A COMPARATIVE TRANSIENT ANALYSIS
OF METAL AND OXIDE FUELED LMFBR

by

D. Saphier and J. T. Madell

Components Technology Division

MASTER

BASE TECHNOLOGY

September 1979

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

The facilities of Argonne National Laboratory are owned by the United States Government. Under the terms of a contract (W-31-109-Eng-38) among the U. S. Department of Energy, Argonne Universities Association and The University of Chicago, the University employs the staff and operates the Laboratory in accordance with policies and programs formulated, approved and reviewed by the Association.

MEMBERS OF ARGONNE UNIVERSITIES ASSOCIATION

The University of Arizona	The University of Kansas	The Ohio State University
Carnegie-Mellon University	Kansas State University	Ohio University
Case Western Reserve University	Loyola University of Chicago	The Pennsylvania State University
The University of Chicago	Marquette University	Purdue University
University of Cincinnati	The University of Michigan	Saint Louis University
Illinois Institute of Technology	Michigan State University	Southern Illinois University
University of Illinois	University of Minnesota	The University of Texas at Austin
Indiana University	University of Missouri	Washington University
The University of Iowa	Northwestern University	Wayne State University
Iowa State University	University of Notre Dame	The University of Wisconsin-Madison

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use or the results of such use of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights. Mention of commercial products, their manufacturers, or their suppliers in this publication does not imply or connote approval or disapproval of the product by Argonne National Laboratory or the United States Government.

TECHNICAL MEMORANDUM

ANL-CT-80-1
LMFBR Reactor Core
Systems (UC-79e)

A COMPARATIVE TRANSIENT ANALYSIS
OF METAL AND OXIDE FUELED LMFBR

by

D. Saphier and J. T. Madell

Components Technology Division

BASE TECHNOLOGY

September 1979

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

TABLE OF CONTENTS

	<u>Page</u>
Abstract	x
1.0 Introduction	1
2.0 Summary and Major Conclusions of the Study	5
3.0 Description of the Systems Being Analyzed	11
3.1 The LMFBR Primary Loop Component	11
3.2 The Heterogeneous Metal Fueled Core	14
3.3 The Oxide Fueled Core	16
3.4 Loop and Pool-Type Reactors	16
3.5 The Transient Inducing Events Used in this Study	16
4.0 The Mathematical Models Used in the Study	20
4.1 A Fuel Pin Model for the Multichannel Transient Analysis of a Reactor Core	21
4.2 The Upper Plenum Module	27
5.0 The Application of the DSNP Simulation Language to Simulate the LMFBR Primary Loop	29
5.1 Basic DSNP Characteristics	29
5.2 Structure of a DSNP Simulation Program	31
5.3 The DSNP Modules and Definitions Used in this Study	33
5.4 The LMFBR System and the DSNP Block Diagrams	37
6.0 Results of the Simulation Study	39
6.1 Comparing Transient Response of Metal versus Oxide Fueled Cores	40
6.2 Comparing Transient Response of Loop-Type versus Pool-Type LMFBR Primary Loops Using Metal or Oxide Fueled Cores	71

TABLE OF CONTENTS

<u>Appendices</u>		<u>Page</u>
1:	Data for simulating the metal fueled 1000 MWe LMFBR primary loop.	78
2:	Data for simulating the oxide fueled 1000 MWe LMFBR primary loop.	83
3:	"METAL.LOOP" the DSNP program to simulate reactor scram on low flow in a metal fueled, single channel, loop-type, LMFBR primary coolant loop.	85
4:	"METALA.LOOP" the DSNP program to simulate reactor scram on low flow in a metal fueled, multi-channel, loop-type, LMFBR primary coolant loop.	89
5:	"OXIDEC.LOOP" the DSNP program to simulate the U1 event in an oxide fueled average, and hot channels, loop-type, LMFBR primary coolant loop.	93
6:	"OXIDED.POOL" the DSNP program to simulate the U1 event in an oxide fueled, single-channel, pool-type, LMFBR primary loop.	97
7:	A Summary of DSNP Statements	101
References		114

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1.	Core coolant exit and upper plenum temperature transients resulting from a UI event in oxide and metal fueled LMFBRs	7
2.	Average fuel-pin maximum cladding temperature transient resulting from a UI event in oxide and metal fueled LMFBRs	8
3.	Upper plenum coolant temperature transients resulting from a UI event in loop-type and pool-type metal fueled LMFBRs	10
4.	A simplified schematic description of LMFBR loop-type and pool-type primary loop	12
5.	Top view of the pool-type reactor showing the location of the six IHXs inside the reactor vessel	13
6.	One-sixth core layout of a heterogeneous metal fueled LMFBR	15
7.	The A1 transient induced in an oxide core. Flow trip initiated at 1 sec, followed by the reactor scram at 70% of normal flow	18
8.	The UI transient induced in a metal core. The reactor scram is activated at $t=0$ sec, followed by a pump trip at 500 m sec.	19
9.	Axial and radial schematic representation of an equivalent fuel-pin subchannel	22

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
10.	Subdividing a fuel-pin into I radial nodes	23
11.	The flow stratification function	28
12.	DSNP Program Segment Description	32
13.	The LMFBR primary loop block diagram	38
14.	The LMFBR primary loop flowchart	38
15.	The DSNP flowchart for simulating an LMFBR primary	38
16.	Flow transients resulting from primary pump trip at 1 sec and secondary pump trip at 6 sec	41
17.	Fission and decay power transients resulting from an A1 event	42
18.	Coolant temperature transients at core exit, upper plenum and IHX inlet resulting from an A1 event	43
19.	Coolant temperature transients at core exit, upper plenum and IHX inlet resulting from an A1 event	44
20.	Primary loop temperature transients at different locations resulting from an A1 event	45
21.	Primary loop temperature transients at different locations resulting from an A1 event	46
22.	Fuel pin and cladding midwall temperature transient resulting from an A1 transient	48
23.	Fuel pin and cladding midwall temperature transients resulting from an A1 event	49
24.	Coolant exit temperatures resulting from an A1 event from the core average subchannel, ZTC, from the internal blanket subchannel ZTC2, and from the radial blanket average subchannel, ZTC3 and whole reactor average for an A1 event	50

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
25.	The collapsing of coolant temperatures along an average core subchannel resulting from an A1 event	51
26.	The collapsing of coolant temperatures along an average core subchannel, resulting from an A1 event	52
27.	Collapsing of the cladding midwall temperatures resulting from an A1 event	53
28.	Collapsing of the cladding midwall temperatures resulting from an A1 event	54
29.	Collapsing of the fuel inner node temperatures resulting from an A1 event	55
30.	Collapsing of the fuel inner node temperatures resulting from an A1 event	56
31.	Flow transients resulting from primary pump trip at 1 sec and secondary trip at 6 sec	58
32.	Transient in the total reactor power resulting from a U1 event	59
33.	Transient in the total reactor power resulting from a U1 event	60
34.	Coolant temperature transients at core exit, upper plenum and IHX inlet, resulting from a U1 event	61
35.	Coolant temperature transients at core exit, upper plenum and IHX inlet, resulting from a U1 event	62
36.	Instantaneous rate of change in the core coolant exit temperature. DYDT24 is for the coolant average channel and DYDT78 is for the hot channel	63

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
37.	Instantaneous rate of change in the core coolant exit temperature. DYDT24 is for the coolant average channel and DYDT78 is for the hot channel	64
38.	Instantaneous rate of change in the upper plenum coolant temperature resulting from a U1 event	65
39.	Instantaneous rate of change in the upper plenum coolant temperature resulting from a U1 event	66
40.	Average and hot channel coolant exit temperature transient resulting from a U1 event	67
41.	Average and hot channel coolant exit temperature transient resulting from a U1 event	68
42.	Average and hot channel cladding temperature transients resulting from a U1 event	69
43.	Average and hot channel cladding temperature transients resulting from a U1 event	70
44.	Collapsing of the central node fuel temperatures in core average and hot channels fuel pins, resulting from a U1 event	72
45.	Collapsing of the central node fuel temperatures in core average and hot channels fuel pins, resulting from a U1 event	73
46.	Coolant temperature transients at core exit, upper plenum and IHX inlet, resulting from a U1 event	74
47.	Coolant temperature transients at core exit, upper plenum and IHX inlet, resulting from a U1 event	75

LIST OF FIGURES

<u>No.</u>	<u>Title</u>	<u>Page</u>
48.	Primary loop temperature transients at different locations resulting from a U1 event	76
49.	Primary loop temperature transients at different locations resulting from a U1 event	77

Abstract

The neutronics and thermodynamics of an LMFBR primary system have been simulated using the DSNP simulation language. A detailed fuel pin and its subchannel model were developed and included in the DSNP library. This permits the reactor core to be simulated with any number of pins having any number of radial and axial nodes.

The metal fueled core transients were compared to transients of an oxide fueled core, the conclusion being that for the same perturbations the temperature transients are faster in the metal core. A comparison between pool-type and loop-type reactors was also performed, leading to a conclusion that the transients in the upper plenum temperatures are much slower in the pool-type reactor than in the loop-type reactor.

Acknowledgements

The authors wish to acknowledge the cooperation of Jon Beitel (AP) in providing information on the metal fuel pin design, Gary M. Schwab (SAI) for assistance in adding graphics capabilities to DSNP, and to P. A. Howard (CT) for suggestions on modelling the Upper Plenum. We also express our appreciation to Carolyn Dueweke for deciphering and typing the report on a tight schedule.

1.0 INTRODUCTION

At the direction of DOE/RRT, Conceptual Design Studies (CDS) are presently being conducted for the next generation LMFBR. These studies, which are being performed by the industrial reactor vendors, began late in 1978 and are scheduled for completion in March, 1981. The end product of the studies is a single LMFBR design, including safety analysis, cost and schedule, on which a decision to build a large (~1000 MWe) breeder reactor plant will be based. The CDS organization is broken down into a number of tasks for the design of various plant systems; for example, Task 1 is Core Design and the Task 1 Core Design Group, consisting of all of the participants, have agreed on the ground rules, criteria, etc. for the trade-off studies and eventually for a single core design.

The Core Design activities are separated into three levels. Level I, in which most of the activity is concentrated, deals with the design of an oxide fueled, and stainless steel clad core using near-term technology and conservative design approaches. The Level II core uses an advanced oxide or a carbide fuel, an advanced alloy for cladding and duct, and advanced design features for which there is less data than for the Level I design. This core could replace the original oxide core in four or five years after reactor start-up.

Level III uses far-term technology, such as advanced alloys, metal fuels and design features for which there are no data. The goal of this core is to achieve high performance, e.g., a breeding ratio greater than 1.45, a doubling time less than 12 years and fuel cycle costs lower than the other two core

designs. The ground rules, criteria and some design parameters have been established for the metal fuel core. Level III trade-off studies on the metal are being performed at ANL by the Applied Physics Division and are concentrating on those features which are special to metal fueled cores. Work is also being performed by the Components Technology Division to investigate two features of metal fueled cores which differ from those of the oxide and may raise problems in using a metal fuel as a replacement core in a plant which was optimized for an oxide core. The first feature is the power coefficient, to which a metal fuel would contribute a very small doppler coefficient and possibly a large positive sodium density effect. The study of this feature will be reported in another Technical Memorandum.

The investigation of the second feature of particular interest in metal fueled cores deals with the transient responses of the core to an off-normal event, i.e. two kinds of reactor scrams. The thermal diffusivity of the sodium-bonded Pu-U-Zr metal alloy fuel pin is considerably higher than that of the helium-bonded oxide pin. During a thermalhydraulic transient the temperature within and downstream of a metal core changes more rapidly than in an oxide core. The resulting higher thermal stresses (and thermal shock for rapid changes) may adversely impact the structural life of the affected components. These components may be the cladding, the above-core components, the reactor vessel outlet nozzle, the pump and the intermediate heat exchanger (IHX). In Level III studies the cladding is designed for metal fuel conditions but the downstream components have been designed for the original oxide core.

The objective of the work presented here is to model a metal and an oxide core in a transient analysis computer code and to determine the transient response of the fuel, cladding and coolant, both in the core and throughout the

primary system. Since many of the design features of the CDS core designs are still open, the analysis is a comparative one in which the cores are modeled in a consistent way so that the basic effects of the metal and oxide fuels can be compared. No structural analysis of the resulting thermal stresses is included in this study.

The oxide core design parameters were taken from information provided by the Task 1 Core Design Group, ⁽⁴⁾ which has performed some trade-off studies but has not yet arrived at a completed core design. Information on the metal fuel design was obtained from AP ^(4,8) which also was in the midst of their trade-off studies. A heterogenous core was chosen, primarily because this configuration was also selected for the power coefficient study. Although the metal fueled core could use any advanced alloy for duct and cladding, a slightly modified stainless steel was assumed for convenience in this study, i.e. the cladding has little effect on the transient response and good data on steel is available. The primary system temperatures and flows, and the dimensions and configuration of the upper plenum were obtained from the Upper Plenum Mixing Program which had solicited the data from the individual contractors. The IHX model was simply a scaled-up version of the IHX from the CRBRP, ⁽⁶⁾ which had been modeled for a previous study. Since the steady-state and transient flow rates were specified, the pump was not modeled for hydraulic purposes.

Two transients were used in the investigation, a reactor scram from full power with a pump trip to pony motor speed, and a reactor scram on a low flow signal (caused by a pump trip and a run-down to pony motor speed). The first transient is a common upset event typically used in performing thermalhydraulic and structural analyses in the primary system. In the second transient core temperatures initially increase because of undercooling and then decrease rapidly

after the reactor scram. The total temperature swing is greater in the second transient.

The report of this study is structured in the following way. The summary and conclusions are presented first (Section 2) for the convenience of the casual reader. The physical system (Section 3) is then described, followed by a description of the mathematical models (Section 4) used to represent the system. The application of the DSNP Simulation Language is explained in Section 5. The results of the calculations are given in Section 6. Detailed data and some of the DSNP simulation programs are given in the Appendices.

2.0 SUMMARY AND MAJOR CONCLUSIONS OF THE STUDY

The dynamics of four 1000 MWe LMFBR systems were analyzed using the DSNP* simulation language. (1-3). The four systems were the metal and oxide fueled reactors having both loop-type and pool-type designs. The components present in the primary loop included the core, the lower and upper plena, the intermediate heat-exchanger (IHX), and the pipe segments leading from the upper plenum to the IHX and from the IHX to the lower plenum. A simplified flowchart of the system is shown in Section 3.1, Fig. 4. In this study the neutronics and thermodynamics of the power plant were simulated. The flow variation as function of time during the simulated transient was given as input data, and therefore, the hydrodynamic equations were not solved. Hydrodynamic modules are, however, available in DSNP.

The core can be represented in DSNP by any number of fuel pins. Each fuel pin having a central cylindrical fuel region a sodium bonded cladding, an equivalent coolant channel and an equivalent cylindrical duct around the coolant channel. Any number of axial and radial nodes can be used to represent the fuel pin in the simulation. For economical reasons, however, only average channels and the hot channels were simulated, they being representative values of the different core regions.

The major conclusion from analyzing the simulation results given in detail in Section 6 are the following:

- 1) The LMFBR core having metal (U-15Pu-10Zr) fuel will have more severe temperature transients than a similar core using oxide (U-Pu O₂) fuel.
- 2) The resulting thermal shock to the downstream components is significantly reduced for both the oxide and metal core, if a pool-type instead of loop-type construction are used.

The above conclusion are clearly demonstrated in the following figures. In

* DSNP stands for Dynamic Simulator for Nuclear Power-plants.

