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Computer Programs Developed at the Reactor Physics Department

Bojan Žefran, Andrej Trkov, Slavko Slavič, Marjan Kromar, Jan Malec, Sebastian Pleško, Luka Snoj
Jožef Stefan Institute
Jamova cesta 39, SI-1000 Ljubljana, Slovenia
Bojan.Zefran@ijs.si

ABSTRACT

The paper gives an overview and references of the programs that have been developed at the Reactor Physics Department of the Jožef Stefan Institute in the last 40 years and plans for the future.

The Reactor Physics Department has developed several computer program packages. The department's researchers have created a comprehensive package for designing a power reactor core, which has been utilized to calculate fuel cycles for the Krško Nuclear Power Plant (CORD-2). The paper briefly presents the programs developed for calculations on the TRIGA research reactor (programs: TRIGLAV, the research reactor simulator (RRS), PULSTRI...) and programs developed to perform calculations and support the operation of Krško Nuclear Power Plant (programs: CORD-2, GNOMER, LOADF, DMRES, FAR, Shuffle...). These programs are also commonly used for education and training. Some programs are available from Nuclear Energy Agency (NEA) Data Bank Computer Program Services and Radiation Safety Information Computational Center (RSICC), making them accessible to researchers and engineers around the world.

1 INTRODUCTION

At the Reactor Physics Department (F8) at the Jožef Stefan Institute (JSI) the research is focused on neutron, photon and electron transport, nuclear data evaluation and sensitivity methods. In the domain of reactor physics is directed mostly towards development of new calculational methods for research and power reactors. One of the main activities of the department is the development of new tools - program packages that enable this reactor calculations.

Development of computing programs started in the eighties. New computing programs had to be developed because programs were not available at that time or were not suitable for our calculations. The first programs were developed on Cyber CDC computers and DEC PDP. A huge step forward was when we got on JSI Reactor centre the first DEC VAX and IBM PC XT with support from IAEA in the eighties. In 1998 we started with the first demo computer cluster Vega [1] which was a testing predecessor of later computer clusters Mangrt, Krn, Razor and Skuta (with more than 104 computer nodes, more than 5000 physical Xeon cores) [2].

2 COMPUTER PROGRAMS

2.1 Programs developed for TRIGA reactor

TRIGA-JSI is the Slovenian research reactor provided by General Atomics, located at the Jožef Stefan Institute near Ljubljana. In this chapter the programs for calculations of the TRIGA reactor are described.

2.2 TRIGLAV

TRIGLAV [3] is a computer program for reactor calculations of mixed cores in TRIGA Mark II research reactors. It can be used for fuel element burn-up calculations, as well as power and flux distribution calculations and reactivity predictions. Development started in the nineties [4]. At present, TRIGLAV has a database of more than 40 registered users around the world. It is also used for teaching purposes. TRIGLAV-W [5] is an MS Windows graphics user interface for the TRIGLAV package. **TRIGAP** [6] and **TRIGAC** [7] are precursors of the TRIGLAV program developed in the eighties and are available from the NEA Data Bank Computer Program Services. **STRIGA** [8] is a new program package which uses the Monte Carlo Serpent code for cell calculation. All programs are input compatible.

2.3 The Research Reactor Simulator (RSS)

A research reactor simulator (RRS) was developed [9], that works in real time for teaching and training purposes. It is useful for students and future reactor operators who do not have access to a real research reactor. The RRS uses the 6-group point kinetics equation with feedback to model the changes in reactor power, fuel temperature and reactivity over time. It also includes the effects of temperature feedback and xenon poisoning. The RRS uses graphics acceleration to show the simulation results and a simple integration scheme with a short simulation step to update the simulation parameters. This makes the simulation responsive to the user’s input, which is important for fast transients in research reactors. The RRS is designed for TRIGA-type reactors, but it can be modified to simulate other reactors with similar thermal-hydraulic behaviour by changing the physical parameters. Since 2020, the simulator source code is freely available from GitHub [10].

