E+02   Q = 8.68555E+02

Figure 8a   Temperature Field - Scram, Pump Trip - Time = 30 Seconds



VARR II

05 JUL 78

TIME = 4.0122E+01 CYCLE = 12542

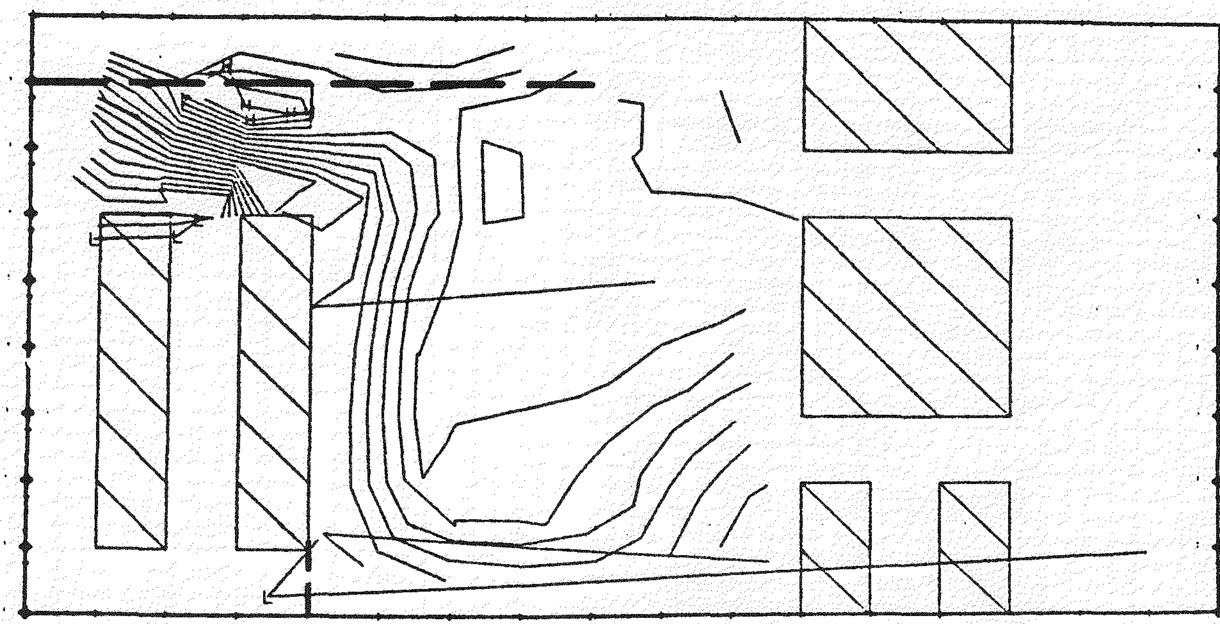
TEMPERATURE CONTOURS

QMAX 8.848E+02 QMIN 6.2524E+02

Q(K)=QMIN+K*DQ DQ = 1.2363E+01

| | |
|---|---|
| Q = 6.37601E+02 | Q = 6.49964E+02 |
| Q = 6.62327E+02 | Q = 6.74690E+02 |
| Q = 6.87053E+02 | Q = 6.99416E+02 |
| Q = 7.11779E+02 | Q = 7.24142E+02 |
| Q = 7.36505E+02 | Q = 7.48868E+02 |
| Q = 7.61231E+02 | Q = 7.73594E+02 |
| Q = 7.85957E+02 | Q = 7.98320E+02 |
| Q = 8.10683E+02 | Q = 8.23046E+02 |
| Q = 8.35409E+02 | Q = 8.47772E+02 |
| Q = 8.60135E+02 | Q = 8.72498E+02 |

Figure 8b Temperature Field - Scram, Pump Trip - Time = 40 Seconds



VARR II

05 JUL 78

TIME = 5.0051E+01 CYCLE = 12657

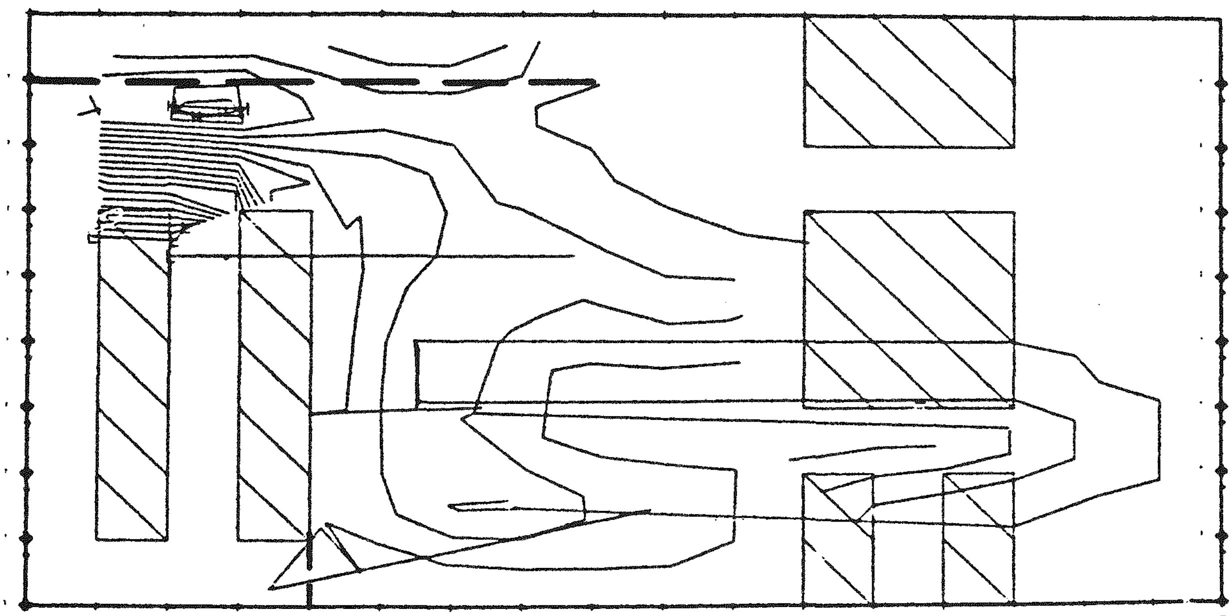
TEMPERATURE CONTOURS

QMAX 9.0068E+02 QMIN 6.2466E+02

Q(K)=QMN+K*DQ DQ = 1.3144E+01

| | |
|---|---|
| Q = 6.37805E+02 | Q = 6.50949E+02 |
| Q = 6.64093E+02 | Q = 6.77237E+02 |
| Q = 6.90381E+02 | Q = 7.03525E+02 |
| Q = 7.16669E+02 | Q = 7.29813E+02 |
| Q = 7.42957E+02 | Q = 7.56101E+02 |
| Q = 7.69244E+02 | Q = 7.82388E+02 |
| Q = 7.95532E+02 | Q = 8.08676E+02 |
| Q = 8.21820E+02 | Q = 8.34964E+02 |
| Q = 8.48108E+02 | Q = 8.61252E+02 |
| Q = 8.74396E+02 | Q = 8.87540E+02 |

Figure 8c Temperature Field - Scram, Pump Trip - Time = 50 Seconds



VARR II

05 JUL 78

TIME = 7.0048E+01 CYCLE = 12796

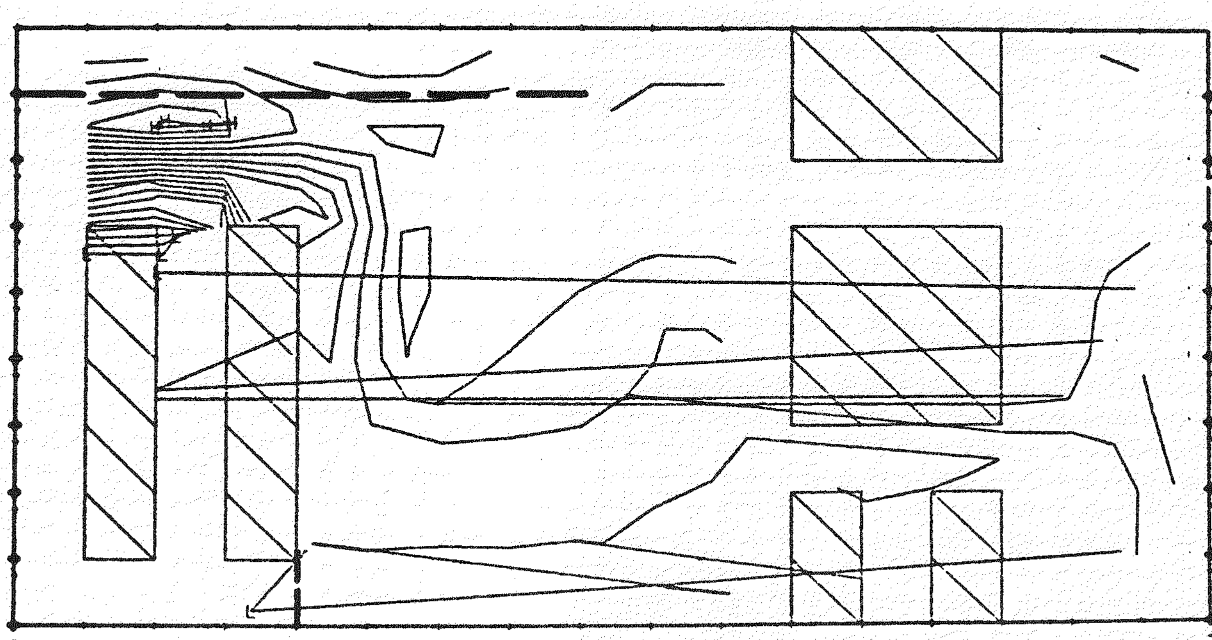
TEMPERATURE CONTOURS

QMAX 9.3473E+02 QMIN 5.9562E+02

Q(K)=QMN+K*DQ DQ = 1.6148E+01

| | |
|---|---|
| Q = 6.11765E+02 | Q = 6.27913E+02 |
| Q = 6.44061E+02 | Q = 6.60210E+02 |
| Q = 6.76358E+02 | Q = 6.92506E+02 |
| Q = 7.08654E+02 | Q = 7.24802E+02 |
| Q = 7.40950E+02 | Q = 7.57099E+02 |
| Q = 7.73247E+02 | Q = 7.89395E+02 |
| Q = 8.05543E+02 | Q = 8.21691E+02 |
| Q = 8.37840E+02 | Q = 8.53988E+02 |
| Q = 8.70136E+02 | Q = 8.86284E+02 |
| Q = 9.02432E+02 | Q = 9.18580E+02 |

Figure 8d Temperature Field - Scram, Pump Trip - Time = 70 Seconds



VARR II

05 JUL 78

TIME = 1.0004E+02 CYCLE = 12946

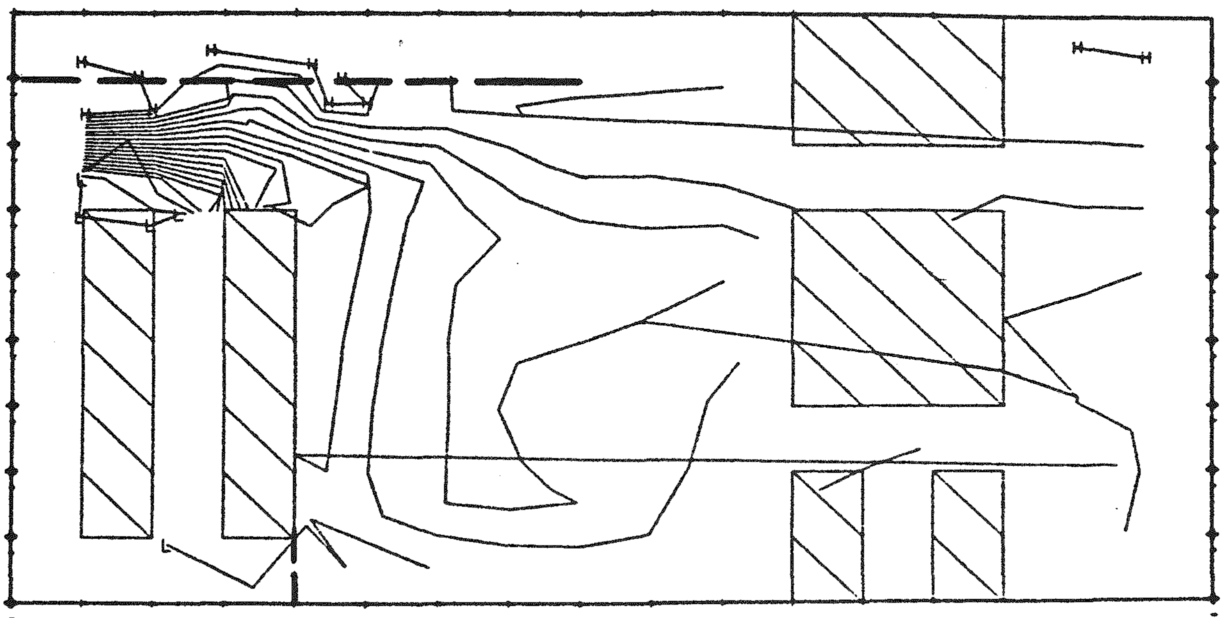
TEMPERATURE CONTOURS

QMAX 9.3526E+02 QMIN 6.0181E+02

Q(K)=QMN+K*DQ DQ = 1.5879E+01

| | |
|---|---|
| Q = 6.17688E+02 | Q = 6.33567E+02 |
| Q = 6.49445E+02 | Q = 6.65324E+02 |
| Q = 6.81203E+02 | Q = 6.97081E+02 |
| Q = 7.12960E+02 | Q = 7.28839E+02 |
| Q = 7.44717E+02 | Q = 7.60596E+02 |
| Q = 7.76475E+02 | Q = 7.92354E+02 |
| Q = 8.08232E+02 | Q = 8.24111E+02 |
| Q = 8.39990E+02 | Q = 8.55868E+02 |
| Q = 8.71747E+02 | Q = 8.87626E+02 |
| Q = 9.03504E+02 | Q = 9.19383E+02 |

Figure 8e Temperature Field - Scram, Pump Trip - Time = 100 Seconds



VARR II

05 JUL 78

TIME = 2.0005E+02 CYCLE = 13472

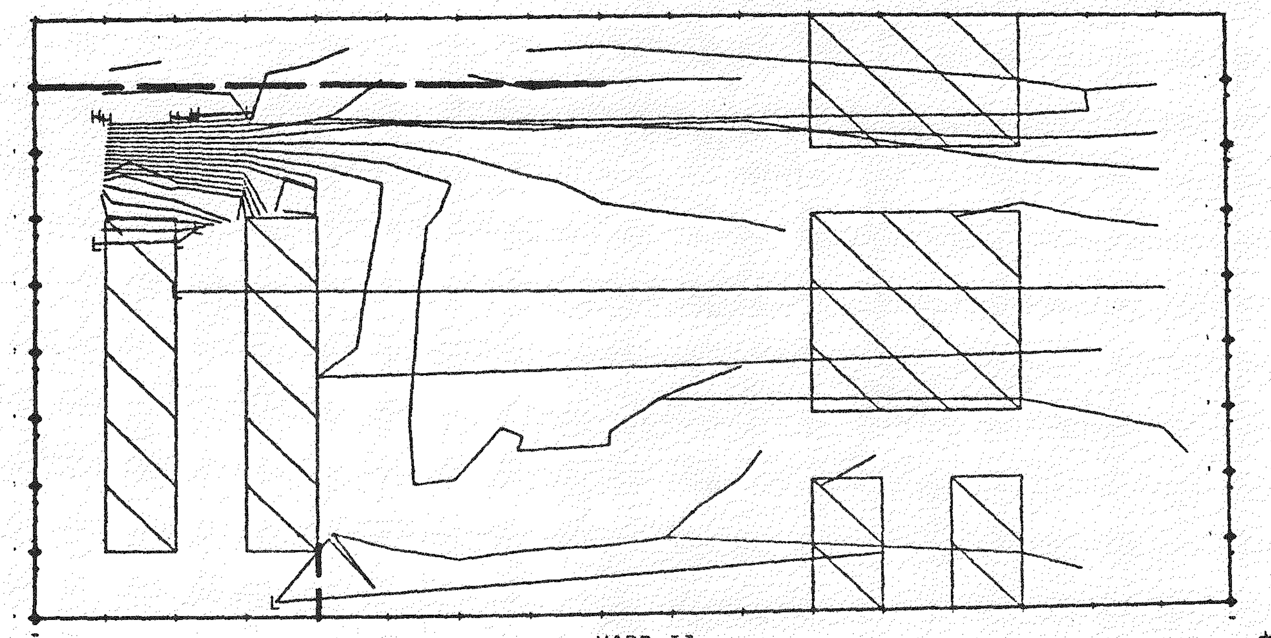
TEMPERATURE CONTOURS

QMAX 8.7448E+02 QMIN 6.1504E+02

Q(K)=QMN+K*DQ DQ = 1.2354E+01

Q = 6.27397E+02 Q = 6.39752E+02
Q = 6.52106E+-2 Q = 6.64460E+02
Q = 6.76814E+02 Q = 6.89168E+02
Q = 7.01522E+02 Q = 7.13877E+02
Q = 7.26231E+02 Q = 7.38585E+02
Q = 7.50939E+02 Q = 7.63293E+02
Q = 7.75648E+02 Q = 7.88002E+02
Q = 8.00356E+02 Q = 8.12710E+02
Q = 8.25064E+02 Q = 8.37419E+02
Q = 8.49773E+02 Q = 8.62127E+02

Figure 8f Temperature Field - Scram, Pump Trip - Time = 200 Seconds



VARR II

06 JUL 78

TIME = 3.0009+02 CYCLE = 13931

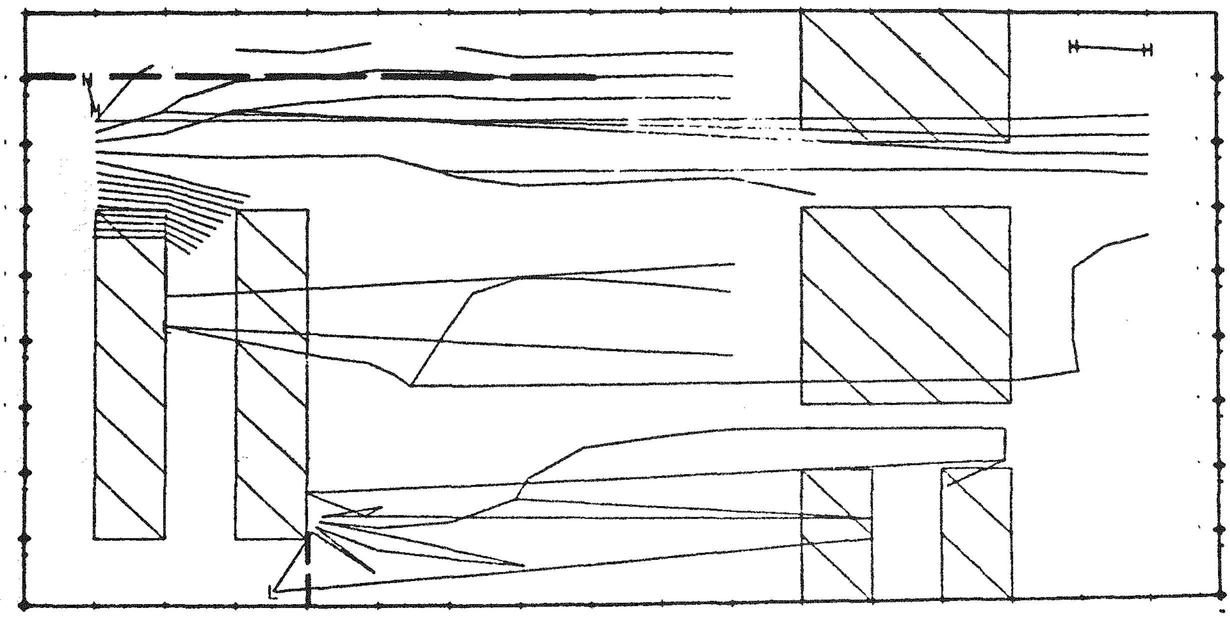
TEMPERATURE CONTOURS

QMAX 8.9104E+02 QMIN 5.9584+02

Q(K)=QMN+K*DQ DQ = 1.4057+01

| | |
|---|---|
| Q = 6.09900E+02 | Q = 6.23957E+02 |
| Q = 6.38014E+02 | Q = 6.52071E+02 |
| Q = 6.66128E+02 | Q = 6.80185E+02 |
| Q = 6.94242E+02 | Q = 7.08299E+02 |
| Q = 7.22356E+02 | Q = 7.36413E+02 |
| Q = 7.50470E+02 | Q = 7.64527E+02 |
| Q = 7.78584E+02 | Q = 7.92641E+02 |
| Q = 8.06698E+02 | Q = 8.20755E+02 |
| Q = 8.34812E+02 | Q = 8.48869E+02 |
| Q = 8.62926E+02 | Q = 8.76983E+02 |

Figure 8g Temperature Field - Scram, Pump Trip - Time = 300 Seconds



VARR II

06 JUL 78

TIME = 4.0017E+02 CYCLE = 14288

TEMPERATURE CONTOURS

QMAX 8.5588E+02 QMIN 5.9868E+02

Q(K)=QMN+K*DQ DQ = 1.2248E+01

| | |
|---|---|
| Q = 6.10932E+02 | Q = 6.23180E+02 |
| Q = 6.35427E+02 | Q = 6.47675E+02 |
| Q = 6.59922E+02 | Q = 6.72170E+02 |
| Q = 6.84417E+02 | Q = 6.96665E+02 |
| Q = 7.08913E+02 | Q = 7.21160E+02 |
| Q = 7.33408E+02 | Q = 7.45655E+02 |
| Q = 7.57903E+02 | Q = 7.70151E+02 |
| Q = 7.82398E+02 | Q = 7.94646E+02 |
| Q = 8.06893E+02 | Q = 8.19141E+02 |
| Q = 8.31389E+02 | Q = 8.43636E+02 |

