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The SAS4A/SASSYS-1 Safety Analysis Code System

Nuclear Engineering Division

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Chapter 1:
Introduction

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INTRODUCTION

1.1 SAS4A/SASSYS-1 Background

The SAS4A [1-1] and SASSYS-1 [1-2] computer codes were developed at Argonne National Laboratory in the Integral Fast Reactor (IFR) Program [1-3] for thermal, hydraulic, and neutronic analysis of power and flow transients in liquid-metal-cooled nuclear reactors (LMRs). The SAS4A code was developed to analyze severe core disruption accidents with coolant boiling and fuel melting and relocation, initiated by a very low probability coincidence of an accident precursor and failure of one or more safety systems. The SASSYS-1 computer code, originally developed to address loss-of-decay-heat-removal accidents, has evolved into a tool for margin assessment in design basis accident (DBA) analysis and for consequence assessment in beyond-design-basis accident (BDBA) analysis.

The SAS4A code contains detailed, mechanistic models of transient thermal, hydraulic, neutronic, and mechanical phenomena to describe the response of the reactor core, its coolant, fuel elements, and structural members to accident conditions. The core models in SAS4A provide the capability to analyze the initial phase of core disruptive accidents, through coolant heat-up and boiling, fuel element failure, and fuel melting and relocation. Originally developed to analyze oxide fuel clad with stainless steel, the models in SAS4A have now been extended and specialized to metallic fuel with advanced alloy cladding.

The SASSYS-1 code contains the same core models as SAS4A for fuel element heat transfer and single- and two-phase coolant thermal/hydraulics. In addition, SASSYS-1 has the capability to provide a detailed thermal/hydraulic simulation of the primary and secondary sodium coolant circuits and the balance-of-plant steam/water circuit. These sodium and steam circuit models include component models for heat exchangers, pumps, valves, turbines, and condensers, and thermal/hydraulic models of pipes and plena. SASSYS-1 also contains a plant protection and control system modeling capability, which provides digital representations of reactor, pump, and valve controllers and their response to input signal changes.

In the time since the last publication of the SAS4A and SASSYS-1 documents as Refs. 1-1 and 1-2, significant modeling additions and enhancements have been made as IFR program needs focused model development activities. This report is Volume 1 of a five-volume set of reports that update and replace References 1-1 and 1-2 as the base-line documentation of the SAS4A and SASSYS-1 computer codes and models. The contents and chapter organization of the five volumes are given in Table 1.1-1.

The chapter organization shown in Table 1.1-1 reflects the major model delineation in SAS4A/SASSYS-1. In terms of computer software module organization, Chapter 3, et seq., each corresponds to a major code module. Although SAS4A and SASSYS-1 are generally portrayed as two computer codes, they share common code architectures, the same data management strategy, and a number of basic subroutines. In practice, the SAS4A path through this common framework executes modules corresponding to models in Chapters 3 through 5 and 8 through 16, while the SASSYS-1 path encompasses Chapters 3 through 12.

Since References 1-1 and 1-2 were last revised, specific attention has been focused on the role of SAS4A and SASSYS-1 in the Integral Fast Reactor program at Argonne National Laboratory. This has resulted in 1) addition of new models and modification of existing models to treat metallic fuel, its properties, behavior, and accident phenomena, and 2) addition and validation of new capabilities for calculating design basis transients for the EBR-II reactor and plant [1-4], the IFR prototype. This report documents the status of the modeling in SAS4A and SASSYS-1. Detailed descriptions of the models listed in Table 1.1-1 are given, including model formulations, solution techniques, and input descriptions. (Model validation is the subject of a separate series of reports). The next section gives brief functional descriptions of the SAS4A/SASSYS-1 models, and highlights new capabilities.

