Overview of ACR Computer Codes

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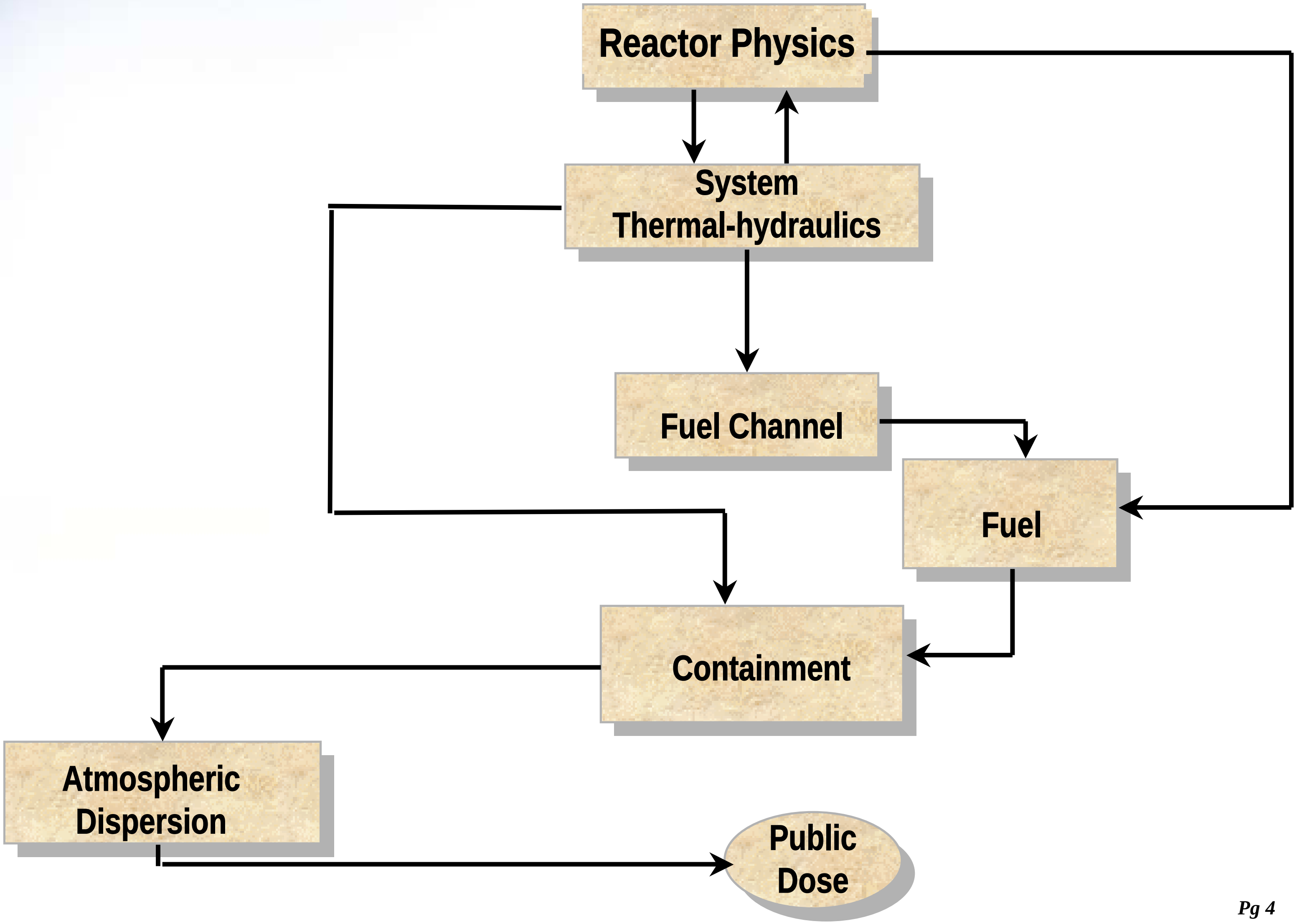
Outline