Figure 8h Temperature Field - Scram, Pump Trip - Time = 400 Seconds

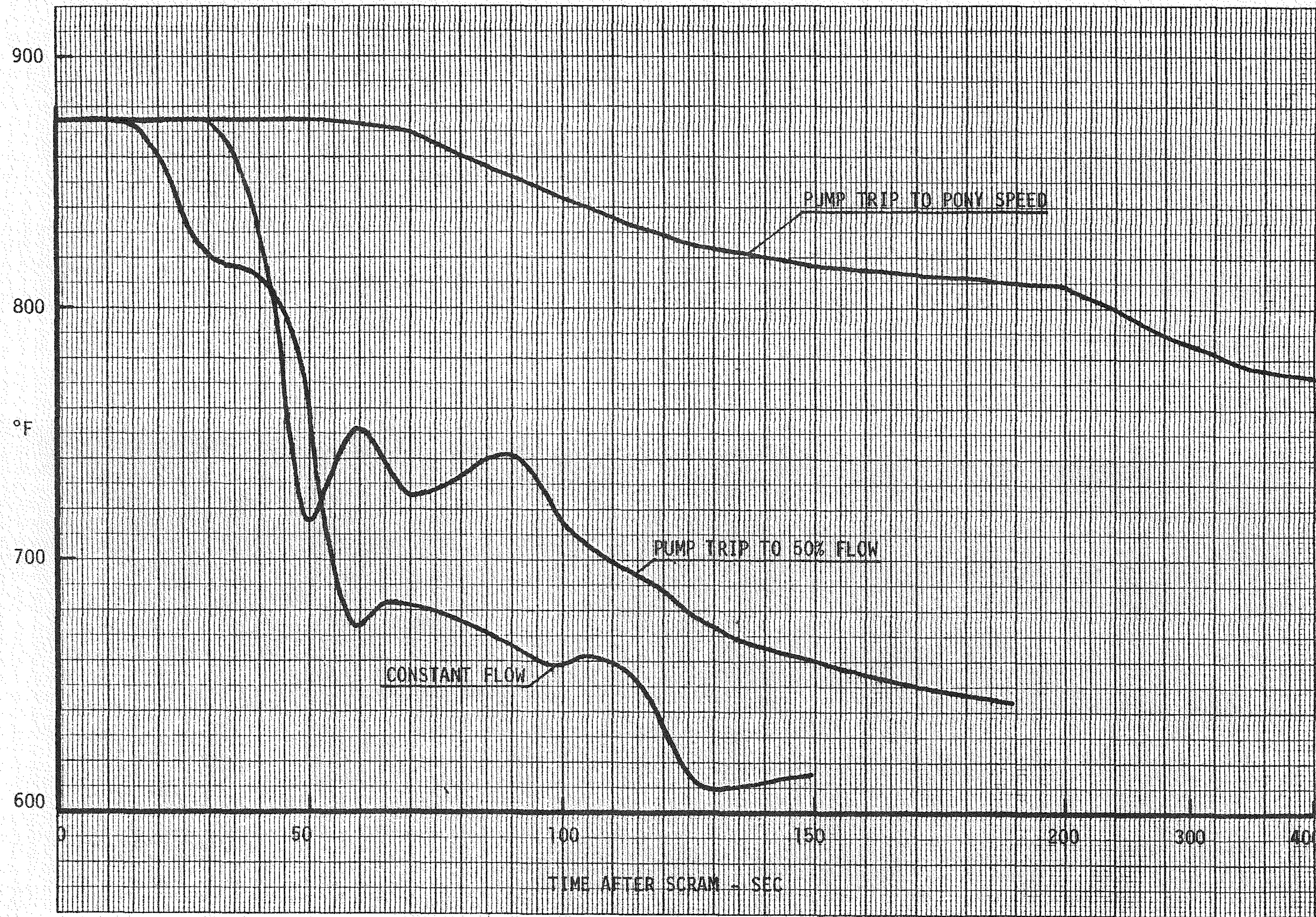



FIGURE 9 - IHX INLET TEMPERATURE AFTER A SCRAM

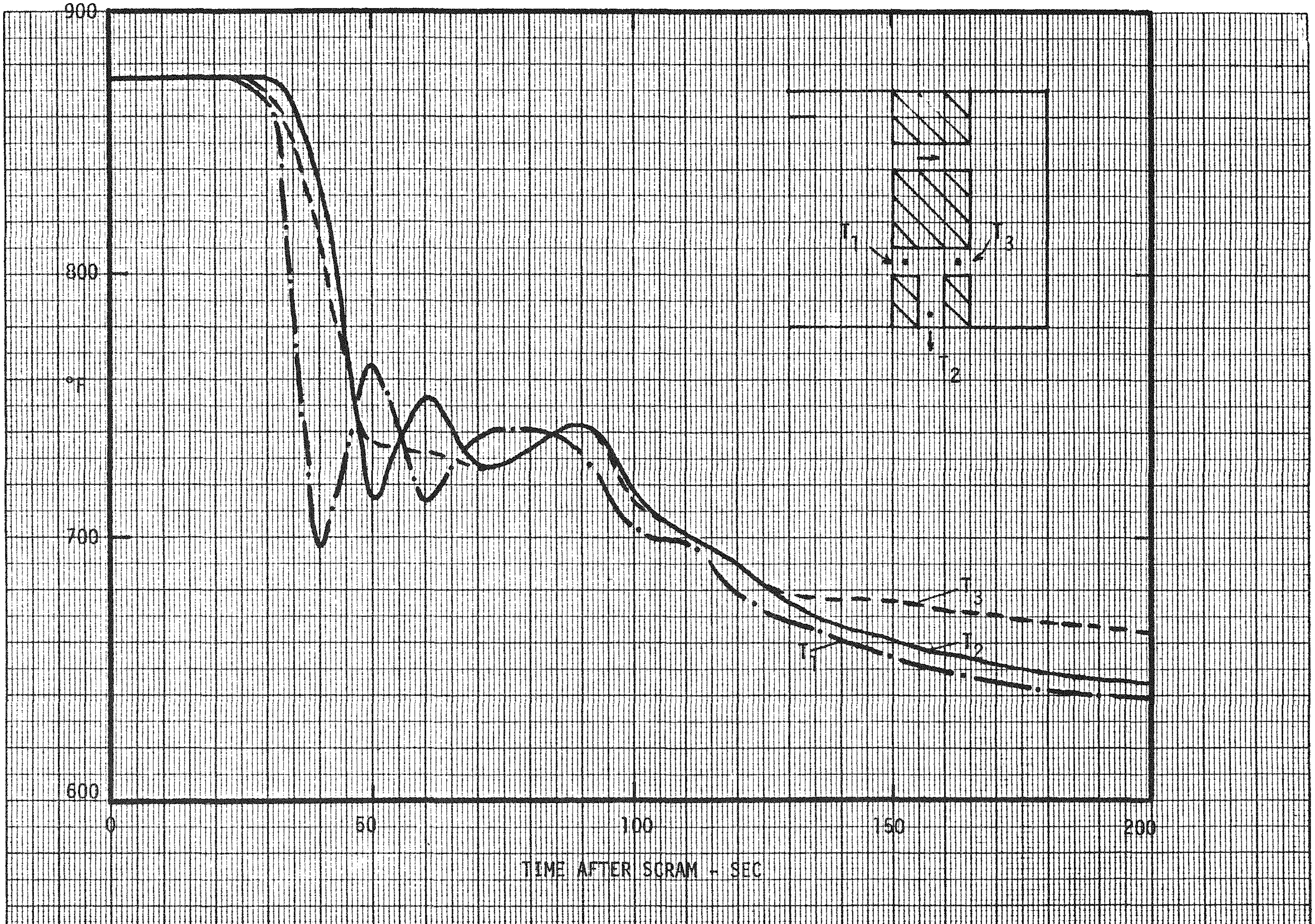



FIGURE 10 - IHX INLET TEMPERATURE; PUMP TRIP TO 50% FLOW

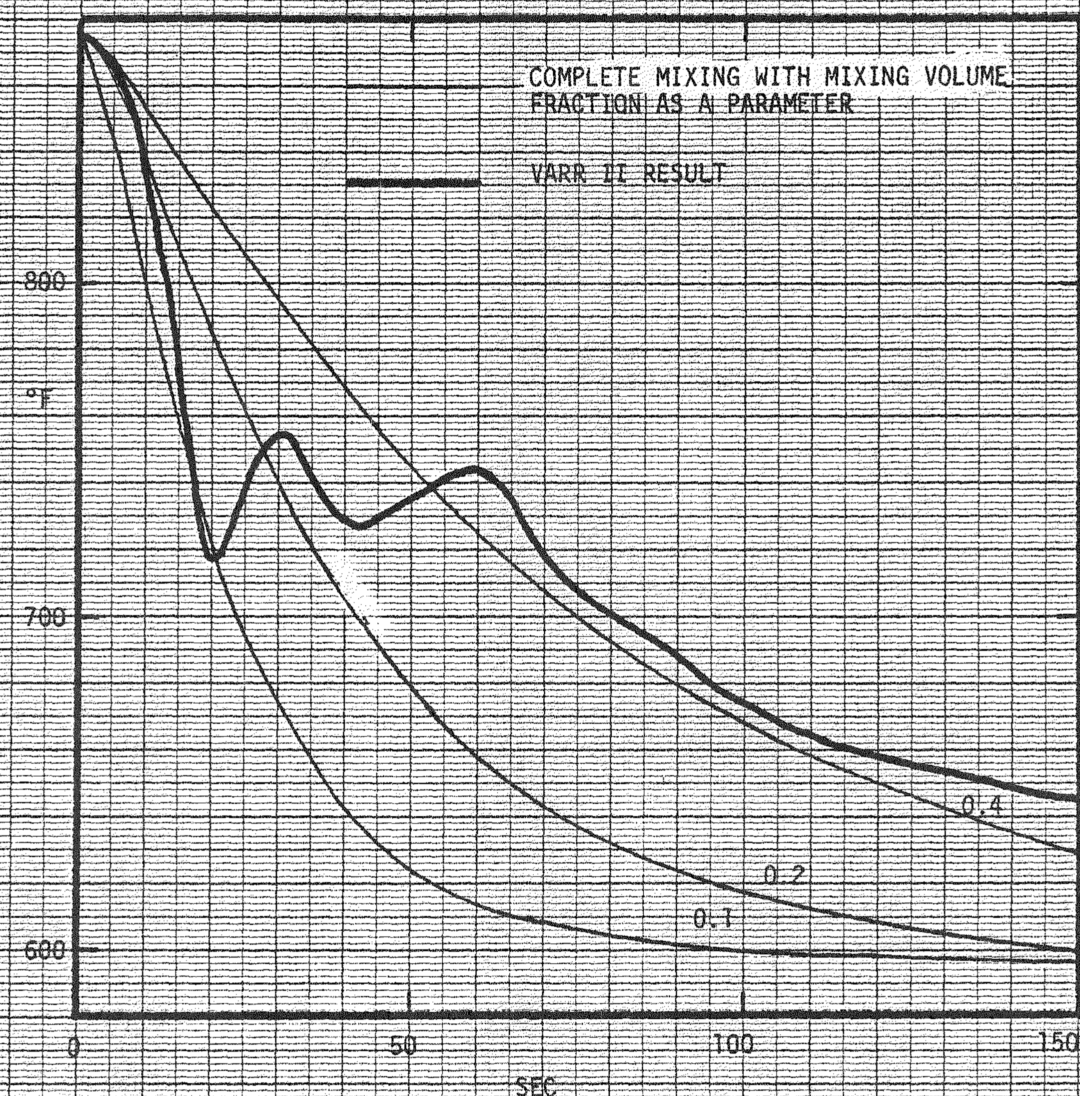



FIGURE 11 - COMPARISON OF IHX INLET TEMPERATURE CALCULATED BY VARR II WITH PERFECT MIXING RESULTS (50% FLOW)

Appendix VA

# Preliminary Design of an Alternate Bent-Tube IHX for the 1000 MWe Pool Reactor

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NOTATIONS IN THIS COLUMN INDICATE WHERE CHANGES HAVE BEEN MADE

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## LIST OF FIGURES

TABLES

## 1. INTRODUCTION

Foster Wheeler has previously completed a 2 1/2-month preliminary design effort on an intermediate heat exchanger (IHX) for a 1000 MWe pool reactor plant. The IHX was a straight tube design with primary sodium inside the tubes and intermediate sodium in the shell. This work was summarized in Foster Wheeler report ND/77/56 dated 10/12/77.

The above work was extended for an additional three months to make a comparative study on a bent tube IHX which would meet the same design requirements as the previous straight tube IHX. The design features in the bent tube unit are similar to those which were used for the British PFR and are being proposed for CFR. These features include a double sine-wave bend in each tube, an internal bore weld between the tube and tubesheet, and a grid-type support plate.

This report describes the bent tube heat exchanger and discusses the structural and thermal/hydraulic design with particular emphasis on seismic and scoping transient analysis. Comparisons are made between the straight tube and bent tube heat exchangers based on technical considerations and cost.

## 2. MECHANICAL DESIGN

### 2.1 Introduction

The design layout for the bent tube IHX is shown on FWEC drawing 51-3145-6-2000, which is included at the end of this report. The tube bundle in this design incorporates the design features that have been proposed for the British CFR-IHX. These features have been changed to the minimum possible extent in order to meet the requirements of the GE design conditions. Figure 1 compares the major design features of the present bent tube IHX with the straight tube IHX which is described in Reference 1.

The IHX described in this report is designed for operation in the vertical position within a sodium pool. It includes a removable bundle which is supported by a hanging support that is located at the top of the IHX. The tube bends provide the required flexibility to accommodate the thermal differences between the shell and tubes of this sodium-to-sodium fixed tubesheet heat exchanger.

### 2.2 Design Description

The IHX is suspended within the sodium pool which surrounds the reactor. In place of a pressure boundary type shell, a cylindrical sleeve is provided as part of the reactor vessel internals. The sleeve is a permanent part of the reactor vessel and consists of an upper and lower section with an axial space between sections for primary sodium entry from the hot sodium pool. The primary sodium flows upward in the annulus between the sleeve and tube bundle, turns 90° to pass through flow openings in the support cylinder, passes over the IRACS coil, flows downward through the tubes, and exits through the bellows seal into the cold pool. The intermediate sodium flows down through the central downcomer, makes a 90° turn through openings in the bundle shroud, flows upward through the shell side of the tube bundle, and exits to the outlet annulus below the upper tubesheet.

The upper half of the IHX contains the plug, shielding, and IRACS as taken from General Electric drawing AFS-SK-PE-002, Rev. 1. The removable plug contains radiation shielding which is gas cooled. The IRACS bundle consists of an 8 in. pipe helical coil with the inlet and outlet connections penetrating the plug. The coils will be supported to prevent damage due to vibrations and to restrain the coils against lateral seismic loads. The support design will be done at a later time.

The bundle support has been provided with a flanged connection to bolt the IHX to the deck. The bolting will be sized to accept the lateral and vertical seismic loads plus the pressure loads. The joint will be sealed with double metallic "O" rings with a tell-tale between "O" rings which can be monitored to determine leak tightness. A metal canopy can be welded to the outside of the flange diameter to provide a back-up welded seal. The use of this seal is optional as the double "O" ring seal should be adequate. The plug support has the same construction described for the bundle support and has the same sealing design.

2.2 Design Description (cont'd.)

A protective cover has been provided at the upper end of the IHX to minimize a potential sodium fire hazard in the event of an intermediate sodium pipe break. This cover is intended to be gas tight to contain the cooling gas which circulates within the cover.

The lower half of the IHX contains the tube bundle and the seal between the hot and cold sodium pools. The seal at the bottom of the IHX is a flanged spool cylinder with a double expansion bellows. The bellows absorb the thermal growth differential between the reactor shell and the IHX shell. A flow deflector mates to the flanged spool cylinder to direct the primary sodium flow as it exits into the cold pool.

The IHX tube bundle is removable and is supported from the reactor deck. The upper tubesheet is fixed and supported from the hanging support. The lower tubesheet is also fixed and welded to the cylinder between the tubesheets. The thermal growth differential between the cylinder and the heat transfer tubes is accommodated by the two bends in each tube.

The tubes are 7/8 in. diameter and are arranged on a circumferential pitch which is 1.309 in. in the circumferential direction and averages 1.250 in. in the radial direction. The tube arrangement is shown on FWEC drawing 51-3145-5-2001 which is at the end of this report. The 4860 tubes are arranged in six identical 60° segments. Each tube has a sine wave bend near the top of the bundle and an identical bend near the bottom of the bundle. These bends are similar to those proposed for the British CFR design. The tubes are attached to the tubesheets using full penetration internal bore welds (IBW) which utilize a machined spigot on the tubesheet face. The tubes fit into a socket on the spigot and are welded with a rotating welding head which fits inside the tube. The welding and inspection techniques would be similar to those used on the FFTF IHX with appropriate refinements which are derived from the CRBRP steam generator program.

The grid design for the tube supports is also shown on drawing 51-3145-5-2001. It is conceptually similar to the CFR IHX design, but the members have been strengthened for the seismic requirements as discussed in Section 4.1.3. The grid support assembly consists of an internal and external ring with radial spokes between rings. The spokes are equally spaced on 30° increments and alternate between straight bars and wiggley bars to fit the tube pattern. The grids which hold the tubes consist of press formed wedge-like members that contact the tube walls. These formed segments are spot welded to a segmental curved bar. The grid segments are positioned in an alternating pattern so that a tube at one level is displaced in the outboard direction by 0.07 in. and is then displaced in the inboard direction by an equal amount at the next higher or lower level. This arrangement results in lateral forces between the tube and the grid members which clamp the grid support to the tubes. The grid assembly is retained at the inner rim by a C-shaped ring that is welded to the outer wall of the central strongback cylinder. The C-shaped ring has an axial

2.2 Design Description (cont'd.)

clearance which permits the grid assembly to move up and down with the tubes. There is also an outer ring around the grid assembly to provide structural continuity between the inner ring, outer ring, and the radial members.

Each bundle section between tube support grids contains an inner and outer flow shroud. These shrouds have been provided to control the sodium flow and to prevent channeling between the inner and outer row of tubes at the shroud walls. These shrouds are suspended from the retaining ring on the strongback and the outer rings on the grid assembly. The lower end of the shrouds will be retained circumferentially but will be free to move in the axial direction to accommodate thermal growth differentials. Expansion bellows have also been provided for the thermal growth differentials in the upper end of the intermediate sodium outlet cylinder and the double wall sodium inlet downcomer.

A piston ring between the intermediate sodium double wall liner and the intermediate sodium downcomer is located at the lower end of the intermediate sodium downcomer. The purpose of the piston ring is to minimize the by-pass flow of intermediate sodium.

A thermal barrier of argon gas in the annulus between the double walls of the intermediate sodium downcomer liner protects the double walls from the temperature gradients that exist as well as to minimize regenerative heat transfer effects on the intermediate side.

Lateral restraints at strategic locations between concentric cylinders prevent excessive vibration. A lateral restraint at the lower tubesheet takes the seismic forces. The seismic loads at this location will be transmitted to the pool structural steel which must be designed to accept these loads.

Drainage of intermediate sodium will be provided by the insertion of a suction tube to drain out the intermediate sodium pool below the lower tubesheet. Vents and drains will be provided as required.

2.3 Maintainability

2.3.1 In-service Inspection of Heat Transfer Tube

The IHX has been designed so that the shield plug including the auxiliary cooling bundle can be removed from the IHX shell by cutting and intermediate sodium outlet pipe directly below the expansion bellows and by breaking the upper pipe connections. Once the plug is removed, accessibility to the upper tubesheet for in-service inspection of the tubes is provided.

We have reviewed the HEDL Report HEDL-TME-75-29 entitled "In-service Examination of IHX Tubing with Eddy Current NDT Equipment" and have concluded:

2.3.1 In-service Inspection of Heat Transfer Tube (cont'd.)

1. It is entirely feasible to design remote tube probing equipment, a concept which is shown in Figure 2.

2. No eddy current examination method was found to avoid the signal from residual sodium on the inside surface of the tube.

It appears that the IHX bundle must be removed from the sodium pool and be decontaminated before the tube inspection can be performed. Further study and development is required before a tube inspection procedure can be recommended.

2.3.2 Tube Plugging Procedure

FWEC has developed a tube plugging mechanism for straight tubes that can be remotely activated. This mechanism which operates as a linkage device can be passed through (from top tubesheet to bottom tubesheet) a pre-selected tube; make a 90° turn; and engage the tube that is to be plugged in the lower tubesheet. The device places an explosive tube plug in the tube; the plug is detonated; and the handling device is then retracted. The products from the explosive plug are contained within the plug. Plugging of the tube in the upper tubesheet can be performed in the same manner except that the linkage device is not required.

Further development is required to determine if the FWEC tube plugging mechanism can be modified to pass through a bent tube. Further development is also required to determine the feasibility of using an explosive tube plug in a sodium environment which represents the condition in the pool type IHX. The other course to follow is to remove and decontaminate the bundle and use a conventional welded or explosive tube plug.

2.3.3 Bellows Removal

The expansion bellows located in the upper end of the intermediate sodium outlet cylinder can be removed by making two circumferential cuts in the upper outlet pressure boundary. The first cut will be directly below the bellows separating it from the intermediate sodium outlet nozzle. The second cut will be made in the cylinder connecting the shield plug to the intermediate sodium outlet nozzle. Additional cuts will be necessary to break the upper pipe connections. The auxiliary cooling inlet-outlet nozzle should be located in the maximum outboard direction to provide enough radial space for the cutting tool.

FWEC has made a detailed conceptual maintenance study for the bellows removal and replacement for the CRBRP-IHX contract. This study has concluded that maintenance of the bellows can be made without difficulty provided that the proper tooling is available.

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## 3. THERMAL HYDRAULIC ANALYSIS

### 3.1 Thermal Performance

The thermal design and performance requirements for the bent tube pool IHX are shown in Table 2. The bent tube pool IHX design utilizes 7/8" O.D. stainless steel tubing with a circumferential pitch of 1.3096" and an average radial pitch of 1.2504". The 10' 3" diameter limitation can accommodate a total of 4860 tubes.

A summary of thermal sizing of the bent tube IHX is shown in Table 3. A 90% confidence level is sought for the heat transfer coefficients and tube material properties using the RSS method. The heat transfer coefficients used in this analysis are the same as those given in Reference 1. The partially inactive regions due to the tube support plates and the inlet and exit bundle region are added to provide additional conservatism. The total tube length including the bends is 25.09 feet. The distance between tubesheet faces is 24.45 feet. The overall thermal design margin is about 18%.

### 3.2 Hydraulic Performance

#### 3.2.1 Tube Side Pressure Drop

In this design, the primary sodium is on the tube side. The pressure drop on the primary side is limited by the difference in levels between the hot and cold side, which is about 5.5 feet of sodium (2 psi equivalent). A summary of tube side pressure drop of the bent tube pool IHX design is shown on Table 4. The pressure loss is due mainly to frictional and other losses in the tubes and in the exit passage. The total pressure loss on the primary side from nozzle to nozzle is estimated to be 3.2 psi which is above the allowable loss of 2 psi. Note that the pressure drop in the exit passage is calculated based on the GE-supplied configuration. Redesign of this exit passage may reduce the overall pressure drop to 6.3 ft of sodium (2.28 psi) if the duct diameter is increased twice the present diameter.

#### 3.2.2 Shell Side Pressure Drop

The total shell side pressure drop from the inlet nozzle to the outlet nozzle is calculated to be 13.1 psi. The flow distribution in the tube bundle is essentially axial except at the inlet and exit bundle regions. The pressure drop through the support grids (with about 70% perforation) is small. The shell side pressure drop is summarized in Table 5.

