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Interactive Nuclear Plant Analyzer for VVER-440 Reactor

William Shier
William Horak
Robert Kennett

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Subject Catetory 1. Operational Training and Simulation

International Projects Division

Brookhaven National Laboratory
Associated Universities, Inc.
Upton, Long Island, New York 11973

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William Shier
William Horak
Robert Kennett

Brookhaven National Laboratory
Upton, New York USA 11973

William Shier
Research Engineer

Building 130
Brookhaven National Laboratory
Upton, New York USA 11973
Tel: 516-282-2385
Fax: 516-282-3957

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Interactive Nuclear Plant Analyzer For a VVER-440 Reactor*

William Shier
William Horak
Robert Kennett

Brookhaven National Laboratory
Upton, New York USA 11973

KEYWORDS: nuclear plant analyzer, VVER-440, training and operational event analysis, Computer Visual System, RELAP5/MOD2

INTRODUCTION

An interactive nuclear plant analyzer (NPA) has been developed for a VVER-440, Model 213 reactor for use in the training of plant personnel, the development and verification of plant operating procedures, and in the analysis of various anticipated operational occurrences and accident scenarios. This NPA is operational on an IBM RISC-6000 workstation and utilizes the RELAP5/MOD2 computer code[1] for the calculation of the VVER-440 reactor response to the interactive commands initiated by the NPA operator. Results of the interactive calculation can be displayed in the following forms:

1) On a pictorial representation of the reactor primary and secondary system (referred to as a mask) through a color graphics monitor;

2) On a mask representing the reactor control panel where the plant operating information and system status are displayed; and

3) Through graphical display of various RELAP5 variables as a function of time. Up to six plot frames can be simultaneously displayed, each with up to four variables.

In addition, hardcopy output is available for each item listed above.

Results displayed on the reactor mask are shown through the user defined, digital display of various plant parameters and through color changes that reflect changes in primary system fluid temperatures, fuel and clad temperatures, and the temperatures of other metal structures. In addition, changes in the status of various components and system can be initiated and/or displayed both numerically and graphically on the mask.

STRUCTURE OF THE NPA

As shown in Figure 1, the NPA consists of four main parts that include three software packages and a display device. The three software packages are discussed in the following paragraphs:

*This work is performed under the auspices of the United States Department of Energy.

VVER SIMULATION MODEL

The model developed for the VVER-440 V213 plant is shown schematically in Figure 2. This model consists of two main coolant loops with one loop representing the response of five VVER-440 loops and the second loop representing a single plant loop. Each loop contains models for steam generators, main coolant pumps, and the associated piping. Overall, the plant is represented by 84 control volumes and 84 flow junctions. Several important details of the modelling are summarized below.

Pressure Vessel Model: The pressure vessel is represented with seven control volumes with additional detail in the heated core region discussed below. The downcomer has been split to provide individual connections to the lumped, intact loop nozzles and the single loop nozzle.

Core Model: The VVER-440 core is represented as a single channel with five axial nodes. The heated region has three nodes; a chopped cosine function was used to model the axial power distribution.

Primary System Piping: Considerable detail has been included in the modelling of the hot and cold leg piping. This detail has been provided to represent the loop seals that are located in the hot and cold leg piping adjacent to the primary side of the steam generators.

Steam Generator Model: The model developed for the VVER horizontal steam generators includes ten primary side control volumes and ten heat slabs that transfer heat to the secondary system. Each of the heat slabs was sub-divided into 3 radial regions to allow the calculation of a temperature distribution through the walls of the steam generator tubes.

Secondary System Model: Each secondary system was represented by a single control volume that was sub-divided into three regions. All heat from the primary side was transferred to the middle, two phase region; feedwater flow enters the bottom region that was filled with subcooled liquid. Models for the turbine isolation valves and the relief and safety valves were provided.

Emergency Injection Systems: Detailed models for three systems designed to inject coolant to the primary following depressurization events have been provided. These models include four accumulators, three high pressure injection pumps, and four low pressure injection pumps.