- Disciplines involved
- Physics analysis tools
- System thermal-hydraulics analysis tools
- Fuel analysis tools
- Fission product analysis tools
- Moderator analysis tools
- In-core damage analysis tools
- Containment analysis tools
- Atmospheric Dispersion and Public Dose tools

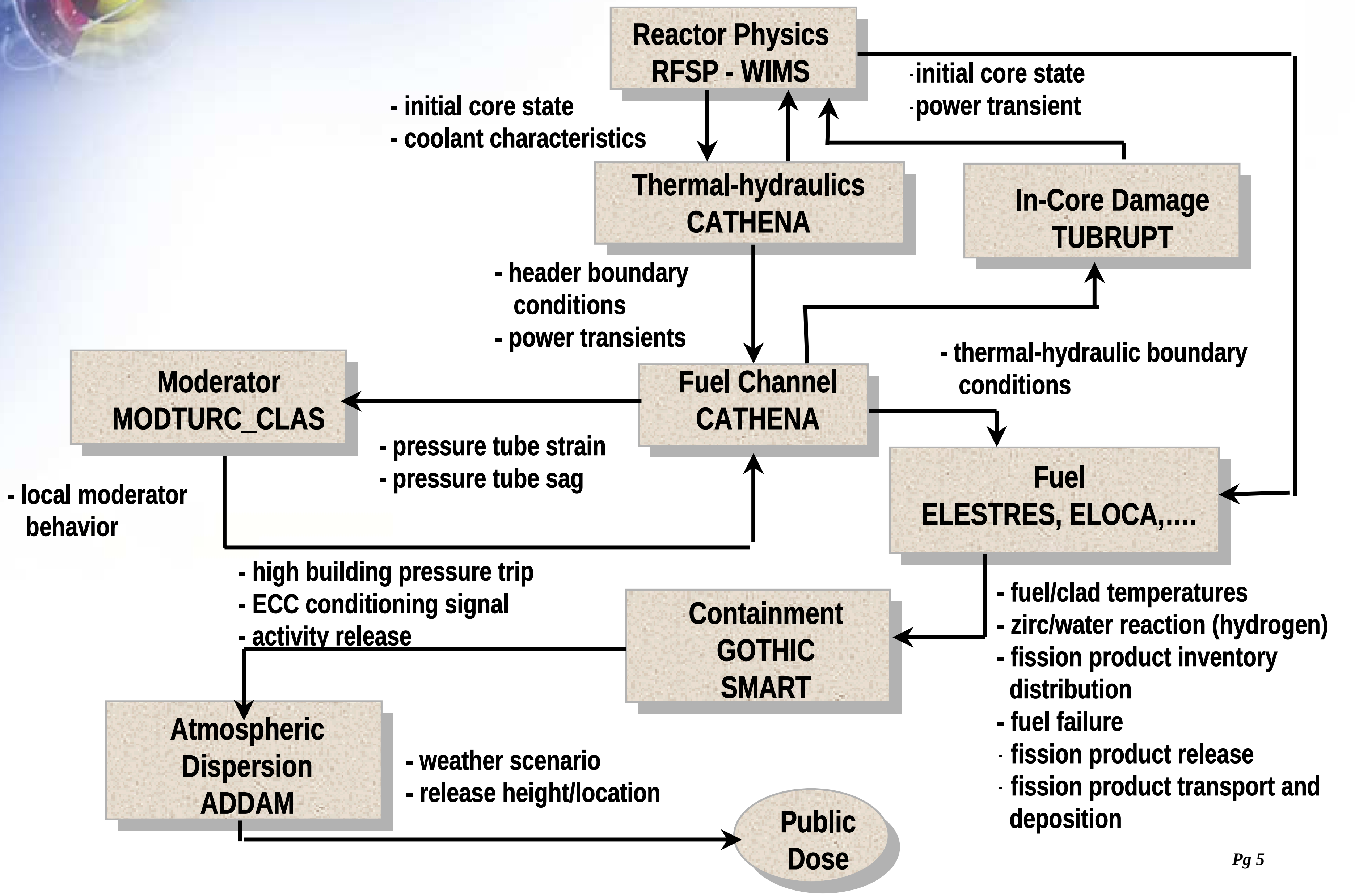
Disciplines Involved

- **Reactor Physics**
- **System Thermal-hydraulics**
- **Fuel and Fuel Channel**
- **Containment**
- **Atmospheric Dispersion and Public Dose**