#### 3.2.3 Flow Distribution in the Shell Side Inlet Region

The flow distribution in the shell side bundle inlet region requires particular attention. The flow distribution in the area is essentially the axial/cross flow type. A sufficient quantity of the cold fluid must be allowed to penetrate to the outer edge of the bundle so that uniform axial flow can be achieved. Flow maldistribution in this region will affect the overall performance of the unit. For a pool type IHX, the thermal transi

3.2.3 Flow Distribution in the Shell Side Inlet Region (cont'd.)

effects will be most severe in the lower tubesheet area. Severe flow maldistribution in this area will create a large thermal gradient which can affect the structural integrity of the lower tubesheet region.

The flow distribution in the lower entrance region was analyzed using the COMMIX computer code. This code solves the complete Navier-Stokes equations. Turbulent effect is taken into account through the use of the effective diffusivity as given by Dwyer for rod bundles (Reference 2). Only the lower two spans of the tube bundle were modeled.

The velocity vectors at full load are shown in Figure 3. Analysis indicates that a flow maldistribution of about ±17% is found after the first baffle. This is reduced to ±4% after crossing the second baffle. This implies that the assumption of uniform axial flow may be valid after the second baffle plate.

At 12% shell side mass flow rate, essentially the same degree of flow maldistribution is found in the bundle inlet region.

3.3 Temperature Distribution in Tube Bundle

3.3.1 Tube Bundle Temperature Distribution at Full Load

In order to insure that the tube-to-tube temperature differential of the present design is within the acceptable level, the temperature distribution of the IHX tube bundle was investigated using an axisymmetric, two-dimensional (r-z), thermal performance code. In this investigation, uniform axial flow distribution was assumed from the first to the last baffle plate on the shell side. Primary side flow was assumed to be equally distributed among all tubes. Figure 4 shows the radial temperature distribution across the tube bundle at three different axial locations; namely, the shell side entrance region, middle of the bundle, and the exit bundle region. The intermediate temperature difference in the inlet region between the outermost tube and the innermost tube location is about 73°F. This is due to the cross flow effect at the entrance region. The temperature near the outer radius is higher. This radial temperature differential will decrease towards the shell side exit region. In the exit region, the hotter shell side sodium near the outer radius will flow towards the inner radius, thus mixing with the colder sodium. The temperature difference becomes negligible at the exit region.

Figure 5 shows the length averaged radial temperature distribution. The average tube bundle temperature is found to be about 712°F. The coldest tube is found near the inner bundle radius. These temperatures have been used for structural evaluation of heat transfer tubing.

### 3.3.2 Temperature Distribution in the Shell Side Inlet Region During Intermediate Loop Loss Transient

During this transient event, the intermediate sodium flow drops from 100% full flow to 12% flow. This 12% intermediate flow is maintained by the pony motor and natural circulation. The primary side flow remains at 100% flow during the entire transient. The time response of the overall IHX is shown in Figure 6. The monotonic behavior of the temperature response indicates that the most severe thermal gradient will occur at the steady end of the transient event (about 3 minutes into the transient). The temperature distribution at this point was investigated.

The steady-state two dimensional axisymmetric thermal program was used to examine the temperature distribution of the whole bundle. Uniform axial flow velocity was assumed except in the inlet and outlet bundle regions on the shell side where crossflow exists. On the intermediate side, sodium enters the bundle at 550°F and $2.43 \times 10^6$ lb/hr (12% of full flow). On the primary side, 100% flow enters at 850°F. Results indicate that heat transfer takes place mainly in the first span in the intermediate inlet region. The shell side sodium temperature reaches 850°F after the first two lower spans. The largest thermal gradient can be found near the lower tubesheet. The radial temperature distribution at the lower tubesheet area is shown in Figure 7. If we assume that the tubesheet will take essentially the same temperature as the primary outlet sodium, the average tubesheet will have a temperature of about 815°F. The primary sodium temperature out of the innermost tube is about 699°F.

### 3.4 Thermal Sizing for 9' 3" Straight Tube IHX

For the purpose of cost comparison, a 1" OD straight tube unit was sized to fit into the 9' 3" diameter limit (as compared to 10'3" in the reference straight tube design). In order that the primary side pressure drop is kept within the 7 ft sodium limit, the pitch must be reduced from the 1.4" given in Reference 1 to 1.28" so that sufficient tubes can be packed into the 9' 3" limit. The design conditions are the same as that shown in Table 2. Table 6 summarizes the thermal sizing of this unit. Note that the pressure loss includes only the frictional plus the inlet and exit loss through the tubes. Because of the smaller pitch, the shell side pressure loss is also expected to increase.

### 3.5 Comparison - Straight Tube vs. Bent Tube Design

One of the major differences between the straight tube and the bent tube design is the ability of the latter to take large $\Delta T$ between tubes. In the straight tube design, considerable attention must be paid to the proper design of the flow baffle/support plate to induce cross/axial flow on the shell side of the unit in order to cut down on the tube temperature differential if tubes must be plugged. In the bent tube design, the shell side

3.5 Comparison - Straight Tube vs. Bent Tube Design (cont'd.)

flow is essentially axial except in the inlet and exit bundle regions. Because crossflow is minimum, the pressure loss on the shell side tends to be much smaller for the bent tube design in comparison to the straight tube design. Due to the presence of bends, the tube side pressure drop will be larger for the bent tube design.

In the bent tube design, the flow baffle at the entrance region of the intermediate side is critical. Since there is very little crossflow, any radial temperature differential that is created at the entrance region will persist all the way to the exit region. If severe flow maldistribution is present at the inlet region, overall thermal performance will suffer.

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# 4. STRUCTURAL ANALYSIS

## 4.1 Component Sizing

### 4.1.1 General Pressure Boundary Sizing

The tubes, shells, and heads were preliminarily sized for the load-controlled conditions of seismic loading, using simplified hand calculation methods. It was found that the bundle inner and outer cylindrical shells, as well as the outer hanger shell, are critical for seismic loadings. Initial calculations indicated the potential need for one intermediate seismic support at the upper tubesheet elevation in addition to the existing supports at the top (hanger) and bottom (lower tubesheet) of the IHX. This seismic requirement was refined in Section 4.2 below by means of an ANSYS computer analysis. The results of that computer analysis showed that by thickening the bundle inner shroud to 1 1/4", only one (lower) support is required. Also, a 1" thickness for the hanger and outer cylinder shells was found to be adequate, based on the ANSYS seismic results.

For the same unit weight and seismic response spectrum ('g'-loadings), the straight tube unit would require the same cylinder and hanger shell thicknesses as the bent tube unit.

Pressure loadings were found to be the controlling condition for sizing the lower hemi-head of the lower tubesheet. This head requires a minimum pressure thickness of 0.15" for the controlling PLBR emergency condition (Table 7). However, in order to reduce lower tubesheet rotations during pressure load conditions, minimum thickness of 1/2" was used for the lower hemi-head of the bent tube IHX unit. This thickness could be somewhat reduced for the straight tube unit because the lower tubesheet would require less support from the head because of the straight tube "staying" action on the tubesheet.

The 7/8" OD x 0.0394" minimum wall tubes were verified to be structurally adequate for the controlling external pressure of 250 psi (Table 7) based on the ASME B & PVC Section III buckling criteria. The above specified minimum tube wall thickness includes a 0.005" scratch allowance and a 0.002" corrosion allowance (total allowance = 0.007"). An investigation into the tube deflections in the bend region due to the temperature differential ($\Delta T$) between a plugged tube and its neighbor showed that the $\Delta T$ which would cause tube touching is 47°F. This value includes an allowance for manufacturing tolerances ($\pm$1/16 in. on each tube) and the elastic tube deflections. The maximum $\Delta T$ between a plugged tube and its neighbor must be calculated in order to assess if tube touching will occur due to a plugged tube. The thermally induced stress in the tube bend region due to differential temperature between the tubes and the bundle shells was calculated to be 82 psi/°F of temperature differential using the tube model of Figure 19. This stress value indicates that the stresses in the tube bends are low.

### 4.1.2 Tubesheets

Hand calculation sizing of the upper and lower tubesheets for the PLBR bent tube IHX unit resulted in the following thicknesses, based on the criteria of Table 7 and the perforated ligament properties of Table 8.

| | Upper Tubesheet | Lower Tubesheet |
|---|---|---|
| PLBR (Bent Tube) | 11" | 12" |

The lower tubesheet requires greater thickness than the upper tubesheet because it has support only at the OD with a pressure blow-off load at the hemi-head of the inner diameter of the lower tubesheet. The upper tubesheet utilized the controlling emergency condition from Table 7, 250 psig sodium water reaction for the hot end of the unit. The lower tubesheet at the cold end of the unit was also sized by the controlling emergency condition but with a higher $S_m$ allowable stress at the lower temperature. The stress multiplier of 2.8 and the equivalent Poisson's Ratio ($\mu$*) and modulus of elasticity (E*) were utilized in the stress calculations to size the tubesheet thickness.

The tubesheet thickness hand calculations used annular plate formulae with no rotational support assumed from the cylinder attachments and the tubes. For the bent tube unit, the tubes offer no significant axial support to the tubesheets. However, for the straight tube unit, the tubes themselves will lend staying action to the tubesheets, resulting in a reduction of the calculated bent tube unit tubesheet thicknesses. Because buckling is of concern for straight tubes, the straight tube unit tubesheet thicknesses would have to be increased somewhat in order to reduce the tubesheet rotations. These two effects of straight tube staying action and tube buckling considerations tend to offset each other, resulting in similar tubesheet thicknesses for bent and straight tube designs.

An ANSYS finite element model of the lower tubesheet was generated to verify the above load-controlled hand calculation thickness sizing and to analyze for the critical PLBR intermediate loop loss transient. Figure 8 presents the ANSYS finite element model of the lower tubesheet using ANSYS element STIF No. 42, which is an axisymmetric quadrilateral isoparametric structural element. Figures 13 and 14 are enlarged plots of the inner crotch and outer junction regions. The 12" lower tubesheet thickness and other model dimensions are shown in Figure 8. The applied pressure loading is shown in Figure 9; the model was run for the 250 psig sodium water reaction emergency pressure (see Table 7). The pressure at the perforated ligament region of the tubesheet was reduced by the percent solid factor of 0.64, based on the averaged rectangular and triangular pitch patterns ($\eta$ average = 35.5% $\cong$ .355). The ligament region properties used in ANSYS were factored as indicated in Table 8.

4.1.2 Tubesheets (cont'd.)

Table 9 presents the lower tubesheet load-controlled stress summary for the seven (7) cross sections indicated on Figure 9. The FWEC in-house ANSYS Post-Processing Computer Program N2050 was utilized to linearize the ANSYS two-dimensional model stresses for ASME Section III Code evaluation. The critical linearized pressure stress results are presented in Table 9, which shows that the 12" thick lower tubesheet is structurally adequate. The minimum margin of safety is noted to be +0.12 (Table 9) at Section 6, which is in the crotch region at the inside of the lower tubesheet. This controlling stress at Section 6 (and Section 2 outer junction) is conservatively compared with the $P_L + P_B$ allowable stresses, although the stress is at a discontinuity and could be classified as $P_L + Q$. The perforated region stresses at Section 3, 4, and 5 (Table 9) are appropriately factored up by the stress multiplier of 2.8 and the biaxiality K factor in accordance with the procedure of Article A-8000 of ASME Section III Code.

The 12 inch thickness for the lower tubesheet is therefore structurally adequate for the load-controlled sizing conditions.

4.1.3 Tube Support Grids

The recommended grid configuration and grid member dimensions are shown in FWEC drawing 51-3145-5-2001 which is included at the end of this report. The recommendations are based on the structural analysis performed on the grids for a unit seismic ('g') loading in both horizontal and vertical directions. The structural analysis was performed using a 180° equivalent 2-D beam ANSYS model (Figure 17). For the horizontal seismic loading a contact area of 120° was assumed on the inside surface. The properties of the beams in the circumferential direction represented the combined stiffness of the circumferential rings, wiggley bars, and the tubes. These properties were determined from unit load cases run on the ANSYS model shown in Figure 18. The analysis results indicated that the original grid design was severely overstressed. This necessitated the use of a wiggley bar between each radial spoke to decrease the spacing to every 30° in addition to increasing the width and depth of the circumferential rings, original radial spokes, and the new wiggley bar grid. In addition to the above modifications, a 1.0 inch thick ring at the outer perimeter of the grid was required to obtain the acceptable stress levels. These changes in the grid thicknesses required a slightly larger radial and circumferential tube pitch compared to the proposed British design.

4.1.4 Tube Flow Induced Vibrations

The bent tubes on the pool IHX are exposed to cross flow at the bundle entrance and exit regions and also through the upper and lower bend regions. This sodium flow across the tubes can give rise to vortex shedding

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4.1.4 Tube Flow Induced Vibrations (cont'd.)

and flow-induced vibrations of the tubes. In order to determine if there is a tube resonance problem, the natural frequencies of the tubes were calculated using the ANSYS computer program and the tube model shown in Figure 19. The model consists of 22 pipe elements, with only half the tube length modeled. A pinned end condition was taken at the tube mid-length and a fixed end condition modeled at the tubesheet. In order to bound the problem, two runs were made. The first assumed a pinned condition at the support plates. The second assumed a fixed condition (no rotation or translation) at the support plate locations. In all cases, the mass of the sodium inside the tube and the entrained fluid outside the tube were lumped with the tube mass. The natural frequencies and mode shapes for the first modes in the bend and inlet region are shown in Figure 20 for each of the two cases.

The vortex shedding frequencies were then calculated in the bundle entrance and exit regions using the fluid velocities and worst case tube pitch pattern. The vortex shedding frequency is calculated to be a maximum of 91 cps in the entrance region and 17 cps in the bend regions. It is good engineering practice to assure that the natural frequencies of the tubes that might be excited by the entrance and exit flow should be 50% higher than the vortex shedding frequencies. It can be seen that even the tube natural frequencies with fixed supports at the plates are marginal with respect to this 50% criteria. Since the fixed condition at the support plate gives an upper bound on the tube's natural frequency, it is concluded that the tube vibration amplitude must be demonstrated to be small by test. The 50% criteria on tube natural frequency is a good bounding calculation which assures no resonance. Since the FWEC calculations cannot satisfy this critieria, it is recommended that a flow test be performed to qualify the tubes.

4.2 Seismic Analysis

The seismic analysis performed was a response spectrum type analysis using the SSE horizontal spectrum supplied as part of Appendix 'A' of the General Electric specification. The IHX structure was modeled using ANSYS elements STIF 61 and STIF 21 (Figure 21). These elements are two dimensional harmonically loaded shell and two dimensional mass elements, respectively.

Most of the shell stiffnesses were modeled in a straightforward manner by inputting the appropriate thickness and radii. However, certain areas like tubesheets and cut-outs in the shells were modeled with equivalent material properties to account for the reduced stiffness. Tube bundle stiffnesses and non-linearities, such as sliding friction and gaps, were ignored in the present analysis.

4.2 Seismic Analysis (cont'd.)

The mass modeling of the PLBR-IHX was performed to include all fluid and metal parts. Fluid masses were included by inputting equivalent densities to those metal parts postulated to be responsible for controlling the motion of various portions of the fluid. Weight of the tube bundle and sodium in the bundle was input as lumped mass elements at the inner shroud corresponding to tube support grid locations.

Results of the seismic analysis using the original geometry and the existing supports at the top (hanger) and bottom (lower tubesheet) indicated that resulting loads at the inners shroud were unacceptable. Two alternate approaches were explored to reduce the loads in the inner shroud to acceptable levels. The first approach involved the use of an intermediate seismic support at the upper tubesheet elevation, whereas the second approach involved increasing the inner shroud thickness. Both approaches reduced the seismic loads to acceptable levels, but the reduction was more significant when the inner shroud thickness was increased to 1.25". In addition, increasing shroud thickness is preferable to adding an additional seismic support at the upper tubesheet level.

The seismic loadings on the major load carrying members for the straight tube design will be similar to those of the bent tube design. It is judged that the seismic support requirements of the bent and straight tube designs will be the same.

4.3 Transient Analysis

4.3.1 Transient Selection

A qualitative comparative evaluation of the PLBR-IHX transients with the CRBRP-IHX transients was conducted. This comparison indicates that the PLBR upset transient "Loss of One IHTS Loop without Scram" is less severe than the controlling CRBRP-IHX emergency transient (Sodium-Water Reaction). The effect of transient conditions on the lower tubesheet is evaluated below using the ANSYS axisymmetric model of Figure 8.

The PLBR loss of loop transient is the more critical of the two transients specified for the pool IHX. This controlling upset transient causes a significant upshock in primary outlet temperature at the lower tubesheet. The upper tubesheet is unaffected by this transient but is downshocked by the reactor scram upset transient. However, the effect of this scram transient on the upper tubesheet is judged to be less severe than the effect of the intermediate-loop-loss upshock transient on the lower tubesheet.

Thus, the bounding transient analysis for the pool IHX is the PLBR loop-loss upshock transient on the lower tubesheet (without scram). This upset transient is specified to occur 50 times.

4.3.1 Transient Selection (cont'd.)

This upshock transient causes a monotonic increase of primary sodium temperature at the lower tubesheet due to a sudden reduction of flow of the intermediate coolant fluid from full flow to 12% flow in about 2 minutes (120 seconds). The OD of the tubesheet monotonically increases to a higher temperature than does the ID of the tubesheet due to the reduced intermediate fluid cross flow. The primary outlet temperature variation in the radial direction is about 150°F, and the intermediate fluid temperature radial variation across the tubesheet diameter is about 300°F (see Figures 10 and 11). The transients remain at this quasi-steady state condition for a long period of time, thereby retaining this "worst-case" radial temperature gradient across the tubesheet diameter. Therefore, to perform the thermal transient analysis, only this quasi-steady state condition need be evaluated as it bounds the stresses that exist in reaching this condition.

4.3.2 Thermal Computer Analysis of Lower Tubesheet

Figure 10 presents the lower tubesheet ANSYS thermal model and thermal boundary conditions. The model utilizes the STIF 55 element for the metal and sodium annulus gap between the inner head and lower hemi-head of the tubesheet. The STIF 55 element is an axisymmetric quadrilateral element which is the thermal equivalent of the structural element STIF 42.

Since the perforated region of the tubesheet cannot be modeled by equivalent thermal properties, a separate ligament model was generated to calculate the nodal temperatures in the perforated region (see Figures 15 and 16). The ligament model utilizes the same STIF 55 thermal element as the lower tubesheet. The ligament model is axisymmetric about the tube hole centerline of the tubesheet and extends to an average pitch radius between tube holes. See Figure 15 for dimensions of the ligament model and Figure 16 for the thermal boundary conditions.

The first step of the thermal analysis utilizes the ligament model of Figure 15 to generate perforated region nodal metal temperatures from the thermal boundaries of Figure 16. The ligament model was analyzed to simulate about six (6) radial locations across the tubesheet using the thermal hydraulic boundary conditions in order to capture the primary and intermediate temperature gradients across the tubesheet diameter.

The resulting metal temperatures of the ligament model were next imposed on the nodes of the perforated region of the axisymmetric tubesheet model (Figure 10) in order to obtain the radial metal temperature distribution shown in Figure 11. It should be noted that the ligament model metal temperatures were primarily dictated by the primary fluid flow through the tubesheet holes because of the much greater exposed area of the ligament to the primary fluid. The intermediate fluid at the top surface of the ligament model (top of tubesheet) showed almost negligible influence on the perforated region metal temperatures. The forced ligament model temperature (Figure 11) along with the quasi-steady state thermal boundary conditions of Figure 10 were used to generate metal temperatures for use in a thermal stress solution of the lower tubesheet.

4.3.2 Thermal Computer Analysis of Lower Tubesheet (cont'd.)

Figure 12 presents the critical thermal stress cross sections and controlling element surfaces for the linearized and peak surface extrapolated thermal stresses presented in Tables 10 and 11, respectively. Figures 13 and 14 show enlarged views of the inner crotch and outer junction regions of the lower tubesheet, respectively, with the selected thermal stress cross sections and elements indicated. The FWEC in-house ANSYS post-processor program N2050 is used to calculate the linearized and peak surface thermal stresses for ASME Code evaluation. Tables 10 and 11 present the linearized and peak thermal stresses for the cross section indicated in Figure 12. The stresses at cross section 3 in the perforated region of the tubesheet (Figures 12 and 13) include the stress multiplier of 2.8 ($1/\eta$ = 1/.355 from Table 9) and the biaxiality K = 1.1, as required by Article A-8000 of ASME Section III for perforated plates. The maximum linearized surface stress range is 53,499 psi from Table 10, occurring at element 319 of Section 4, which is located at the inner crotch region of the tubesheet (see Figures 12 and 13). This stress is predominately caused by the thermal discontinuity between the thin head and the tubesheet. The maximum peak surface stress is 60,094 psi from Table 11, occurring at element 309 of Section 5, which is located at the top ID of the tubesheet (see Figure 12).

The stresses documented above exceed Code Case 1592 limits using elastic analysis methods. Thus, an inelastic analysis is required to show structural adequacy of the lower tubesheet junctions. The controlling parameters in the inelastic analysis are expected to be fatigue damage. Creep damage and accumulated strain (ratchetting) will not be critical. FWEC experience with the CRBRP-IHX lower tubesheet regions indicates that this PLBR-IHX lower tubesheet will have a high probability of success in meeting the Code limits upon performing an inelastic analysis.

The thermal analyses presented above for intermediate loop loss transient is a condition in which the primary fluid upshocks. At all times the primary fluid temperature exceeds the intermediate fluid temperature. Since fatigue damage has been identified as critical for the lower tubesheet, all transients which can increase the stress range must be evaluated. This means that transients must be identified in which the intermediate fluid temperature exceeds the primary fluid temperature. If none of these transients exist, then it is judged that the lower tubesheet region will have a high probability of success in obtaining satisfactory fatigue damage upon performing inelastic analyses. If stress reversal transients exist, they must be identified and evaluated; and their stresses must be considered in the fatigue evaluation of the lower tubesheet.

The above thermal stress results indicate the possibility of eliminating the double head design at the lower tubesheet region. The purpose of the inner hemi-head is to shield the lower tubesheet hemi-head and crotch

4.3.2 Thermal Computer Analysis of Lower Tubesheet (cont'd.)

region from high temperature gradients ($\Delta T$). The quasi-steady state ANSYS thermal results for the intermediate loop-loss transient show that a $\Delta T$ of 40°F exists across the outer head. This 40°F temperature gradient produces only 10% of the total thermal stress (with 90% of the stress produced by discontinuity effects). The inner hemi-head absorbs about 90°F $\Delta T$, and the sodium annulus gap sees about 10° $\Delta T$. Thus, even if the total $\Delta T$ of 140°F (40°F + 90°F + 10°F) were taken by the lower tubesheet outer head at the crotch region, the additional thermal stresses created by the higher $\Delta T$ would be about 20,000 psi, giving a total linearized thermal stress range of about 80,000 psi. Assuming that there are no additional transients which can cause stress reversal, it is judged that a high probability of success exists in satisfying the Code allowables upon performing an inelastic analysis, with the inner hemi-head removed.