Figure 1, the average core coolant temperature transients as well as the upper plenum coolant temperature transients are shown for a UI event. The UI event is expected to take place many times during a reactor lifetime and is therefore typical of transient operating conditions. In this event, the reactor SCRAM is activated, followed by the primary pump trip 500 ms later. It is seen from Figure 1 that the rate of change of the core coolant temperature is much faster in the metal core. The temperature at the core exit drops by 122.1C (220F) in 2.2 sec in the metal core, while at the same time the temperature drop in the oxide core is only 72.7 (131F). The first minimum in the core average exit temperature at 115.5C is achieved at 8.5 s in the oxide core, as compared to only 4s in the metal core, with a temperature drop of 137.4C. This more "sluggish" response of the oxide core is the result of the oxide fuel pin having about four times the heat content of the metal fuel pin, but only about one tenth of the metal fuel heat conductivity. The oxide core will therefore give up more heat during the UI transient cooling phase, but it will give it up much more slowly than the metal core.

Considering the temperature transients in the upper plenum, it is seen from Figure 1 that the metal core has a higher initial rate of change, but that about 10 seconds later the temperatures continue to change at about the same rate. During the first 20 seconds of the transient, the upper plenum temperature drops by 25.6C in the oxide core and by 26.2C in the metal core. In Fig. 2 the transient in the maximum cladding temperature is shown. As can be seen the transient is slower and has smaller amplitude in the oxide core than in the metal core. Two seconds after the UI event is initiated the maximum cladding temperature drop in a metal fueled core is 158C, while in the oxide core the temperature drop is only 89C.

In Fig. 3 the temperatures in the upper plena of a loop and pool-type metal fueled reactors are compared. It is seen that the temperature transients

Figure 1: Core coolant exit and upper plenum temperature transients resulting from a UI event in oxide and metal fueled LMFBRs

Figure 2: Average fuel-pin maximum cladding temperature transient resulting from a UI event in oxide and metal fueled LMFBRs

are milder in the upper plenum of a pool type reactor because of the much larger sodium volume in this reactor type. Eighty seconds after the transient was initiated, the temperature drop in the loop type reactor is 39.4C (71F) while in the pool-type reactor it is only 21C (38F). Making the same comparisons for oxide fueled loop- and pool-type reactors, similar results are obtained.

Figure 3: Upper plenum coolant temperature transients resulting from a UI event in loop-type and pool-type metal fueled LMFBRs

3.0 DESCRIPTION OF THE SYSTEM BEING ANALYZED.

This study is a comparative analysis of transient performance of four LMFBF systems, namely: the heterogeneous metal fueled loop- and pool-type reactors and the oxide fueled loop and pool type reactors. Details on the simulated systems are given below.

3.1 THE LMFBF PRIMARY LOOP COMPONENTS.

Simplified schematic diagrams of LMFBF primary loops, both for the loop and the pool-type reactors is shown in Figure 4. Both systems are of 1000 MWe producing about 2700 MWt. The hotleg temperature (or the average mixed core exit temperature) is 507C in the metal core and 547C in the oxide core. The cold-leg (or core inlet temperature) is 343C in the metal core, and 381C in the oxide core. In the simulation the core can be represented by any number of fuel pins with their equivalent coolant subchannels and a cylindrical duct around the subchannel. There can be different types of fuel pins in the core and the blanket.

From the core the coolant flows to the upper plenum where an ideal mixing is assumed under normal flow condition. Under reduced flow conditions stratification takes place; that is, only part of the fluid in the upper plenum participates in the mixing process.

In the loop-type reactor the sodium from the upper plenum exits the pressure vessel through the exit nozzle and into a pipe leading to one of the four IHX's. The sodium pump providing the flow driving force is located in this pipe - the hot leg. In the pool-type reactor the IHX is inside the pressure vessel, and the sodium enters the six IHX's directory from the upper plenum. In the IHX the primary sodium is on the shell side, and is cooled by the intermediate sodium flowing on the tube side.

Fig. 4 A Simplified Schematic Description of LMFBR
Loop-type and Pool-type Primary Loop.

Fig. 5 Top View of the Pool-type Reactor Showing the Location of the Six IHXs Inside the Reactor Vessel.

From the IHX the cold sodium passes through a pipe (the cold leg) to the lower plenum. In the pool-type reactor (as shown in Fig. 4) the sodium pump is in the cold leg of the primary loop inside the pressure vessel. In the pool-type reactor the six IHX and the sodium pumps are arranged as shown in Fig. 5.

3.2 THE HETEROGENEOUS METAL FUELED CORE

The proposed metal fueled LMFBR has composite metal fuel made up from 15% Pu, 10% Zr and 75% natural or depleted uranium. To improve breeding, power distribution and to reduce the positive Na coefficients, a heterogeneous arrangement of blanket elements among fuel elements was proposed, as shown in the one sixth-core segment in Fig. 6. There are 240 fuel sub-assemblies having 217 fuel pins each, 121 internal blanket subassemblies having 127 fuel pins each and 204 radial blanket subassemblies having 127 fuel pins each.

In the simulation the core thermodynamics is represented by an average fuel pin for each the fuel, the internal blanket, and the external blanket regions, one fuel pin representing the hottest subassembly and a fuel pin representing the hot channel. The hot channel in the heterogeneous core is located in the 8th row in a subassembly producing 9.78 MWt. Temperature hot channel factors were taken from Ref. 4. Both direct factors and statistical (3 σ) were used. Combining all of the factors the following fuel-pin subchannel changes were made for the hot channel.

Change flow in subchannel by a factor of 0.862

Change power in subchannel by a factor of 1.14

Change cladding thickness by a factor of 1.07

Change coolant cross flow area by factor of 1.01

Change heat transfer coefficient by a factor of 0.826

The fuel pin model in DSNP was appropriately modified to permit the inclusion of the hot channel factors.

Detailed data on the heterogeneous metal core necessary for the simulation of the system are given in Appendix A. The material properties of the U-15Pu-10Zr

Number of Assemblies	
Core	240
Internal Blanket	121
Radial Blanket	204
Control	18

Fig. 6 One-Sixth Core Layout of a Heterogeneous Metal Fueled LMFBR

fuel were obtained from Ref. 5.

3.3 THE OXIDE FUELED CORE

No detailed information on a 1000 MWe oxide fueled LMFBR was available for this study. Instead the characteristics of the Clinch River Breeder Reactor Plant were upgraded and used in the simulation.^(6,7) Detailed data as used in the simulation study are given in Appendices 1 and 2 both for the pool- and loop-type systems. Many of the unknown parameters such as pipe length and diameter, IHX design etc. were made equal for all the reactor systems under investigation so as not to shade the basic core characteristics of the oxide and metal cores.

3.4 LOOP-AND POOL-TYPE REACTORS

The major differences between the two reactor types, being of importance to the present study, are the much larger upper plenum in the pool-type reactor, and a large lower plenum or cold-pool below the reactor in addition to the inlet plenum. In the loop-type reactor the IHX and the pipes to and from the IHX are external to the reactor vessel, while in the pool type the IHX is inside the reactor vessel and the piping is eliminated altogether. In the loop-type reactor the pump is in the hot leg while in the pool-type reactor the pump is in the cold-leg of the loop. These major differences can be observed on the schematic drawings shown in Fig. 4.

3.5 THE TRANSIENT INDUCING EVENTS USED IN THIS STUDY

There are two events that were used in this study to initiate transients in the simulated system. They are both transients which are expected to take place several times during the reactor lifetime. The first event designated here as A1, includes the tripping of all the primary pumps and a flow coast-down to 8% of normal flow (pony motors) as shown in Fig. 7. When the safety system detects

a reduction of flow to 70%, it will scram the reactor. The power trip as a function of time is also shown in Fig. 7.

The second event is designated U1 and it begins with activating the reactor scram at full power followed by the tripping of all the pumps and a flow coast down to 8% of its normal value. The flow and power transients associated with this event in a metal core are shown in Fig. 8. Both of the transients are characterized with the maximum possible temperature change both in the core and the upper plenum. The maximum rate of change of the temperature possible at the core exit, the cladding, and upper plenum, are major factors to be considered when structural parts of the LMFBR are being designed.

In the A1 event there are small differences between the oxide and metal core power transients due to different delayed neutron fractions, neutron lifetime and feedback reactivity coefficients of the two cores.

RUN OXIDE-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR OXIDE CORE.

F- 7. The A1 transient induced in an oxide core. Flow trip initiated at 1 sec, followed by the reactor scram at 70% of normal flow.

RUN METALB-3: SIMULATION OF THE UI EVENT IN AN LMFBR METAL FUELED PRIMARY LOOP.

Fig. 8. The UI transient induced in a metal core. The reactor scram is activated at $t=0$ sec, followed by a pump trip at 500 m sec.

4.0 THE MATHEMATICAL MODELS USED IN THIS STUDY

In this section the mathematical models developed in this study are presented. Most of the models used for the simulation are standard DSNP modules and described in detail in Ref. 2, "The Level-One Modules Library for DSNP." The mode in which they should be used in simulating a power plant are described in detail in Ref. 1, "The Simulation Language of DSNP." These modules already in DSNP will be only briefly mentioned.

The core neutronics is simulated by solving the neutron kinetic equations with six group of delayed neutrons. These equations are solved in the NEUTR1 module.

The fission products heat generation is assumed to be a fixed part of the total power at steady state. In the present simulations it was set to 200 MWt or 7.3%. The fission products are subdivided into four groups each having different decay constant and production rate. The appropriate equations are solved in the DSNP module GAMAR1.

The IHX model includes heat balance equations for three radial nodes, namely a primary coolant node, a secondary coolant node and a wall node. There can be any number of axial nodes in the model. Five nodes are used in the present simulations. Various heat transfer correlations and material property functions are available in DSNP and are used by the IHX module IHXMA1 which solves the necessary equations.

The PIPE module generates a function in which the pipe inlet variables are stored at consecutive time or temperature increments. Whenever either the time or the temperature increments are larger than a certain predetermined value the information at the present time step is stored. Outlet values are calculated using an nth degree interpolation scheme and calculating the appropriate flow rate through the pipe.

The feedback reactivity effect is computed in the FDBEK1 module which uses average core temperatures. A safety module SAFTY 1 is provided which activates the reactor scram whenever any of the system variables exceeds its predetermined value.

4.1 A FUEL PIN MODEL FOR THE MULTICHANNEL TRANSIENT ANALYSIS OF A REACTOR CORE

The level-one DSNP model for the core thermodynamics, CORTP 1, which uses a lumped parameter model, was not sufficient for the present study. A new, level-two, multichannel model was developed, CORTP2. In this model any number of core subchannels can be simulated to obtain detailed temperature distribution in the axial and radial direction, both in the core and the individual fuel pin. Each subchannel consist of an individual cylindrical fuel pin enclosed in a cladding. The gap between the fuel pellets and the cladding might include any type of bonding material. The coolant flows in the axial direction around the fuel pin in a cylindrical channel whose effective flow cross section area is obtained by dividing the subassembly flow cross sectional area by the number of fuel pins in the subassembly. Finally, the coolant channel is enclosed by an equivalent duct representing the subassembly duct material and any additional structural material present in the core and participating in the heat transfer process. An axial and radial crosscut through a subchannel is shown in Fig. 9. In the axial direction the fuel pin can have three regions, namely the lower axial blanket, the fuel region and the upper axial blanket. The fuel pin can be subdivided into any number of axial and radial nodes, according to the detail for which the temperature distribution is requested.

In addition to the new core thermodynamic module, a new power distribution module, TPOWR2, was developed providing detailed axial and radial power distribution for the core thermodynamic calculations.

Fig. 9 Axial and Radial Schematic Representation of an equivalent fuel-pin Subchannel

The heat transfer equation in a cylindrical geometry assuming no conduction in the axial direction is given by the partial differential equation.

$$\frac{1}{r} \frac{\partial}{\partial r} (kr \frac{\partial T}{\partial r}) + W(r,t) = C_p \rho \frac{\partial T}{\partial t} \quad (1)$$

where

$\rho = \rho(r, T)$ is the density.

$C_p = C_p(r, T)$ is the heat capacity,

$k = k(r, T)$ is the heat conductivity,

T is the fuel temperature,

t is the time

r is the radius

W is the heat produced in the fuel pin.

By subdividing the fuel pin into I radial nodes as shown in Fig. 10

Fig. 10 Subdividing a Fuel-Pin Into I radial Nodes.

and integrating upon each cylindrical shell, the following heat balance equation is obtained (see also Ref. 7)

$$V_i C_p \rho_i \frac{dT_i}{dt} = -\bar{k} \frac{\partial T}{\partial r} \Big|_{r=r_{i-1}} A_{i-1} + \bar{k} \frac{\partial T}{\partial r} \Big|_{r=r_i} A_i + W_i \quad (2)$$

where

$$V_i = \pi(r_i^2 - r_{i-1}^2) \Delta Z \quad (3)$$

$$A_i = 2\pi r_i \Delta Z \quad (4)$$

$$\bar{k}_i = k(\bar{T}_i); \quad \bar{T}_i = (T_{i+1} + T_i)/2 \quad (5)$$

$$\left. \frac{\partial T}{\partial r} \right|_{r=r_{i-1}} \approx \frac{\Delta T_{i-1}}{\Delta r_{i-1}} = \frac{T_i - T_{i-1}}{\frac{r_i - r_{i-1}}{2} + \frac{r_{i-1} - r_{i-2}}{2}} = 2 \frac{T_i - T_{i-1}}{r_i - r_{i-2}} \quad (6)$$

$$\left. \frac{\partial T}{\partial r} \right|_{r=r_i} \approx \frac{\Delta T_i}{\Delta r_i} = \frac{T_{i+1} - T_i}{\frac{r_{i+1} - r_i}{2} + \frac{r_i - r_{i-1}}{2}} = 2 \frac{T_{i+1} - T_i}{r_{i+1} - r_{i-1}} \quad (7)$$

and ΔZ is the axial segment for which the heat balance is performed. Combining equations 2, 6 and 7 the finite difference equation (8) for the fuel pin is obtained.

$$Q_i \frac{dT_i}{dt} = UA_i (T_{i+1} - T_i) - UA_{i-1} (T_i - T_{i-1}) + W_i \quad (8)$$

where

$$UA_i = k_i 4\pi r_i \Delta Z / (r_{i+1} - r_{i-1}) \quad (9)$$

and

$$Q_i = C_{p_i} V_i \rho_i = M_i C_{p_i}$$

For the innermost fuel node

$$UA_1 = 4\pi k_1 \Delta Z r_1 / r_2 \quad (10)$$

Assuming now that the fuel pin is subdivided into I radial nodes ($i=1, \dots, I$), and J axial nodes ($j=1, \dots, J$) the actual equations solved in DSNP to obtain the temperature distribution in a fuel pin subchannel are given below

A) For the Innermost Fuel Node,

$$M_{1j} C_{p_{1j}} \frac{dT_{f_{1j}}}{dt} = W_{f_{1j}} - AU_{1j} (T_{f_{1j}} - T_{f_{2j}}) \quad (11)$$

and the initial conditions are obtained from

$$T_{f_{1j}} = T_{f_{2j}} + W_{f_{1j}} / AU_{1j} \quad (12)$$

B) For the i th Fuel Node,

$$M_{ij} C_{p_{ij}} \frac{dT_{f_{ij}}}{dt} = W_{f_{ij}} + AU_{i-1,j} (T_{f_{i-1,j}} - T_{f_{ij}}) - AU_{ij} (T_{f_{ij}} - T_{f_{i+1,j}}) \quad (13)$$

and the initial conditions are obtained from,

$$T_{f_{ij}} = T_{f_{i+1,j}} + \sum_{i=1}^I W_{f_{i,j}} / UA_i \quad (14)$$

C) For the Outermost Fuel Node

$$M_{Ij} C_{p_{Ij}} \frac{dT_{f_{Ij}}}{dt} = W_I + AU_{I-1,j} (T_{f_{I-1,j}} - T_{f_{Ij}}) - AU_{Ij} (T_{f_{Ij}} - T_{L_j}), \quad (15)$$

where T_{L_j} is the cladding midwall temperature for the jth axial node.