Discipline Links



Computer Code Connections



Physics Analysis Tools - 1

WIMS-AECL:

- General-purpose lattice cell code
- WIMS-AECL is a multi-group transport code for reactor lattice calculations
- The lattice code uses cross-sections derived from EBDF/B-6 data library
- Fuel burnup and isotope depletion

Physics Analysis Tools - 2

WIMS-AECL:

- **Inputs:**
  - Physical dimensions of the cell
  - The geometrical arrangement
  - The composition of the cell
  - Temperature and density of the materials in the cell
- **Outputs:**
  - Cell-averaged parameters are tabulated as functions of fuel burnup, fuel temperature, and coolant density
  - It produces 2-group cell-averaged parameters for RFSP-CERBERUS calculations

Physics Analysis Tools - 3

RFSP:

- Code to generate nominal power distributions and reactor operations, including re-fueling and burnup steps
- It calculates space-time-dependent flux and power distributions using 2-group lattice parameters as functions of:
  - Fuel burnup, fuel temperature, and coolant density
- The fuel cross sections are averaged over the residence (dwell) time of the fuel at each point in the core
- Obtains bundle bowers, channel power, and bundle irradiation histories
- It is coupled with the CATHENA code to use the up-to-date thermal-hydraulics data as LOCA proceeds

Physics Analysis Tools - 4

RFSP

- **Inputs:**
  - Cross sections from WIMS
  - Core size and mesh size
  - Device incremental cross sections
  - Coolant temperature and density, and fuel temperature from CATHENA thermal-hydraulics code
- **Outputs:**
  - Channel and bundle power distributions within the core
  - Thermal and fast flux distributions within the core