NPA CAPABILITIES

As discussed previously, the NPA has been designed for use in staff training, plant procedure development, and the analysis of various operational occurrences and accident scenarios. Thus, the NPA interactive capabilities were developed to provide considerable flexibility in the plant actions that can be initiated by the NPA operator.The current capabilities are summarized below:

Scram initiation
Reactor coolant pump trip
High pressure safety injection system initiation
Low pressure safety injection system initiation
Pressurizer safety valve opening
Steam generator relief/safety valve opening
Feedwater system initiation and trip
Turbine trip
Emergency feedwater initiation

Display Generation Software: The NPA uses the Computer Visual System (CVS) [2] to build the static portions of the drawing (or mask) that represents the system being modelled. In addition, CVS is used to define the components and other areas of the mask that are to be driven dynamically or that are used to provide interactive information to the analysis software. For the NPA system described in this paper, the CVS software has been used to develop two masks that include a representation of the control panel and a schematic of the primary and secondary VVER-440 systems that have been modelled with the RELAP5/MOD2 code.

RELAP5/MOD2: The current NPA system uses the RELAP5 code to perform the analysis of the VVER-440 response to the various transients and accident scenarios that can be initiated interactively through the primary system mask. RELAP5 has been used extensively for the analysis of pressurized water reactor loss of coolant accidents (LOCAs), abnormal occurrences, and anticipated transients without scram. The hydrodynamic model is a one dimensional, two fluid model for the flow a two phase steam water mixture. The basic field equations include the continuity, momentum, and energy equations solved for each of the two phases. Heat transfer is modelled with the one dimensional heat conduction equation that is coupled with the hydrodynamic calculation through a number of surface heat transfer regimes. Process models are available for choked flow, branching, and representation of pipe ruptures. Component models can be used to represent pumps, valves, and accumulators. Considerable flexibility is available for the representation of very complex systems.

Nuclear Plant Analyzer: This software package [3] provides the animation of the data generated by the analysis software described above. In this animation, data are transformed to colors, dials, and various other indicators for display on the system masks. The NPA consists of program libraries that, in themselves, are not executable, That is, the NPA must be linked to a source of data. This data source can be an analysis program, a data acquisition program, or a data base program. For the application described in this paper, the linking has been accomplished with the RELAP5 code. The NPA must also be provided with the appropriate instructions to perform the animation of the data. These instructions are prepared using CVS and are stored in a computer file that is accessible to the NPA.

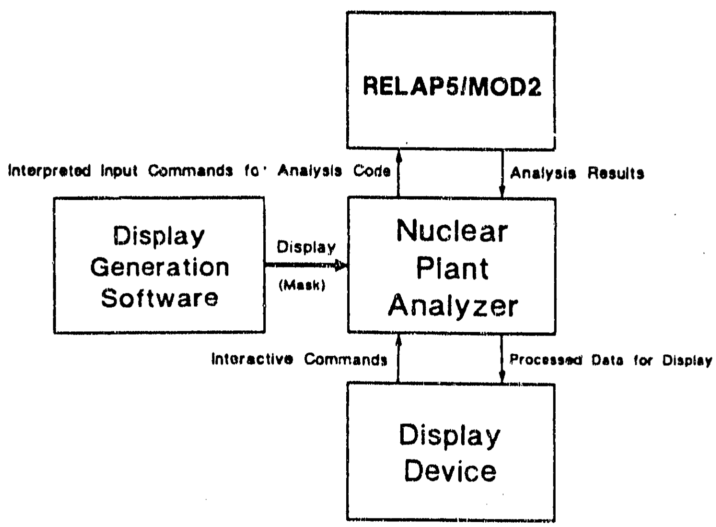

Figure 1: Overview of Nuclear Plant Analyzer

These functions provide considerable capability to the NPA operator for initiating various plant actions that could occur during both normal and abnormal plant operation. In addition, with the existing structure of the NPA, additional features can readily be implemented to accommodate specific operational requirements.