The initial temperature for the outermost fuel node is obtained from,

$$T_{f_{Ij}} = T_{L_j} + \sum_{i=1}^I W_{ij} / AU_{Ij}, \quad (16)$$

where AU_{Ij} is the heat transfer coefficient across the gap between the fuel pellet and the cladding and is given by,

$$AU_{Ij} = 2\pi\Delta X / \left(\frac{1}{8k_f} + \frac{1}{r_I H_g} + \frac{1}{k_L} \ln \left\{ \frac{R_{L_i} + R_{L_i}}{2R_{L_i}} \right\} \right), \quad (17)$$

where r_I , R_L , and R_{L_i} are the fuel pin radius, the cladding internal radius, and the cladding external radius, respectively; k_I and k_L are fuel and cladding conductivity.

H_g is the gap heat transfer coefficient. For a fuel pin of radius r_o , a gap interval of Δ and conductivity k , it is given by Eq. 18,

$$H_g = \frac{k}{r_o \ln \left(\frac{r_o + \Delta}{r_o} \right)} \quad (18)$$

D) For the Cladding Node,

$$M_{L_j} C_{p_j} \frac{dT_{L_j}}{dt} = W_{L_j} + AU_{Ij} (T_{f_{Ij}} - T_{L_j}) - UA_{L_j} (T_{L_j} - \bar{T}_{C_j}) \quad (19)$$

where

$$\bar{T}_{C_j} = (T_{C_j} + T_{C_{j+1}}) / 2$$

and T_{C_j} and $T_{C_{j+1}}$ are the coolant node inlet and outlet temperatures, W_{L_j} is the

heat liberated in the cladding material due to gamma radiation.

The initial cladding temperature is calculated by

$$T_{L_j} = \bar{T}_{C_j} + \left(\sum_{i=1}^I W_{ij} + W_{L_j} \right) / UA_{L_j} \quad (20)$$

Several correlation are being used to calculate the cladding to coolant heat transfer for the specified pitch-to-diameter ratio and flow regime. These are evaluated in UCORC1 and described in detail in Ref. 2.

E) For the Coolant Node

For all the nodes in the subchannel the node average temperatures are calculated. For the coolant however the energy balance is based on the node inlet and outlet enthalpy

$$M_{C_j} \frac{dH_{j+1}}{dt} = W_{C_j} + AU_L (T_{L_j} - T_{C_j}) - AU_D (\bar{T}_{C_j} - T_{D_j}) - G_C (H_{j+1} - H_j) \quad (21)$$

$$\text{and } \bar{T}_{C_j} = \frac{H_{j+1} + H_j}{\frac{C}{P_{j+1}} + \frac{C}{P_j}} \quad (22)$$

The initial value of the enthalpy for the jth node is given by

$$H_{C_{j+1}} = H_{C_j} + W_j / G_C \quad (23)$$

where G_C is the flow rate in the subchannel, W_j the total heat produced in the jth axial node while W_{C_j} is the amount of heat released in the coolant due mainly to the absorption of γ radiation from the fission products and the fission process.

F) For the Duct Node

$$M_{D_j} (C_p)_{d_j} \frac{dT_D}{dt} = UA_{L_j} (\bar{T}_{C_j} - T_{D_j}) \quad (24)$$

and UA_{D_j} is evaluated in the same way as UA_C by one of the correlations available in DSNP.

The heat produced in each of the nodes described above, is computed in the power distribution model TPOWR2.

The total power produced in the core and blankets is given by

$$W = PWJ + WGT \quad (25)$$

where PWJ is the fission power and WGT the heat produced by the fission products.

The total power generated in a particular subchannel is given by

$$WP = \alpha_p \cdot W \quad (26)$$

where α_p is the fraction of power produced in the subchannel. (Average power in a particular region is obtained by dividing the total power generated in that region by the number of fuel pins in the region).

The power generated in the fuel pin is

$$WF = \alpha_f \cdot WP \quad (27)$$

The power generated in the cladding is

$$WL = \alpha_L \cdot WP \quad (28)$$

and the power generated in the coolant is

$$WC = \alpha_C \cdot WP \quad (29)$$

where α_C is the fraction of heat generated in the coolant, α_L is the fraction of heat generated in the cladding, and $\alpha_f = 1 - \alpha_C - \alpha_L$ is the fraction of heat generated in the fuel pin. For each simulated fuel pin an axial power distribution function $f(x)$ is provided. By multiplying this function by the expressions in Eqs. 27-29 the power generated in a given node is obtained.

$$\begin{aligned} WF_{ij} &= WF \cdot f(x_j)/I \\ WL_j &= WL \cdot f(x_j) \\ WC_j &= WC \cdot f(x_j) \end{aligned} \quad (30)$$

4.2 THE UPPER PLENUM MODULE

The upper plenum as well as the lower plenum are assumed to be ideal mixing volumes. In the DSNP modules, UPLEN1 and LPLEN1, a two node ideal mixing model is simulated.

The expression for the coolant node is

$$\alpha V_C \rho_C C_p \frac{dT_C}{dt} = G_C (T_{C_i} - T_C) - \alpha UA (T_C - T_W) \quad (31)$$

where T_{C_i} is the coolant inlet temperature

and for the metal node containing all the structural materials and the walls of the upper plenum is

$$\alpha M_W C_W \frac{dT_W}{dt} = \alpha UA (T_C - T_W) , \quad (32)$$

where U and A are the heat transfer coefficient and area between the coolant and the structure; V_C is the coolant volume in the plenum, ρ its density, and C_p its specific heat.

However, when the flow is reduced significantly below normal flow only part of the upper plenum volume participates in the mixing process. Stratification takes place and an interface is formed between the upper hot coolant and the mixed colder coolant. This boundary reduces the plenum effective mixing volume. A coefficient α was introduced, therefore in the upper plenum Eqs. 31 and 32. Its value under normal operating conditions is 1. Under reduced flow conditions its value is given by the function in Fig. 11.

Fig. 11 The flow stratification function.

5.0 THE APPLICATION OF THE DSNP SIMULATION LANGUAGE TO SIMULATE THE LMFBR

The simulation programs in this study were developed by using the DSNP language. The actual listing of some of the programs is given in the Appendices. The major advantage of using the DSNP is the simplicity by which a power plant can be simulated, the very small number of statements required to write a simulation program, and the inherent flexibility which permits the simulation of a large variety of systems. A short description of DSNP is given below, as well as some details on the present simulation programs development. Full details can be found in Ref. 1-3.

5.1 BASIC DSNP CHARACTERISTICS

The Dynamic Simulator for Nuclear Power-plants (DSNP) is a special purpose block oriented continuous digital simulation language. It was developed mainly to facilitate the preparation of dynamic simulations of a large variety of nuclear power plants. It is a user oriented language that allows the development of simulation programs directly from power plant block diagrams and flow charts.

Central to the DSNP language is a large number of functional blocks representing physical components of nuclear power plants. Many of the more complex components are represented by several blocks or modules. The nuclear reactor, for example, has a kinetic module, a power distribution module, a feedback module, a thermodynamic module, a hydraulic module, and a radioactive decay heat module. These modules are usually stored in a specific library, either in the form of a subroutine written in DSNP, a function, a block of statements, a macro, or a combination of the above.

In addition to the component modules (ranging from 5 to 500 equivalent FORTRAN statements), DSNP has many basic functional blocks such as integrators, pipes, delays, transfer functions, and functions representing properties of materials used in nuclear power plants. These functions are used

extensively in preparing library modules and can also be used directly in a DSNP program.

To develop a simulation of a large scale nuclear power plant, the user only has to follow the flowchart and list the DSNP modules that represent the components needed for the simulation in an appropriate logical sequence. If necessary, the appropriate DSNP connection modules are included, the integration methods to be used in the various loops of the power plant are defined, and the input data are supplied in a simple straightforward manner.

With a more advanced knowledge of programming, the user can develop his own modules and store them in the user's library. This permits complete flexibility in modeling and programming techniques.

User oriented input and output (I/O) in a simplified form is provided. A specific format is not required and the listed variables will be printed at user defined intervals in a special easy to read tabular form, I/O statements can be located anywhere in the program in an arbitrary sequence.

A DSNP simulation program has several sequential segments. Three of these, BEGIN, SIMULATE, and TERMINATE, must be present in every simulation program. The precompiler analyzes these segments, performs the appropriate translations, inserts the requested modules from the libraries, links these modules together, searches the necessary data sets, and finally produces a FORTRAN simulation program with an appropriate data set to be used by this program.

DSNP is a free field language and statements can be written anywhere except for column one where an identifier flag is placed. As many statements as space permits can be inserted in a single record, and statements can be continued on any number of subsequent cards. FORTRAN is considered to be a subset of DSNP and can

be inserted anywhere in the simulation program without restrictions. Actually ordinary FORTRAN programs can be submitted to DSNP with no detrimental effect.

The DSNP has a flexible and powerful macro processor. The system macro capability permits one to develop user defined macros in addition to the basic system macros. It is possible to develop new DSNP instructions, to compile nonstandard FORTRAN statements, when present, and to make language extensions.

The user has the option of developing a system simulation in a very simple form using only the component modules available in the DSNP library with a minimal knowledge of DSNP programming and no previous knowledge of other programming techniques, or by mastering all of the DSNP programming techniques and the FORTRAN language, producing new modules and DSNP statements from basic functional blocks while making extensive use of the DSNP macro capability. As a result, although DSNP is a special purpose simulation language, it also includes facilities available in other simulations languages such as CSMP, MIMIC, ACSL and others.

5.2 STRUCTURE OF A DSNP SIMULATION PROGRAM

The DSNP program can have up to six basic segments. Each of the segments, except the first, is identified by a flag character in column one of its first record. The BEGIN, SIMULATE, and TERMINATE segments must be placed in each program although they might not have any executable statements. The other segments are optional. The program segments must be arranged sequentially as shown in Fig. 12.

The DECLARATIONS segment includes all the system definition and is followed by any statement to be executed prior to initial conditions calculations. The BEGIN segment contains all the DSNP statement necessary to perform the system initialization, and to calculate the system steady state initial conditions.

The dynamic section of the program contains one or more SIMULATE segments.

FIRST
COLUMN
FLAG

```

DECLARATIONS*****
*
*   Various declarations of Functions, Connectors,
*   Pipes, and Macro Modules.
*****

B   BEGIN AT 0.0 *****
*
*   Static part and Initial Conditions calculations.
*****

S   SIMULATE LOOP01 METHOD TDV=2 *****
*
*   First dynamic simulation loop.
*****

S   SIMULATE LOOPii METHCD TDV=j*****
*
*   Any other simulation loop up to a maximum
*   of MAXLOP simulation loops.
*****

T   TERMINATE AT 10.0 seconds *****
*
*   Any post simulation statements to be executed
*   after the dynamic simulation has been terminated.
*****

F   ADDITIONAL SUBROUTINES *****
*
*   Any number of subroutines or functions called
*   from other parts of the program can be inserted
*   here.
*****

L   LIBRARY LEVEL-ZERO *****
*
*   Any number of additional library modules in the
*   form of 'NAMEX'0 can be inserted here.
*****

```

Fig. 12 DSNP Program Segment Description.

Each segment can have a different integration scheme, and the integration performed with different time steps. The TERMINATE statement indicates the simulation termination time. This segment contains any "post simulation" statements the user wishes to execute. It is also common to place all the printing instructions in this section, as well as the necessary data statements.

Optionally two additional segments can be located in a DSNP program. An "F" segment containing any additional subroutines the user wishes to use, and an "L" segment containing a user supplied zero-level library with user developed DSNP modules.

5.3 THE DSNP MODULES AND DEFINITIONS USED IN THIS STUDY

The modules or rather DSNP statements calling for the modules to be included in the simulation are listed below in order of their appearance in the simulation program. Each module call is terminated by a digit indicating the level of sophistication. (See also Appendices 3 to 6.)

- 1) SAFTY1 (SC) - Simulates the reactor safety system. The parameter SC is the name of a function providing the SCRAM reactivity versus time.
- 2) CNTRL1 - Simulates the plant control system. Can accommodate also any arbitrary reactivity insertion or withdrawal functions.
- 3) FDBEK1 - Simulates the reactor feedback effects including Doppler, sodium and expansion coefficients.
- 4) NEUTR1 - Simulates the neutron kinetic equations with six groups of delayed neutrons.
- 5) GAMAR1 - Simulates the radioactive decay heat generation.
- 6) TPOWR2 - Simulates the reactor power distribution in the core.
- 7) LPLEN1 - Simulates the reactor lower plenum.
- 8) PIPEii - Simulates a pipe segment, and the two characters, ii, are the name given to a particular segment.
- 9) CORTP2(ii) - Simulates the reactor thermodynamics, and ii is the material indicator of the coolant flowing through the core. SO- is for sodium.

- 10) CNCTii - Is a "connector" which connects any number of variable pairs one to another.
- 11) UPLEN1 - Simulates the upper plenum thermodynamics.
- 12) FHXMil - Simulates the thermodynamics of a heat exchanger, and i is an identifying character given to a particular unit when defined.

Several of the DSNP components require a definition prior to their usage. Those used in the present simulation are listed below.

1) DFPDISTi (AP, AL, AC, JP, IP, DISTR (.....), FPF)

Defines the power distribution in the i-th fuel pin and the parameters are:

AP - fraction of total power generated in the i-th fuel pin.

AL - fraction of the power generated in the cladding.

AC - fraction of the power generated in the coolant.

JP - number of axial nodes.

IP - number of radial nodes.

DISTR(f1, f2...f(JP)) - contains the axial distribution function f1 f2... Must have JP entries.

FPF - power maldistribution factor for hot channel calculations.

2) IHXMil(IHX, NXW, ZPDI, MAT1, MAT2)

Defines a heat exchanger designated as i, where i can be any character, and the parameters are:

IHX - number of axial segments to be simulated.

NXW - number of parallel pipes or channels to be simulated.

ZPDI - pitch to diameter ratio.

MAT1 - material indicator of the primary coolant.

MAT2 - material indicator of the secondary coolant.

3) DFPINS(A1, TP1, A2, TP2....)

Defines the names and number of axial nodes of all the fuel pins to be simulated.

A1, A2... etc. - a single character name of the fuel pin.

JP1, JP2... - the number of segments-nodes used in the simulation of a particular fuel pin.

- 4) DFFUEL1(JP, IP, J1, J2, MATF, MATB, MATL, MATD, MATC, XL, XC, XU, RF, RLI, RLX, RC, RD, SF, SB, PD, MATG, FF, IJ, AFTF, AFTL, AFTC, LOOP, FCF, FHF)

Defines a fuel pin subchannel by the name i (any character) and the parameters are:

JP - number of axial nodes

IP - number of radial nodes

J1 - active core first axial node

J2 - active core last axial node

MATF - fuel material indicator

MATB - blanket material indicator

MATL - cladding material indicator

MATD - duct material indicator

MATC - coolant material indicator

XL - length of lower axial blanket

XC - length of active core

XU - length of upper axial blanket

RF - fuel pin radius

RLI - cladding inner radius

RLX - cladding outer radius

RC - equivalent coolant channel radius

RD - equivalent duct outer radius

SF - fraction of fuel theoretical density

SP - fraction of blanket theoretical density

PD - pitch to diameter ratio

MATG - gap bonding material indicator

FF - fraction of total flow flowing through the subchannel

IJ - integer value of $JP*(IP-2)$

AFTF - fuel temperature core averaging factor

AFTL - cladding temperature core averaging factor

AFTC - coolant temperature averaging factor

LOOP - indicating the integration loop in which this module
is located

FCF - flow maldistribution factor

FHF - heat transfer maldistribution factor

5) DFPIPEii(FIN, FEX, VPLD, EF, ET, G, KK, MP)

Defines a pipe segment by the name ii (any two character combination),
and the parameters are:

FIN - pipe inlet variable

FEX - pipe exit variable

VPLD - volume of the pipe

EF - minimum change in pipe inlet variable initiating a storage
operation

ET - minimum increase in time, since last storage initiating a
storage operation.