Thermal-Hydraulic Analysis Tools - 1

CATHENA

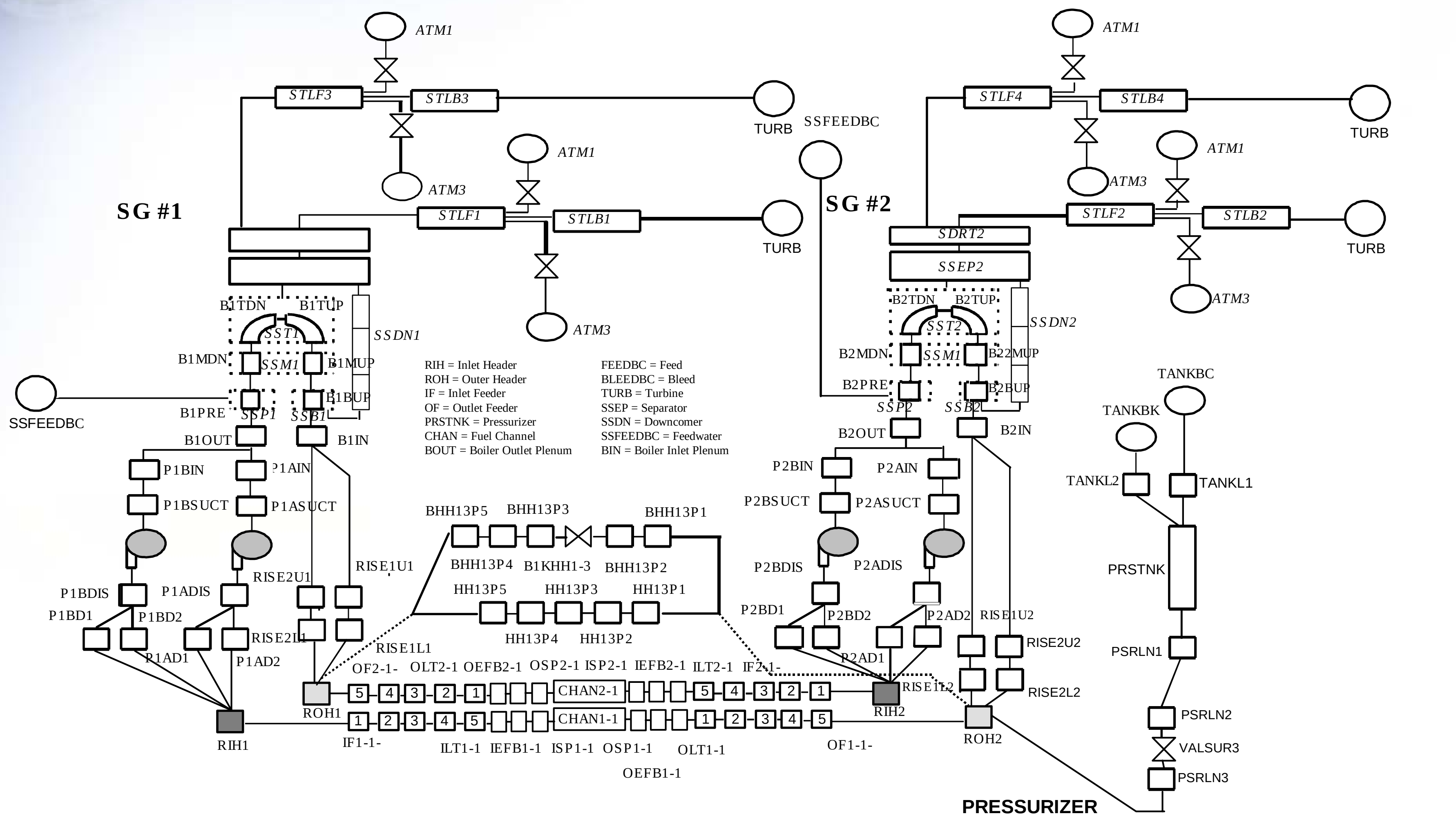
- Non-equilibrium two fluid system thermal-hydraulics code
- Full network defined by user in the input files
- Has D_2O and H_2O properties
- Generalized heat transfer package:
  - Multiple surfaces per thermal-hydraulic node
  - Models heat transfer in and between fuel pins
  - Has built-in temperature dependent properties (has options for user input properties)

Thermal-Hydraulic Analysis Tools - 2

CATHENA

- **Inputs:**
  - Geometry and layout of piping
  - Channel power distributions from RFSP
  - System controls and properties
  - Reactor power transients from RFSP
- **Outputs:**
  - System thermal-hydraulic behavior
  - Boundary conditions for detailed single channel analyses
  - Coolant and fuel temperatures for RFSP