2.4 PULSTRI

PULSTRI is a Fortran computer program [11] for mixed core TRIGA Reactor pulse calculations (maximum temperature, prompt energy, peak power). Pulse is calculated in adiabatic Fuchs-Hansen approximation. Temperature and burn-up dependence of fuel temperature reactivity coefficient and heat capacity is considered. A new program for pulse calculation is under development and paper will be published.

2.5 TEMPUL

TEMPUL [12] is a one-dimensional Fortran computer programme for calculating radial fuel temperature distribution in a fuel element immediately after the pulse. It was developed for the analysis of boiling crisis and DNB conditions in TRIGA core after the transient.

2.6 TRISTAN

TRISTAN [13] is a Fortran computer program for calculating steady-state axial temperature distribution and flow velocity through a vertical coolant channel in low power TRIGA reactor core, cooled by natural convection.

2.7 Programs developed for Krško Nuclear Power Plant

In this chapter programs developed for calculations for Krško Nuclear Power Plant (NEK) – a Westinghouse PWR reactor are described. Codes for NPP are developed, validated and verified according to the QA procedure.

2.8 CORD-2

This program package [14] is designed for pressurized water reactors and can be used for simple calculations as well as more accurate core design calculations after refuelling. CORD-2 is a collection of Fortran programs and system procedures for the maintenance of data libraries describing the reactor core. It is used for core design calculations at JSI for NEK from the nineties. CORDSP-W [15] is MS Windows interface for graphical display of the results. New improvements in 2023 includes: Linux implementation, parallelization and GitHub software control.

2.9 GNOMER

One of the most widely used Fortran programs developed by the Reactor Physics Department is GNOMER [16]. This program solves the multigroup neutron diffusion equation in 1D, 2D, and 3D cartesian geometry using the nodal method to solve the multi-group neutron diffusion equation, allowing for the calculation of global core power distributions with thermohydraulic feedbacks. It can also be used to calculate power distributions and homogenized cross sections over a fuel assembly. It is used in CORD-2 and LOADF program package. New improvements include 3-D reactor kinetics [17].

2.10 COREP

The COREP code [18] is an alternative code to the GNOMER, allowing the calculation of global core power distributions with thermohydraulic feedbacks. It solves the multigroup neutron diffusion equation in 3D cartesian geometry using the analytical nodal method. It is capable to accurately predict pin power distributions needed for the determination of power peaking factors in the core.

2.11 LOADF

LOADF [19] program that uses modules of the CORD-2 package and provides online simulations of reactor operations. The LOADF program is designed to simulate the actual operation of the reactor in real time or in offline mode for the analysis or optimisation of planned transients. Relative concentrations and axial distributions of xenon and iodine are calculated, corresponding to core conditions, which match as closely as possible the measured values. Accurate estimate of the xenon concentration level can improve the estimate of the shutdown margin. First version was installed in the nineties. WinLF [20] is MS Windows interface to LOADF program for running simulations on PC.

2.12 SHUFFLE

SHUFFLE is a program package for preparing and monitoring fuel loading operations at the plant. It allows for planning and reloading operations to be easier and safer by creating, editing, and checking steps in the shuffling plan.

The first version [21] has been written in the Clipper program language in 1992 under the DOS operating system. Since then, it is used during preparation of refuelling and during

refuelling in NEK. Major upgrade was update to MS Windows operating system with Alaska programming langue [22].

2.13 FAR

Fuel Assembly Register (FAR) covers all aspects of the nuclear material accounting at the plant, allowing for simplified control and updating of fuel element properties during the plant's lifetime. Like program SHUFFLE, it was first developed in MS DOS [23] and then upgraded to MS Windows [24].

New improvements in 2023 includes a module for the dry storage. Intensive work is in progress for rewriting the program in PHP + SQLite and merge it with SHUFFLE [25].