SUMMARY

The interactive nuclear plant analyzer developed for the VVER-440 reactor provides the capability to analyze many transient events that could be required for staff training, plant procedure development and validation, and detailed analysis of plant safety system response. Executing on an IBM RISC-6000 workstation, the NPA is an efficient tool for developing improvements for many areas of the plant operation.

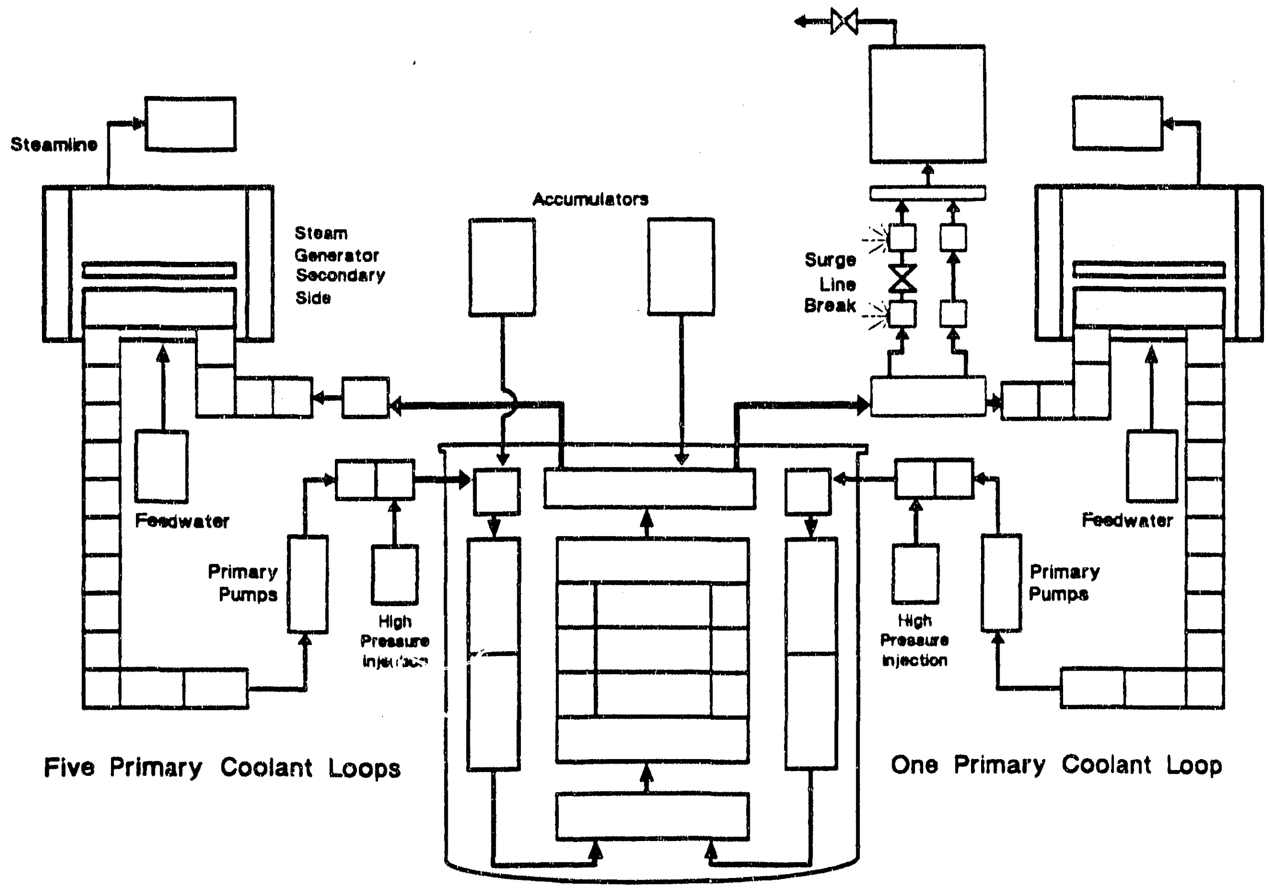

Figure 2: Primary System VVER–440 Mask

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