Development of the Processing Software Package for RPV Neutron Fluence Determination Methodology

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1. Introduction

Neutron fluence determination is a base element of the VVER RPV surveillance program. According to this program the RPV current state and residual lifetime estimation are accomplished. The program requires calculational and experimental neutron fluence determination.

Because of the inaccessibility of the RPV surveillance positions for measurements the neutron fluence is determined by calculation only. Verification/validation of the fluence calculation is performed by measurements at the appropriate positions at the RPV vicinity.

According to the IAEA recommendations the safety NPP activities have to be performed under a Quality Assurance (QA) requirements. In this relation the calculation processing has to be carried out in a manner that allows eliminating of all possible sources of uncertainties. All steps in calculation processing have to be computerized to avoid possible human errors and mistakes, to ensure maximal authenticity of the input data as well as conditions for input data revision.

Neutron fluence verification is based on the data of measured induced activities from threshold detectors irradiated in the air cavity behind RPV, during one or more cycles. Experimental data with low uncertainties are recommended for verification of the calculation methods.

According to the INRNE methodology the neutron transport calculation is carried out by two steps. At the first step reactor core eigenvalue calculation is performed. This calculation is used for determination of the fixed source for the next step calculation of neutron transport from the reactor core to the RPV. Both calculation steps are performed by state of the art and tested codes. The interface software package DOSRC [1] developed at INRNE is used as a link between these two calculations. The package transforms reactor core calculation results to neutron source input data in format appropriate for the neutron transport codes (DORT[2], TORT[3] and ASYNT[4]) based on the discrete ordinates method. These codes are applied for calculation of the RPV neutron flux and its responses – induced activity, radiation damage, neutron fluence etc.

Fore more precise estimation of the neutron fluence, the INRNE methodology has been supplemented by the next improvements:

- implementation of more advanced codes (PYTHIA[5]/DERAB) for neutron-physics parameter calculations;
- more detailed neutron source presentation;
- verification of neutron fluence by statistically treated experimental data.

The implementation of mentioned improvements has required modification of the interface package by new options and functions, as well as creation of the new software.

2. Function of the interface package

The interface software package used for RPV neutron fluence calculation transforms the output data of reactor core code to input data of discrete ordinates method' transport code. In particular, the output data of assembly-wise power density and fuel burn-up distribution in 3D-geometry from PYTHIA/DERAB code are transformed to input neutron source data in (r, θ, z)-geometry in a format appropriate for neutron transport DORT/TORT and ASYNT code.

The scheme of interface software package is shown in Fig.1. The purpose of some base package modules and files is described below.

The SRC_HEX module calculates the neutron and activity source in hexagonal geometry. The activity source is preparing for the calculation of activities from ^{60}Co, ^{54}Mn, ^{93m}Nb of copper, iron and niobium foils respectively that are used as ex-vessel detectors. The SRC_HEX module output file named REAC.OUT is input file for SKV module. The SKV module processes data when more than one cycle it is calculated. It summarizes the cycle-sources accounting the time between cycles.

The SRCREAC module transforms the neutron/activity source from hexagonal to radial-azimuth geometry for the mesh format of discrete ordinates' codes. It records the transformed data in files for every axial interval.