Table 1.1-1: SAS4A/SASSYS-1 Documentation Organization

Chapter	Subject
1	Introduction (this chapter)
2	SAS4A/SASSYS-1 User's Guide
3	Pin Heat Transfer and Single-Phase Coolant Thermal/Hydraulics Model
4	Reactor Point Kinetics and Reactivity Feedback Models
5	PRIMAR-4: Primary and Intermediate Loop Thermal/Hydraulics Model
6	Plant Control and Protection Systems Model
7	Balance-of-Plant Thermal Hydraulics Model
8	DEFORM-4 Oxide Fuel and Cladding Mechanics Model
9	DEFORM-5 Metal Fuel Cladding Mechanics Model
10	SSCOMP Metal Fuel Characterization Model
11	FPIN2 Metal Fuel and Cladding Mechanics Model
12	TSBOIL Two-Phase Coolant Thermal/Hydraulics Model
13	CLAP Molten Cladding Dynamics Model
14	PLUTO2 Fuel-Coolant Interaction Model
15	PINACLE In-Pin Fuel Relocation Model
16	LEVITATE Fuel Relocation Model

1.2 Model Descriptions and New Capabilities

Both SAS4A and SASSYS-1 provide a detailed, multiple-channel thermal/hydraulic treatment of the reactor core. Each channel represents a fuel pin, its cladding, the associated coolant, and a fraction of the subassembly duct wall. Other positioning hardware, such as wire wraps or grid spacers, is usually lumped into the structure field with the duct wall. Within a channel, the flow is assumed to be one-dimensional in the axial direction, and the temperature field in the fuel, cladding, coolant, and structure is assumed to be two-dimensional in the radial and axial directions. Usually, a channel represents an average fuel element in a subassembly or a group of subassemblies. A channel may also represent pins in blanket or control subassemblies. Alternately, a single channel may also be used to represent the hottest pin in an assembly, or any other subset of a subassembly. The axial extent of a channel covers the entire length of a subassembly, including the core, the axial blankets, the fission gas plenum and the spaces above and below the pin/cladding geometry. Different channels may be used to account for radial and azimuthal design geometry, power, coolant flow, and burnup variations within the reactor core. From ten to thirty channels normally provide sufficient discretization, depending on the core design.

Chapter 2 contains a user's guide for SAS4A/SASSYS-1 applications, including a complete description of the standard input file.

Chapter 3 contains the description of the formulation for the SAS4A/SASSYS-1 pin heat transfer and single-phase coolant thermal/hydraulics model. A major new addition to this model is the capability to treat channel-to-channel heat transfer due to conduction and convection at all axial locations between the channel inlet and outlet, permitting a consistent multiple-pin subassembly treatment. Also, the subassembly-to-subassembly heat transfer model has been improved, and axial conduction in the coolant has been added. These modeling additions have been proven in validation analyses of EBR-II Shutdown Heat Removal Tests [1-5], and are required for accurate predictions of intra-subassembly flow and temperature variations in EBR-II during transients from normal to shutdown operating conditions.

Chapter 4 contains the description of the formulation for the SAS4A/SASSYS-1 reactor points kinetics and reactivity feedback models. The new addition to this module is an option for an EBR-II-specific reactivity feedback model that is being validated with analysis of reactor operating data and used for predictive calculations of margins in design basis analyses. This module provides the reactor power level to the core thermal/hydraulics models for determination of the heating rate in the fuel, and receives core materials temperature and geometry information to calculate the reactivity feedbacks employed in the solution of the point kinetics equations.

Chapter 5 presents a full description of the formulation for the PRIMAR-4 sodium loops thermal/hydraulic model. This model provides boundary coolant pressure and flow conditions for the core channel models, including transient heat losses through normal and emergency heat removal systems and the transient performance of pumps. The major new addition to PRIMAR-4 is the option for multiple core inlet and outlet coolant plena, permitting exact representation of the actual EBR-II coolant systems geometry.

The plant control and protection system model described in Chapter 6 is unchanged from prior versions of SASSYS-1, except for the addition of an option to allow dynamic allocation of model data storage at execution time.