2.14 DMR043, DMReS

The Department has developed a new method for measuring the reactivity worth of control clusters known as "Rod Insertion method", and the associated digital reactivity meter software (DMR043 and DMReS), which significantly reduce the time required for post-refuelling start-up tests at nuclear power plants [26]. DMR043 was designed for start-up tests at the Krško Nuclear Power Plant in the eighties on IBM PC XT platform and upgraded to 80386 with GPIB interface. Flux signal is read with electrometer from the power range detectors.

DMReS [27] is a new Windows version of DMR043 main program and modules: Inhour, Bordil, BorEnd, ITC; RodIn, and DMRdil. The programs are also widely used for education and training on the TRIGA reactor for domestic and foreign students. The programs received the bronze award for innovation from "Chamber of Commerce and Industry of Slovenia (CCIS)" in 2014. New improvements in 2023 include the addition of a module for Keithley electrometer verification.

DMRPIS is the online version of the DMR program which runs on the NEK PIS system from Cycle 29 (2016). The flux signal in this version is read from the intermediate power range detectors.

2.15 CEBIS

CEBIS [28] is a Fortran code for calculations of reactor core multiplication factor, flux and power distributions in one dimensional cartesian, cylindrical and spherical geometries using the finite difference method. It is intended for reactor physics calculations of steady-state thermal multiplying systems in two group diffusion approximation. Besides the direct solution, the program gives also the adjoint solution of the diffusion equation.

2.16 FASVER

FASVER2 [29] is a Fortran code that solves the two-group two-dimensional (x-y geometry) steady-state diffusion equation using the finite difference method. It is designed for the octant geometry of a typical PWR core with reflector. The adjoint equation may also be solved. FASVER4 performs the same calculations as FASVER2, but for one quadrant geometry of a PWR core. It was used in CORD-0, the precursors of the CORD-2 package.

2.17 Time2Boil

Time2Boil [30] is MS windows program coded at JSI with Alaska programming langue, according to NEK algorithm for calculating of the thermo-hydraulic parameters of the spent fuel pool during an accident condition at NEK.

3 OTHER COMPUTER CODES AND UTILITY CODES

• **Matfss** [31] is very popular and widely used Fortran program that helps the user to calculate the element and isotope number densities and self-shielding factors, given the chemical composition of the components, their weight-% fraction in the mixture, the mass and dimensions of the sample.

• **ENDSAM** [32] is a code for random sampling and validation of covariance data of resonance parameters in ENDF-6 format. The ENDSAM code produces an arbitrary number of new files in ENDF-6 format by randomly sampling resonance parameters (in accordance with corresponding covariance matrices) for a chosen nuclide in a given evaluated data file in ENDF-6 format.

• **Susd3dW** [33] is MS Windows interface to the Susd3d program. The package was developed to help users in the preparation of input cards, rapid modification and execution of the complete chain of codes including TRANSX, PARTISN and SUSD3D. It enables user-friendly viewing of results.

• **Tracos** (track counting system) [34] is a program for the evaluation of etched track charged particle as imaged under an optical microscope. A pattern recognition program, Trackmatch, which was used for tracking charged particle trajectories through a stack of etch detectors, run in parallel mode.

• **PlotS** is general purpose graph plotting program. It is used as module in e.g.,. WinLF; DMReS and Susd3dW.

4 CONCLUSION

The Reactor Physics Department has developed a wide variety of computer programs (see figure 1) that are used in the field of nuclear energy. These programs have been specifically designed for a range of applications. Some of them are available for download from the NEA Data Bank Computer Program Services and the RSICC (see figure 2 and 3). The development of these programs demonstrates the department's commitment to advancing the field of nuclear energy using cutting-edge technology and scientific research.