## 5. COSTS

### 5.1 Reduced Diameter IHX

In Reference 1, the straight tube IHX estimated cost was \$20.50 per KW(t) for a 485 MW(t) size unit. As part of the current work, the IHX was resized for a smaller tube bundle using the same size tubing and design requirements. This smaller size is discussed in Section 3.4 of this report. The significant dimensional differences between the two sizes are:

| | Original | New |
|---|---|---|
| Deck penetration diameter, ft | 10.25 | 9.25 |
| Number of tubes | 4,420 | 3,987 |
| Length of tubes between tubesheets, ft | 25.12 | 26.08 |
| Tube pitch, in. | 1.40 | 1.28 |
| Surface area, $ft^2$ | 29,052 | 27,208 |

The comparative cost of the new, smaller diameter IHX is estimated to be \$19.25 per KW(t). This cost includes the same factors that were used in Reference 1. The factors were 5% for tools and fixtures, 10% for engineering follow in the shop, 7.1% for G&A, and 12% for fee.

### 5.2 Cost of Design Features

The drawings of the straight tube and bent tube heat exchangers show different concepts for the roof plug, auxiliary cooling coils, and sodium hot-to-cold pool seal. However, it is possible to use either of the alternate designs in any combination with either the straight tube or bent tube design. Therefore, the cost differentials between straight and bent tube are confined to comparisons of specific design features within the tube bundle. It is assumed that all other costs would be comparable. Costs shown include G&A and fee.

Costs are divided into five areas as shown below:

a. Tubing

The straight tube unit uses 119,524 feet of 1 in. by 0.045 min. wall tubing while the bent tube unit has 132,305 feet of 7/8 in. by 0.040 in. min. wall tubing. There is a net cost decrease of \$33,785 for the tubing in the bent tube unit.

b. Tube Bending

The bent tube unit requires a double sine wave bend in each tube. The cost for labor to make the bends is \$280,000 which is an increase for the bent tube unit.

c. Machining Tubesheets

The bent tube unit has more tube holes. It will also require machined spigots on one face of each tubesheet. The cost increase for labor to make the upper and lower tubesheet in the bent tube unit is $216,150.

d. Support Structure

The 11 drilled support plates, tie rods, and spacers in the straight tube design are replaced by 7 grid supports in the bent tube design. The labor for making the support plates, etc. is $144,722 more than the grids.

e. Assembly

The differential cost in assembly includes the front face fillet weld versus the internal bore weld, the differences in support structures, and inspection procedures. The net difference is a $115,000 increase for the bent tube units.

The costs can be summarized as follows:

| Item | Bent Tube |
|---|---|
| Tubing Material | $- 33,785 |
| Tube Bending | +280,000 |
| Tubesheets | +216,150 |
| Supports | -144,722 |
| Assembly | +115,000 |
| Net | $+432,643 |

It is assumed that the balance of the material and labor costs will be the same for both designs. Therefore, the total cost increase for the bent tube design is $432,643 or $0.89 per KW(t). This represents a 4.3% increase from the straight tube design.

6. FUTURE WORK

The preliminary assessment of the bent tube IHX has indicated that it is a technically acceptable alternative to the straight tube IHX at a slight cost penalty. There are some ares which should be pursued in more detail to better define the bent tube design. These areas are:

a. Perform a transient flow and temperature distribution analysis in the lower tubesheet area as a function of time. The work to date has been for one instant in time which is assumed to be the worst case.

b. Perform a more detailed stress analysis of the lower tubesheet including a simplified inelastic analysis. It may be possible to eliminate the flow deflector at the outer row of holes in the lower tubesheet and to eliminate the double head at the lower end of the intermediate sodium downcomer.

c. Design the grid-type support plates to provide a non-uniform open area in order to optimize the intermediate flow distribution.

d. Review the overall system seismic response to define the inputs into the IHX to validate the proper coupling between the IHX and the system.

e. Refine the analysis of the intermediate sodium inlet and outlet regions to design the perforations in the downcomer so they will meet the flow and seismic requirements.

f. Perform a design analysis for the bellows.

g. Design the support structure for the IRACS.

h. Reduce the pressure drop on the primary sodium side by minor design changes (such as redesign of the exit passage or possibly removing one tube bend).

In addition to the analytical areas, a flow distribution model should be used to verify experimentally the analytical flow distribution predictions.

There are no areas which require additional development to support the fabrication of the bent tube IHX. If in situ tube plugging is considered at a later time, a concept must be developed which can be used with the bent tubes. Specific development programs for either the bent tube or straight tube design will be identified at a later date. At present, it appears that there are no significant differences in the magnitude of the development effort which would be required for either design.

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References:

1. "Preliminary Design of an Intermediate Heat Exchanger for the 1000 MWe Pool Reactor," FWEC Report No. ND/77/56

2. Dwyer, O. E. "Liquid Metal Heat Transfer," Brookhaven National Laboratory, Report No. BNL-11936R, Jan. 1969

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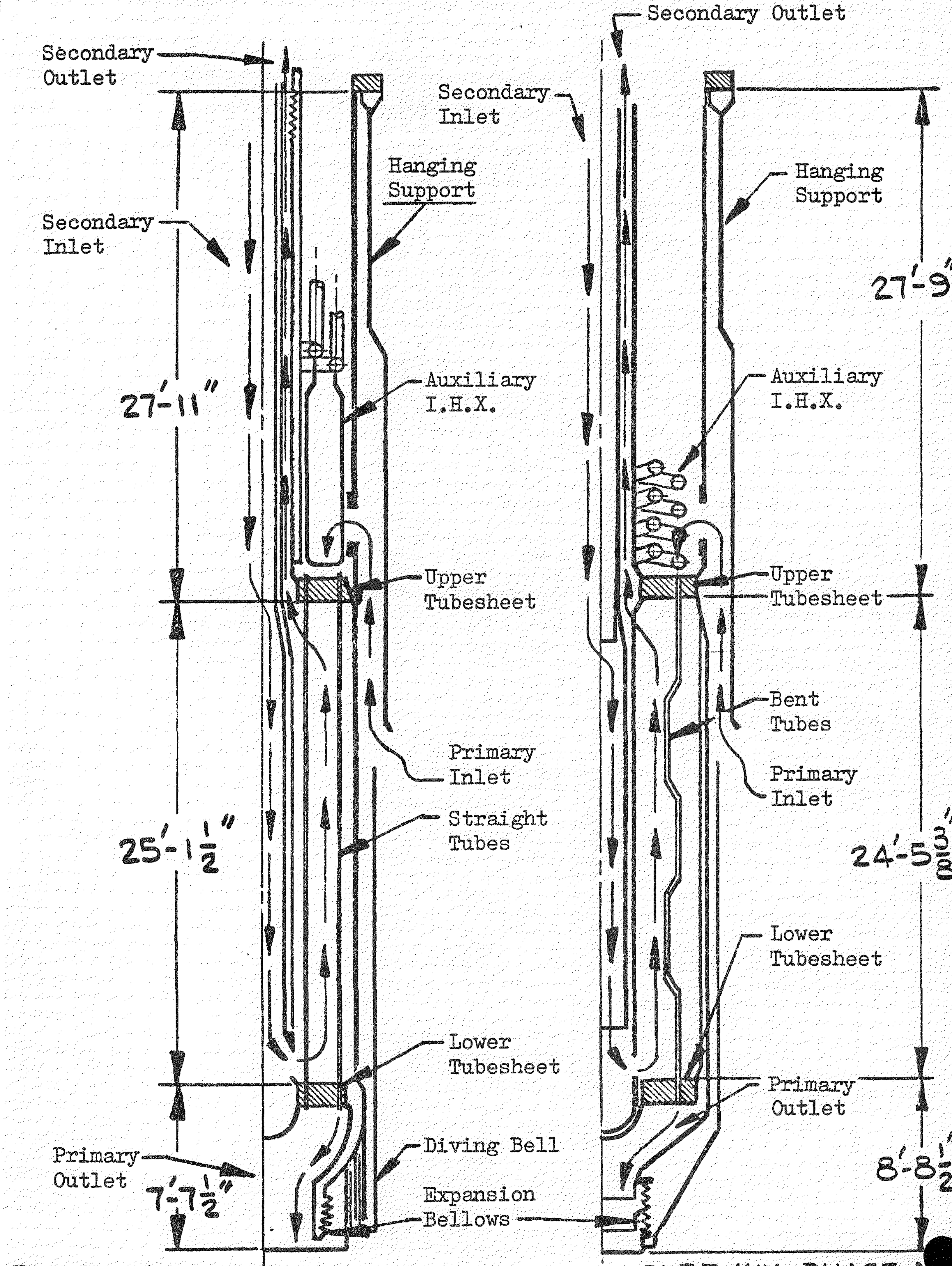


FIGURE 1 - COMPARISON OF IHX DESIGN FEATURES

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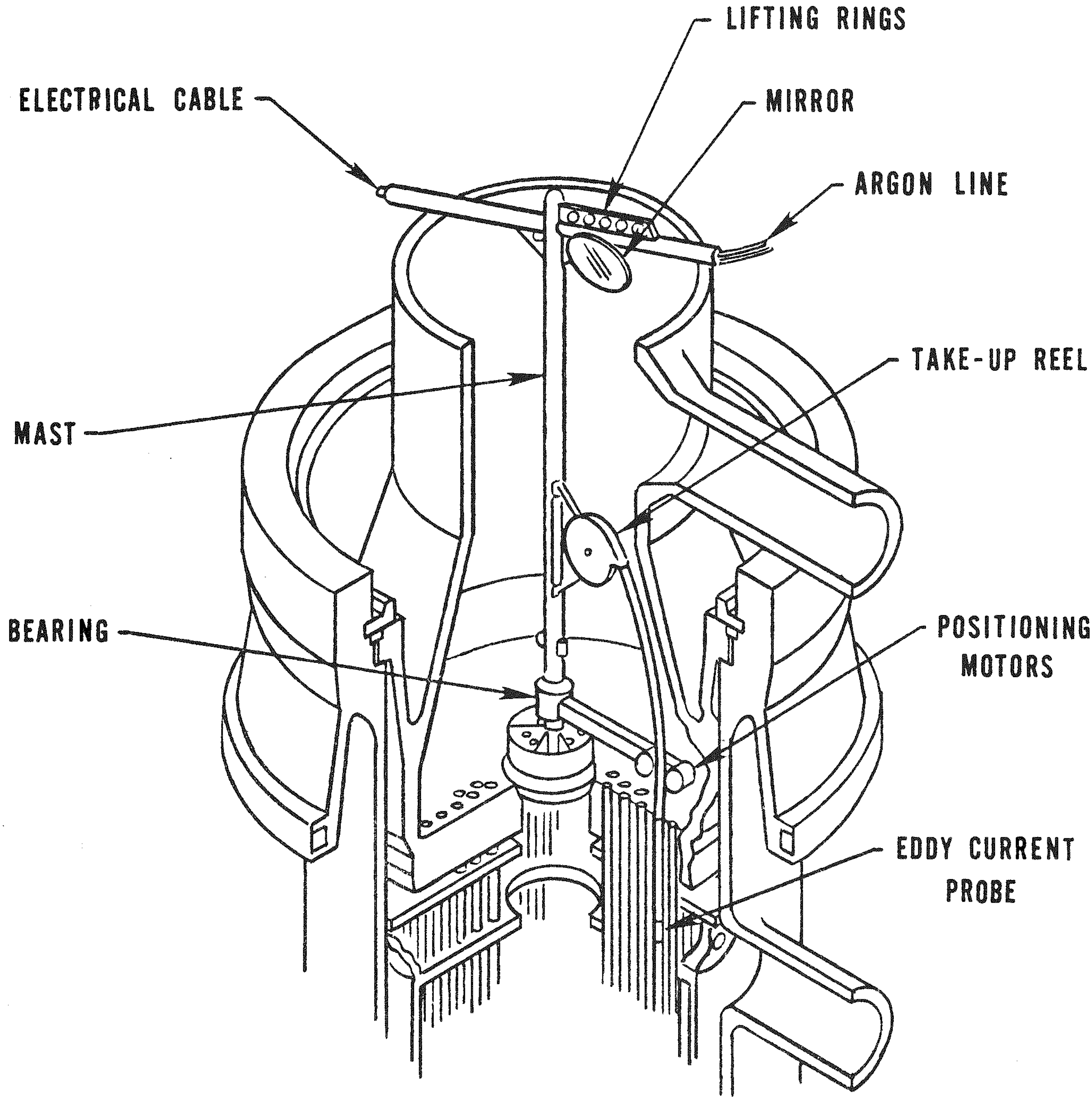


CONCEPTUAL REMOTE TUBE PROBING EQUIPMENT IN PLACE

FIGURE 2

TAKEN FROM HEDL 7501-34.3

| | | | |
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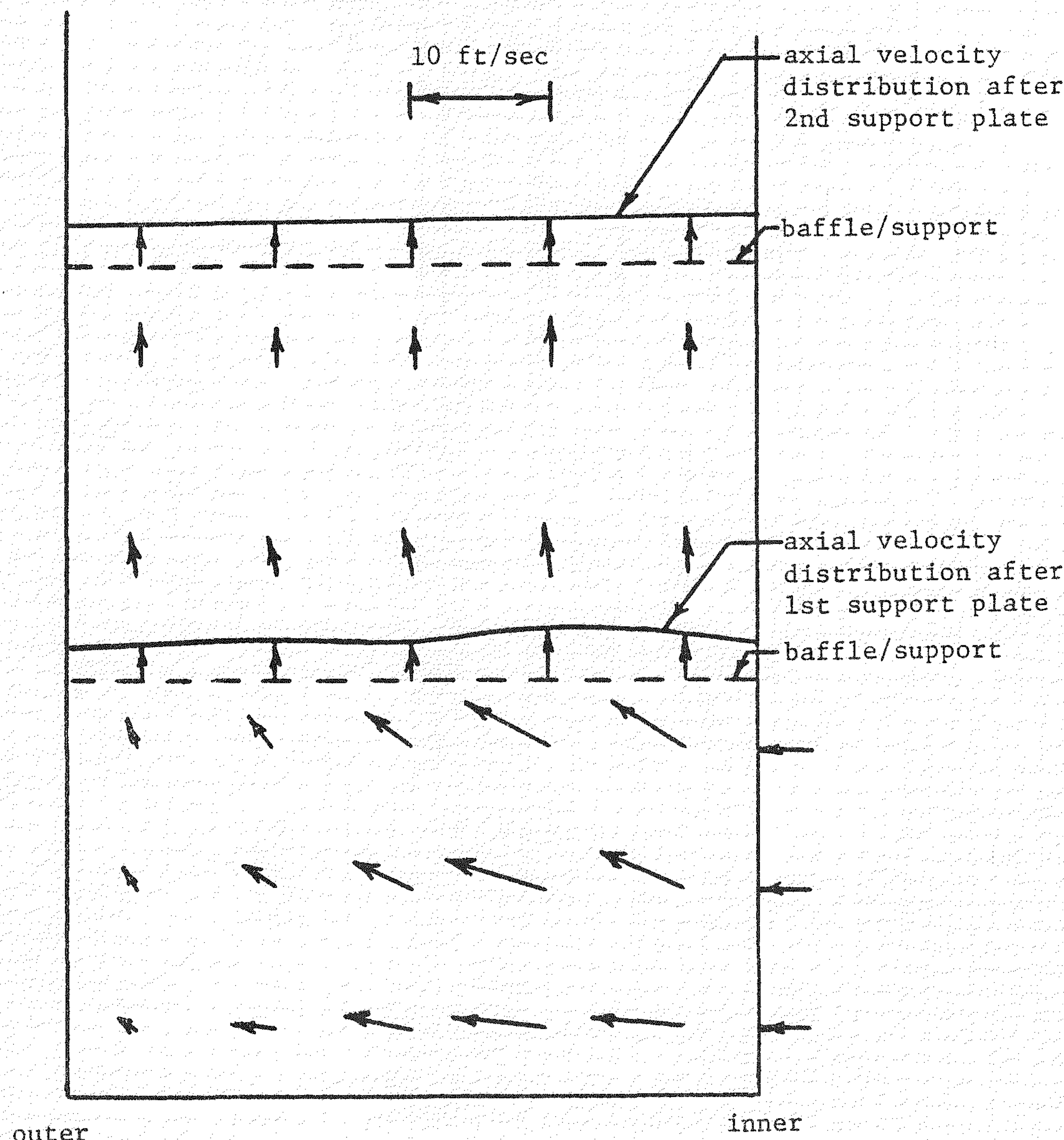


FIGURE 3 - VELOCITY VECTOR AT INLET REGION

(FULL LOAD)

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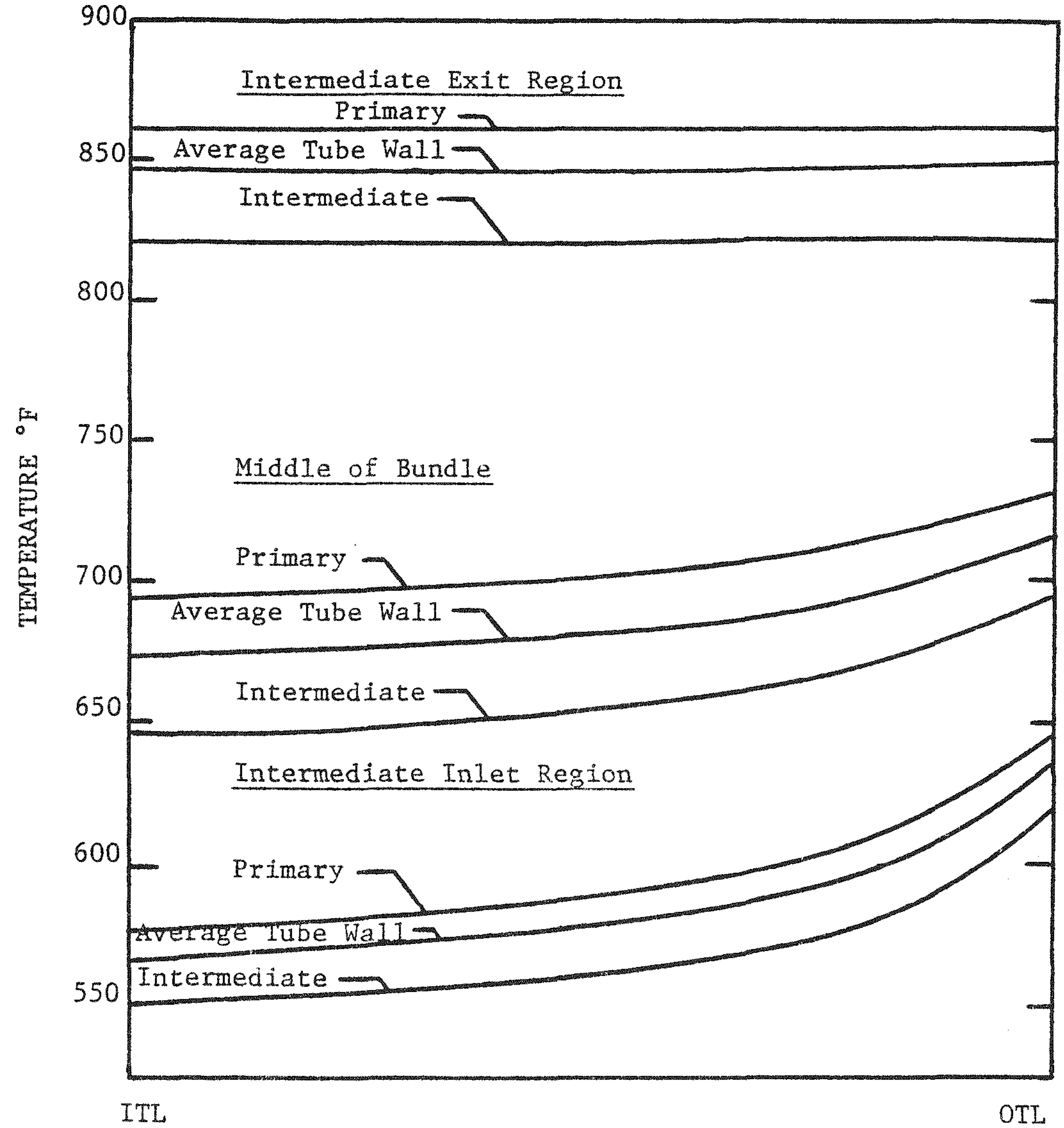