Thermal-Hydraulic Analysis Tools - 3



CATHENA Nodalization diagram of the ACR RCS circuit

Thermal-Hydraulic Analysis Tools - 4

CATHENA Single Channel Analysis

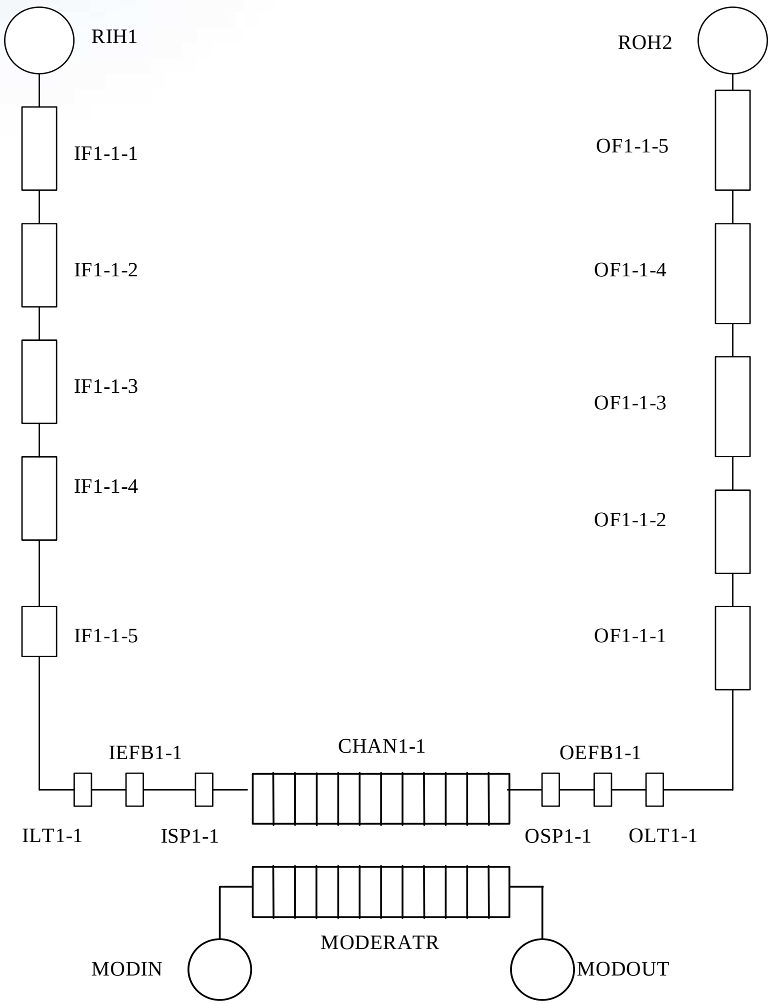
- Single channel model calculates the detailed fuel and fuel channel thermal-hydraulic transient

Thermal-Hydraulic Analysis Tools - 5

CATHENA Single Channel Analysis

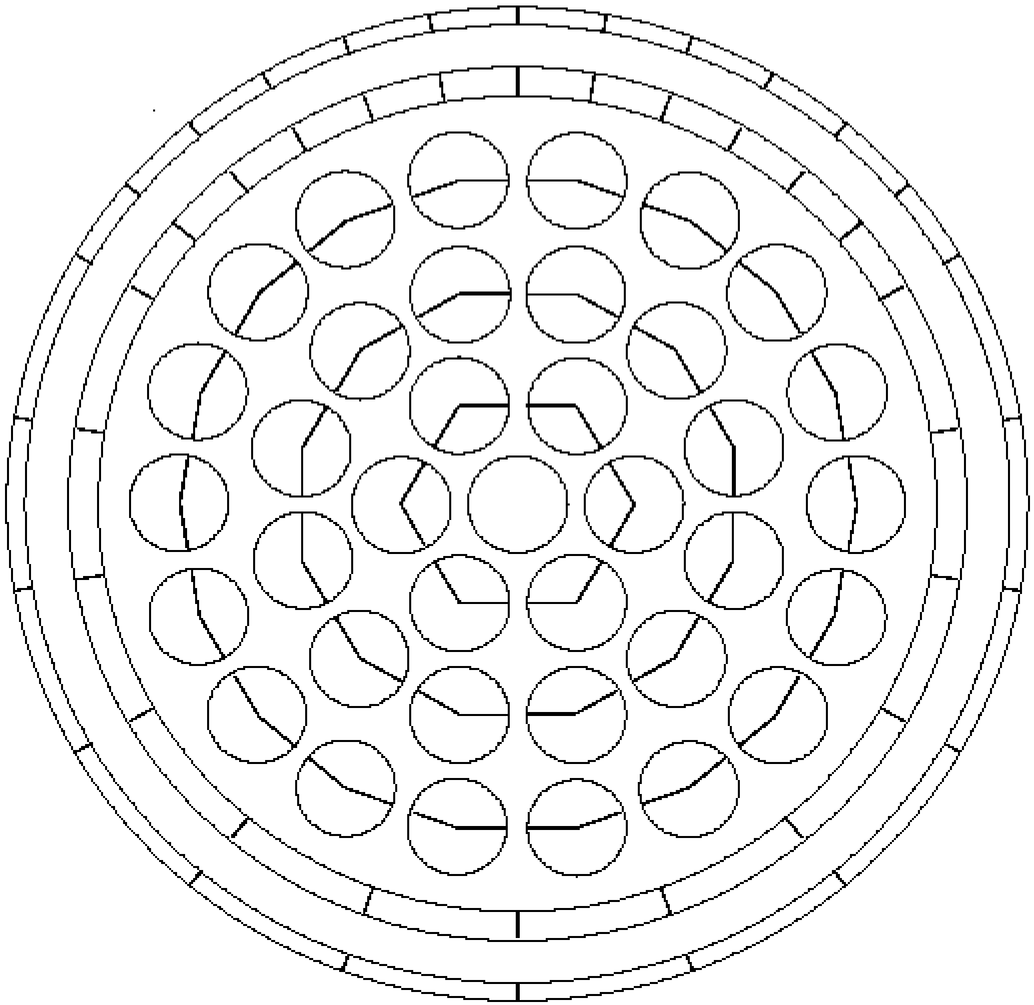
- **Inputs:**
  - fuel and fuel channel geometry
  - fuel and fuel channel axial and radial power distribution
  - transient header boundary conditions from CATHENA full circuit calculations
  - power transient from RFSP-CERBERUS calculations
- **Outputs:**
  - fuel boundary conditions (pressure, temperature, and fuel-to-coolant heat transfer coefficient) for ELOCA
  - pressure tube temperatures and strain
  - initial conditions for TUBRUPT in-core damage calculations
  - hydrogen generation