The balance-of-plant (BOP) model described in Chapter 7 is new for SASSYS-1. It was implemented to permit 1) improved simulation of EBR-II design basis transients,

2) whole-plant analysis of IFR designs for optimization of advanced reactor control system strategies, and 3) core temperature margin assessments in unprotected accident sequences (i.e. beyond design basis accidents (BDBA) and anticipated transients without scram (ATWS)). In these latter sequences, core response depends strongly upon the performance of the balance-of-plant, because the core neutronic and thermal/ hydraulic behavior is determined by the availability of heat sinks outside the core. The BOP model couples to PRIMAR-4 at the steam generator.

Chapter 8 provides a description of the DEFORM-4 fuel element behavior model for stainless steel-clad oxide fuel, which is unchanged from prior versions of SAS4A/SASSYS-1.

Chapter 9 contains the description of the DEFORM-5 model, which treats the transient behavior of stainless steel and advanced (HT-9) cladding for metal fuel elements. This is a new model for SAS4A and SASSYS-1, and is aimed at predicting margin to cladding failure, and timing and location of failure in limiting transients. It includes physical phenomena unique to metallic fuel, such as fuel/cladding chemical interactions.

The SSCOMP model described in Chapter 10 has been revised to reflect newly available metal fuel material properties evaluations recorded in the IFR Material Properties Handbook [1-6]. An efficient correlation technique has been implemented in all SAS4A and SASSYS-1 material properties routines that accurately generates the data from the IFR Handbook for use in all the modules of the code. It is planned to revise the material migration capability in SSCOMP for ternary fuel, to add models for fission gas generation and release, swelling, and all other phenomena needed to describe the transition from cold, clean, unirradiated conditions to hot irradiated conditions.

Chapter 11 contains the description of a major new addition to SAS4A and SASSYS-1 codes, the FPIN2 metal fuel pin mechanics model [1-7]. FPIN2 is a validated model for metal fuel pin transient behavior. Unlike DEFORM-5, which treats only the cladding response, FPIN2 provides a finite-element solution of the fuel and cladding mechanics equations for the elastic/plastic response, including fission gas pressurization and migration, molten cavity formation and growth, and fuel/cladding chemical interaction and cladding thinning. The interface between SAS4A/SASSYS-1 and FPIN2 has been designed to permit stand-alone execution of FPIN2 for direct verification, and to replace the FPIN2 thermal/hydraulics calculation with the SAS4A/SASSYS-1 counterparts for coupled calculations. The application for this model is design basis analysis of driver and experimental fuel elements in EBR-II for the purpose of margin-to-failure assessments.

The TSBOIL module for liquid metal coolant boiling and two-phase thermal/hydraulics calculations has been retained intact from previous versions of SAS4A/SASSYS-1, with the addition of a set of modifications to describe the sudden release of noncondensible fission gas from a cladding rupture in the upper fission gas plenum of metal fuel elements and the subsequent plenum blow-down and liquid coolant expulsion. This option has been used to assess the safety implications of long-term fuel element irradiations in EBR-II [1-8].

The CLAP and PLUTO2 models described in Chapters 13 and 14 are relevant only to oxide fuel, and have remained unchanged since the previous documentation.

The PINACLE model described in Chapter 15 and the LEVITATE model described in Chapter 16 have been upgraded for applications to metallic fuel [1-9]. The model enhancements added to PINACLE and LEVITATE for metal fuel include fuel/cladding and fuel/structure chemical interactions and fission gas generation and migration with fuel swelling. Preliminary analyses of TREAT M-Series in-pile metal fuel tests have been completed [1-10], and applications to severe accident sequences in metal-fueled IFR cores have been completed and documented [1-11].

REFERENCES

NOTICE

Several references in this document refer to unpublished information. For a list of available open-literature citations, please contact the authors.