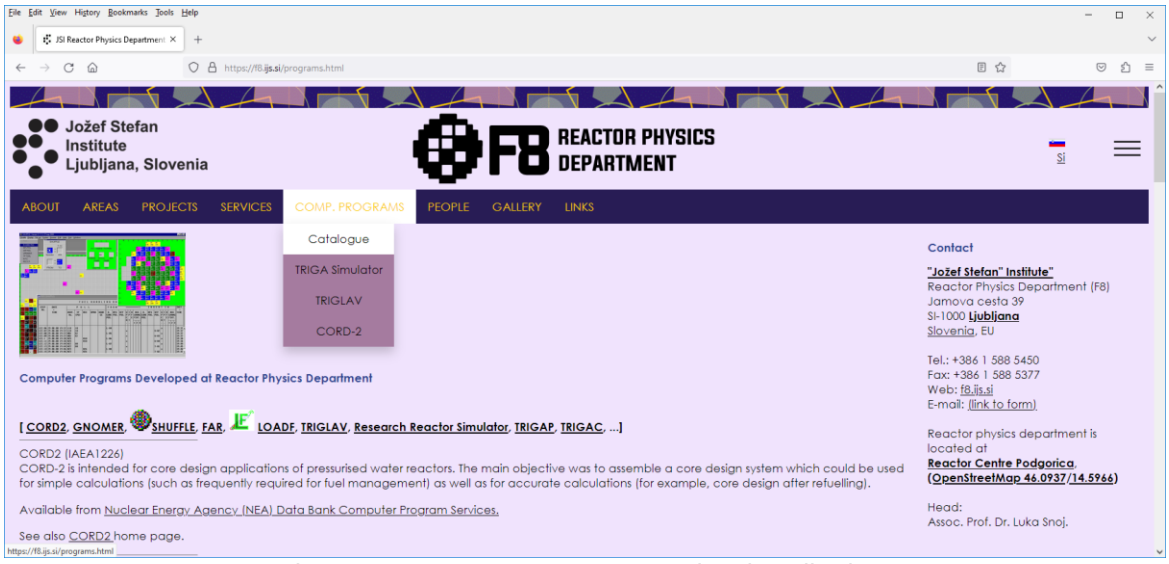

Figure 1: Computer programs are also described on the Reactor Physics Department (F8) home page [35].

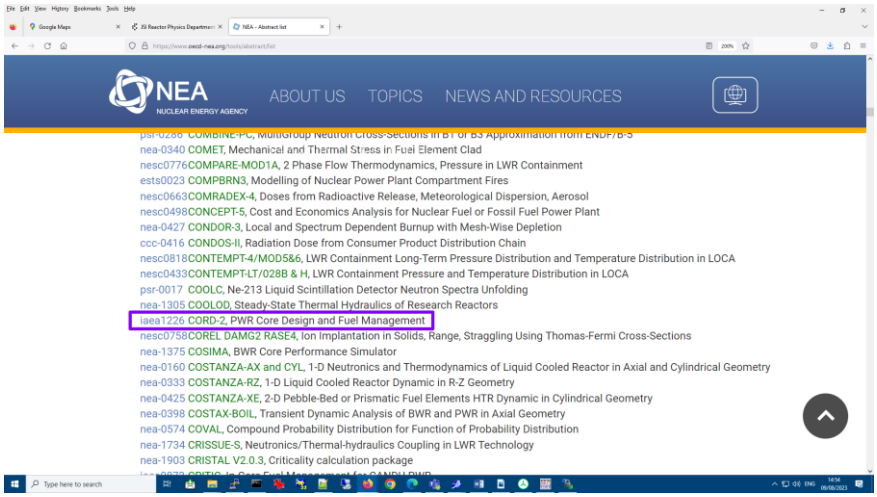

Figure 2: Link to CORD-2 - JSI program from the Nuclear Energy Agency (NEA) Data Bank Computer Program Services home page.

Figure 3: Links to some JSI programs from the Safety Information Computational Center (RSICC) home page.

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