FIGURE 4 - TEMPERATURE DISTRIBUTION AT FULL LOAD

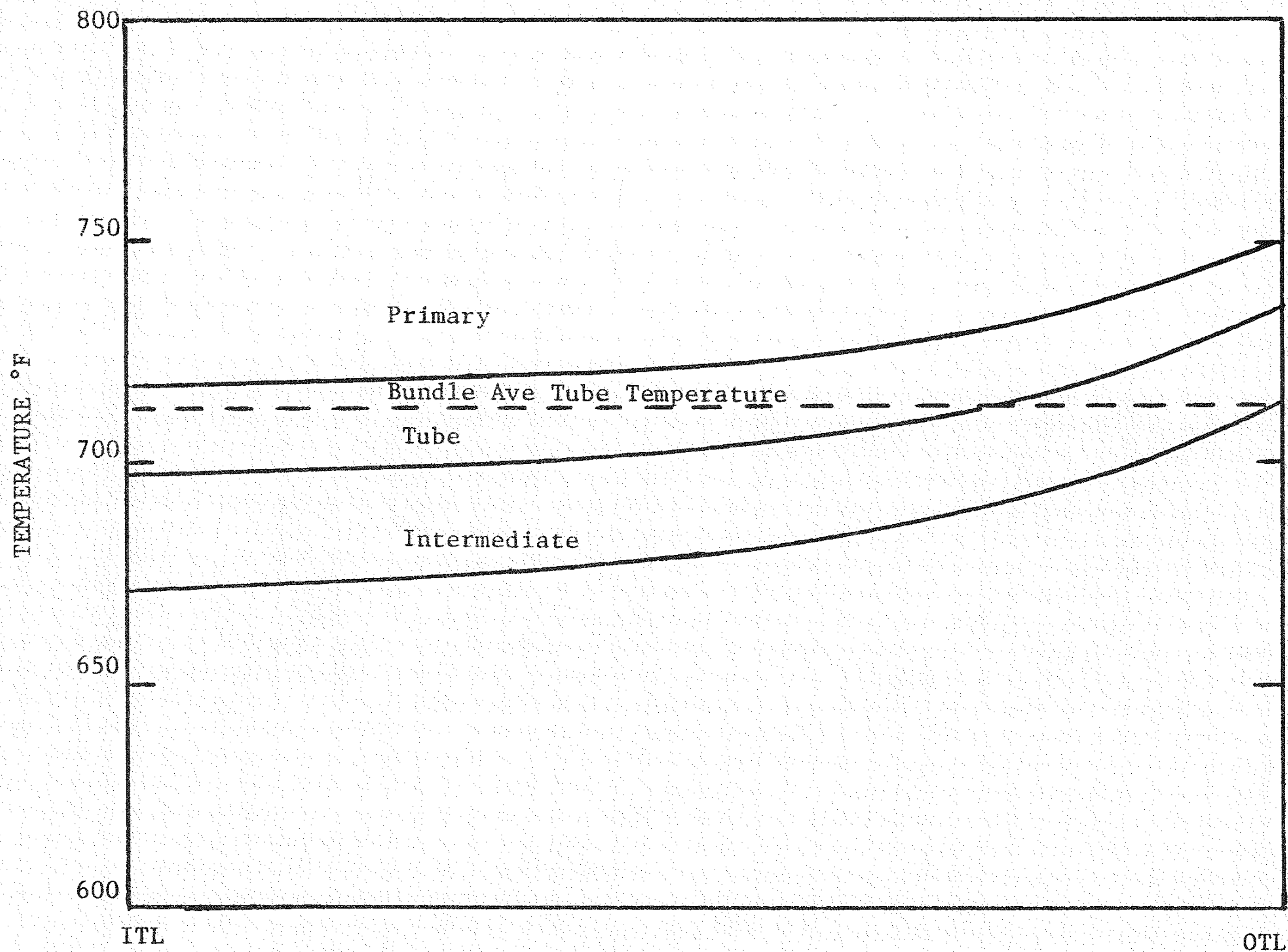


FIGURE 5 - LENGTH AVERAGED RADIAL TEMPERATURE DISTRIBUTION AT FULL LOAD

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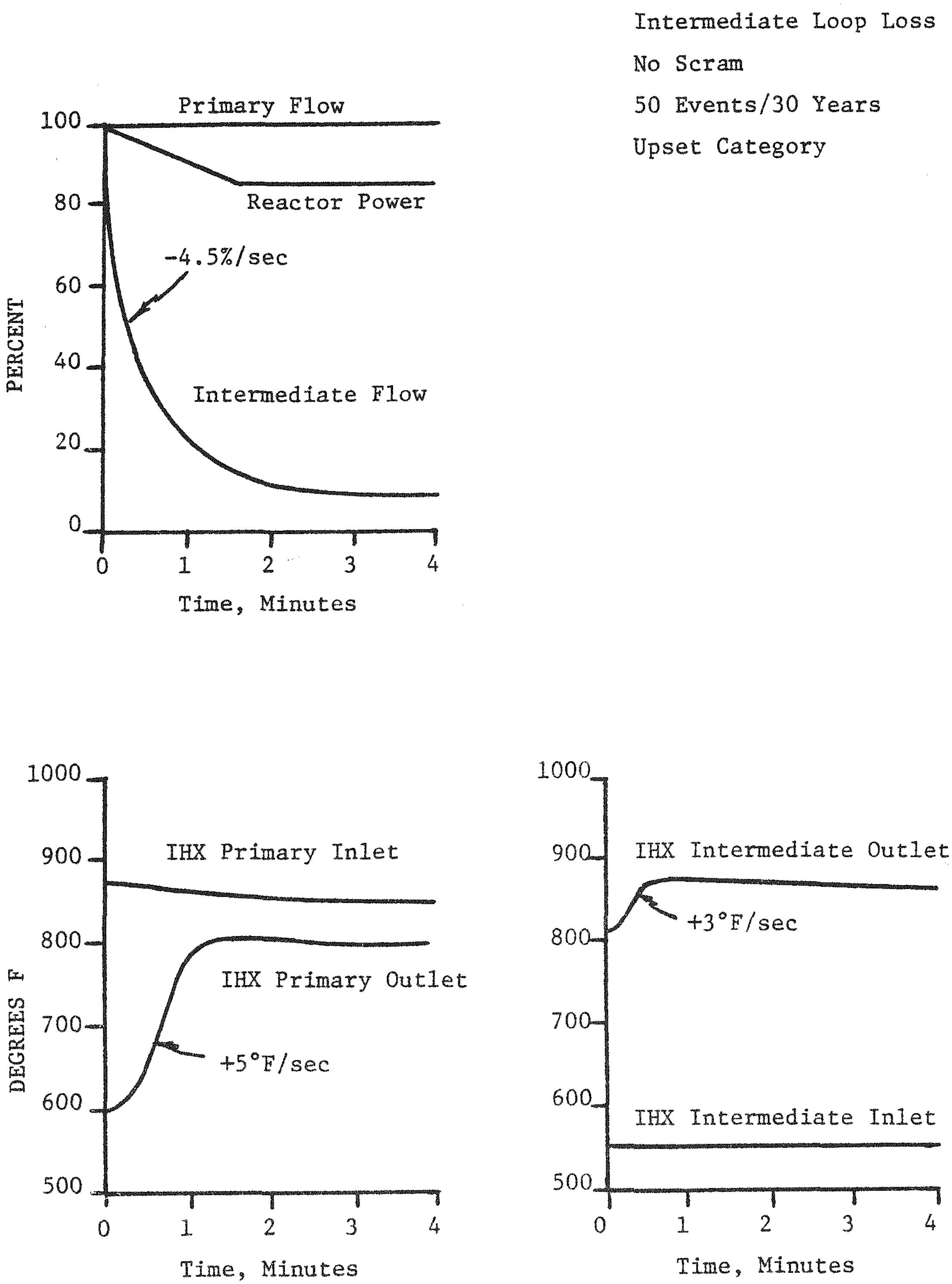


FIGURE 6 - GE POOL PLANT TRANSIENTS

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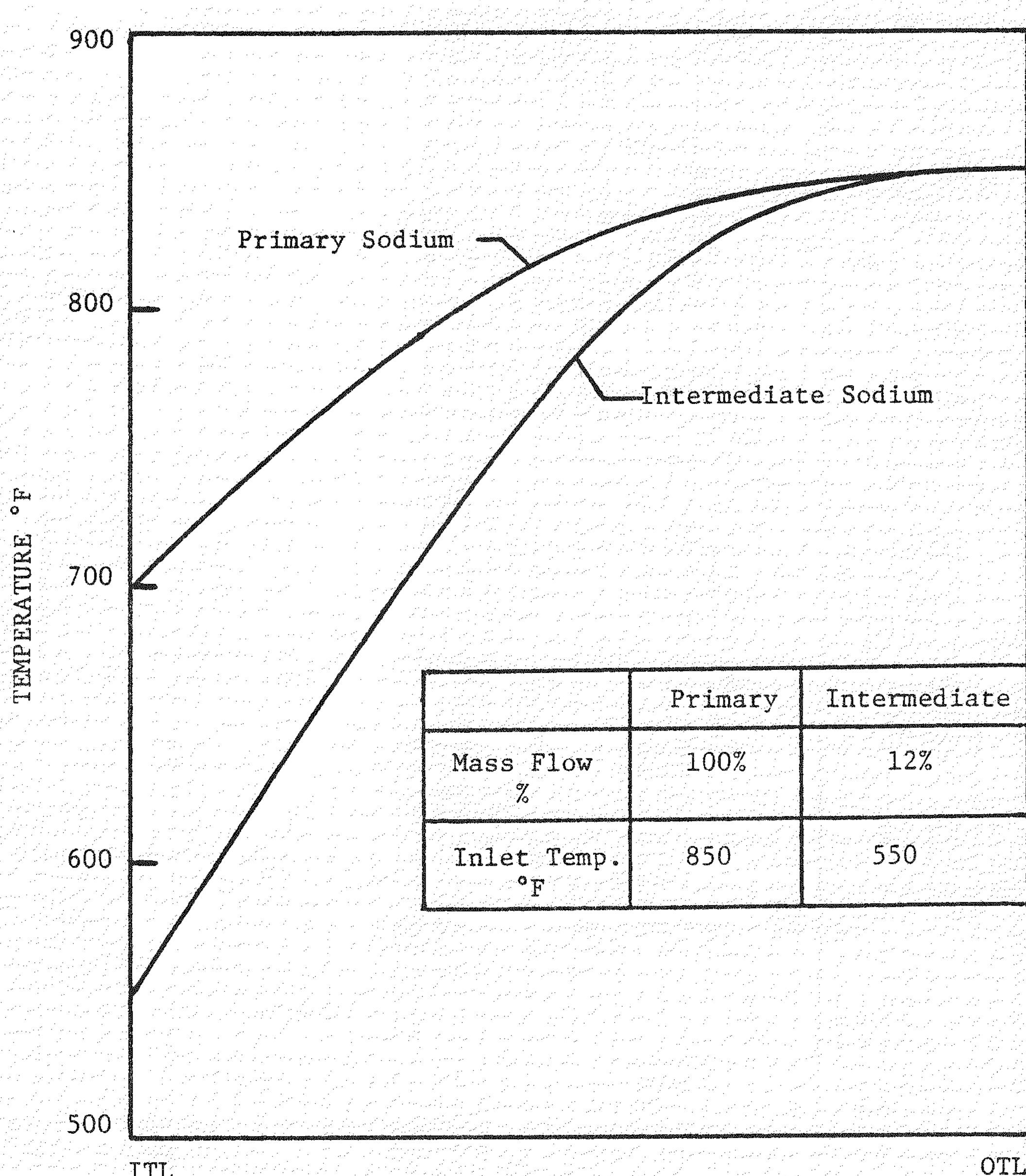


FIGURE 7 - SODIUM TEMPERATURE AT LOWER TUBESHEET

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FIGURE 8

LOWER TUBESHEET ANSYS MODEL SHOWING DIMENSIONS AND REGIONS

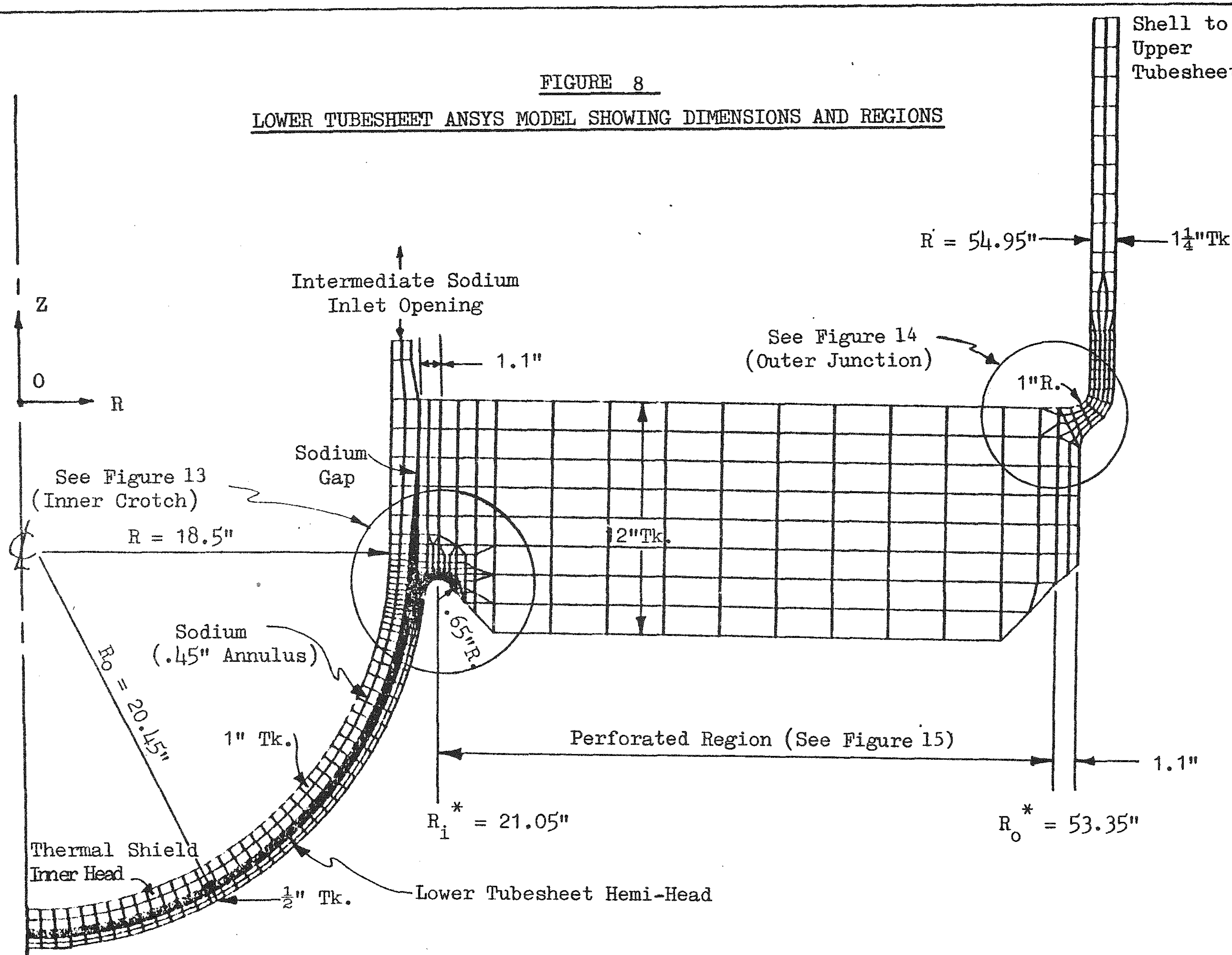




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FIGURE 9

LOWER TUBESHEET ANSYS MODEL SHOWING LOAD-CONTROLLED BOUNDARY CONDITIONS AND PRESSURE CROSS-SECTIONS

(See Table 9 for Stresses)

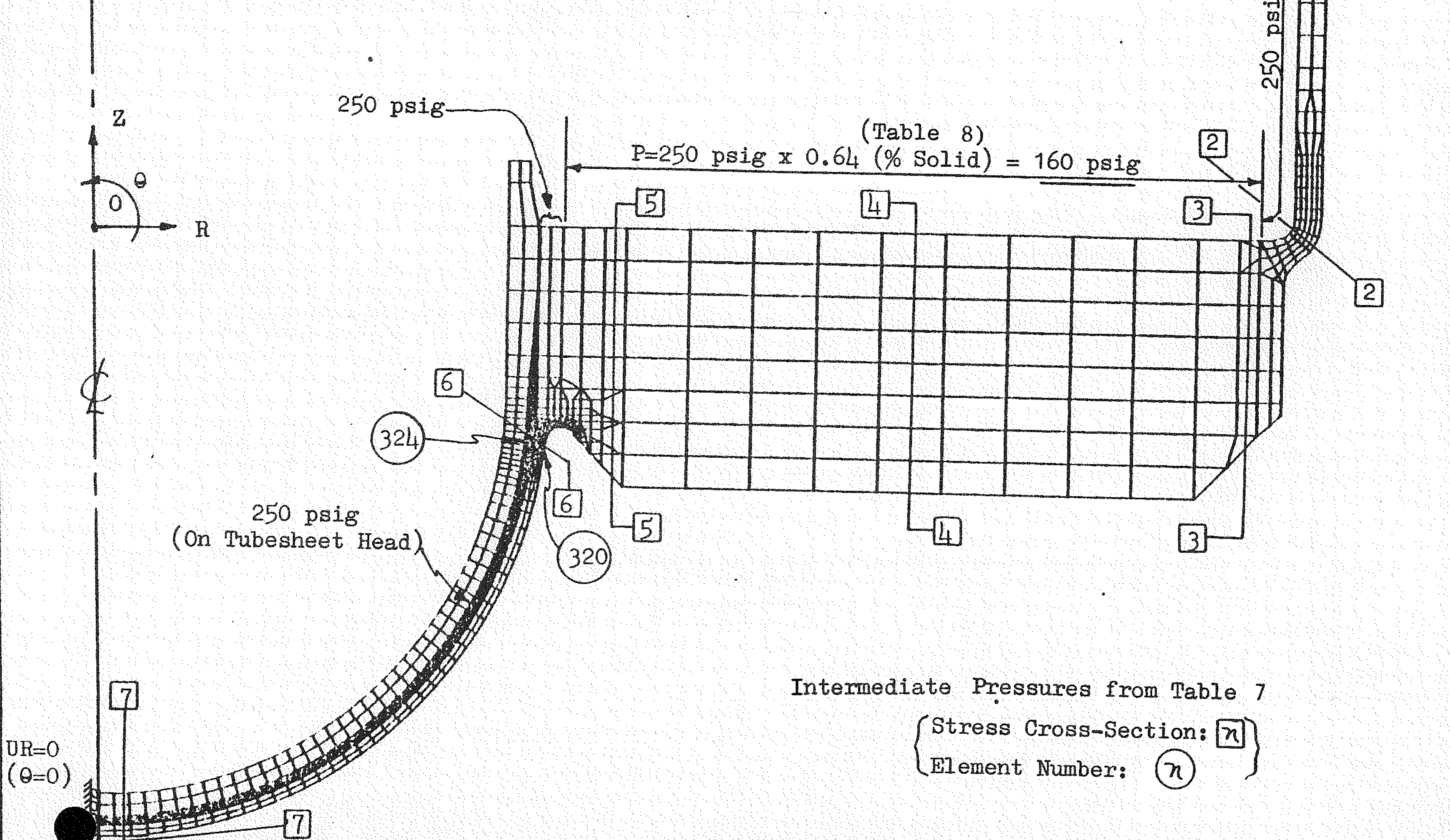


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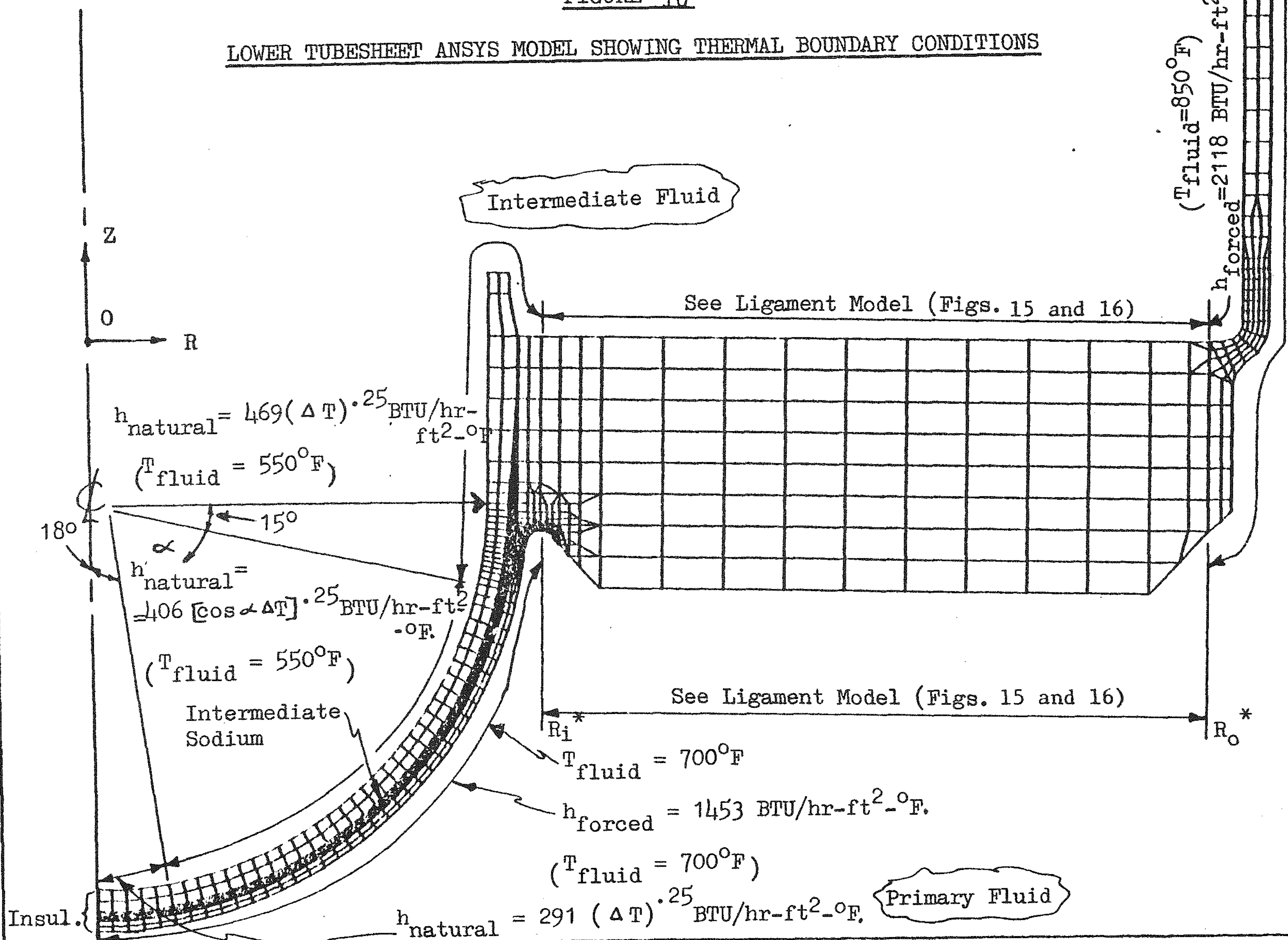
FIGURE 10

LOWER TUBESHEET ANSYS MODEL SHOWING THERMAL BOUNDARY CONDITIONS



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## FIGURE 11

LOWER TUBESHEET ANSYS MODEL SHOWING THERMAL STRESS BOUNDARY CONDITIONS

(See Figure 10 for Thermal Boundaries)