G - volumetric flow rate through pipe

KK - degree of interpolation used to evaluate the pipe exit variable

MP - number of pipe storage locations to be assigned to this particular
segment

6) FNCTii(K, N, X1, X2,...XN, Y1, Y2,...YN)

Defines a function by the name ii, and the parameters are:

K - the degree of interpolation to be used with the ii function

N - number of X, Y pairs defining the function

X1 to XN are the numerical values of the independent variable

Y1 to YN are the values of the function

7) SCRAMF (V1, V2, COM)

Defines conditions under which the reactor SCRAM will be activated.
If the variables V1 becomes bigger than V2 the SCRAM is activated.
COM indicates the name of the common block in which the variable
can be found.

Other DSNP statement found in the simulation are:

- 1) DESTROY - to free macro space during the compilation process.
- 2) CONVERGR or CONVERGA causes the IC calculations to converge on a particular variable.
- 3) P in column 1 causes all the variables listed in this record to be printed on each time step defined by the "BY TO" statement.
- 4) DATA(COM) causes data to be stored in the COM common block of variables.

5.4 THE LMFBR SYSTEM AND THE DSNP BLOCK DIAGRAMS

A simplified block diagram of the LMFBR primary system is shown in Fig. 13, which shows the major system components. Getting into more details, the flow chart in Fig. 14 is obtained. This represents the thermodynamic and neutronic processes taking place in the primary loop. Each of these processes or components has a DSNP counterpart as shown in Fig. 15. This figure is a DSNP flowchart and comparing Fig. 14 to 15 it is seen that a one-to-one correspondence exist between the two. The DSNP program as can be seen in the Appendices, is basically the listing of these module names in a logical order-usually in the order of energy propagations.

Fig. 13 The LMFBF Primary Loop Block Diagram.

Fig. 14 The LMFBF Primary Loop Flowchart.

Fig. 15 The DSNP Flowchart for Simulating an LMFBF Primary Loop.

6.0 RESULTS OF THE SIMULATION STUDY

The four reactor systems studied under the present comparative analysis were perturbed by the A1 and U1 events as described in Section 3.5. The resulting transient temperatures as well as some temperature distributions along the core axial direction at different times, are presented below. The figures presenting temperature distribution at different times also show a cross section through the fuel pin indicating the locations for which the temperatures are given. In all the simulations one axial and 3 radial nodes have been used. The graphs were generated directly by the DSNP graphic package, and therefore the legend contains the names of DSNP variables as listed below.

FHAI - IHX secondary flow
FPAI - IHX primary flow
PNJ - normalized neutronic power
TEAHX - IHX secondary coolant exit temperature
TEAPI - IHX primary coolant inlet temperature
TEAPX - IHX primary coolant exit temperature
TECI - core coolant inlet temperature
TECX - core coolant exit temperature
TENA - upper plenum coolant temperature
WGN - heat generated by the fission products
ZFLCOR - coolant flow through the core
ZTC1, ZTC2, ZTC3, ZTCM - subchannel coolant temperatures at fuel, internal blanket, radial blanket and hot channel, respectively.
ZTF1, ZTF2, ZTF3, ZTFM - subchannel central node fuel temperatures, at the fuel, internal blanket, radial blanket and hot channel, respectively.
ZTL1, ZTL2, ZTL3, ZTLM - subchannel cladding temperatures at the fuel, internal blanket, radial blanket and hot channel, respectively.
ZTHMW - total reactor power

6.1 COMPARING TRANSIENT RESPONSE OF METAL VERSUS OXIDE FUELED CORES

The A1 Event

The oxide and metal fueled cores were first submitted the A1 event described in Fig. 7. The flow coast-down of the core and primary coolant in this event starts at 1 sec in the primary loop and reaches 8% of normal flow (Pony motors) after about 40 seconds. The intermediate pumps are tripped at 6 seconds. The core, IHX primary and secondary flows as a function of time for the first 30s of the transient are shown in Fig. 16. The normalized neutronic power and the decay heat transients are shown in Fig. 17. The reactor scram is activated at about 2.8 sec; that is, when the flow reduces to 20% of its normal value, as shown in Fig. 7. It is seen that the decay heat production decreases much more slowly than the fission heat production. The decay heat causes the coolant exit temperature to rise for the second time during the transient, as shown in the results below.

The transient temperatures for the core coolant exit, the plenum, and the IHX inlet, are shown in Fig. 18 and 19. The difference between the two reactors is obvious. In the metal core the transients are much faster due to the smaller heat content of the fuel pin and its much larger heat conductivity. In the metal core the temperature drops about 155C (279F) in just 4.3 sec, while in the oxide core the temperature drops 145C(261F) in 9 sec.

In Fig. 20 and 21 more coolant temperature transients are shown at different locations along the primary loop, as well as the exit temperature on the IHX secondary side. This transient is shown for 80 s following the perturbation. As can be seen, the transients are somewhat faster in the metal core than in the oxide core. The major difference, however, is in the coolant exit temperatures. The next two figures show the temperature collapsing during an

RUN METAL-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR HETEROGENOUS METAL CORE

Fig. 16. Flow transients resulting from primary pump trip at 1 sec and secondary pump trip at 6 sec

RUN OXIDE-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR OXIDE CORE.

Fig. 17. Fission and decay power transients resulting from an Al event

RUN METAL-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR HETEROGENEOUS METAL CORE.

Fig. 18. Coolant temperature transients at core exit, upper plenum and IHX inlet resulting from an AI event

RUN OXIDE-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR OXIDE CORE.

Fig. 19. Coolant temperature transients at core exit, upper plenum and IHX inlet resulting from an AI event

RUN METAL-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR HETEROGENEOUS METAL CORE.

Fig. 20. Primary loop temperature transients at different locations resulting from an AI event

RUN OXIDE-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR OXIDE CORE

Fig. 21. Primary loop temperature transients at different locations resulting from an Al event

A1 transient in a metal and oxide average fuel pin. The simulated fuel pin has 3 radial and 9 axial nodes. Fig. 22 shows the temperature in the 6th node (just above the center node) of an average metal fuel pin for the fuel innermost radial node, the second node and the outer node, and for the cladding midwall node. Fig. 23 shows the same transient for an average oxide fuel pin. It is seen that the temperature in the metal fuel pin collapses in about 2.5 s while in the oxide fuel pin it takes about 8 s. Note also that while in the metal fuel pin the maximum fuel temperatures are above the mid-plane of the fuel pin (node 6), the maximum temperature in the oxide fuel pin is midway (no account was given to possible control rod perturbations). In both subchannels the maximum cladding temperature is at the end of the active core and the beginning of the upper axial blanket (node 7).

Fig. 24 compares the outlet temperatures from an average fuel subchannel, an average internal blanket subchannel, an average radial blanket subchannel and the average mixed core coolant exit temperature for a metal core. This figure is the result of simulating the LMFBR core with four subchannels.

The next six figures show temperature distributions at different times. Each of the figures indicates the location of the temperature profile on the adjacent drawing of the fuel-pin cross section. Note also that the location of the coolant nodes is different from all the other nodes. Figs. 25 and 26 show the coolant temperatures along an average channel at different times. Again, it can be observed that coolant temperatures in the metal core collapse much faster. Figs. 27 and 28 show the average channel cladding midwall temperatures at different times. Figs. 29 and 30 give the fuel pin central node axial temperature distribution at different times, for the metal and oxide cores, respectively.

The U1 Event

In the U1 event the reactor scram is activated at $t = 0$ followed by tripping all the primary pumps at 500 ms and tripping the intermediate pumps at 1 s,

RUN METAL-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR HETEROGENEOUS METAL CORE.

Fig. 22. Fuel pin and cladding midwall temperature transient resulting from an Al transient

RUN OXIDE-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR OXIDE CORE.

Fig. 23. Fuel pin and cladding midwall temperature transients resulting from an Al event

RUN METALA-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR HETEROGENEOUS METAL CORE.

Fig. 24. Coolant exit temperatures resulting from the A1 event from the core average subchannel, ZTC, from the internal blanket subchannel ZTC2, and from the radial blanket average subchannel, ZTC3 and whole reactor average for an A1 event.

RUN METAL-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR HETEROGENEOUS METAL CORE.

Fig. 25. The collapsing of coolant temperatures along an average core subchannel resulting from an AI event

RUN OXIDE-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR OXIDE CORE.

Fig. 26. The collapsing of coolant temperatures along an average core subchannel, resulting from an AI event

RUN METAL-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR HETEROGENEOUS METAL CORE

Fig. 27. Collapsing of the cladding midwall temperatures resulting from an Al event

RUN OXIDE-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR OXIDE CORE.

Fig. 28. Collapsing of the cladding midwall temperatures resulting from an Al event

RUN METAL-3: SIMULATION OF THE KINETICS AND PRIMARY THERMODYNAMICS OF AN LMFBR HETEROGENEOUS METAL CORE

Fig. 29. Collapsing of the fuel inner node temperatures resulting from an A1 event

RUN OXIDED-3: SIMULATION OF THE U1 EVENT IN A POOL TYPE OXIDE FUELED LMFBR PRIMARY LOOP.

Fig. 30. Collapsing of the fuel inner node temperatures resulting from an A1 event

as shown in Fig. 8. The flow transients in the core, IHX primary and secondary loops are shown in Fig. 31 for the first 30 seconds of the transient. The resulting power transient is shown in Figs. 32 and 33. Fig. 32 depicts the first six seconds of the transient while Fig. 33 shows the change in power between 5 and 80 sec. The first figure shows the rapid change in power due to the scram, from 2700 to 200 MW while the second shows the much slower change in power due to the delayed neutrons and the fission products activity.

The coolant hot leg temperatures for a U1 event are shown in Fig. 34 for the metal core, and Fig. 35 for the oxide core. As in an A1 event it is obvious that the metal core response is faster than the oxide core response.

Figs. 36 and 37 show the instantaneous rate of change in the coolant exit temperatures for the metal and oxide cores, respectively. It shows them both for the core average channel and the hot channel. The maximum instantaneous rate of change of the coolant exit temperature in a core average subchannel is 85 C/s for the metal core and about 56 C/s for the oxide core. In the hot channels the corresponding numbers are 95 C/s and 73 C/s. The rate of change in the upper plenum coolant temperatures are given in Fig. 38 for the metal core and in Fig. 39 for the oxide core. The maximum instantaneous rate of change is about 2 C/s for the oxide and 3 C/s for the metal core.

A comparison between the average and the hot channel temperatures is presented in the following figures: Figures 40 and 41 show average and hot subchannel coolant exit temperatures for the metal and oxide cores respectively. The cladding average and hot channel temperatures for the metal and oxide cores is shown in Figs. 42 and 43. The cladding temperature at the 7th node (maximum cladding temperature) is shown for both cases.

RUN METALB-3: SIMULATION OF THE UI EVENT IN AN LMFBR METAL FUELED PRIMARY LOOP.

Fig. 31. Flow transients resulting from primary pump trip at 1 sec and secondary trip at 6 sec

RUN METALB-3: SIMULATION OF THE UI EVENT IN AN LMFBR METAL FUELED PRIMARY LOOP.

Fig. 32. Transient in the total reactor power resulting from a UI event

RUN METALB-3: SIMULATION OF THE UI EVENT IN AN LMFBR METAL FUELED PRIMARY LOOP.

Fig. 33. Transient in the total reactor power resulting from a UI event

RUN METALB-3: SIMULATION OF THE U1 EVENT IN AN LMFBR METAL FUELED PRIMARY LOOP.

Fig. 34. Coolant temperature transients at core exit, upper plenum and IHX inlet, resulting from a U1 event

RUN OXIDEB-3: SIMULATION OF THE UI EVENT IN AN LMFBR OXIDE FUELED PRIMARY LOOP.

Fig. 35. Coolant temperature transients at core exit, upper plenum and IHX inlet, resulting from a UI event

RUN METALC-3: SIMULATION OF THE UI EVENT IN AN LMFBR METAL FUELED PRIMARY LOOP.

Fig. 36. Instantaneous rate of change in the core coolant exit temperature. DYDT24 is for the coolant average channel and DYDT78 is for the hot channel.

RUN OXIDEC-3: SIMULATION OF THE U1 EVENT IN AN LMFBR OXIDE FUELED PRIMARY LOOP.

fig. 37. Instantaneous rate of change in the core coolant exit temperature. DYDT24 is for the coolant average channel and DYDT78 is for the hot channel.

RUN METALC-3: SIMULATION OF THE UI EVENT IN AN LMFBR METAL FUELED PRIMARY LOOP.

Fig. 38. Instantaneous rate of change in the upper plenum coolant temperature resulting from a UI event

RUN OXIDEC-3: SIMULATION OF THE U1 EVENT IN AN LMFBR OXIDE FUELED PRIMARY LOOP.

Fig. 39. Instantaneous rate of change in the upper plenum coolant temperature resulting from a U1 event

RUN METALC-3: SIMULATION OF THE U1 EVENT IN AN LMPBR METAL FUELED PRIMARY LOOP.

Fig. 40. Average and hot channel coolant exit temperature transient resulting from a U1 event

RUN OXIDEC-3: SIMULATION OF THE U₁ EVENT IN AN LMFBR OXIDE FUELED PRIMARY LOOP.

Fig. 41. Average and hot channel coolant exit temperature transient resulting from a U₁ event

RUN METALC-3: SIMULATION OF THE UI EVENT IN AN LMFBR METAL FUELED PRIMARY LOOP.

Fig. 42. Average and hot channel cladding temperature transients resulting from a UI event

RUN OXIDEC-3: SIMULATION OF THE U1 EVENT IN AN LMFBR OXIDE FUELED PRIMARY LOOP.

Fig. 43. Average and hot channel cladding temperature transients resulting from a U1 event

The collapsing of the fuel temperatures in the fuel pin central node resulting from the U1 event for the metal and oxide cores is shown in Figs. 44 and 45. In this case only two temperature profiles are given. At 0 and 2 s for metal core and 0 and 9 s for the oxide core.

6.2 COMPARING TRANSIENT RESPONSE OF LOOP-TYPE VERSUS POOL-TYPE PRIMARY LOOPS USING METAL AND OXIDE FUELED CORES

As a result of much larger upper plenum in the pool-type reactors, the transients in temperatures in the upper plenum are milder than in the loop-type core. This can be seen when comparing coolant temperature transients from Fig. 46 to Fig. 20, in the metal core, and Fig. 47 to Fig. 21, in the oxide core. Other coolant temperatures along the primary loop are shown in Figs. 48 for the metal loop-type core and in Fig. 49 for the oxide loop-type core. Comparing these figures to similar figures for the loop-type reactors it is seen that the delays caused by the long pipe segments between the core and the IHX have been eliminated from the primary loop; that is, the IHX is responding faster to any changes in the reactor operating conditions.

RUN METALC-3: SIMULATION OF THE UI EVENT IN AN LMFBR METAL FUELED PRIMARY LOOP.

- ZTF1, T= 0.0000
- ZTF1, T= 2.0000*10⁰
- △ ZTFM, T= 0.0000
- + ZTFM, T= 2.0000*10⁰

Fig. 44. Collapsing of the central node fuel temperatures in core average and hot channels fuel pins, resulting from a UI event

RUN OXIDEC-3: SIMULATION OF THE U1 EVENT IN AN LMFBR OXIDE FUELED PRIMARY LOOP.

□ ZTF1, T= 0.0000
 ○ ZTF1, T= 9.0000*10⁰
 △ ZTFM, T= 0.0000
 + ZTFM, T= 9.0000*10⁰

Fig. 45. Collapsing of the central node fuel temperatures in core average and hot channels fuel pins, resulting from a U1 event

RUN METALD-3: SIMULATION OF THE UI EVENT IN A POOL TYPE LMFBR METAL FUELED PRIMARY LOOP.

Fig. 46. Coolant temperature transients at core exit, upper plenum and IHX inlet, resulting from a UI event

RUN OXIDED-3: SIMULATION OF THE UI EVENT IN A POOL TYPE OXIDE FUELED LMFBR PRIMARY LOOP.