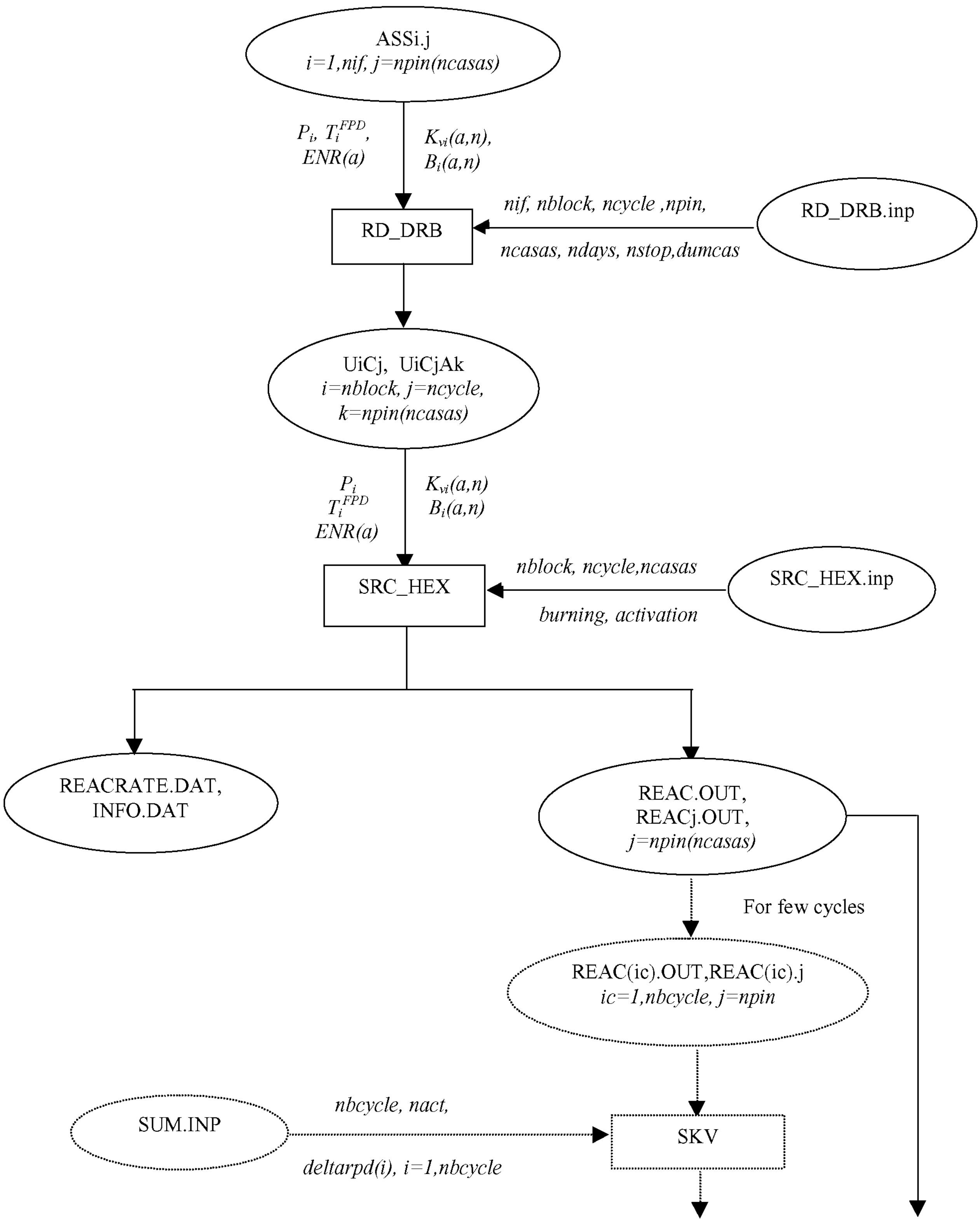
The COLLECT module collects all axial level data and records them in the files: Kv.A – for neutron source data, Co/Mn/Nb.A – for activity source data. The data of these output files are recorded in 96**card format used for TORT and ASYNT code input.