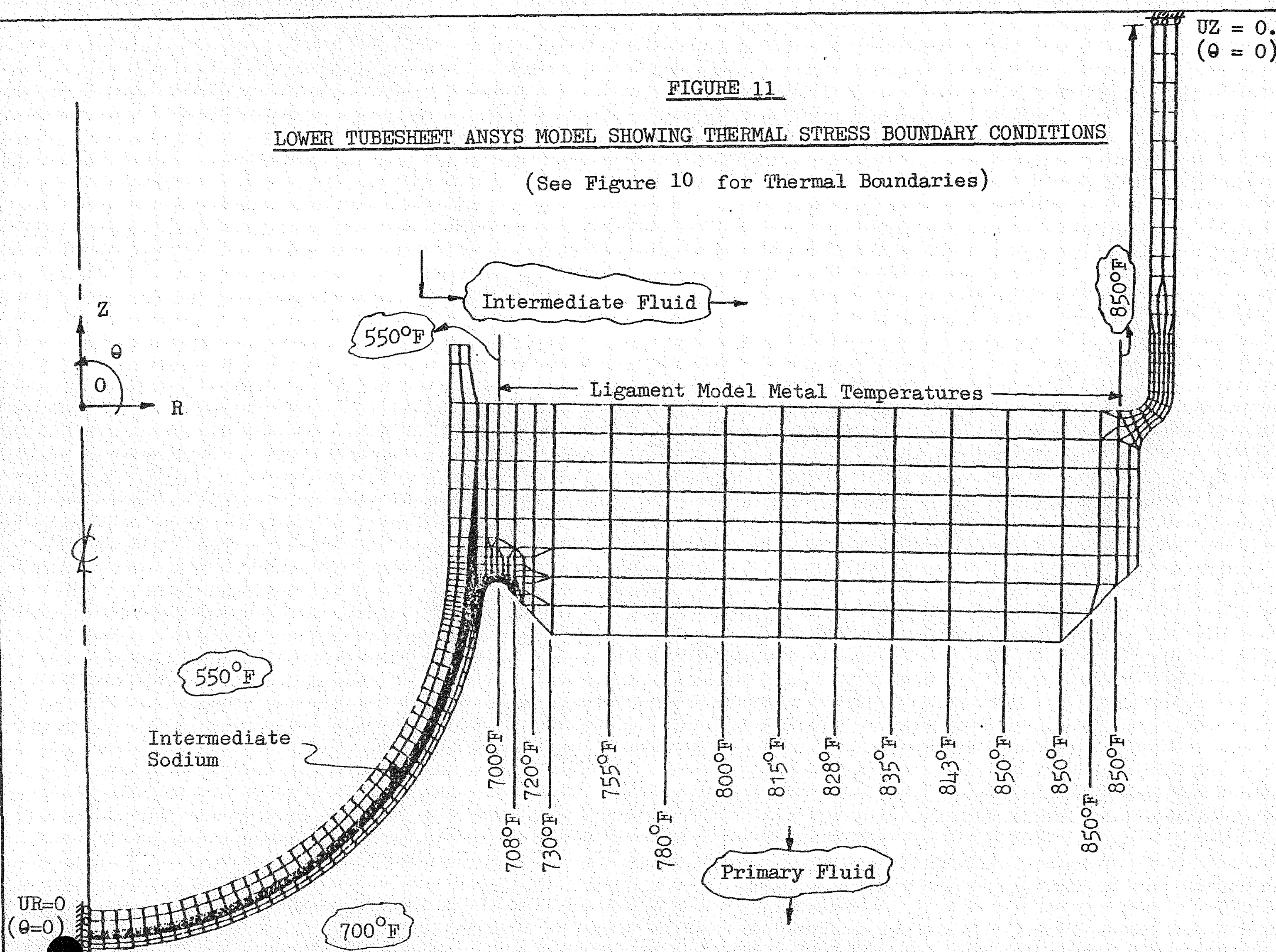


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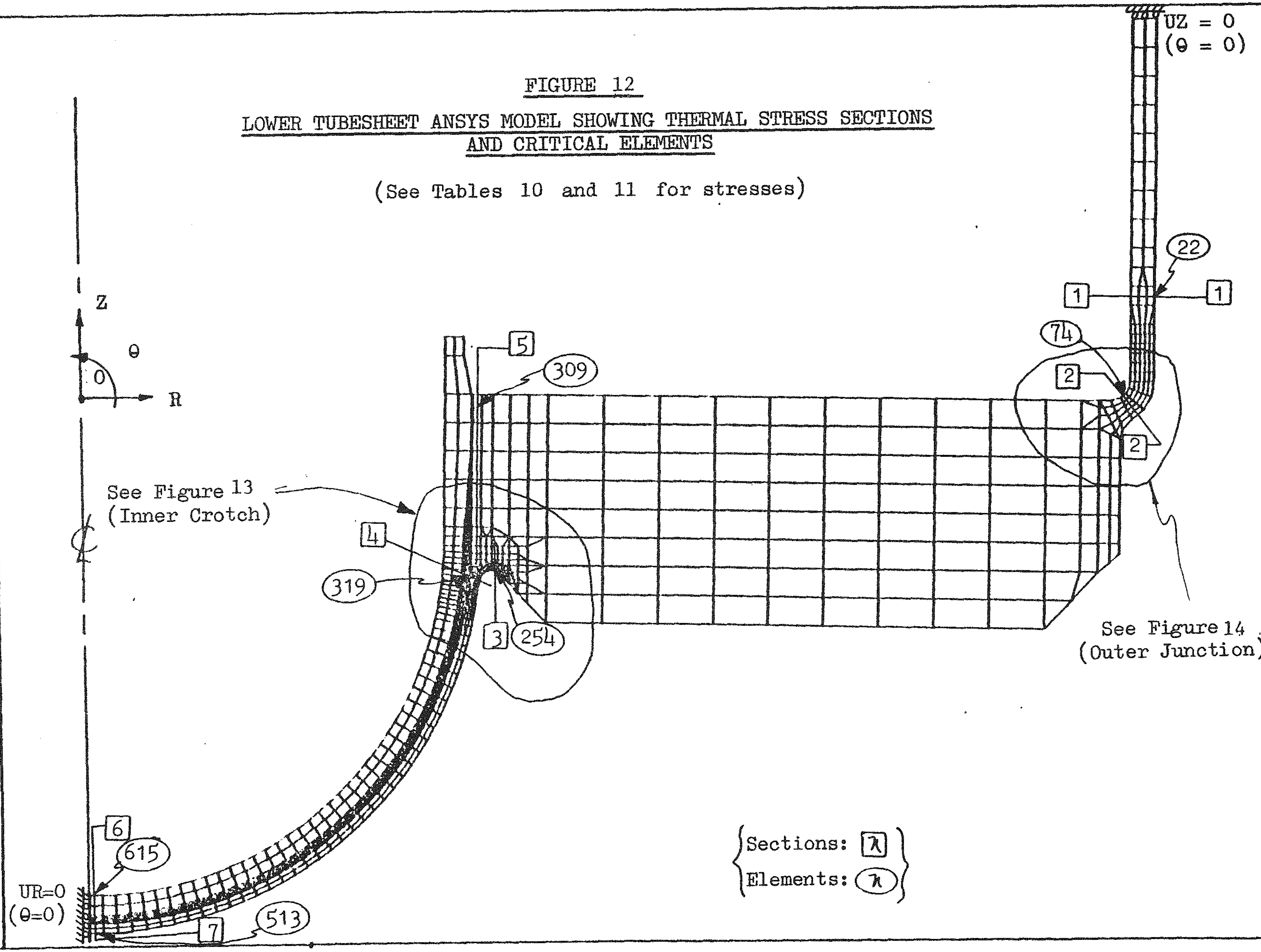
FIGURE 12

LOWER TUBESHEET ANSYS MODEL SHOWING THERMAL STRESS SECTIONS AND CRITICAL ELEMENTS

(See Tables 10 and 11 for stresses)

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## FIGURE 13

ENLARGED PLOT OF LOWER TUBESHEET

INNER CROTCH AREA SHOWING DIMENSIONS AND THERMAL SECTIONS

(See Figure 8)

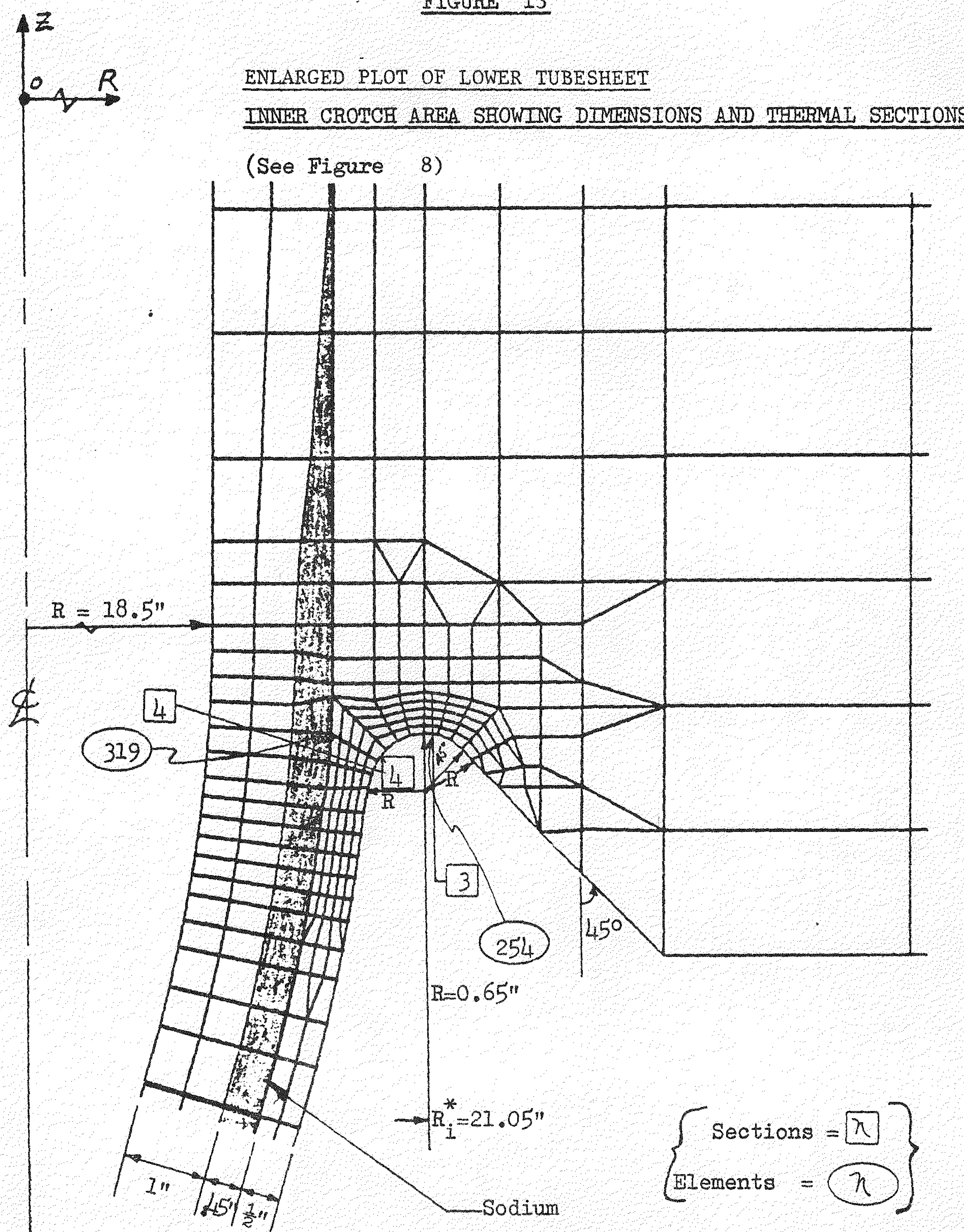

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FIGURE 14

ENLARGED PLOT OF LOWER TUBESHEET OUTER JUNCTION AREA SHOWING DIMENSIONS AND THERMAL SECTIONS

(See Figure 8)

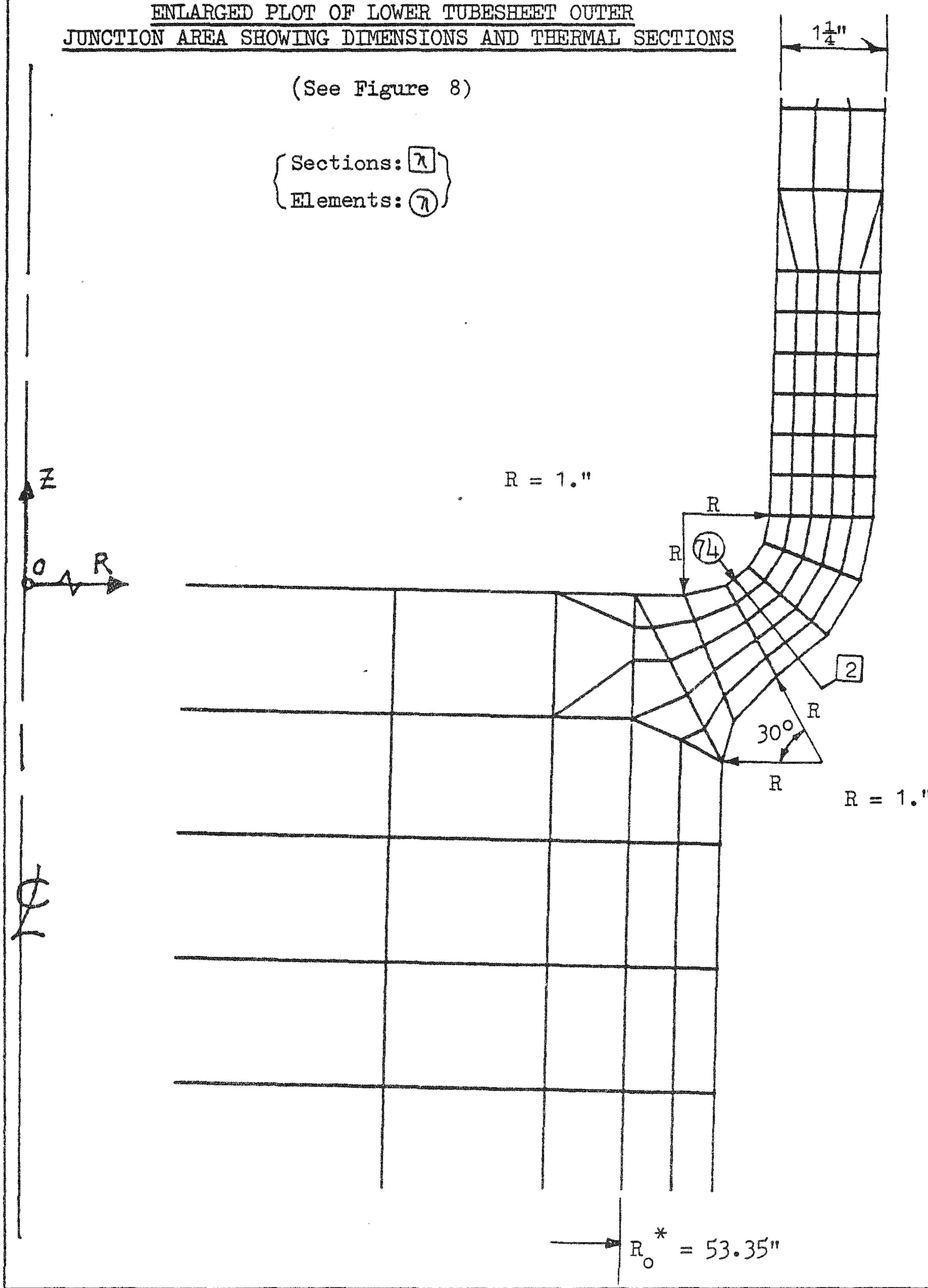

FIGURE 15

LOWER TUBESHEET ANSYS LIGAMENT MODEL FOR PERFORATED REGION SHOWING DIMENSIONS

(See Figure 8)

0.8" I.D. (Tube I.D.)X
1.24" O.D. (Average Pitch)

(See Table 8 for Perforated Ligament Properties)

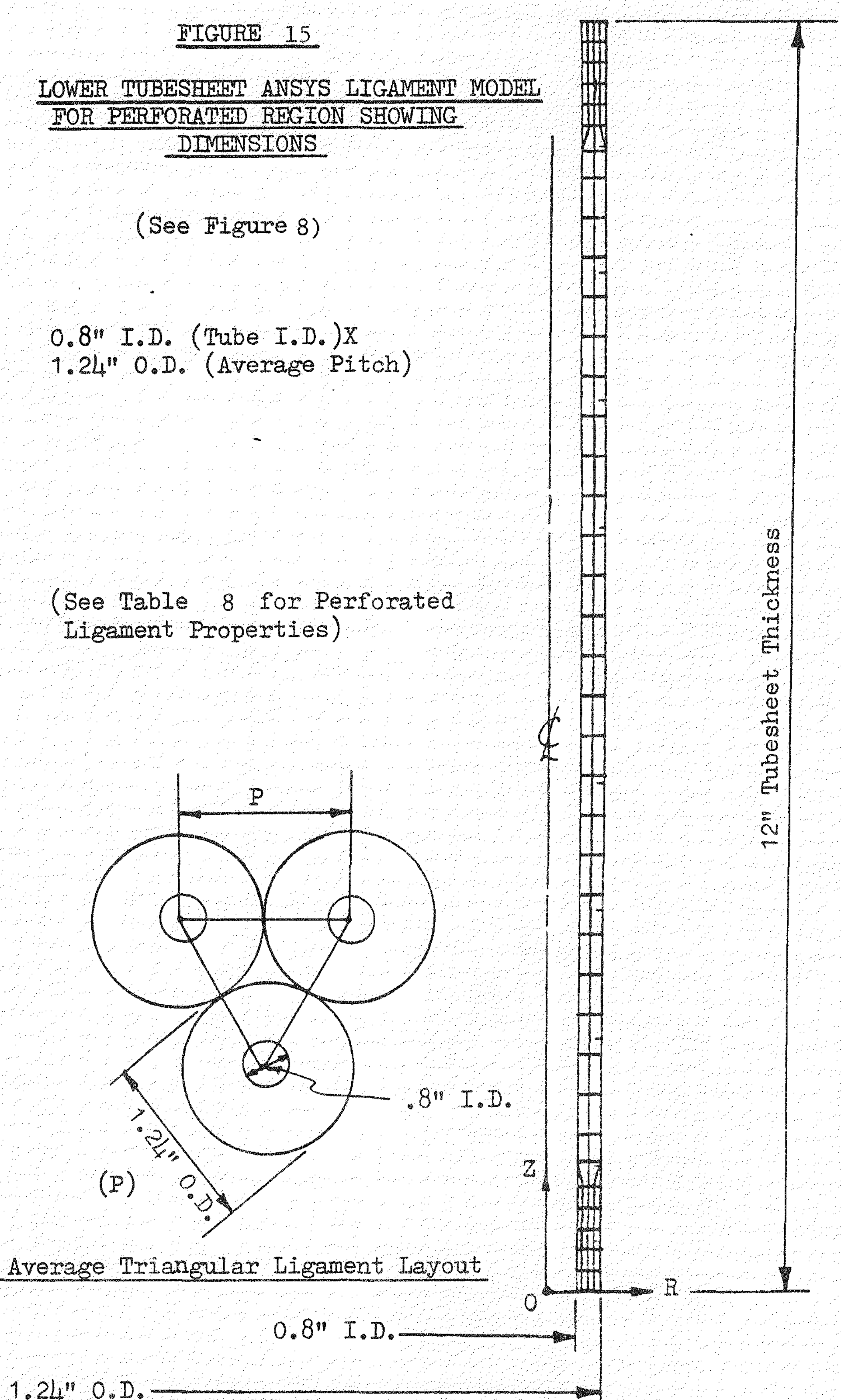

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**FIGURE 16**

**LOWER TUBESHEET ANSYS LIGAMENT MODEL FOR PERFORATED REGION SHOWING THERMAL BOUNDARY CONDITIONS**

(See Figures 15 and 10)

