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Development and verification of a software system for the probabilistic safety analysis of nuclear plants as part of the proryv project

L.V. Abramov, A.M. Bakhmetyev, I.A. Bylov*, A.A. Vasyuchenkov

JSC "Afrikantov OKB Mechanical Engineering" (JSC "Afrikantov OKBM") 15 Burnakovskiy proyezd, 603704 Nizhny Novgorod, Russia

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Abstract

Probabilistic safety analysis (PSA) normally requires the development of a sophisticated computer model of the nuclear plant with a comprehensive reliability and safety study based on respective software. In 2013–2015, CRISS 5.3, a PSA software system, was developed and verified by Afrikantov OKBM as part of the effort, entitled New Generation Codes, under the *Proryv* (Breakthrough) project.

The paper presents a review of the software tools used in the industry for the PSA of nuclear units and analyzes the capabilities of these tools.

It also describes in brief the CRISS 5.3 software system intended to model and analyze safety systems and the nuclear plant as the whole as part of probabilistic safety analyses at all nuclear plant lifecycle stages.

The paper presents results of the CRISS 5.3 code verification through the comparison of the analysis results obtained using the CRISS 5.3 system against analytical formulas and results of a qualitative and quantitative analysis based on certified nuclear plant PSA software tools.

Keywords: Probabilistic safety analysis; Nuclear plant; Verification; Software; Failure tree; Event tree.

Introduction

Probabilistic safety analysis (PSA) requires the development of a sophisticated computer model of the nuclear plant with a comprehensive safety and reliability study based on respective software.

An effort, "New Generation Codes", is being under way as part of the federal target program "Nuclear Power Technologies of a New Generation for a Period of 2010–2015 and up to the Year 2020″ and the *Proryv* (Breakthrough) project. As part of this effort, a PSA software system, called CRISS 5.3, was developed and verified by Afrikantov OKBM in 2013–2015.

Nuclear plants developed under the *Proryv* project feature the following:

- sophisticated probabilistic logical models of the nuclear plant;
- consideration of a great amount of accident sequences, including those of a low probability;
- a reliability analysis of systems with a high redundancy level;
- a reduction, by several orders of magnitude during an analysis, of the cutoff level for the minimal cutset probabilities.

These features have defined the major requirements to the developed PSA software system.

We shall consider the PSA software systems used in Russian nuclear power and describe in brief the CRISS 5.3 structure, key functions and verification results.

A review of nuclear psa software systems

The two major software systems used presently in Russia for the PSA of nuclear units are RiskSpectrum, Sweden, [1] and CRISS, Russia, [2].

* Corresponding author.

E-mail addresses: levabramov@okbm.nnov.ru (L.V. Abramov), alexbakh@okbm.nnov.ru (A.M. Bakhmetyev), vab@okbm.nnov.ru (I.A. Bylov).

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Table 1
Development of the Russian CRISS PSA software system.

Time interval	System	Features	Practical use
Late 1980 s – early 1990s	TREES CRISS	EC-1066	AST-500, BN-600, BN-800, and VPBER-600 reactors, small reactors
Late 1990s	CRISS 2.0	IBM PC, MS DOS	PSA of Voronezh AST and Siberian Chemical Combine AST reactors
2001–2002	CRISS 3.0 CRISS 3.1	IBM PC,MS DOS →MS Windows	PSA of GT-MHR project, PSA of KLT-40S floating nuclear power unit
2004–2009	CRISS 4.0	IBM PC,MS Windows 98	PSA of BN-600, small and medium reactors Nuclear personnel training
Since 2009	CRISS 5.1	IBM PC, MS Windows XP, 7	PSAs of BN-600, BN-800, BN-1200, KLT-40S floating nuclear power unit, RITM-200 nuclear icebreaker's propulsion plant PSA of MCC spent fuel storage

RiskSpectrum is one of the most common nuclear plant PSA software tools. Specifically, RiskSpectrum is designed to address the entire spectrum of tasks involved in the development and analysis of the nuclear plant's probabilistic logical model as part of level 1 and 2 PSAs [3]. Currently RiskSpectrum software is used in Russia to perform PSAs level 1 and 2 for nuclear units with VVER and RBMK reactors.

The CRISS software system has been developed and improved by Afrikantov OKBM during past 25 years. Different generations of the CRISS software system have been broadly used since the late 1980 s and the early 1990 s to support the design and to perform the PSAs of nuclear plants of different types (Table 1).

Currently in operation is CRISS 5.1, a fifth-generation software system [4]. The system was certified by Rostekhnadzor in 2011 for the probabilistic safety analysis of nuclear installations.

The upgraded nuclear plant PSA software system shall provide for:

– unlimited dimensionality of probabilistic logical models;
– high-speed analysis of highly dimensional sophisticated models;
– avoidance of errors in integrating individual models of systems and accident sequences into an integrated nuclear plant model;
– use of versatile models to take into account common-cause failures as applied to highly redundant systems.

The upgrading of the CRISS software system also included the implementation of an algorithm for determining the optimal composition of the system with regard for economic criteria with the given reliability level.

Criss 5.3 software system

The CRISS 5.3 software system is designed to model and analyze safety systems and the nuclear plant as the whole as part of PSAs at all nuclear plant lifecycle stages.

The CRISS software system was developed on the base of "client-server" architecture using the common administered database where user rights to make changes are differentiated. Oracle Database 11 g Express Edition is used as the DBMS.

The system's server part contains the database including reliability data, fault trees, event trees and analysis options databases. The server part supports the integrity of data in storage and the user authentication based on the available information. The client part supports the user interfaces with the software system's database, the developing of probabilistic models using fault tree and event tree editors, qualitative and quantitative analyses of probabilistic models, and the examination and documentation of analysis results.

The computational module of the upgraded CRISS 5.3 software system uses parallel computing algorithms and ensures a shorter time for the probabilistic logical model analysis as compared to the certified version of the CRISS 5.1 software system.

A generalized flowchart of the software system is shown in Fig. 1.

The CRISS software system allows to:

– accumulate in database information about safety systems, accidents initiating events, human errors taken into consideration and components reliability data including common cause failures (CCF) models parameters, initiating events frequencies, operability tests scheduling for safety systems components;
– management of relational databases;
– cross-copying, import and export of project data;
– create and edit fault trees using AND, OR, M-out-of-N and negation logic operators;
– create and edit event trees;
– perform fault trees and event trees qualitative and quantitative analysis with automated CCF modelling using binomial failure rate, beta-factor, alpha-factor and multiple Greek letters models;
– perform importance analysis, sensitivity analysis and uncertainty analysis. Uncertainty analysis is performing by Monte Carlo method based on selection of random base events reliability data values);
– failure mode and effects analysis;
– edit minimal cutsets;