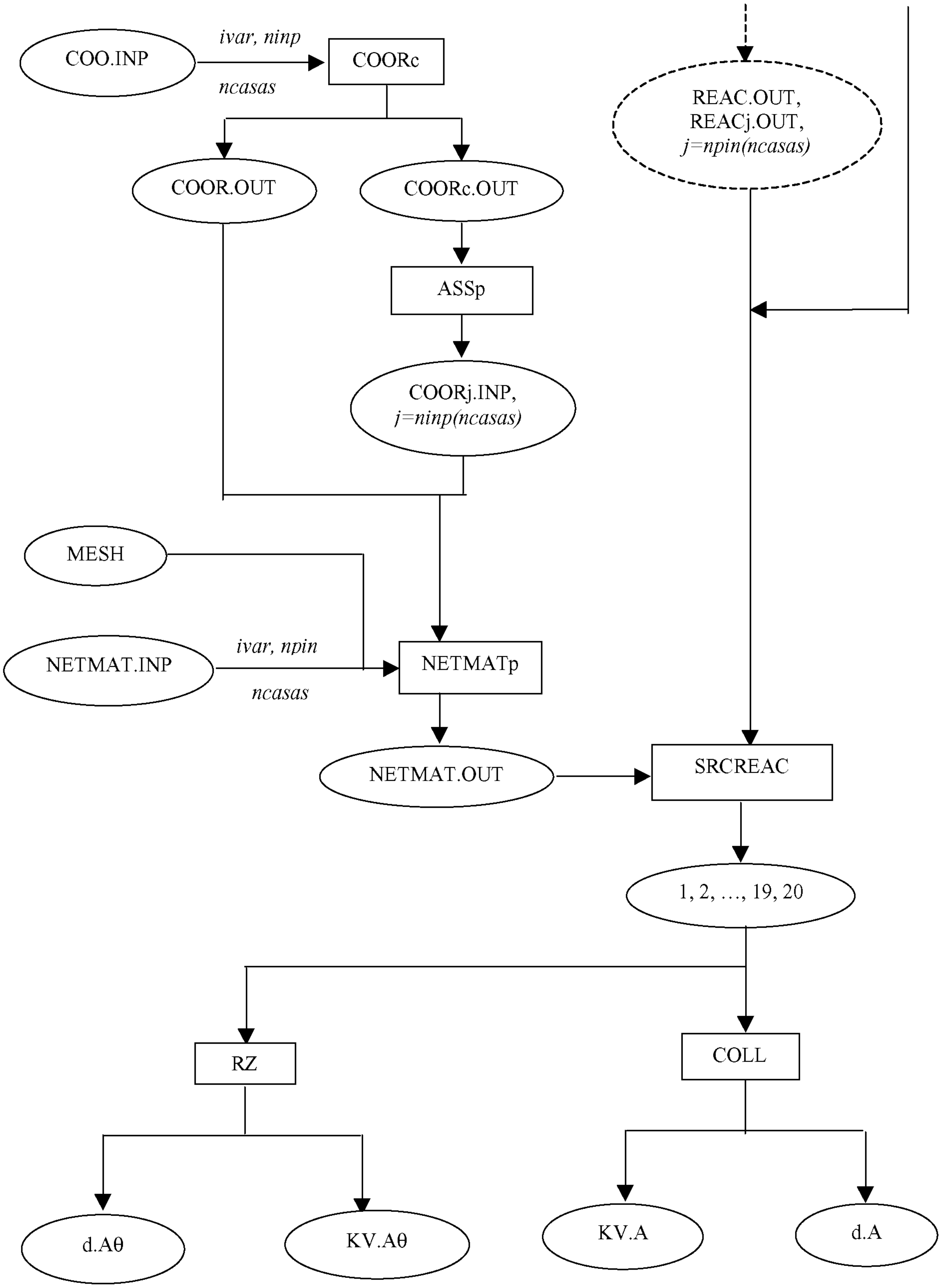
The RZ module selects all axial level data for given azimuth direction θ. It records them to files: Kv/Co/Mn/Nb.Aθ. These output files' data are recorded in 96** card format used for DORT code input.

3. Improvement of the interface software package

The interface software package has been enhanced in a way to process the data as for assembly-wise so for pin-wise source presentation from the new version of PYTHIA/DERAB code. Its output data file contains normalized assembly- and pin-wise power distribution and fuel burn-up data. The different PYTHIA/DERAB output files appropriate for standard core loading of VVER-1000 and VVER-440 as well as for dummy-cassettes core loading of VVER440 could be processed. The neutron source is represented in (r,θ,z)-geometry in the input format of DORT/TORT/ASYNT for neutron fluence calculation. The interface software package is additionally improved in order to eliminate handmade intervention into output files of codes.

Fig. 1. The interface software scheme





d = Co/ Mn/ Nb
θ = *nang(a), a=1, nangle*

The interface package is enhanced by new module's structure. The application of such module's structure allows when changing the output file structure of reactor core code or other structure elements, to modify only the relevant module of the interface package.

A new module RD_DRB is included in the package. This module selects the following data: type of assembly, normalized power distribution, fuel element burn-up and steady state history in real and full power days. This information is read from the PYTHIA/DERAB code' output file and put into files with definite format. This module adds the zero power states to the power history as well.