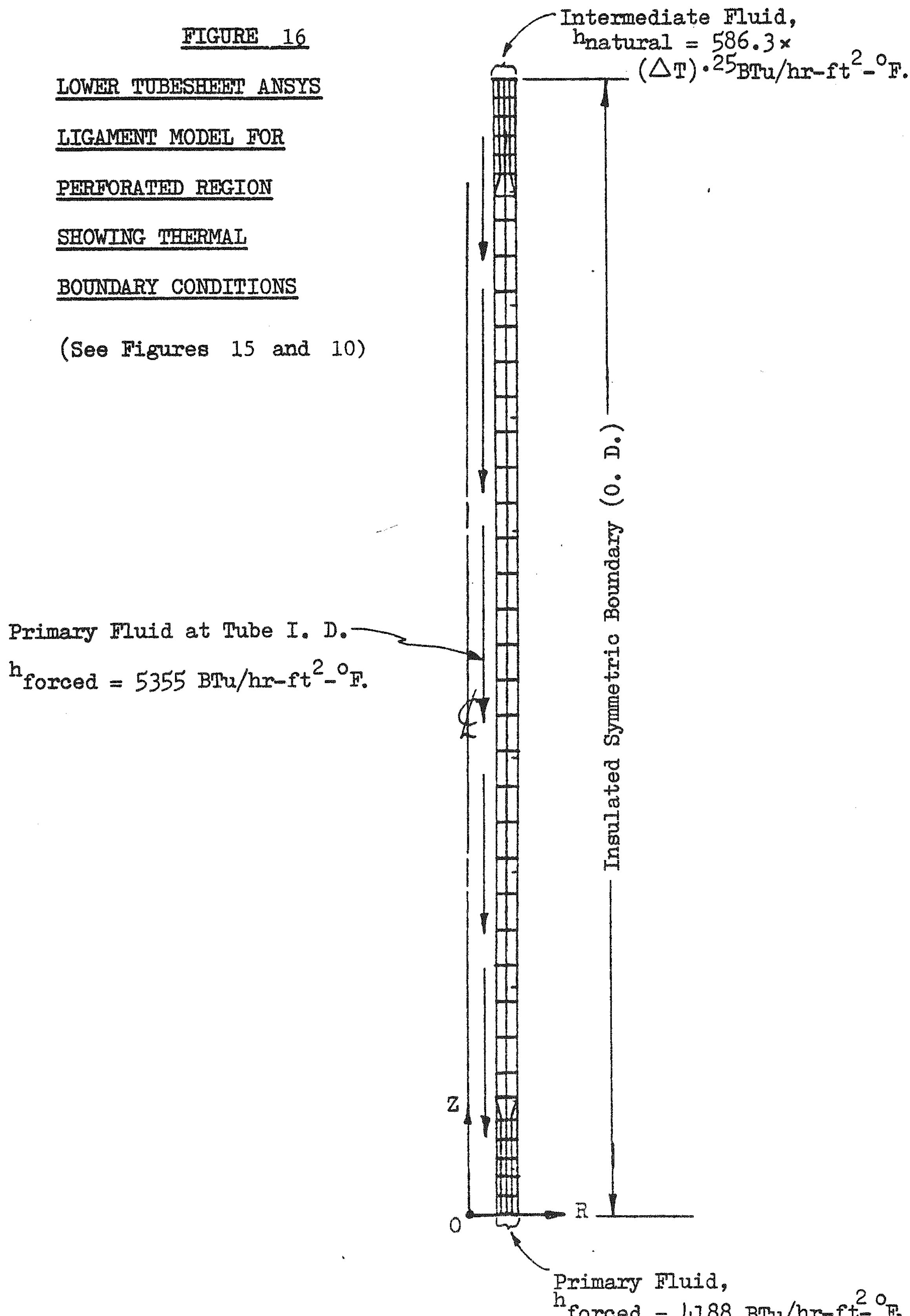


FIGURE 17 PLBR-IHX GRID FINITE ELEMENT MODEL
2-D BEAM MODEL OF TUBE SUPPORT GRIDS

Lateral Seismic Load Condition

1. Along lines AB and CD:
   UY = ROTZ = 0

2. Along line EF:
   UX = UY = ROTZ = 0

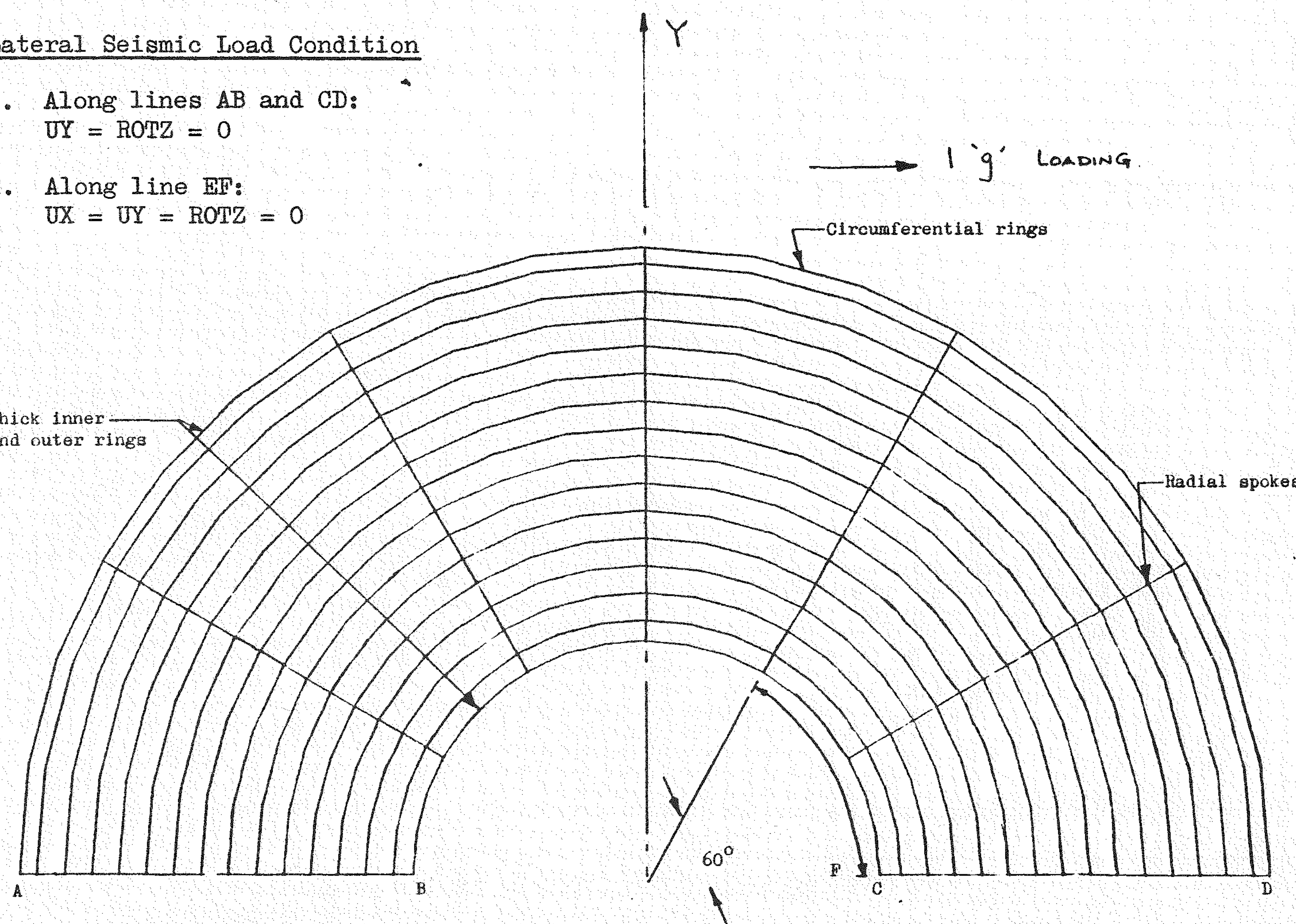
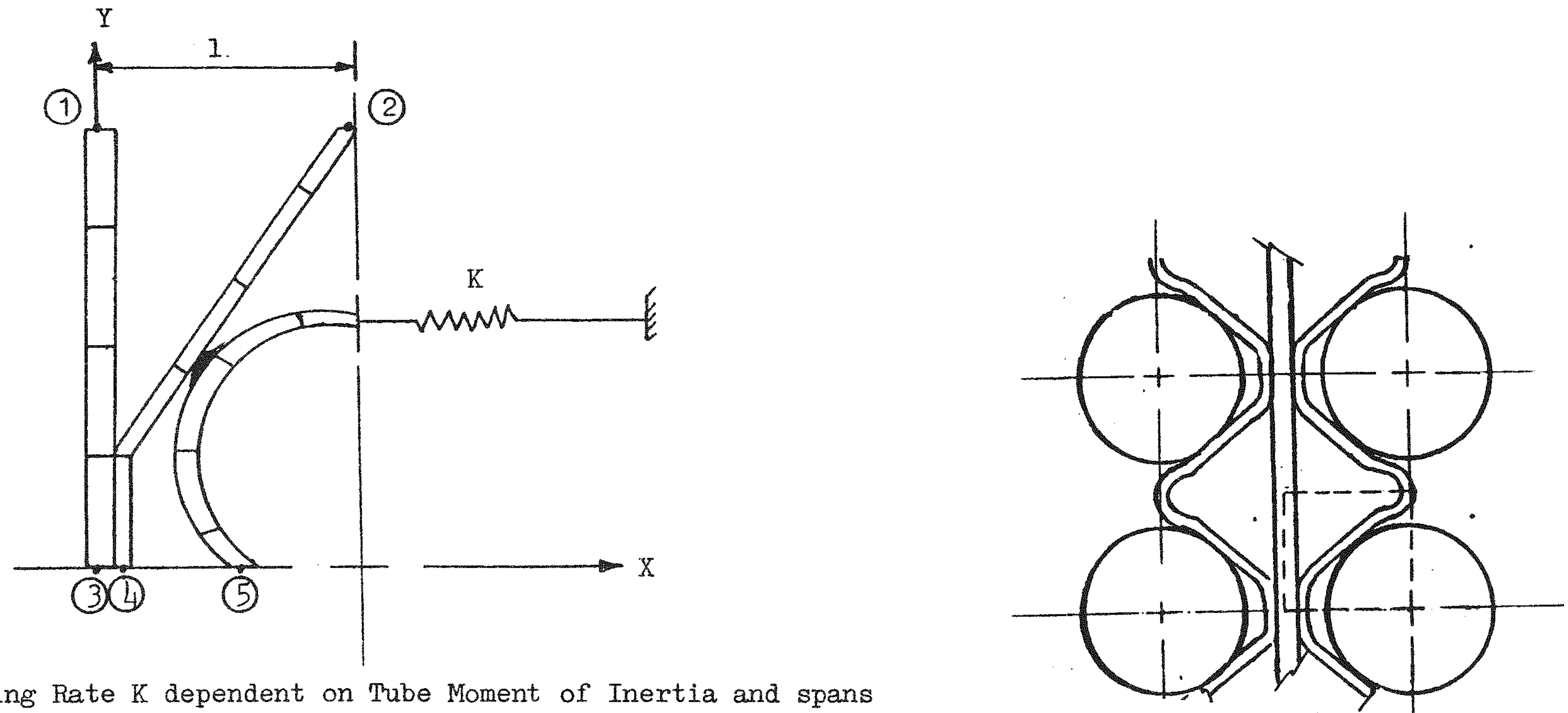


FIGURE 18 PLBR-IHX FINITE ELEMENT MODEL OF THE REPEATING GRID PATTERN




Spring Rate K dependent on Tube Moment of Inertia and spans between grids.

UNIT STIFFNESS RUNS

- Axial Direction Y
  Apply displacement at 1 and 2 react at 3 4 5.
- Bending Stiffness About Z Axis
  Apply $U_y$ and ROTZ = $U_y/l$ at 2 . Apply ROTZ = $U_y/l$ and $U_y = 0$ at 1.
  At 3 4 5 $U_x$, $U_y$, ROTZ = 0.



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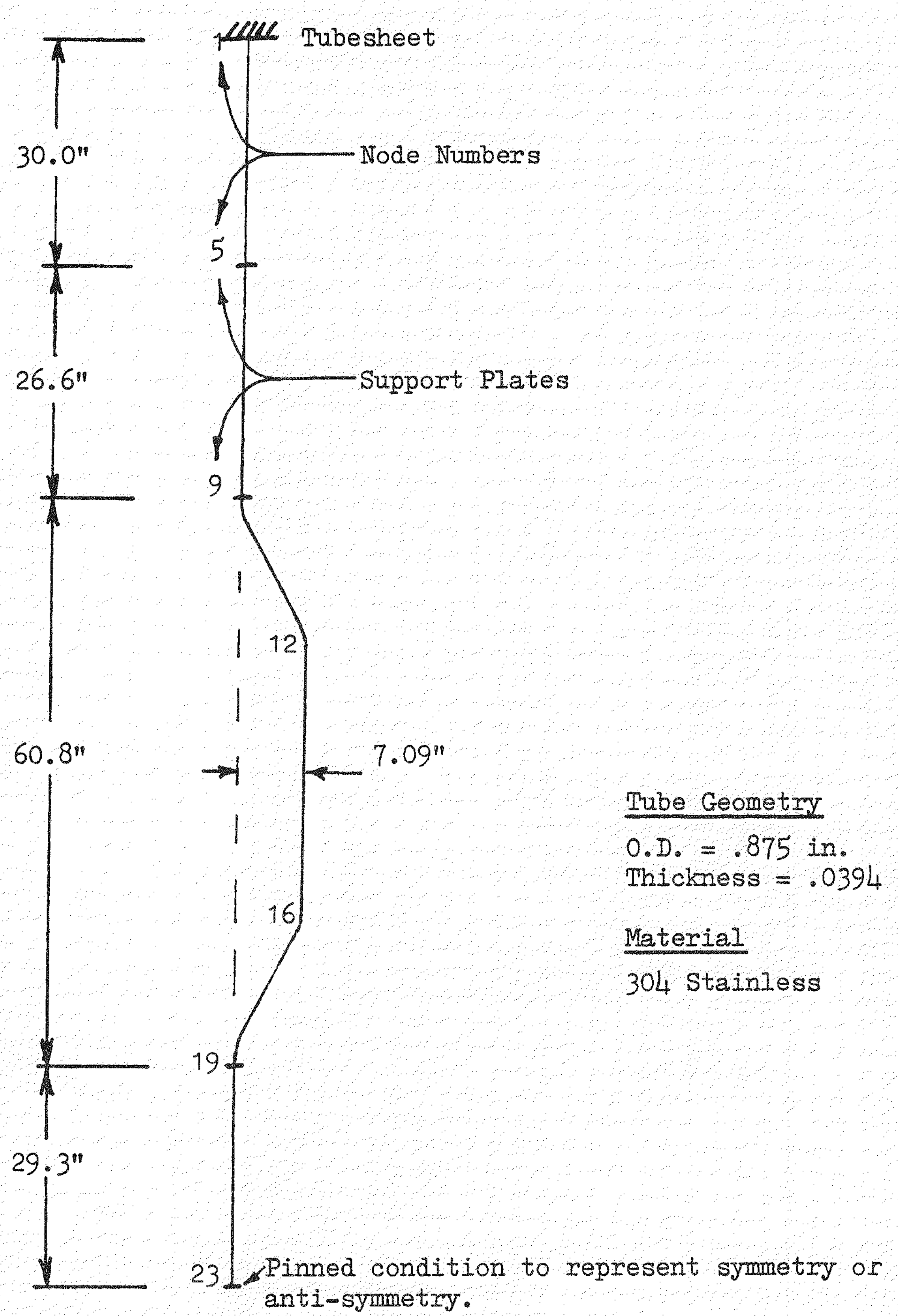
FIGURE 19 PLBR-IHX ANSYS PIPE ELEMENT MODEL OF BENT TUBE




Tube Geometry

O.D. = .875 in.
Thickness = .0394 in.

Material

304 Stainless

FIGURE 20 PLBR-IHX TUBE MODE SHAPES AND NATURAL FREQUENCIES

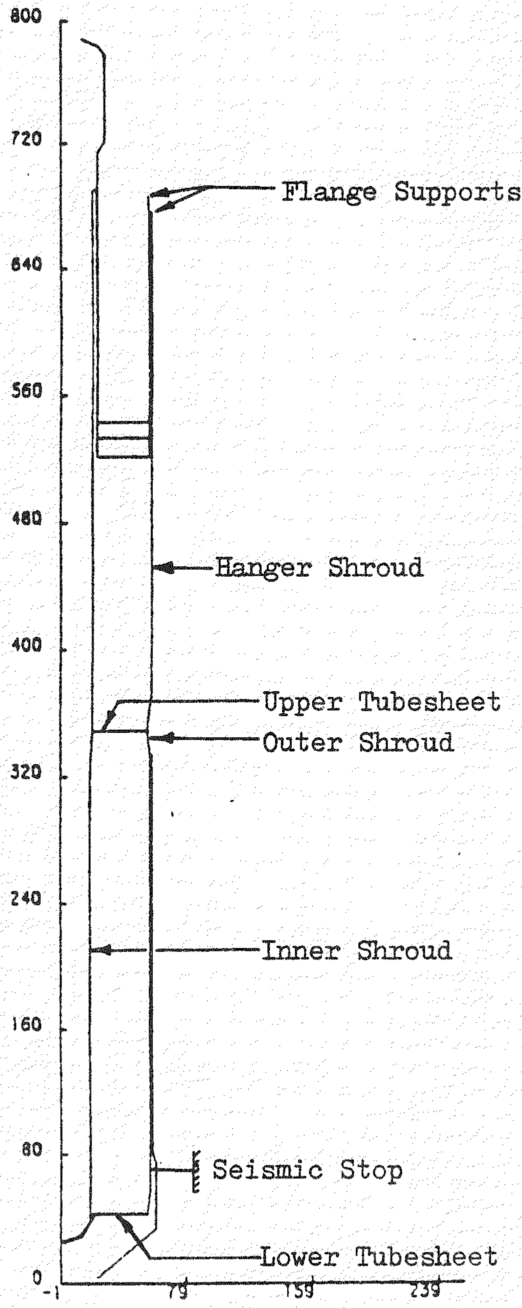
27.85 cps
Lowest Mode in Bend Region
Fixed Condition at Plates

12.64 cps
Torsional Mode in Bend Region
Pinned Condition at Plates

146.59 cps
Lowest Bending Mode at Top Span
Fixed Condition at Plates

99.82 cps
Lowest Bending Mode at Top Span
Pinned Condition at Plates

FIGURE 21 SEISMIC ANALYSIS - GE POOL IHX




1. Computer Model

ANSYS axisymmetric shell model with non-axisymmetric loading.

2. Loading

SSE horizontal response spectra input per GE PLBR-IHX specification.

3. Results

| COMPONENT | MAXIMUM SHELL BENDING MOMENT (in-lb) |
|---|---|
| Inner Shroud | $3.07 \times 10^6$ |
| Outer Shrouds | $8.494 \times 10^6$ |
| Hanger Shroud | $6.86 \times 10^6$ |
| Grids | Horizontal Force = 0.9 g |

## TABLE 1 DESIGN COMPARISON

| | PLBR-IHX PHASE A | PLBR-IHX PHASE A EXTENSION |
|---|---|---|
| I.H.X. Size | 6 Per Loop<br>486 Mwt per I.H.X. | 6 Per Loop<br>486 Mwt per I.H.X. |
| Tubes | 4420-1" O.D. x .045 Min Wall x 25'-1½" Lg. | 4860 - 7/8" O.D. x .040" Min. Wall x 24'-5-3/8" |
| Tube Configuration | Straight | Double Sine Wave |
| Upper Tubesheet<br>Lower Tubesheet | Fixed<br>Floating | Fixed<br>Fixed |
| Bundle Size | 42" I.T.L.<br>106.75" O.T.L. | 42.56" I.T.L<br>107.54 O.T.L. |
| Tube Pitch | 1.40" △ Pitch | 1.250" Radial<br>1.309" Circum. |
| Tube Support Type | Perforated Disc (Tube Slides through Supp. Pl. Holes) | Grid Type (Tube Clamped to Grid) |
| Opening Size for IHX Entry | 10' - 3" | 10' - 3" |

## TABLE 2 IHX DESIGN AND PERFORMANCE DATA

- Primary Flow Location - Tube Side
- Design Temperatures:

  Primary ........ 900°F
  Intermediate ........ 835°F

- Operating Temperatures:

  Primary Inlet ........ 875°F
  Primary Outlet ........ 594°F

  Intermediate Inlet ........ 550°F
  Intermediate Outlet ........ 815°F

  Auxiliary Inlet ........ 580°F
  Auxiliary Outlet ........ 845°F

- Number of Units ........ 6
- Design Pressure:

  Primary Side ........ 10 psig
  Intermediate Side ........ 250 psig

- Unit Thermal Rating

  Primary IHX ........ 486 MWt
  Auxiliary IHX ........ 3 MWt

- Unit Flow Rate

  Primary Na ........ $19.25 \times 10^6$ #/Hr.
  Intermediate Na ........ $20.29 \times 10^6$

- Pressure Drop; Max:

  Tube Side ........ 2.0 psi
  Shell Side ........ 30 psi

- Material of Construction ........ Type 304 SS
- Auxiliary Heat Removal Coil to be located Above Main IHX Tube Bundle
- Intermediate Sodium

  -Supplied through Central Downcomer
  -Inlet and Outlet Nozzles Located Above Shield Deck

- Primary Seal at IHX lower end to Isolate Hot and Cold Pool Sodium

TABLE 3 - THERMAL SIZING OF 486 MWt BENT TUBE POOL IHX

| | Tube Length*, ft. |
|---|---|
| Basic Sizing | 21.22 |
| Shell Side By-pass Effect (1%) | 21.81 |
| Uncertainties, 90% Confidence Level (ho, hi, kw, δw, RSS Method) | 23.19 |
| Partial Inactive Region of Support Plates (7 support plates, 2.375" thick each) | 23.89 |
| Partially Inactive Length in the Inlet and Exit Bundle Area | 25.09 |
| Tubesheet-to-Tubesheet Length | 24.45 |

Notes:

1. No. of tubes = 4860
2. Wall thickness = 0.0394" (+15%, -0%)
3. Circumferential Pitch = 1.3096"
4. Ave. Radial Pitch = 1.2504"
5. Tube OD = 7/8"
6. Two bends

*Length shown is accumulated length resulting from all preceding effects.

TABLE 4 TUBE SIDE PRESSURE DROP OF POOL IHX

| Item | $\Delta P$, psi |
|---|---|
| 1. Entrance to the IHX | 0.091 |
| 2. Friction in the annulus | 0.017 |
| 3. 90° turn from annulus | 0.183 |
| 4. Perforation of the annulus | 0.031 |
| 5. Vertical portion of auxiliary IHX | 0.008 |
| 6. 90° turn to tubes | 0.017 |
| 7. Horizontal portion of auxiliary IHX | 0.008 |
| 8. Tubes (friction, 2-bends, entrance and exit) | 1.863 |
| 9. Exit passage | 1.000 |
| TOTAL | 3.218 |

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NOTATIONS IN THIS COLUMN INDICATE WHERE CHANGES HAVE BEEN MADE

## TABLE 5 SHELL SIDE PRESSURE DROP OF POOL IHX

| Item | $\Delta$P, psi |
|---|---|
| 1. Friction in upper part of downcomer | 1.364 |
| 2. Expansion in the middle of downcomer | 0.232 |
| 3. Friction in lower part of downcomer | 0.225 |
| 4. Expansion at the lower part of downcomer | 0.288 |
| 5. 90° turn to the bundle | 0.963 |
| 6. Perforation in downcomer | 0.278 |
| 7. Tube bundle | 1.672 |
| 8. 90° turn from the bundle | 2.609 |
| 9. Friction in the annulus | 1.630 |
| 10. Expansion in the annulus | 1.830 |
| 11. 90° turn to outlet nozzle | 1.971 |
| TOTAL | 13.062 |

NOTATIONS IN THIS COLUMN INDICATE WHERE CHANGES HAVE BEEN MADE

FWC FORM 172 - 4

TABLE 6 THERMAL SIZING FOR 9' 3" STRAIGHT TUBE DESIGN

| | |
|---|---|
| Thermal Duty, Mw(t) | 486.0 |
| Btu/hr | $1658. \times 10^{8}$ |
| Flow Rate, lb/hr | |
| Primary Sodium | $19.25 \times 10^{6}$ |
| Intermediate Sodium | $20.29 \times 10^{6}$ |
| Sodium Temperature, $^{o}F$ | |
| Primary Inlet | 875.0 |
| Primary Outlet | 593.6 |
| Intermediate Inlet | 549.4 |
| Intermediate Outlet | 815.0 |
| LMTD | 51.69 |
| Tube O.D.; Tube Wall Thickness, inch | 1.000; 0.0485 |
| Number of Tubes | 3987 |
| Tube Pitch, inch | 1.28 |
| Average Velocity, ft/sec. | |
| Tube Side | 5.63 |
| Shell Side | 5.95 |
| Active Heat Transfer Length, ft | 25.39 |
| Tubesheet-to-tubesheet Length, ft | 26.08 |
| Pressure Drop Through Tubes (Frictional, inlet and exit loss), Psi | 1.47 |

FWC FORM 172 - 4 — NOTATIONS IN THIS COLUMN INDICATE WHERE CHANGES HAVE BEEN MADE

TABLE 7 STRUCTURAL SIZING CONDITIONS AND CRITERIA

PLBR (Bent Tube)

**Design:**

P= 115 PSIG @ $900^{o}$F. ($S_o$ = 14,600 PSI.)

**Emergency:** *

P= 250 PSIG @ $875^{o}$F. ($S_m$ = 14,700 PSI.)

"Cold" End (Lower Tubesheet): **

P= 250 PSIG @ $600^{o}$F. ($S_m$ = 16,400 PSI.)

* Controls for "Hot" End; - Stress Allowable = $1.2S_m$ = 17,640 PSI. (1.2 x 14,700 PSI.) (Shell Primary)

** Controls for "Cold" End; - Stress Allowable = $1.8S_m$ = 1.8 x 16,400 PSI. = 29,520 PSI. (Lower Tubesheet Bending)
($1.2S_m$ = 1.2 x 16,400 PSI. = 19,680 PSI. Primary)

Notes:

1) All material is SS TP304.
2) All pressures are intermediate with 0 PSIG primary pressure assumed.
3) Code allowable criteria from ASME Code Case 1592 for elevated temperature and ASME Section III for "Cold" end.