Fig. 47. Coolant temperature transients at core exit, upper plenum and IHX inlet, resulting from a UI event

RUN METALD-3: SIMULATION OF THE UI EVENT IN A POOL TYPE LMFBR METAL FUELED PRIMARY LOOP.

Fig. 48. Primary loop temperature transients at different locations resulting from a UI event

RUN OXIDED-3: SIMULATION OF THE UI EVENT IN A POOL TYPE OXIDE FUELED LMFBR PRIMARY LOOP.

Fig. 49. Primary loop temperature transients at different locations resulting from a UI event

Appendix 1: Data for Simulating the Metal Fueled Heterogeneous 1000 MWe
LMFBR Primary Loop

1) Core Data

Power	2740 MWt
Coolant Inlet Temperature	343.3 C
Total Flow	13105 kg/s
Average ΔT in core	163.6 C
Power generated in fuel	1996.5 MWt
Power generated in internal blanket	550.3 MWt
Power generated in radial blanket	189.3 MWt
Power generated in reflector	3.9 MWt
Flow through fuel	8322.5 kg/s
Flow through internal blanket	2978.6 kg/s
Flow through radial blanket	1774.9 kg/s
Flow through reflector	29 kg/s
Average ΔT in fuel	187.8 C
Average ΔT in internal blanket	213.8 C
Average ΔT in radial blanket	83.5 C
Maximum ΔT in fuel	219.3 C
Maximum ΔT in internal blanket	213.8 C
Maximum ΔT in external blanket	225.6 C

Number of fuel pins	240*217 = 52080
Number of internal blanket pins	121*127 = 15367
Number of external blanket pins	204*127 = 25908
Fraction of power from decay heat	7.3%
Fraction of power generated in cladding	0.13%
Fraction of power generated in coolant	0.0123%

2) Fuel Pin Data

	<u>Fuel</u>	<u>Blanket</u>
Fuel pin (pellet) radius R1[m]	.002883	.0047244
Cladding internal radius R2[m]	.003327	.0051308
Cladding external radius R3[m]	.003683	.0054864
Coolant channel equivalent rad. R4[m]	.00482	.00630
Duct & Structure equiv. rad. R5 [m]	.00503	.00658
Pitch to diameter ratio	1.22	1.074
Active core length [m]	.9144	
Upper axial blanket length [m]	.381	
Lower axial blanket length [m]	.381	

Fuel Composition - 15% Pu + 10% Zr + 75% U (100% TD)

Axial Blanket - U (100% TD)

Internal Blanket - U (100% TD)

Radial Blanket - U (100% TD)

Coolant - Na

Gap Bonding Material - Na

Cladding Material - D9

3) Subassembly Data

a = 0.0706 m

b = 0.0676 m

pins;fuel = 217, blanket = 127

Material D9

4) Axial Power Distribution

(node 1 is center of core)

I	X (inches)	Core	Internal Blanket	Radial Blanket
1	0	1	1	1
2	2	.993	.992	.993
3	4	.971	.970	.971
4	6	.934	.933	.934
5	8	.884	.882	.884
6	10	.881	.817	.821
7	12	.746	.740	.746
8	14	.660	.652	.660
9	16	.565	.555	.563
10	17.5	.486	.476	.486
CORE ↑				
BLANKET ↓				
11	18.5	.107	.230	.257
12	20	.085	.187	.216
13	22	.063	.143	.172
14	24	.074	.109	.138
15	26	.035	.083	.109
16	28	.026	.063	.0698
17	30	.014	.048	.0698
18	32	.014	.037	.0557
19	33	.012	.032	.0497

5) Core Physical Data

Delayed Neutron Data

$\lambda_1 = 0.013$	$\beta_1 = 8.0245 \text{ E-5}$
$\lambda_2 = 0.031$	$\beta_2 = 7.7189 \text{ E-4}$
$\lambda_3 = 0.134$	$\beta_3 = 7.0134 \text{ E-4}$
$\lambda_4 = 0.332$	$\beta_4 = 1.4247 \text{ E-3}$
$\lambda_5 = 1.3$	$\beta_5 = 6.8928 \text{ E-4}$
$\lambda_6 = 3.5$	$\beta_6 = 2.1157 \text{ E-4}$

$$\beta_t = 3.878 \text{ E-3}$$

Average neutron lifetime $\ell = 2.338 \text{ E-7}$

Doppler coefficient $T \frac{dk}{dt}$	$\Delta k / ^\circ\text{C}$
Core, fuel only	-0.0014 -1.1 E-6
Core + IB + RB	-0.003 -2.56 E-6

Sodium Void Coefficient Δk	β	$\Delta k / ^\circ\text{C}$
Core	0.0125	3.23
Core + AB	0.0119	3.08
Core + AB + IB	0.0215	5.54 5.7 E-6

6) Upper Plenum Data	<u>Loop</u>	<u>Pool</u>
Volume of Na [m^3]	487	1083
Mass of metal structures [kg]	20000	40000
Heat transfer coef. UA [J/C-s]	3.77E7	5.0E7

7) Lower Plenum Data	<u>Loop</u>	<u>Pool</u>
Volume of Na [m ³]	25	320
Mass of metal structures [kg]	5000	50000
Heat transfer coef. UA [J/C-s]	7.5E6	3.5E7

8) Intermediate Heat Exchanger (IHx) Data

Primary Hot leg Temperature	507 C
Primary Cold leg Temperature	343 C
Secondary Hot leg Temperature	482 C
Secondary Cold leg	262 C
Primary flow	3276 kg/s
Secondary flow	2425 kg/s
Number of tubes	250
Length of tubes	5 m
Inner tube diameter	0.01 m
Outer tube diameter	0.013 m
Wall Conductivity	937 J/m .c.s.
Flow Crossection area	0.4 m ²
Pitch to diameter ratio	1.4

Appendix 2: Data for Simulating the Oxide Fueled 1000 MWe LMFBR Primary Loop

(Data except where otherwise stated, are equal to the metal fueled LMFBR or are not available)

1) Core Data

Coolant Inlet Temperature	380.9 C
Total flow	13780 kg/s
Average ΔT in core	166 C
Total number of fuel pins	50 000
Fraction of power in clad	2%
Fraction of power in coolant	5%

2) Fuel Pin Data

Fuel pin (pellet) radius R1 [m]	.0025
Cladding internal radius R2 [m]	.00254
Cladding external radius R3 [m]	.00292
Coolant channel equivalent radius R4 [m]	.00365
Duct & Structural equivalent radius R5 [m]	.00410
Pitch to diameter ratio	1.2
Active core length [m]	1.5
Upper axial blanket length [m]	0.3
Lower axial blanket length [m]	0.3

Fuel Composition 20% Pu O₂, 80% UO₂ (93% TD)

Blanket Composition UO₂ (96% TD)

Cladding Material 316 SS

5) Core Physical Data

Delayed Neutron Data

$\lambda_1 = 0.0129$	$\beta_1 = 8.723 \text{ E-5}$
$\lambda_2 = 0.0308$	$\beta_2 = 7.499 \text{ E-4}$
$\lambda_3 = 0.132$	$\beta_3 = 6.648 \text{ E-4}$
$\lambda_4 = 0.325$	$\beta_4 = 1.306 \text{ E-3}$
$\lambda_5 = 1.34$	$\beta_5 = 6.950 \text{ E-4}$
$\lambda_6 = 3.27$	$\beta_6 = 1.949 \text{ E-4}$

$$\beta_t = 3.6 \text{ E3}$$

$$\text{Average neutron lifetime} = 6\text{E-7}$$

$$\text{Doppler coefficient, } T^{\Delta k}/\Delta F = -0.03$$

$$\text{Expansion coefficient, } \Delta k/\Delta T = 4.\text{E-6}$$

$$\text{Sodium coefficient, } \Delta k/\Delta T = 4.5\text{E-6}$$

8) Intermediate Heat Exchanger Data

Primary Hot Leg Temperature	546.9 C
Primary Cold Leg Temperature	380.9 C
Secondary Hot Leg Temperature	517.4 C
Secondary Cold Leg Temperature	329.1 C
Primary Flow	3445 kg/s
Secondary Flow	3002 kg/s

Appendix 3: "METAL.LOOP" The DSNP Program to Simulate Scram on Low Flow in a
Metal Fueled Single Channel Loop-Type LMFBR Primary Coolant Loop
(AI event).

This DSNP program contains;

13 Definitions,

21 IC statements,

18 Dynamic simulation statements,

1 Terminal statement and

22 I/O statements.

When compiled by the DSNP precompiler 3457 FORTRAN Statements are generated
including 68 subroutines.

This program simulates the LMFBR primary loop as explained in this report.
Additional information on the program can be found in Ref. 1-3.

The listing of the DSNP program is given on the following pages including the
necessary JCL cards.

Listing of the DSNP METAL.LOOP Program

```

1000 //METAL3 JOB (F22757,04,,15),DAVE,PRTY=N,NOTIFY,REGION=240K
2000 SAPHIER D 22757 03572-00114
3000 //*MAIN ORG=RM019
4000 //STEP1 EXEC RUN,DSN='B22757.COMP.LOAD',M=G,DUMP=NULLFILE
5000 //GO.SYSIN DD *
6000 C. PLIST 20 TO 06;
7000 . COMON /MAIN05/ FHA10;
8000 . DDFILE(13);
9000 . CNCTCU(TENI,TECX);
10000 . DFPDIST1(1.31132D-5,1.3D-3,1.23D-4,9,3,DISTR(1.72D-2,3.84D-2,
11000 . 13.85D-2,19.7D-2,21.78D-2,19.7D-2,13.85D-2,3.84D-2,1.72D-2),ZZZ1);
12000 . DESTROY;
13000 . IHXMA1(5,250,1.4,SO,SO);
14000 . DESTROY;
15000 . DFPINS(1,9);
16000 . DFFUEL1(9,3,3,7,PZ,UR,SS,SS,SO,.381,.9144,.381,2.883D-3,3.327D-3,
17000 . 3.683D-3,4.82D-3,5.03D-3,1.0D,1.0D,1.22D,SO,1.39943D-5,9,
18000 . 1.,1.,1.,1,ZZZ1,ZZZ1);
19000 . DESTROY;
20000 . DFPIPELC(TEMx,IECI,1.5D1,4.D-3,1.0D,ZFLCOR/ZROPxA,2,40);
21000 . DFPIPEUI(TENx,TEAPI,1.D1,1.D-2,1.0D,FPAI/ZROCX,2,89);
22000 . DFPIPEIL(TEAPx,TEMI,1.D1,1.D-2,1.0D,FPAI/ZROPxA,2,89);
23000 . FNCTFC(1,42,0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,
24000 . 14.,15.,16.,17.,18.,19.,20.,21.,22.,23.,24.,25.,26.,
25000 . 27.,28.,29.,30.,31.,32.,33.,34.,35.,36.,37.,38.,39.,
26000 . 40.,100.,
27000 . 1.,.8386,.6745,.5616,.4824,.4169,.3662,.3236,.2932,.2660,
28000 . .2430,.2233,.2043,.1913,.1805,.1714,.1623,.1542,.1460,
29000 . .1384,.1315,.1253,.1200,.1152,.1110,.1070,.1030,.0995,
30000 . .0971,.0950,.0921,.0903,.0882,.0870,.0857,.0845,.0832,
31000 . .0827,.0819,.0810,.0805,.0800);
32000 . FNCTSC(1,18,0.,0.04,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.2,
33000 . 1.4,1.6,1.8,2.0,100., 0.0,0.0,
34000 . -.00233,-.00978,-.02202,-.03399,-.04431,-.05293,-.05984,
35000 . -.06620,-.07078,-.07311,-.07570,-.07693,-.07735,-.07755,
36000 . -.07762,-.07762);
37000 . SCRAMF(0.7D0*ZFLCOR,ZFLCOR,CORTP5);
38000 C***** INITIAL CONDITIONS *****
39000 BEGIN AT 0.0
40000 . FHA10=FHA1
41000 . 1 CONTINUE
42000 . SAFTY1(SC);
43000 . CNTRL1;
44000 . FDBEK1;
45000 . NEUTR1;
46000 . GAMAR1;
47000 . FPAI=ZFLCOR/ZZZ4
48000 . 2 CONTINUE
49000 . TPOWR2;
50000 . LPLEN1;
51000 . PIPELC;
52000 . CORTP2(SO);
53000 . CNCTCU;

```

```

54000 . UPLEN1;
55000 . PIPEUI;
56000 . IHXMA1;
57000 . PIPEIL;
58000 . CONVERGR(TECX,0.001,2,10,P);
59000 . CONVERGA(TEAPX,0.1,1,10,P);
60000 C***** FIRST DYNAMIC LOOP *****
61000 SIMULATE LOOP01 STIFF1 TDV=2
62000 . SAFTY1(SC);
63000 . CNTRL1;
64000 . FDBEK1;
65000 . NEUTR1;
66000 . GAMAR1;
67000 . IF(TIME.GE.ZZZ1) ZFLCOR=ZFLCRO*FUNCFC(TIME-ZZZ1);
68000 . IF(TIME.GE.ZZZ6) FHAI=FHAI0*FUNCFC(TIME-ZZZ6);
69000 . FPAI=ZFLCOR/ZZZ4
70000 . TPOWR2;
71000 . LPLEN1;
72000 . PIPELC;
73000 . CURTP2(SD);
74000 . CNCTCU;
75000 . UPLEN1;
76000 . PIPEUI;
77000 . IHXMA1;
78000 . PIPEIL;
79000 C***** TERMINAL SECTION *****
80000 TERMINATE AT 8.D1
81000 P BY 1.D-1 TO 2.D0 BY 2.D-1 TO 5.D0 BY .5D0 TO 2.D1 BY 1.D0 TO 8.D1
82000 P 'RUN METAL-3: SIMULATION OF THE KINETICS AND PRIMARY
83000 P 'THERMODYNAMICS OF AN LMFBR HETEROGENOUS METAL CORE.'
84000 P PNJ,WGN,ZWTHMW,PWJ,WGT,
85000 P ZWPIN1,ZWPEX1,ZEGIIA,ZEGIXA
86000 P TECI,TECX,TECA,TELA,TEFA,ZFLCOR,FPAI,FHAI,ZROCX
87000 P TEMA,TENA,TEMFA,TENFA,TENI,TEMI,
88000 P RKS,RKD,RKE,RKFB,REAK,
89000 P TEAP(1-5),TEAW(1-5),TEAH(1-5),TEAPI,TEAPX,TEAHI,TEAHX
90000 P ZTC1(1-10),ZTL1(1-9),ZTF1(1,1-9),ZTF1(2,1-9),ZTF1(3,1-9)
91000 P ZWIJ1(1-9,1)
92000 . DATA(TIMER)=DTMAX/5.0D-2/, LETM/2/, DELT/1.0-5/, TICPU/3.D1/,
93000 . DTMIN/1.0D-7/,TIMEDS/5.D1/,TIMEDE/5.3D0/,IPLOT/9/;
94000 . DATA(TPOWR)=PW0/2540.D+6/;
95000 . DATA(CORTP)=UCA/9.5D6/,ULA/14.D7/,CF/1.047D3/, CL/6.28D2/,
96000 . TELA/5.D2/,ZFLCOR/1.3105D4/,
97000 . CC/2.512D3/,VC/5.D0/,QML/1.D3/,TECI/3.433D2/,QMF/2.D4/;
98000 . DATA(GAMAR)=IGAM/4/,GAM/1.D-5,3.D-3,1.D-2,4.D-2,0.D0/,BGM/2.7D-1,
99000 . 2.1D-1,1.6D-1,3.6D-1,0.D0/,GA/5.0D-1/, WGT0/200.D6/;
100000 . DATA(CNTRL)=EXREC(1)/3.D-3/,EXREC(2)/-3.D-3/,TIEXR(1)/1.0D0/,TIEXR(2)/
101000 . 5.D0/,EXREC(3)/0.D0/, TIEXR(3)/1.D2/, IEXR/0/;
102000 . DATA(FDBEK)=RKFB/0.D0/, RKDC/-3.D-3/, RKEC/-4.D-6/, RKSC/5.7D-6/;
103000 . DATA(LPLEN)=TEMA/3.5D2/,TEMI/3.5D2/,VMC/25.D0/,UMA/7.5D6/,CM/8.37D2/,
104000 . QLPF/5.D3/;
105000 . DATA(URLEN)=TENA/7.D2/,TENI/7.D2/,VNC/4.87D2/,UNA/37.7D6/,
106000 . QUPF/20.D3/;