The PYTHIA/DERAB code' output data are stored in sets of files. The number of the sets depends on the number of assemblies for which pin-wise calculation is performed. Each file of a set has to be renamed by fixed name ASSi.j, where: i is the file number in the set, and j is the number of pin-wise calculated assembly. The RD_DRB output files for reactor unit number n, cycle number k and number of pin-wise calculated assembly j, are: UnCk and UnCkAj. The file UnCk contains assembly normalized power distribution and burn-up data relevant to the assembly, axial level of the reactor core and steady state of the cycle. The files of type UbCkAj contain the pin distribution of the same data for the j-assembly.

The module SRC_HEX creates additional output files REACj.OUT with pin-wise data for the neutron source and activity source of the iron, copper and niobium detectors.

The ASSp module generates COORj.INP file with polygons coordinates describing pins' geometry for certain assembly which are input data for the NETMATp module. The last module generates factors determining the impact of every pin or assembly to discrete ordinates' mesh interval and put them into file NETMAT.OUT.

The SKV module summarizes the cycles' sources of as for assembly so for pin-wise data.

Additional improvements have been performed for completing the QA requirements. The processing of PYTHIA/DERAB output files is combined with new input files that provide the needed information and comments in a way to eliminate the possible handmade errors or mistakes. All needed data: number of PYTHIA/DERAB output files in the set, unit number, cycle number, amount and number of pin-wise presented assembly, date of cycle beginning, date of cycle end, keyword for dummy-cassette availability, number of zero power states during the cycle, date beginning of zero power state, date of zero power states end, are recorded in the input file RD_DRB.inp. The input file SKV.inp contains the number of cycles for summarizing, number of activation detectors and time intervals between the cycles.

4. Development of software for experimental data statistics processing

New software for statistical processing of experimental data from activation detectors irradiated behind RPV is developed. The experimental data is statistically processed before their application in the verification procedure in order to obtain data with minimized uncertainty.

The space detectors' activity distribution is adjusted by linear form of orthogonal-normalized polynomials. These polynomials provide less error in rounding off than the standard polynomial application. The coefficients of the linear form are determined using the Least Square Method. The determination of the orthogonal-normalized polynomials is based on the recurrent relation of Forsythe [6]. The coefficients in linear form are calculated using the experimental data.

Hypothesis testing of "coefficient equal to zero" is carried out for determining of the optimal polynomials' degree (which gives sufficiently well adjustment to the data). It is performed by applying the Fisher's criterion [7] to the ratio between the coefficients' square and dispersion because both quantities are statistically independent and distributed as χ^2. The linear form with so determined polynomial degree describes the adjusted experimental data. The uncertainty of these adjusted data is less than the uncertainty of the initial experimental data.

The experimental data for ^{60}Co, ^{54}Mn and ^{93m}Nb activities for axial and azimuth situated detectors are recorded in input files Zexp.prn and Texp.prn.

The MNK module has been developed for statistical processing of the data by the Least Square Method. The results of this processing are recorded in the R&C2.res file which contains tables with coordinates of measurement points, experimental data values, values of adjusted activity and their uncertainty at the points of calculation.

The application of this adjustment procedure allows obtaining with lowest uncertainty the measured activity of wire. This procedure is important for the verification of calculated results as well as for developing of generalized adjustment methodology for obtaining the "best estimated" neutron fluence onto RPV [8].

5. Conclusion

The software package for processing of data for neutron fluence estimation was modified for implementation of improvements corresponding to QA requirements.

The module's structure of interface software package was enhanced. The new module's structure allows modifying only of the relevant module of interface package when the output file structure of reactor core code is changed. Handmade editing of the codes and module's output files is eliminated. The needed information and comments are recorded in input files in order to avoid the possible handmade errors or mistakes.

New software for statistical processing of activation detector experimental data is developed. This processing provides results with possible lowest uncertainty that is important for calculation verification.

The improved software will be implemented into the INRNE neutron fluence methodology and respectively applied in future RPV neutron fluence analyses for Kozloduy NPP.

Acknowledgment:
This work was carried under the contracts of International Atomic Energy Agency, Vienna RC/10992 and RC/10319.

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