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NOTATIONS IN THIS COLUMN INDICATE WHERE CHANGES HAVE BEEN MADE

## TABLE 8 PERFORATED LIGAMENT PROPERTIES FOR LOWER TUBESHEET

Average of Rectangular & Triangular Pitches, $\eta = 0.355$ (Efficiency)

Stress Multiplier = $1/\eta = 2.8$

Average $E^*/E = 0.38$, Average $\mu^* = 0.27$

% Solid = 64% = 0.64

ANSYS Tubesheet Axisymmeric Model Input (See Figure 8):

| PERFORATED PROPERTY | VALUE | SOLID (REAL) PROPERTY** |
|---|---|---|
| $E^* = E_x^* = E_z^*$ (In-Plane) | $0.38 \times E$ | E= Modulus of Elasticity |
| $E_y^*$ (Axial) | $0.64 \times E$ | E= Modulus of Elasticity |
| $\alpha_m = \alpha_x = \alpha_y = \alpha_z$ (Expansion Coefficient) | $\alpha$ | Thermal Coeff. of Expansion |
| $\rho^*$ (Density) | $0.64 \times \rho$ | $\rho$ = Density |
| $\mu^*_{xy} = \mu^*_{zy}$ | 0.30 | $\mu$ = Poisson's Ratio |
| $\mu^* = \mu^*_{xz} = \mu^*_{zx}$ (In-Plane) | 0.27 | Corresponding to $\mu = 0.30$ |
| $\mu^*_{yz} = \mu^*_{yx} = (E^*/E_y^*) \times \mu^*$ | 0.16 | $\mu$ =Poisson's Ratio |

** Properties are input as temperature dependent for SS TP304 material from the Nuclear Systems Materials Handbook.

TABLE 9 LOWER TUBESHEET LOAD-CONTROLLED STRESS SUMMARY

| SECTION* | CODE CATEGORY | STRESS (1) (PSI.) | CODE ALLOWABLE (2) (PSI) | SAFETY MARGIN |
|---|---|---|---|---|
| 1 | PM | 12,000 | 19,680 | + 0.64 |
| 2 | PL<br>PL+Q | 7,600<br>25,000 | 19,680<br>29,520 (3) | + 1.59<br>+ 0.18 |
| 3 | PM<br>PL+PB | 4,500 (4)<br>19,900 (4) | 19,680<br>29,520 | + 3.37<br>+ 0.48 |
| 4 | PM<br>PL+PB | 2,500 (5)<br>14,600 (5) | 19,680<br>29,520 | + 6.87<br>+ 1.02 |
| 5 | PM<br>PL+PB | 3,800 (5)<br>22,300 (5) | 19,680<br>29,520 | + 4.18<br>+ 0.32 |
| 6 | PL<br>PL+Q | 15,500<br>26,400 | 19,680<br>29,520 (3) | + 0.27<br>+ 0.12 ** |
| 7 | PM | 5,000 | 19,680 | + 2.94 |

*See Figure 9 for Cross-Sections.
~~**Controlling (Minimum) Safety Margin.~~

Notes:

(1) From N2050 Post-Processor Program (SLINER) evaluation of ANSYS analysis.

(2) See Table 7 for criteria.

(3) Conservatively taken as PL+PB allowable.

(4) Includes stress multiplier of 2.8 (Table 8) and biaxiality K=1.7 from Article A-8000 of Section III.

(5) Includes stress multiplier of 2.8 (Table 8) and biaxiality K=1.1 from Article A-8000 of Section III.

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NOTATIONS IN THIS COLUMN INDICATE WHERE CHANGES HAVE BEEN MADE

## TABLE 10

## LOWER TUBESHEET LINEARIZED SURFACE THERMAL STRESSES (1)

| SECTION* | ELEMENT* | SURFACE STRESSES (PSI) | | | STRESS INTENSITY (PSI) |
|---|---|---|---|---|---|
| | | $S_1$ (MERID.) | $S_2$ (HOOP) | $S_3$ (NORMAL) | |
| 1 | 22 | 2007. | -3202. | 102. | 5209. |
| 2 | 74 | 10081. | -4792. | 2052. | 14873. |
| 3 | 254 | 51664. (2) | 42689. (2) | 5341. (2) | 46323. (2) |
| 4 | 319 | -20268. | 33232. | -1114. | 53499. ** |
| 5 | 309 | 703. | 48696. | 5217. | 47993. |
| 6 | 615. | 12460. | 12988. | 76. | 12913. |
| 7 | 513. | 5225. | 5241. | 28. | 5213. |

* See Figure 12 for element and section location.

** Maximum Linearized Surface Stress.

NOTES:

(1) These stresses from the N2050 Post Processor Program (SLINER) for Code evaluation of ANSYS results.

(2) These stresses in perforated region include the stress multiplier of 2.8 (Table 9) and biaxiality k = 1.1, or 2.8 x 1.1 = 3.08 factor.

(3) Allowable stress guideline is 3 x $S_m$ = 3 x 14,700 psi = 44,100 psi at 875°F from Table 7 criteria.

(4) See Table 11 for corresponding peak stresses.

BY | APPROVED | PAGE 52

## TABLE 11

## LOWER TUBESHEET PEAK SURFACE THERMAL STRESSES(1)

| SECTION* | ELEMENT* | SURFACE STRESSES (PSI) | | | STRESS INTENSITY (PSI) |
|---|---|---|---|---|---|
| | | $S_1$ (MERID.) | $S_2$ (HOOP) | $S_3$ (NORMAL) | |
| 1 | 22 | 2260. | -3117. | 0. | 5377. |
| 2 | 74 | 13594. | -3992. | 0. | 17586. |
| 3 | 254 | 59610.(2) | 44229.(2) | 0. | 59610.(2) |
| 4 | 319 | -19816. | 33187 | 0. | 53003. |
| 5 | 309 | 1091. | 60094. | 0. | 60094.** |
| 6 | 615 | 16405. | 17041. | 0. | 17041. |
| 7 | 513 | 6940. | 6949. | 0. | 6949. |

*See Figure 12 for element and section location.

**Maximum Peak Surface Stress.

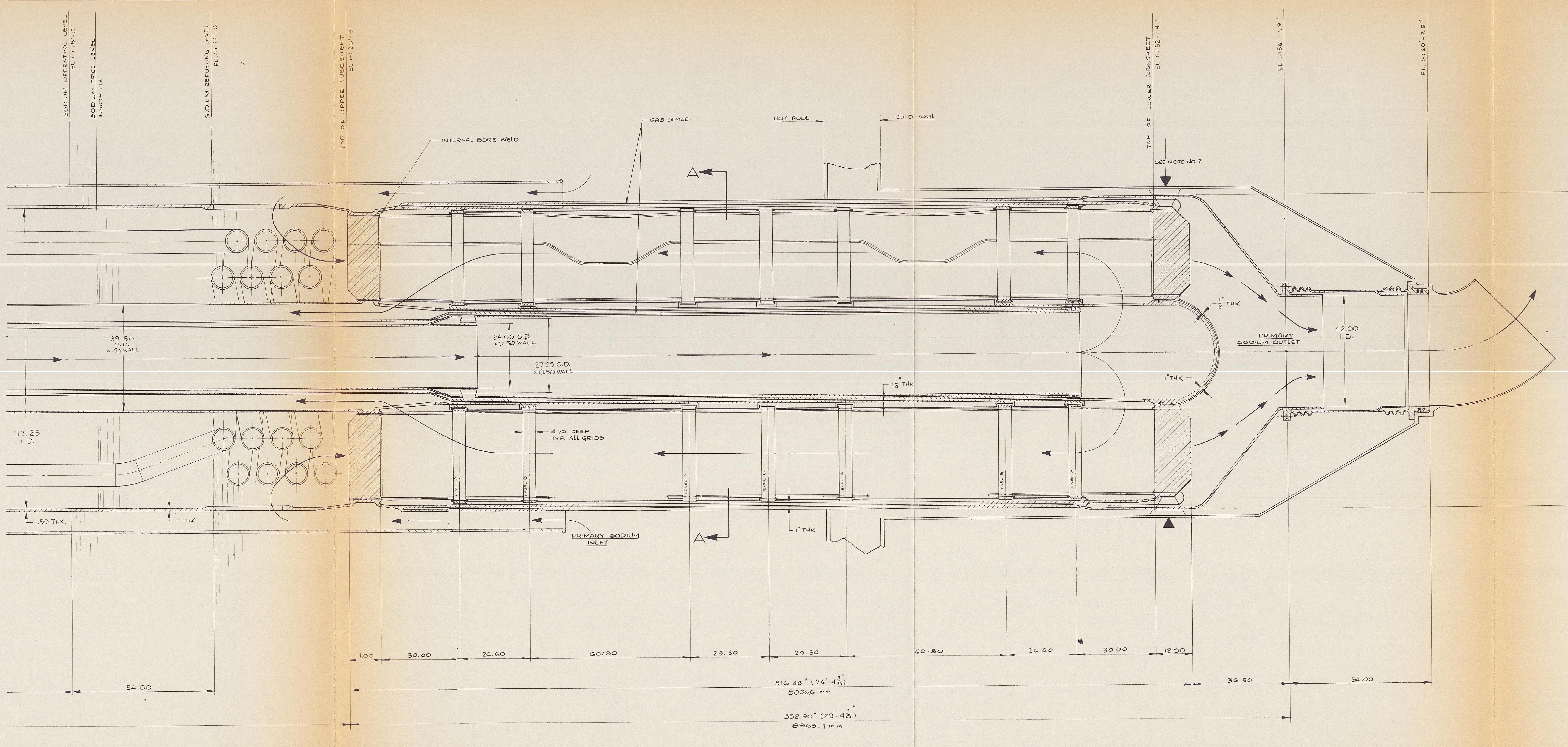
NOTES:

(1) These stresses from the N2050 Post Processor Program (SLINER) for Code evaluation of ANSYS results.

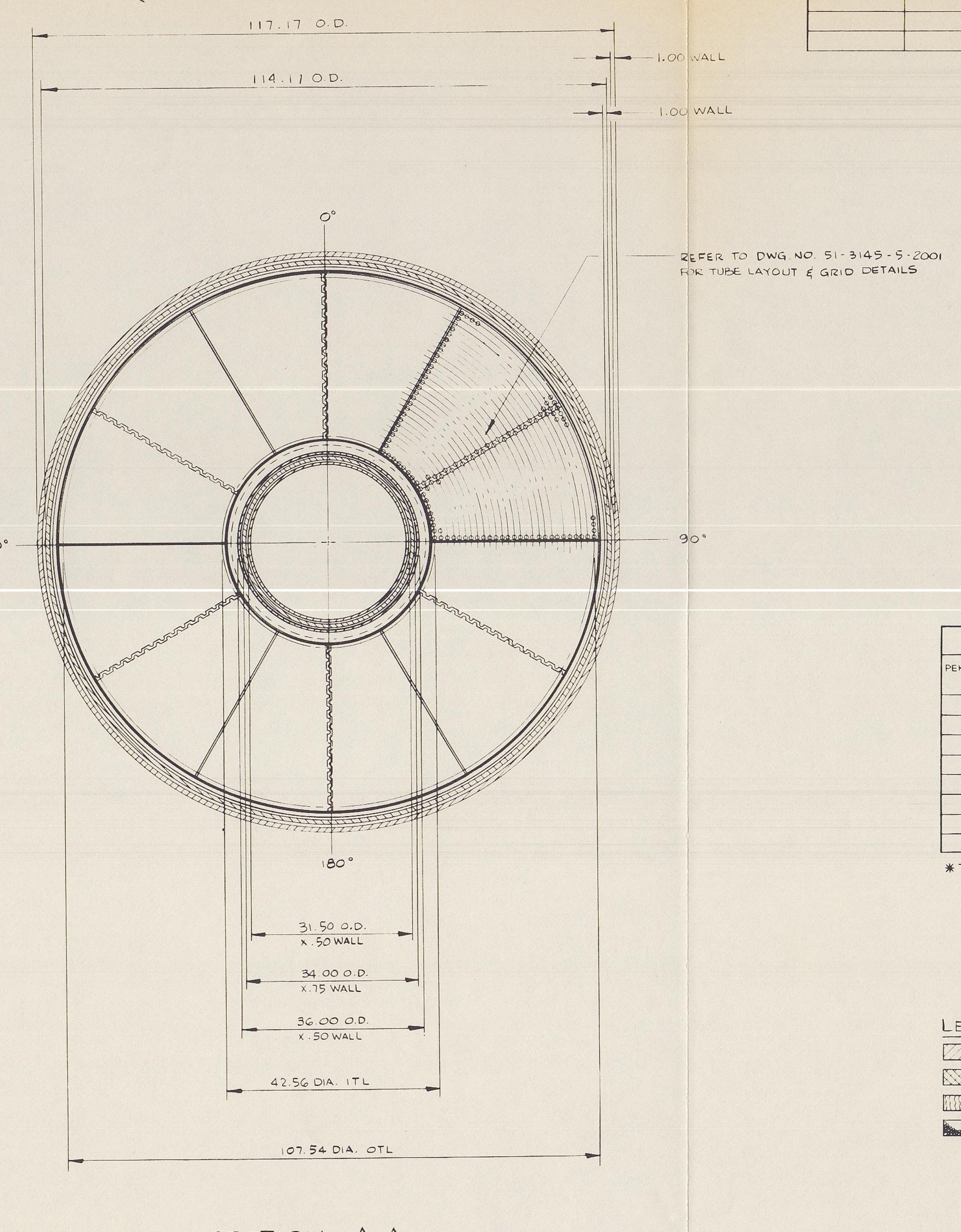
(2) These stresses in perforated region include the stress multiplier of 2.8 (Table 9) and biaxiality k = 1.1, or 2.8 x 1.1 = 3.08 factor.

(3) Allowable stress guideline is 3 x Sm = 3 x 14,700 psi = 44,100 psi at 875°F from Table 7 criteria.

(4) See Table 10 for corresponding linearized stresses.




LONGITUDINAL CROSS SECTION
SCALE 3/32" = 0'-1"




SECTION A-A
SCALE 3/32" = 0'-1"

## REFERENCE DRAWINGS

| DRAWING NO. | DESCRIPTION |
|---|---|
| 51-3145-6-1000 | DESIGN LAYOUT |
| 51-3145-5-2001 | TUBE LAYOUT & GRID DETAILS |
| AFS-SK-PE-002 | IHX PLUG REGION (G.E.) |
| | |
| | |
| | |

## DESIGN AND PERFORMANCE DATA

1. PRIMARY FLOW LOCATION - TUBE SIDE
2. DESIGN TEMPERATURES:
   - PRIMARY 900°F.
   - INTERMEDIATE 835°F.
3. OPERATING TEMPERATURES:
   - PRIMARY INLET 875°F.
   - PRIMARY OUTLET 594°F.
   - INTERM. INLET 550°F.
   - INTERM. OUTLET 815°F.
   - IRACS INLET 580°F.
   - IRACS OUTLET 845°F.
4. NUMBER OF TUBES:
   - PRIMARY BUNDLE - 4860 - .875 O.D. x 0.04 MIN. WALL
   - IRACS BUNDLE - 8.625 O.D. x 0.50 WALL COIL.
5. DESIGN PRESSURE:
   - PRIMARY SIDE 10 PSIG
   - INTERM. SIDE 250 PSIG
6. THERMAL RATING:
   - PRIMARY IHX 486 MWt
   - IRACS 3 MWt
7. FLOW RATE:
   - PRIMARY KNa $19.25 \times 10^6$ #/HR.
   - INTERM. KNa $20.29 \times 10^6$ #/HR.
8. PRESSURE DROP:
   - TUBE SIDE 1.6 PSI
   - SHELL SIDE 27.6 PSI
9. ESTIMATED WEIGHTS:
10. OPERATING PRESSURES:
    - INTERM. SIDE 115 PSIG.

## NOTES

1. VESSEL DESIGNED AND FABRICATED IN ACCORDANCE WITH ASME B&PV CODE, NUCLEAR VESSELS, SECTION III, CLASS I, 1977 EDITION.
2. DO NOT SCALE THIS DRAWING, USE FIGURE DIMENSIONS ONLY.
3. ALL DIMENSIONS APPLY AT A STANDARD TEMPERATURE OF 70°F..
4. ALL DIMENSIONS ARE IN INCHES.
5. DIMENSIONING IS IN ACCORDANCE WITH ANSI Y14.5, 1973 EDITION.
6. SURFACE FINISH SHALL BE IN ACCORDANCE WITH ANSI B46.1, UNLESS OTHERWISE SPECIFIED THE FOLLOWING SURFACE FINISHES SHALL APPLY:
   - a) MATING SURFACES 63
   - b) HEAT TRANSFER TUBES 63
   - c) TUBE SHEET HOLES 125
   - d) ALL OTHER SURFACES 250
7. RADIAL GUIDES, AND STRUCTURE, FOR SEISMIC EVENT LOAD TRANSFER, SHALL BE PROVIDED WHERE NOTED, BY OTHERS.

## PENETRATION SCHEDULE

| PENETRATION NO. | DESCRIPTION | PIPE SIZE O.D. | PIPE SIZE WALL | SLEEVE SIZE O.D. | SLEEVE SIZE WALL | OPENING |
|---|---|---|---|---|---|---|
| P1 | INTERM. SODIUM INLET | 32.00 | .500 | — | — | — |
| P2 | INTERM. SODIUM OUTLET | 32.00 | .500 | — | — | — |
| P3 | AUX. SODIUM INLET | 8.625 | .500 | 10.75 | .365 | — |
| P4 | AUX. SODIUM OUTLET | 8.625 | .500 | 10.75 | .365 | — |
| P5 | MANWAY | — | — | — | — | 24.00 |
| P6 | ARGON GAS SUPPLY | * | * | — | — | — |
| P7 | COOLING GAS INLET | 12.750 | .25 | — | — | — |
| P8 | COOLING GAS OUTLET | 12.750 | .25 | — | — | — |

* TO BE DETERMINED

## MATERIAL SPECIFICATION TABLE

| MAJOR PART | ASME SPEC. | FWEC SPEC. |
|---|---|---|
| FORGINGS | SA-336 TP 304 | |
| NOZZLES | SA-336 TP 304 | |
| HEADS | SA-240 TP 304 | |
| PLATES | SA-240 TP 304 | |
| PIPE | SA-376 TP 304 | |
| TUBING | SA-213 TP 304 | |

## LEGEND

- DENOTES STEEL
- DENOTES SHIELDING
- DENOTES INSULATION
- DENOTES STEEL SHOT

| LETTER | DATE | DR. INIT. | DESCRIPTION |
|---|---|---|---|
| REVISIONS | | | |

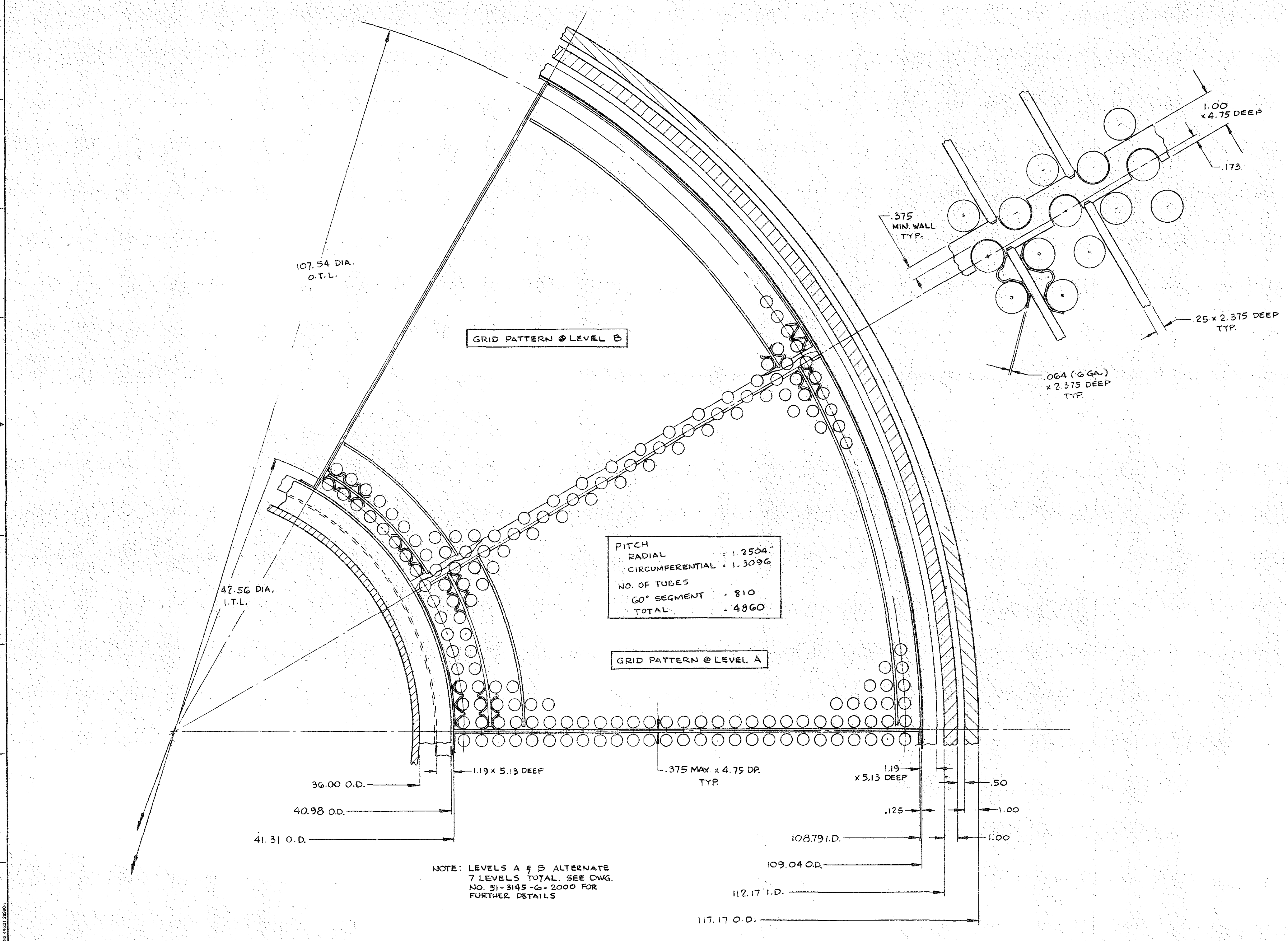
G.E. POOL IHX
DESIGN LAYOUT

DRAWING NUMBER: 51-3145-6-2000
SCALE: AS NOTED - 1"-0"
REVISION: 0

| DWG. MADE & APPROVED BY | INITIAL | DATE | CONT. NO. |
|---|---|---|---|
| DRAFTSMAN | RMS | 6-1-78 | ORDER NUMBERS |
| CHECKER | | | |
| SQUAD LEADER | | | |
| SECTION HEAD | [illegible] | 6-20-78 | |
| CONT. SUPV. | | | |


TOP VIEW
SCALE 3/32 = 0'-1"
NOTE: SEE PENETRATION SCHEDULE
FOR PENETRATION SIZES.
45°
45°
180°
P5
P6
P7
P8
NITROGEN GAS
JET PUMP
156.00
3962.4 mm
DIA.
120.00
72.00
132.00
24.00
60.00
10.00
360.00 (30'-0")
762.0 mm
321.00 (26-9)
8153.4 mm

VA-57




NOTE: LEVELS A & B ALTERNATE
7 LEVELS TOTAL. SEE DWG.
NO. 51-3145-6-2000 FOR
FURTHER DETAILS

## NOTES

1. DO NOT SCALE THIS DRAWING. USE FIGURE DIMENSIONS ONLY.
2. ABBREVIATIONS USED ON THIS DRAWING ARE IN ACCORDANCE WITH AMERICAN STANDARD "ABBREVIATIONS FOR USE ON DRAWINGS".

| REV. | DATE | DR. INIT | DESCRIPTION |
|---|---|---|---|

REVISIONS

# G.E. POOL IHX TUBE LAYOUT & GRID DETAILS

| DRAWING NUMBER | SCALE 3/8 FULL & FULL = 1'-0" |
|---|---|
| 51-3145-5-2001 | REVISION 0 |

| | | |
|---|---|---|
| DRAWN BY | RMS | 5/22/78 |
| CHECKED BY | | |
| APPROVED BY | [signature] | 6-20-78 |

# POOL-TYPE LMFBR PLANT

## 1000 MWe PHASE A - EXTENSION 1 DESIGN

Contents

VOLUME 6:
(Cont'd.)