```

```

107000 . DATA(IHXMA)=TEAPI/449.7D0/,TEAHI/2.62D2/,ARAP/4.D-1/,XARH/1.D-2/,
108000 .      XARP/1.3D-2/,TEAHX/405.D0/,TEAPX/3.43D2/,
109000 .      RAW/7.8D3/,CAW/4.187D2/,BAW/9.374D2/,FHAI/2425.D0/,
110000 .      XAWL/5.D0/,EAPSHA/1.D-1/,EAPSHR/5.D-4/,ITUAMX/10/,ITIAMX/15/;
111000 . DATA(NEUTR)=BETA/8.0245D-5,7.7189D-4,7.0134D-4,1.4247D-3,
112000 .      6.8928D-4,2.1157D-4/, ELAMDA/.013D0,.031D0,.134D0,
113000 .      .332D0,1.3D0,3.5D0/, EL/2.338D-7/;
114000 /*
115000 //GO.FT08F001 DD DSN=&&ISCR5,DISP=(NEW,DELETE),UNIT=SASCR,
116000 //      DCB=(LRECL=80,BLKSIZE=2960,RECFM=FB),SPACE=(CYL,1)
117000 //GO.FT10F001 DD DSN=&&ISCR1,DISP=(NEW,DELETE),UNIT=SASCR,
118000 //      DCB=(LRECL=80,BLKSIZE=2960,RECFM=FB),SPACE=(TRK,(5,5))
119000 //GO.FT13F001 DD DSN=B22757.IDEFD.DATA,DISP=(OLD,KEEP),
120000 //      DCB=(LRECL=80,BLKSIZE=2960,RECFM=FB)
121000 //GO.FT20F001 DD DSN=B22757.DSNPB.FORT,DISP=(OLD,KEEP),
122000 //      DCB=(LRECL=80,BLKSIZE=2960,RECFM=FB)
123000 //GO.FT21F001 DD DSN=&&ISCR2,DISP=(NEW,DELETE),UNIT=SASCR,
124000 //      DCB=(LRECL=80,BLKSIZE=3120,RECFM=FB),
125000 //      SPACE=(CYL,6)
126000 //GO.FT22F001 DD DSN=&&ISCR3,DISP=(NEW,DELETE),UNIT=SASCR,
127000 //      DCB=*.FT08F001,SPACE=(TRK,(5,5))
128000 //GO.FT23F001 DD DSN=&&ISCR6,DISP=(NEW,DELETE),UNIT=SASCR,
129000 //      DCB=*.FT08F001,SPACE=(TRK,(5,5))
130000 //GO.FT24F001 DD DSN=&&ISCR4,DISP=(NEW,DELETE),UNIT=SASCR,
131000 //      DCB=*.FT08F001,SPACE=(TRK,(5,5))
132000 //GO.FT30F001 DD DSN=B22757.LIB1.DATA,DISP=(OLD,KEEP),
133000 //      DCB=(LRECL=80,BLKSIZE=3120,RECFM=FB)
134000 //GO.FT31F001 DD DSN=B22757.LIB2.DATA,DISP=(OLD,KEEP),
135000 //      DCB=(LRECL=80,BLKSIZE=3120,RECFM=FB)
136000 /*
137000 //STEP2 EXEC FGICLG,COND=(5,LT)
138000 //FGI.SYSPRINT DD DUMMY
139000 //SYSIN DD DSN=B22757.DSNPB.FORT,DISP=SHR
140000 //GO.FT10F001 DD DSN=&&ISCR1,DISP=(NEW,DELETE),UNIT=SASCR,
141000 //      DCB=(LRECL=80,BLKSIZE=2960,RECFM=FB),SPACE=(TRK,(5,5))
142000 //GO.FT09F001 DD DSN=B22757.PLOTIN1.DATA,DISP=(NEW,CATLG),UNIT=TSPerm,
143000 //      SPACE=(TRK,(5,5))
144000 //* OUTPUT DATA SETS FOR DUMP CAN BE INSERTED HERE IF NECESSARY.
145000 /*EOF

```

Appendix 4: "METALA LOOP" The DSNP Program to Simulate Reactor scram on Low Flow in a Metal Fueled Multi-Channel Loop-type LMFBR Primary Coolant Loop.

This DSNP program contains:

18 Definitions,

21 IC statements,

18 Dynamic simulation statements,

1 Terminal statement and

24 I/O statements.

When compiled by the DSNP precompiler 4526 FORTRAN statements are generated including 71 subroutines. In this simulation the core thermodynamics is represented by three average subchannels, one for each fuel, internal blanket, and external blanket. A subchannel representing an external blanket subassembly having the maximum ΔT in the heterogenous core is also simulated.

This program simulates an LMFBR primary loop as explained in this report. Additional information on the program can be found in Refs. 1-3.

The listing of the DSNP is given on the following page. The same JCL cards are used as in the METAL.LOOP program shown in Appendix 3.

Listing of the DSNP METALA.LOOP Program

```

7000 .  COMON /MAIN05/ FHAIO;
8000 .  DDFTLE(13);
9000 .  CNCTCU(TENI,TECX);
10000 . DFPDIST1(1.39910D-5 ,1.3D-3,1.23D-4,9,3,DISTR(1.72D-2,3.84D-2,
11000 .    13.85D-2,19.7D-2,21.78D-2,19.7D-2,13.85D-2,3.84D-2,1.72D-2),ZZZ1);
12000 . DFPDIST2(1.30696D-5 ,1.3D-3,1.23D-4,9,3,DISTR(1.72D-2,3.84D-2,
13000 .    13.85D-2,19.7D-2,21.78D-2,19.7D-2,13.85D-2,3.84D-2,1.72D-2),ZZZ1);
14000 . DFPDIST3(2.6665D-6 ,1.3D-3,1.23D-4,9,3,DISTR(1.72D-2,3.84D-2,
15000 .    13.85D-2,19.7D-2,21.78D-2,19.7D-2,13.85D-2,3.84D-2,1.72D-2),ZZZ1);
16000 . DFPDISTM(1.06569D-5 ,1.3D-3,1.23D-4,9,3,DISTR(1.72D-2,3.84D-2,
17000 .    13.85D-2,19.7D-2,21.78D-2,19.7D-2,13.85D-2,3.84D-2,1.72D-2),ZZZ1);
18000 .  DESTROY;
19000 .  IHXMA1(5,250,1.4,SO,SO);
20000 .  DESTROY;
21000 .  DFPINS(1,9,2,9,3,9,M,9);
22000 .  DFFUEL1(9,3,3,7,PZ,UR,SS,SS,SO,.381,.9144,.381,2.883D-3,3.327D-3,
23000 .    3.683D-3,4.82D-3,5.03D-3,1.0D,1.0D,1.22D0,SO,1.21939D-5,9,
24000 .    .72968,.72968,.63506,1,ZZZ1,ZZZ1);
25000 .  DFFUEL2(9,3,3,7,UR,UR,SS,SS,SO,.381,.9144,.381,4.7244D-3,5.1308D-3,
26000 .    5.4864D-3,6.3D-3,6.58D-3,1.0D,1.0D,1.074D0,SO,1.47906D-5,9,
27000 .    .20113,.20113,.22729,1,ZZZ1,ZZZ1);
28000 .  DFFUEL3(9,3,3,7,UR,UR,SS,SS,SO,.381,.9144,.381,4.7244D-3,5.1308D-3,
29000 .    5.4864D-3,6.3D-3,6.58D-3,1.0D,1.0D,1.074D0,SO,5.22761D-6,9,
30000 .    .06919,.06919,.13544,1,ZZZ1,ZZZ1);
31000 .  DFFUELM(9,3,3,7,UR,UR,SS,SS,SO,.381,.9144,.381,4.7244D-3,5.1308D-3,
32000 .    5.4864D-3,6.3D-3,6.58D-3,1.0D,1.0D,1.074D0,SO,5.22761D-6,9,
33000 .    0.0D,0.0D,0.0D,1,ZZZ1,ZZZ1);
34000 .  DESTROY;
35000 .  DFPIPELC(TEMX,TECI,1.5D1,4.D-3,1.0D,ZFLCOR/ZROPXA,2,40);
36000 .  DFPIPEUI(TEMX,TEAPI,1.0D1,1.D-2,1.0D,FPAI/ZROCX,2,89);
37000 .  DFPIPEIL(TEAPX,TEMI,1.0D1,1.D-2,1.0D,FPAI/ZROPXA,2,89);
38000 .  FNCTFC(1,42,0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,
39000 .    14.,15.,16.,17.,18.,19.,20.,21.,22.,23.,24.,25.,26.,
40000 .    27.,28.,29.,30.,31.,32.,33.,34.,35.,36.,37.,38.,39.,
41000 .    40.,100.);
42000 .    1.,.8386,.6745,.5616,.4824,.4169,.3662,.3236,.2932,.2660,
43000 .    .2430,.2233,.2043,.1913,.1805,.1714,.1623,.1542,.1460,
44000 .    .1384,.1315,.1253,.1200,.1152,.1110,.1070,.1030,.0995,
45000 .    .0971,.0950,.0921,.0903,.0882,.0870,.0857,.0845,.0832,
46000 .    .0827,.0819,.0810,.0805,.0800);
47000 .  FNCTSC(1,18,0.,0.04,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.2,
48000 .    1.4,1.6,1.8,2.0,100., 0.0,0.0,
49000 .    -.00233,-.00978,-.02202,-.03399,-.04431,-.05293,-.05984,
50000 .    -.05620,-.07078,-.07311,-.07570,-.07693,-.07735,-.07755,
51000 .    -.07762,-.07762);
52000 .  SCRAMF(0.7D0*ZFLCOR,ZFLCOR,CORTP5);
53000 C***** INITIAL CONDITIONS *****

```

```

54000 BEGIN AT 0.0
55000     FHAIO=FHAI
56000     1 CONTINUE
57000 .   SAFTY1(SC);
58000 .   CNTRL1;
59000 .   FDBEK1;
60000 .   NEUTR1;
61000 .   GAMAR1;
62000     FPAI=ZFLCOR/ZZZ4
63000     2 CONTINUE
64000 .   TPOWR2;
65000 .   LPLEN1;
66000 .   PIPELC;
67000 .   CORTP2(SO);
68000 .   CNCTCU;
69000 .   UPLEN1;
70000 .   PIPEUI;
71000 .   IHXMA1;
72000 .   PIPEIL;
73000 .   CONVERGR(TECX,0.001,2,10,P);
74000 .   CONVERGA(TEAPX,0.1,1,10,P);
75000 C***** FIRST DYNAMIC LOOP *****
76000 SIMULATE LOOP01 STIFF1 TDV=2
77000 .   SAFTY1(SC);
78000 .   CNTRL1;
79000 .   FDBEK1;
80000 .   NEUTR1;
81000 .   GAMAR1;
82000 .   IF(TIME.GE.ZZZ1) ZFLCOR=ZFLCRO*FUNCFC(TIME-ZZZ1);
83000 .   IF(TIME.GE.ZZZ6) FHAI=FHAIO*FUNCFC(TIME-ZZZ6);
84000     FPAI=ZFLCOR/ZZZ4
85000 .   TPOWR2;
86000 .   LPLEN1;
87000 .   PIPELC;
88000 .   CORTP2(SO);
89000 .   CNCTCU;
90000 .   UPLEN1;
91000 .   PIPEUI;
92000 .   IHXMA1;
93000 .   PIPEIL;
94000 C***** TERMINAL SECTION *****
95000 TERMINATE AT 3.D1
96000 P BY 1.D-1 TO 2.D0 BY 2.D-1 TO 5.D0 BY .500 TO 2.D1 BY 1.D0 TO 3.D1
97000 P 'RUN METALA-3: SIMULATION OF THE KINETICS AND PRIMARY '
98000 P 'THERMODYNAMICS OF AN LMFBR HETEROGENOUS METAL CORE.'
99000 P PNJ,WGN,ZWTHMW,PWJ,WGT,
100000 P ZWPIN1,ZWPIN2,ZWPIN3,ZWPINM,ZEGIIA,ZEGIXA
101000 P TECI,TECX,TECA,TELA,TEFA,ZFLCOR,FPAI,FHAI,ZROCX
102000 P TEMA,TENA,TEMFA,TENFA,TENI,TEMI,
103000 P RKS,RKD,RKE,RKFB,REAK,
104000 P TEAPI,TEAPX,TEAH1,TEAHX
105000 P ZTC1(1-10),ZTL1(1-9),ZTF1(1,1-9),
105100 P ZTC2(1-10),ZTL2(1-9),ZTF2(1,1-9),

```

```

105200 P ZTC3(1-10),ZTL3(1-9),ZTF3(1,1-9),
105300 P ZTCM(1-10),ZTLM(1-9),ZTFM(1,1-9),
108000 . DATA(TIMER)=DTMAX/5.0D-2/, LETM/2/, DELT/1.D-5/,TICPU/3.D1/,
109000 . DTMIN/1.0D-7/,TIMEDS/5.D1/,TIMEDE/5.3D0/,IPLOT/9/;
110000 . DATA(TPOWR)=PW0/2540.D+6/;
111000 . DATA(CORTP)=UCA/9.5D6/,ULA/14.D7/,CF/1.047D3/, CL/6.28D2/,
112000 . TELA/5.D2/,ZFLCOR/1.3105D4/,
113000 . CC/2.512D3/,VC/5.D0/,QML/1.D3/,TECI/3.433D2/,QMF/2.D4/;
114000 . DATA(GAMAR)=IGAM/4/,GAM/1.D-5,3.D-3,1.D-2,4.D-2,0.D0/,BGM/2.7D-1,
115000 . 2.1D-1,1.6D-1,3.6D-1,0.D0/,GA/5.0D-1/, WGT0/200.D6/;
116000 . DATA(CNTRL)=EXREC(1)/3.D-3/,EXREC(2)/-3.D-3/,TIEXR(1)/1.0D0/,TIEXR(2)/
117000 . 5.D0/,EXREC(3)/0.D0/, TIEXR(3)/1.D2/, IEXR/0/;
118000 . DATA(FDBEK)=RKFB/0.D0/, RKDC/-3.D-3/, RKEC/-4.D-6/, RKSC/5.7D-6/;
119000 . DATA(LPLEN)=TEMA/3.5D2/,TEMI/3.5D2/,VMC/25.D0/,UMA/7.5D6/,CM/8.37D2/,
120000 . QLPF/5.D3/;
121000 . DATA(UPLEN)=TENA/7.D2/,TENI/7.D2/,VNC/4.87D2/,UNA/37.7D6/,
122000 . QUPF/20.D3/;
123000 . DATA(IHXMA)=TEAPI/449.7D0/,TEAHI/2.62D2/,ARAP/4.D-1/,XARH/1.D-2/,
124000 . XARP/1.3D-2/,TEAHX/405.D0/,TEAPX/3.43D2/,
125000 . RAW/7.8D3/,CAW/4.187D2/,BAW/9.374D2/,FHAI/2425.D0/,
126000 . XAWL/5.D0/,EAPSHA/1.D-1/,EAPSHR/5.D-4/,ITUAMX/10/,ITIAMX/15/;
127000 . DATA(NEUTR)=BETA/8.0245D-5,7.7189D-4,7.0134D-4,1.4247D-3,
128000 . 6.8928D-4,2.1157D-4/, ELAMDA/.013D0,.031D0,.134D0,
129000 . .332D0,1.3D0,3.5D0/, EL/2.338D-7/;

```

Appendix 5: "OXIDEC.LOOP" The DSNP Program to Simulate the UI Event in an
Oxide-Fueled Average and Hot Channels Loop-type Primary Coolant Loop.

