Chapter Pilot: D. PAGEBLAIR

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REVISION HISTORY

Issue	Description	Date
00	First issue for INSA information.	04-01-2008
01	Integration of technical and co-applicant review comments.	29-04-2008
02	PCSR June 2009 Update: – Clarification of text – Inclusion of references.	27-06-2009
03	Consolidated PCSR update: – Minor editorial changes – Clarification of text	26-03-2011
04	Consolidated PCSR update: - References listed under each numbered section or sub-section heading numbered [Ref-1], [Ref-2], [Ref-3], etc	19-07-2012

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1. APOLLO 2 [REF-1]

The APOLLO 2 code generates the two-group macroscopic cross-sections and Assembly Discontinuity Factors used in the diffusion code SMART.

APOLLO 2 solves the Boltzman transport equation using multi-group modelling (and a collision probability method for various 2-D geometries). It can use either the collision probability method or the SN method.

The code also supports a sophisticated self-shielding model and a predictor/corrector method for isotopic depletion of the fuel. In addition, APOLLO 2 includes all relevant modules needed for critical buckling computations, transport equivalences, and space and energy collapses.

For its APOLLO 2 calculations, AREVA uses the "CEA-93" 99 neutron-energy group library supplied by the French research organisation CEA (Commisariat à l'Energie Atomique). Most of the data in this library have been processed from the most recent European cross-section evaluations: JEF 2.2.

Multi-parameter tabulations for cross-sections are generated for each type of fuel present in the reactor. The parameters used are: burnup, boron concentration, xenon level, water density, fuel temperature, rod cluster insertion, and one specific variable for the fuel spectrum history.

2. SMART [REF-1]

The core calculations are performed with the SMART code

SMART is a two-energy-group, 3-D nodal diffusion code, incorporating the latest nodal methods.

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SMART uses the nodal expansion method characterised by the use of nodal coupling equations with discontinuity factors. SMART solves the coupled nodal balance and leakage equations using three different levels of iteration: inner iterations, fission source iterations, and nodal coupling coefficient updates. The nodal coupling coefficients are updated by representing the two-node interface with a quadratic transverse leakage approximation.

The SMART feedback model, which includes a closed channel thermal-hydraulic module, is based on a multi-parameter tabulation for cross-sections. Fuel depletion is modelled using microscopic depletion.

Local reconstruction of the flux, power, burnup, and reaction rates is based on a combination of homogeneous intra-nodal fluxes computed at each step and tabulated power form factors. The homogeneous intra-nodal flux is reconstructed using surface currents, surface fluxes, corner point fluxes, and nodal average flux. Power form factors come from the lattice computation in APOLLO 2.

3. ORIGEN-S [REF-1]

ORIGEN-S is a versatile point-depletion and radioactive decay computer code for simulating nuclear fuel cycles and calculating the core nuclide compositions and materials characteristics.

It represents a revision and update of the original ORIGEN computer code, which was developed at the Oak Ridge National Laboratory (ORNL) and distributed world-wide in the early 1970s. Included in ORIGEN-S are provisions for incorporating data generated by more sophisticated reactor physics codes, a free-format input, and a highly flexible and controllable output. With these features, ORIGEN-S has the capability for simulating a wide variety of fuel cycle flow sheets.

ORIGEN-S uses a matrix exponential method to solve a large system of coupled, linear, first-order ordinary differential equations with constant coefficients.

4. FLICA III-F [REF-1]

The FLICA III-F computer program determines, in a very general way, the steady-state and transient flows of a fluid flowing in separate or connected channels. It is a suitable tool for the thermal-hydraulic analysis of reactor cores or experimental loops with heated rod bundles.

The use of a system of coordinates composed of an axis parallel to the axis of the channel and axes perpendicular to the interfaces between sub-channels makes it possible to impose a non-rectangular geometry.

The channels are essentially described by cross-sectional area, a hydraulic diameter, and a heating perimeter. The connections between sub-channels are mainly defined by the gap width, the hydraulic diameter which represents the resistance to cross-flow, and a representative length to calculate the derivatives of the physical values at the interfaces.

The user is able to impose a given heat flux on any channel, the relative axial flux distribution being either common to all the channels or defined separately for each one.

The boundary conditions are:

- Prescribed inlet or outlet pressure

- Prescribed flow rate inlet distributions or pressure drop between the inlet and outlet

- Given inlet enthalpy distribution or fluid temperature.

The equations are solved with a finite difference method using an iterative scheme at each level.

The two-phase fluid model is the homogeneous one with slip. The code also includes an equation to calculate the actual steam quality up to the dry steam state.

5. STAR-CD [REF-1]

STAR-CD is a software tool for the numerical solution of fluid mechanics equations (Navier-Stokes equations for conservation of mass and momentum, energy equation), made discrete using a finite volume method.

It allows the use of non-structured meshes (hybrid meshes consisting of tetrahedrons, triangular prisms, prisms, etc.) to describe complex geometries. It can be applied to a wide variety of problems, including compressible flows, multiphase flows, and chemical reactions).

The program offers the user different turbulence models (conventional K-ϵ models, non-linear models, large-scale simulation with selection of different sub-mesh models, etc...).

AREVA uses STAR-CD for a wide range of analyses (steady-state or transient hydraulics calculation, local temperature calculation, hydraulic load calculation, mixing, etc...). It has been validated on a wide range of experimental facilities [Ref-2]. The purpose of these analyses is to support plant design and to understand complex hydraulic phenomena observed in situ.

APPENDIX 4 – REFERENCES

External references are identified within this sub-chapter by the text **[Ref]** at the appropriate point within the sub-chapter. These references are listed here under the heading of the section or sub-section in which they are quoted.

1. APOLLO 2

[Ref-1] S Rauck. Science V2 Nuclear Code Package - Qualification Report. NFPSD DC 89 Revision A. AREVA. March 2004. (E)

2. SMART

[Ref-1] S Rauck. Science V2 Nuclear Code Package - Qualification Report. NFPSD DC 89 Revision A. AREVA. March 2004. (E)

3. ORIGEN-S

[Ref-1] S Ebalard. ORIGEN-S: Qualification Manual. EPDS DC 150 Revision C. AREVA. November 2005. (E)

4. FLICA III-F

[Ref-1] M N Jullion. Qualification Report - FLICA III-F Version 3. NFPSD DC 188 Revision A. AREVA. January 2006. (E)

5. STAR-CD

[Ref-1] P Dolleans. STAR-CD Qualification On Dilution Phenomena. NFPSD DC 119. AREVA. October 2004. (E)

[Ref-2] B. Durand. STAR-CD Version 4.02 - Physical Validation Synthesis Report. NEPD-F DC 10160 Revision B. AREVA. February 2010. (E)