This program contains:

14 Definitions,

21 IC statements,

20 Dynamic simulation statements,

1 Terminal statement,

23 I/O statements.

When compiled by the DSNP precompiler 3806 FORTRAN statements are generated including 69 subroutines. In this simulation the core thermodynamics is represented by a single average subchannel. The hot channel in the core is also simulated to obtain maximum worst case temperatures and temperature distributions.

This program simulates an LMFBR primary loop as explained in the report. Additional information on the program can be found in Refs. 1-3.

The listing of the DSNP program is listed on the following page. The same JCL cards are used as in Appendix 3.

Listing of the DSNP OXIDEC.LOOP Program

```

6500 . COMON /MAIN01/ DYDT24,DYDT78;
7000 . COMON /MAIN05/ FHAIO;
8000 . DDFILE(13);
9000 . CNCTCU(TENI,TECX);
10000 . DFPDIST1(2.0D-5,2.0D-2,5.0D-2,9,3,DISTR(1.72D-2,3.84D-2,13.85D-2,
11000 . 19.7D-2,21.78D-2,19.7D-2,13.85D-2,3.84D-2,1.72D-2),ZZZ1);
12000 . DFPDISTM(2.13388D-5,2.0D-2,5.0D-2,9,3,DISTR(1.72D-2,3.84D-2,13.85D-2,
13000 . 19.7D-2,21.78D-2,19.7D-2,13.85D-2,3.84D-2,1.72D-2),1.14);
14000 . DESTROY;
15000 . IHXMA1(5,250,1.4,SO,SO);
16000 . DESTROY;
17000 . DFPINS(1,9,M,9);
18000 . DFFUEL1(9,3,3,7,UP,UO,SS,SS,SO,.3,1.5,.3,2.5D-3,2.54D-3,2.95D-3,
19000 . 3.68D-3,4.13D-3,9.3D-1,9.6D-1,1.2D0,SO,2.0D-5,9,1.,1.,1.,1,
20000 . ZZZ1,ZZZ1);
21000 . DFFUELM(9,3,3,7,UP,UO,SS,SS,SO,.3,1.5,.3,2.5D-3,2.54D-3,2.92D-3,
22000 . 3.65D-3,4.1D-3,9.3D-1,9.6D-1,1.2D0,SO,1.7427D-5,9,0.,0.,0.,1,
23000 . 0.862,0.826);
24000 . DESTROY;
25000 . DFPIPELC(TEMX,TECI,1.5D1,4.D-3,1.0D,ZFLCOR/ZROPXA,2,40);
26000 . DFPIPEUI(TENX,TEAPI,1.D1,1.D-2,1.0D,FPAI/ZROCX,2,89);
27000 . DFPIPEIL(TEAPX,TEMI,1.D1,1.D-2,1.0D,FPAI/ZROPXA,2,89);
28000 . FNCTFC(1,42,0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,
29000 . 14.,15.,16.,17.,18.,19.,20.,21.,22.,23.,24.,25.,26.,
30000 . 27.,28.,29.,30.,31.,32.,33.,34.,35.,36.,37.,38.,39.,
31000 . 40.,100.,
32000 . 1.,.8386,.6745,.5616,.4824,.4169,.3662,.3236,.2932,.2660,
33000 . .2430,.2233,.2043,.1913,.1805,.1714,.1623,.1542,.1460,
34000 . .1384,.1315,.1253,.1200,.1152,.1110,.1070,.1030,.0995,
35000 . .0971,.0950,.0921,.0903,.0882,.0870,.0857,.0845,.0832,
36000 . .0827,.0819,.0810,.0805,.0800);
37000 . FNCTSC(1,18,0.,0.04,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.2,
38000 . 1.4,1.6,1.8,2.0,100., 0.0,0.0,
39000 . -.00233,-.00978,-.02202,-.03399,-.04431,-.05293,-.05984,
40000 . -.06620,-.07078,-.07311,-.07570,-.07693,-.07735,-.07755,
41000 . -.07762,-.07762);
42000 . SCRAMF(TIME,DTMIN,*);
43000 C***** INITIAL CONDITIONS *****
44000 BEGIN AT 0.0
45000 FHAIO=FHAI
46000 1 CONTINUE
47000 . SAFTY1(SC);
48000 . CNTRL1;
49000 . FDBEK1;
50000 . NEUTR1;
51000 . GAMAR1;
52000 . FPAI=ZFLCOR/ZZZ4

```

```

53000      2 CONTINUE
54000 .    TPOWR2;
55000 .    LPLEN1;
56000 .    PIPELC;
57000 .    CORTP2(SO);
58000 .    CNCTCU;
59000 .    UPLEN1;
60000 .    PIPEUI;
61000 .    IHXMA1;
62000 .    PIPEIL;
63000 .    CONVERGR(TECX,0.001,2,10,P);
64000 .    CONVERGA(TEAPX,0.1,1,10,P);
65000 C***** FIRST DYNAMIC LOOP *****
66000 SIMULATE LOOP01 STIFF1 TOV=2
67000 .    SAFTY1(SC);
68000 .    CNTRL1;
69000 .    FDBEK1;
70000 .    NEUTR1;
71000 .    GAMAR1;
72000 .    IF(TIME,GE,.5D0) ZFLCUR=ZFLCR0*FUNCFC(TIME-.5D0);
73000 .    IF(TIME,GE,ZZZ1) FHA1=FHA10*FUNCFC(TIME-ZZZ1);
74000      FPA1=ZFLCOR/ZZZ4
75000 .    TPOWR2;
76000 .    LPLEN1;
77000 .    PIPELC;
78000 .    CORTP2(SO);
79000 .    CNCTCU;
80000 .    UPLEN1;
81000 .    PIPEUI;
82000 .    IHXMA1;
83000 .    PIPEIL;
83500 .    DYDT24=DYDT(24)/ZCPC1(10); DYDT78=DYDT(78)/ZCPCM(10);
84000 C***** TERMINAL SECTION *****
85000 TERMINATE AT 8.D1
86000 P BY 1.D-1 TO 2.D0 BY 2.D-1 TO 5.D0 BY .5D0 TO 2.D1 BY 1.D0 TO 8.D1
87000 P 'RUN OXIDEC-3: SIMULATION OF THE U1 EVENT IN AN LMFBR '
88000 P 'OXIDE FUELED PRIMARY LOOP.'
89000 P PNJ,WGN,ZWTHMW,PWJ,WGT,
90000 P ZWPIN1,ZWPEX1,ZEG11A,ZEG1XA
91000 P TECI,TECX,TECA,TELA,TEFA,ZFLCOR,FPA1,FHA1,ZROCX
92000 P TEMA,TENA,TEMFA,TENFA,TENI,TEMI,
93000 P RKS,RKD,RKE,RKFB,REAK,
94000 P TEAPI,TEAPX,TEAHI,TEAHX
95000 P ZTC1(1-10),ZTL1(1-9),ZTF1(1,1-9)
96000 P ZTCM(1-10),ZTLM(1-9),ZTFM(1,1-9)
96500 P DYDT(137),DYDT(31),DYDT(85),DYDT24,DYDT78
97000 . DATA(TIMER)=DTMAX/5.0D-2/, LETM/2/, DELT/1.0-5/,TICPU/3.D1/,
98000 .    DTMIN/1.0D-7/,TIMEDS/5.D1/,TIMEDE/5.3D0/,IPLOT/9/;
99000 . DATA(TPOWR)=PW0/2540.D+6/;
00000 . DATA(CORTP)=UCA/9.5D6/,ULA/14.D7/,CF/1.047D3/, CL/6.28D2/,
01000 .    TELA/5.D2/,
02000 .    CC/2.512D3/,VC/5.D0/,QML/1.D3/,TECI/3.5D2/,GMF/2.D4/,ZFLCOR/1.378D4/;
03000 . DATA(GAMAR)=IGAM/4/,GAM/1.0-5,3.D-3,1.0-2,4.D-2,0.D0/,BGM/2.7D-1,

```

```
04000 .      2.1D-1,1.6D-1,3.6D-1,0.D0/,GA/5.0D-1/, WGT0/200.D6/;  
05000 . DATA(CNTRL)=EXREC(1)/3.D-3/,EXREC(2)/-3.D-3/,TIEXR(1)/1.0D0/,TIEXR(2)/  
06000 .      5.D0/,EXREC(3)/0.D0/, TIEXR(3)/1.D2/, IEXR/0/;  
07000 . DATA(FDBEK)=RKFB/0.D0/, RKDC/-3.D-2/, RKEC/-4.D-6/, RKSC/4.5D-6/;  
08000 . DATA(LPLEN)=TEMA/3.5D2/,TEMI/3.5D2/,VMC/7.5D0/,UMA/2.5D6/,CM/8.37D2/,  
09000 .      QLPP/1.5D3/;  
10000 . DATA(UPLEN)=TENA/7.D2/,TENI/7.D2/,VNC/4.38D2/,UNA/3.77D6/,  
11000 .      QUPF/2.742D3/;  
12000 . DATA(IHXMA)=TEAPI/546.9D0/,TEAHI/3.291D2/,ARAP/4.D-1/,XARH/1.D-2/,  
13000 .      XARP/1.3D-2/,TEAHX/517.4D0/,TEAPX/3.43D2/,  
14000 .      RAW/7.8D3/,CAW/4.187D2/,BAW/9.374D2/,FHAI/3002.D0/,  
15000 .      XAWL/6.37D0/,EAPSHA/1.D-1/,EAPSHR/5.D-4/,ITOAMX/10/,ITIAMX/15/;  
16000 . DATA(NEUTR)=BETA/8.723D-5,7.499D-4,6.648D-4,1.306D-3,5.95D-4,1.949D-4  
17000 .      /, ELAMDA/1.29D-2,3.08D-2,1.32D-1,3.25D-1,1.34D0,3.27D0/,  
18000 .      EL/6.D-7/;
```

Appendix 6: "OXIDED.POOL" The DSNP Program to Simulate the UI Event in an
Oxide-Fueled Single-Channel Pool-type LMFBR Primary Loop.

This program contains:

12 Definitions,

21 IC statements,

18 Dynamic simulation statements,

1 Terminal statement and

22 I/O statements.

When compiled by the DSNP precompiler 3454 FORTRAN statements are generated, including 68 subroutines. In this simulation a pool-type primary LMFBR is simulated. An average oxide fueled subchannel represents the core thermodynamics.

This program simulates an LMFBR primary loop as explained in the report. Additional information on the program can be found in Refs. 1-3.

The listing of the DSNP program is given on the following page. The same JCL cards are used as in Appendix 3.

Listing of the DSNP OXIDED.POOL Program

```

7000 .  COMON /MAIN05/ FHA10;
8000 .  ODFILE(13);
9000 .  CNCTCU(TENI,TECX);
10000 . DFPDIST1(2.0D-5 ,2.0D-2,5.0D-2,9,3,DISTR(1.72D-2,3.84D-2,13.85D-2,
11000 .      19.7D-2,21.78D-2,19.7D-2,13.85D-2,3.84D-2,1.72D-2),ZZZ1);
12000 .  DESTROY;
13000 .  IHXMA1(5,250,1.4,50,50);
14000 .  DESTROY;
15000 .  DFPINS(1,9);
16000 .  DFFUEL1(9,3,3,7,UP,UO,SS,SS,SO,.3,1.5,.3,2.5D-3,2.54D-3,2.92D-3,
17000 .      3.65D-3,4.1D-3,9.3D-1,9.6D-1,1.2D0,SO,2.0D-5,9,1.,1.,1.,1,
17100 .      ZZZ1,ZZZ1);
18000 .  DESTROY;
19000 .  DFPIPELC(TEMX,TECI,1.5D1,4.0D-3,1.0D,ZFLCOR/ZROPXA,2,40);
20000 .  DFPIPEUI(TENX,TEAPI,2.0D,1.0D-2,1.0D,FPAI/ZROCX,2,89);
21000 .  DFPIPEIL(TEAPX,TEMI,2.0D,1.0D-2,1.0D,FPAI/ZROPXA,2,89);
22000 .  FNCTFC(1,42,0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,
23000 .      14.,15.,16.,17.,18.,19.,20.,21.,22.,23.,24.,25.,26.,
24000 .      27.,28.,29.,30.,31.,32.,33.,34.,35.,36.,37.,38.,39.,
25000 .      40.,100.);
26000 .      1.,.8386,.6745,.5616,.4824,.4169,.3662,.3236,.2932,.2660,
27000 .      .2430,.2233,.2043,.1913,.1805,.1714,.1623,.1542,.1460,
28000 .      .1384,.1315,.1253,.1200,.1152,.1110,.1070,.1030,.0995,
29000 .      .0971,.0950,.0921,.0903,.0882,.0870,.0857,.0845,.0832,
30000 .      .0827,.0819,.0810,.0805,.0800);
31000 .  FNCTSC(1,10,0.,0.04,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0,1.2,
32000 .      1.4,1.6,1.8,2.0,100., 0.0,0.0,
33000 .      -.00233,-.00978,-.02202,-.03399,-.04431,-.05293,-.05984,
34000 .      -.06620,-.07078,-.07311,-.07570,-.07693,-.07735,-.07755,
35000 .      -.07762,-.07762);
36000 .  SCRAMF(TIME,DTMIN,*);
37000 C***** INITIAL CONDITIONS *****
38000 BEGIN AT 0.0
39000     FHA10=FHAI
40000     1 CONTINUE
41000 .  SAFIY1(SC);
42000 .  CNTRL1;
43000 .  FDBEK1;
44000 .  NEUTR1;
45000 .  GAMAR1;
46000 .  FPAI=ZFLCOR/ZZZ4
47000     2 CONTINUE
48000 .  TPOWR2;
49000 .  LPLEN1;
50000 .  PIPELC;
51000 .  CORIP2(SO);
52000 .  CNCTCU;

```

```

53000 . UPLEN1;
54000 . PIPEUI;
55000 . IHXMA1;
56000 . PIPEIL;
57000 . CONVERGR(TECX,0.001,2,10,P);
58000 . CONVERGA(TEAPX,0.1,1,10,P);
59000 C***** FIRST DYNAMIC LOOP *****
60000 SIMULATE LOOP01 STIFF1 IDV=2
61000 . SAFTY1(SC);
62000 . CNTRL1;
63000 . FDBEK1;
64000 . NEUTP1;
65000 . GAMAR1;
66000 . IF(TIME.GE..500) ZFLCOR=ZFLCOR*FUNCFC(TIME-.500);
67000 . IF(TIME.GE.ZZZ1) FHA1=FHA1*FUNCFC(TIME-ZZZ1);
68000 . FPAI=ZFLCOR/ZZZ4
69000 . TPOWR2;
70000 . LPLEN1;
71000 . PIPELC;
72000 . CORTP2(S0);
73000 . CNCTCU;
74000 . UPLEN1;
75000 . PIPEUI;
76000 . IHXMA1;
77000 . PIPEIL;
78000 C***** TERMINAL SECTION *****
79000 TERMINATE AT 8.D1
80000 P BY 1.D-1 TO 2.00 BY 2.D-1 TO 5.00 BY .500 TO 2.D1 BY 1.D0 TO 8.D1
81000 P 'RUN OXIDED-3: SIMULATION OF THE U1 EVENT IN A POOL TYPE '
82000 P 'OXIDE FUELED LMFBR PRIMARY LOOP.'
83000 P PNJ,WGN,ZWTHMW,PWJ,WGT,
84000 P ZWPIN1,ZWPEX1,ZEGIIA,ZEGIXA
85000 P TECI,TECX,TECA,TELA,TEFA,ZFLCOR,FPAI,FHA1,ZRUCX
86000 P TEMA,TENA,JEMFA,TENFA,TENI,TEMI,
87000 P RKS,RKD,RKE,RKFB,REAK,
88000 P TEAP(1-5),TEAW(1-5),TEAH(1-5),TEAPI,TEAPX,TEAH1,TEAHX
89000 P ZTC1(1-10),ZIL1(1-9),ZTF1(1,1-9),ZTF1(2,1-9),ZTF1(3,1-9)
90000 P ZWIJ1(1-9,1)
91000 . DATA(TIMER)=DTMAX/5.00-2/, LETM/2/, DELT/1.D-5/,TICPU/3.D1/,
92000 . DIMIN/1.00-7/,TIMEDS/5.D1/,TIMEDE/5.300/,IPLOT/9/;
93000 . DATA(TPOWR)=PW0/2540.D+6/;
94000 . DATA(CORTP)=UCA/9.506/,ULA/14.D7/,CF/1.04703/, CL/6.2802/,
95000 . TELA/5.D2/,
96000 . CC/2.51203/,VC/5.D0/,QML/1.D3/,TEC1/3.502/,QMF/2.D4/,ZFLCOR/1.37804/;
97000 . DATA(GAMAR)=IGAM/4/,GAM/1.D-5,3.D-3,1.D-2,4.D-2,0.D0/,BGM/2.70-1,
98000 . 2.10-1,1.60-1,3.60-1,0.D0/,GA/5.00-1/, WGT0/200.D6/;
99000 . DATA(CNTRL)=EXREC(1)/3.D-3/,EXREC(2)/-3.D-3/,TIEXR(1)/1.000/,TIEXR(2)/
100000 . 5.D0/,EXREC(3)/0.D0/, TIEXR(3)/1.D2/, IEXR/0/;
101000 . DATA(FDBEK)=RKFB/0.D0/, RKDC/-3.D-2/, RKEC/-4.D-6/, RKSC/4.50-6/;
102000 . DATA(LPLEN)=TEMA/3.502/,TEMI/3.502/,VMC/3.202/,UMA/35.D6/,CM/8.3702/,
103000 . QLPF/20.D3/;
104000 . DATA(UPLEN)=TENA/7.D2/,TENI/7.D2/,VNC/1.08303/,UNA/50.D6/,
105000 . QUPF/40.D3/;

```

```
106000 . DATA(IHXMA)=TEAPI/546.9D0/,TEAHI/3.291D2/,ARAP/4.D-1/,XARH/1.D-2/
107000 .      XARP/1.3D-2/,IFAHX/517.4D0/,TEAPX/3.43D2/,
108000 .      RAW/7.8D3/,CAW/4.187D2/,BAW/9.374D2/,FHA1/3002.D0/,
109000 .      XAWL/6.37D0/,EAPSHA/1.D-1/,EAPSHR/5.D-4/,ITUAMX/10/,ITIAMX/15/;
110000 . DATA(NEUTR)=BELIA/8.723D-5,7.499D-4,6.648D-4,1.306D-3,5.95D-4,1.949D-4
111000 .      /, ELAMDA/1.29D-2,3.08D-2,1.32D-1,3.25D-1,1.34D0,3.27D0/,
112000 .      EL/6.D-7/;
```

Appendix 7: A Summary of DSNP Statements

The Dynamic Simulator for Nuclear Power Plants (DSNP) is a special purpose block oriented simulation language that permits the simulation of nuclear power plants by using a set of simple statements. The dominant feature of DSNP is the ability to transform a power plant flowchart or block diagram directly into a simulation program. The user is required to recognize the DSNP mnemonics for the appropriate physical component or process, and list these statements in a logical sequence according to the flow of physical properties in the simulated power plant.

DSNP is a free field language except for column 1 which contains a control identifying character or symbol. Several statements can be placed in a record between column 2 and 72 inclusive. Each statement must be terminated by a semicolon " ; ". The DSNP statements are subdivided into the following subgroups:

- 1) Control identification symbols in column one
- 2) Control statements
- 3) Structural statements
- 4) Input-Output statements
- 5) Definitions
- 6) Component simulation statements
- 7) Material property functions
- 8) Auxiliary function statements
- 9) Macro instructions

FORTTRAN statements are considered to be a subset of DSNP and can be placed anywhere in the simulation program. Several of the DSNP statements can operate on a block of statements rather than on single statements or expressions. A

block is defined as all the statements between a period in column one and the first semicolon to be found at the end of a record. In the following paragraphs all DSNP statements are listed in alphabetic order.

1. CONTROL IDENTIFICATION SYMBOLS IN COLUMN ONE

- A Blank or space indicates a FORTRAN statement and can be located anywhere in the program
- B BEGIN first record of initial condition section
- C A comment record
- F First record of the subroutines section
- L First record of the zero level or user supplied library
- M Specifies the beginning of macro definition
- P Indicates that the variables on this record should be printed
- S Simulates first record of the program dynamic segment
- T Terminates the first record of program terminal section
- . A "Period" indicates that the record contains DSNP statements
- * Indicates the beginning of a DSNP module

2. CONTROL STATEMENTS

APPEND	Insert a module following this statement
CALL	Same function as INCLUDE, but will also cause execution of the subprogram
COMIN	Insert a COMMON data block
DEBUG	Debug the following module
DESTROY	Release macro space during precompilation
DYMOD	Initialize a dynamic module
DYNAMIC	Defines the dynamic section of a module
GOTO	Transfers control to labeled statement
INCLUDE	Include a module from DSNP library
RETURN	Transfers control from subroutine to the calling program
SORT	Sort statements from a file and include those with the proper prefix
STATIC	Defines static or IC part of a dynamic module
STOP	Unconditionally stops the execution of the program
STOPSIM	Defines conditions to stop the simulation program (other than time)
TERMINAL	Defines the terminal section of a dynamic module

3. STRUCTURAL STATEMENTS

CNTC	Connect two or more variables
CONTINUE	A non-executable statement, serves usual for labeling transfer instructions
CONVERGA	Seek absolute convergence for a variable
CONVERGR	Seek relative convergence for a variable
DO	First statement in a loop to be executed several times
END	Indicates the end of a program, function, or subroutine
FUNCTION	First statement in a function subprogram
IF	Arithmetic or logical (IF to conditionally transfer or execute a statement)
IFE-ELSE	Extended IF operating on blocks of statements
INTGRL	Integrate a single variable
LIMI	Limit the integration process
LNTGRL	Integrate a single variable from a vector of variables
LOAD	Load a function from the library to the program
MNTGRL	Integrates a matrix of variables
NOTI	Conditional integration (prefixes integration statements)
SUBROUTINE	First statement of a subroutine subprogram
VECTOREQ	Assign values to vectors and variables
VNTGRL	Integrate a vector

4. INPUT-OUTPUT STATEMENTS

BY TO	Define printing intervals
DATA	Include data into a block
DDFILE	Input a data set of blocks
DLIST	Copy a file at simulation time
DUMP TO	Output a data block
FORMAT	Describes the format of input or output
P	Print the variables and vectors listed on this record
PLIST	Copy a file at compilation time
READ	Input variables according to list and FORMAT
STEPRIN	Defines conditions for printing a set of variables every time step
WRITE	Output variables according to list and FORMAT

5. DEFINITIONS

COMON	Defines transferable COMMON block of variables
COMMON	Defines a block of variables common to several subprograms
CNCT	Define a connector
DATA	Defines values to be assigned to variables
DEFHPIP	Defines a hydraulic flow segment
DFBOIL	Defines a boiler (evaporator)
DFCAVT	Defines a hydraulic cavity
DFDRUM	Defines a steam drum
DFFUEL	Defines a fuel pin
DFJUNC	Defines a hydraulic junction
DFLOW	Defines a hydraulic flow path
DFMXPLEN	Defines a mixing plenum
DFPDIST	Defines the axial power distribution in a fuel pin
DFPINS	Defines the number of fuel pins in the core simulation
DFPIPE	Defines a thermodynamic pipe or a delay line
DFPUMP	Defines a pump
FNCT	Defines a single variable function
IHSM#1	Defines a heat exchanger
INTEGER	Defines an integer variable
REAL	Defines a floating point variable
SCRAMF	Defines a scram initiating variable and its maximum value

6. COMPONENT SIMULATION STATEMENTS

BOIL#1	Simulates a boiler (evaporator)
CAVT	Simulates a hydraulic cavity
CNTRL1	Simulates reactor control system
CORTP1	Simulates core lumped parameter thermodynamics
CORTP2	Simulates core thermodynamics with any number of fuel pins
DRUM#1	Simulates a steam drum
FDBEK1	Simulates feedback reactivity
FLOW	Simulates a hydraulic flow path
GAMAR1	Simulates radioactive decay heat
IHXM#1	Simulates a heat exchanger
JUNC	Simulates a hydraulic junction
LPLEN1	Simulates core lower plenum
MOTOR1	Simulates an electric motor
MXPLE1	Simulates a mixing plenum
NEUTP1	Simulates neutron kinetics, prompt jump approximation
NEUTR1	Simulates neutron kinetics
NEUTS1	Simulates neutron kinetics, self-integrated model
PIPE	Thermodynamic pipe or delay line
PUMP	Simulates the pump hydraulics
SAFTY1	Simulates reactor safety system
TPOWR1	Simulates core power
TPOWR2	Calculates axial and radial power distribution
UPLEN1	Simulates reactor upper plenum

7. MATERIAL PROPERTY FUNCTION

ALCON1	Aluminum thermal conductivity
ALDCP1	Aluminum specific heat
ALDEN1	Aluminum density
CONDU1	Thermal conductivity of specified material
CPSPE1	Specific heat of specified material
DENST1	Specific density of specified material
POCON1	Plutonium oxide thermal conductivity
PODCP1	Plutonium oxide specific heat
PODEN1	Plutonium oxide density
PUCON1	Plutonium thermal conductivity
PUDCP1	Plutonium specific heat
PUDEN1	Plutonium density
PZCON1	15% Pu + 10% Zr + 75% U thermal conductivity
PZDCP1	15% Pu + 10% Zr + 75% U specific heat
PZDEN1	15% Pu + 10% Zr + 75% U density
RENUP1	Computes Reynolds, Prandtl, and Peclett numbers
SOCON1	Sodium thermal conductivity
SODCP1	Sodium specific heat
SODEN1	Sodium specific density
SODMU1	Sodium dynamic viscosity
SOHXP1	Sodium heat transfer coefficient for primary side of a heat exchanger
SOHXS1	Sodium heat transfer coefficient for secondary side of a heat exchanger
SSCON1	Stainless steel thermal conductivity
SSDEN1	Stainless steel density

SSDCP1	Stainless steel specific heat
STCON1	Steam thermal conductivity
STDCP1	Steam specific heat
STDEN1	Steam specific density
STDMU1	Steam dynamic viscosity
STHXPI	Heat transfer coefficient for primary side heat exchanger using steam
STHXS1	Heat transfer coefficient for secondary side heat exchanger using steam (superheater)
THCON1	Thorium thermal conductivity
THDCP1	Thorium specific heat
THDEN1	Thorium density
TOCON1	Thorium oxide thermal conductivity
TODCP1	Thorium oxide specific heat
TODEN1	Thorium oxide density
TPMUL1	Two phase steam-water friction multiplier
UCCON1	Uranium Carbide thermal conductivity
UCDCP1	Uranium Carbide specific heat
UCDEN1	Uranium Carbide density
UCORC1	Core fuel pin to coolant heat transfer coefficient
UCORL1	Core fuel pin to cladding heat transfer coefficient
UCORL2	Modified fuel to cladding heat transfer coefficient
UOCON1	Uranium oxide thermal conductivity
UODCP1	Uranium oxide specific heat
UODEN1	Uranium oxide density

UPCON1	Uranium + 25% Plutonium oxide thermal conductivity
UPDCP1	Uranium + 25% Plutonium oxide specific heat
UPDEN1	Uranium + 25% Plutonium oxide density
URCON1	Uranium thermal conductivity
URDCP1	Uranium specific heat
URDEN1	Uranium density
VISCO1	Viscosity of specified material
WAGON1	Water thermal conductivity
WADCP1	Water specific heat
WADEN1	Water specific density
WADNU1	Water dynamic viscosity
WAHXP1	Heat transfer coefficient from pipe to water, pipe outer side
WAHXS1	Heat transfer coefficient from pipe to water, pipe internal side
WASAP1	Water or steam saturation temperature for given pressure
WASAT1	Water or steam saturation pressure for given temperature
WASHP1	Water or steam properties for given enthalpy and pressure
WASHV1	Water or steam properties for given enthalpy and specific volume
WASPS1	Water or steam properties given pressure and entropy
WASPT1	Water or steam properties given pressure and temperature
WASPU1	Water or steam properties given pressure and internal energy
WASPV1	Water or steam properties given pressure and specific volume
WASUV1	Water or steam properties given internal energy and specific volume
WBHXP1	Heat transfer coefficient in the film boiling section of a steam generator, boiling outside the pipe

WBHXS1	Heat transfer coefficient in the film boiling section of a steam generator, boiling inside the pipe
ZACON1	Zircaloy thermal conductivity
ZADCP1	Zircaloy specific heat
ZADEN1	Zircaloy density
ZRCON1	Zirconium thermal conductivity
ZRDCP1	Zirconium specific heat
ZRCON1	Zirconium density

8. AUXILIARY FUNCTION STATEMENTS

CPUTM1	Check CPU time left in simulation
FUNC	Get value of a function
GAUSS1	Solves a set of algebraic equations
HOLD	First order hold
LAG	First order lag
LAGN	Nth order lag
LAGRN1	LAGRANGIAN interpolation up to 9th order
PULSE	Produces a unit pulse
RAMP	Produces a ramp function
RPULSE	The inverse of PULSE
RSTEP	Produces an inverse step function
SOLG	Second order complex pole
STEP	Produces a unit step function

9. MACRO INSTRUCTIONS

M <Pattern>=<Replacement> basic macro definition

#	Indicates a macro parameter
& I+J	Increment or decrement I register and replace by value
%A	Macro deleted after first use
%B	Blocking operation
%D	Macro stored as a library module, dormant
%E	End of embedded macro
%F	Copy a data fill
%M	Indicates beginning of embedded macro
%P	Print DSNP statements as comments
%R	Rewind a data file
%S	Set register
%T	Print macro translation process
%V	Insert a compiler variable into translated text
%W	Insert a value into a compiler variable
%X	Prefix output records
%&	Change content of register
&	Change content of register and output
?	Send next output record to specified data set
!	Prefix the current output record

Embedding macro definitions is permitted to any depth

Control characters must be doubled with each level of embedding

References

1. D. Saphier, "The Simulation Language of DSNP: Dynamic Simulator for Nuclear Power Plants", ANL-CT-77-20, Rev 02, Argonne National Laboratory (1978)
2. D. Saphier, "The Level-One Modules Library for DSNP: Dynamic Simulator for Nuclear Power Plants", ANL-CT-77-22, Rev 02, Argonne National Laboratory (1978)
3. D. Saphier, "The Precompiler for DSNP: Dynamic Simulator for Nuclear Power Plants", ANL-CT-77-22, Rev 02, Argonne National Laboratory (1978)
4. Ground Rules and Criteria for the Conceptual Design Study-Task 1.0, Compiled by L. B. Levitt (AI/ESG), revised July 7, 1979.
5. J. H. Kittel, et al, "Properties of Fuels for Alternate Breeder Fuel Cycles", ANL-AFP-38, Argonne National Laboratory (1977)
6. Westinghouse Electric Corporation, "Clinch River Breeder Reactor Plant: Overall Plant Design Description", OPDD 10, ARD (1974)
7. F. E. Dunn, et al, "The SAS2A LMFBR Accident-Analysis Computer Code", ANL-8138, Argonne National Laboratory (1974)
8. Private Communication, J. Beitel (ANL) to D. Saphier (ANL), July and August, 1979.