Thermal-Hydraulic Analysis Tools - 6



CATHENA Nodalization diagram for a single channel

Thermal-Hydraulic Analysis Tools - 7



CATHENA Nodalization diagram of the ACR channel

Fuel Analysis Tools - 1

ORIGEN

- Calculates the time-dependent concentrations and inventories of a large number of isotopes
- The code takes into account the simultaneous generation and depletion of isotopes from the generation and depletion through neutron transmutation, fission, radioactive decay, input feed rates, or physical or chemical removal rates

Fuel Analysis Tools - 2

ORIGEN

- Inputs:
  - Cross sections from WIMS
  - Fuel composition
  - Power / burnup history from RFSP
- Outputs:
  - Initial total inventories of fission products

Fuel Analysis Tools - 3

ELESTRES

- Models the thermal and mechanical behavior of an individual fuel element during its irradiation life under normal operating conditions
- Composed of two models:
  - one-dimensional fuel performance model:
    - thermal model for temperature calculations
    - microstructural model for fission gas and associated calculations
  - two-dimensional stress analysis model:
    - used to calculate axisymmetric deformations of the fuel pellet
- Supplies the initial fuel conditions

Fuel Analysis Tools - 4

ELESTRES

- **Inputs:**
  - Fuel geometry and composition, and
  - Power / burnup history from RFSP
- **Outputs:**
  - Heat generation rates within the fuel pellets for input to ELOCA
  - Clad strain for input to ELOCA
  - Fuel-to-clad gap conductance for input to ELOCA
  - Distribution of fission products (grain bound, grain boundary, and fuel-to-clad gap) for input to SOURCE

Fuel Analysis Tools - 5

ELOCA

- A transient fuel behavior analysis code for calculating the fuel element thermo-mechanical behavior during a postulated transient

Fuel Analysis Tools - 6

ELOCA

- **Inputs:**
  - heat generation rates, clad strain, and fuel-to-clad gap conductance from ELESTRES
  - fuel boundary conditions (pressure, temperature, and fuel-to-coolant heat transfer coefficient) from CATHENA
  - power transient from RFSP-CERBERUS calculations
- **Outputs:**
  - fuel and clad temperatures for input to SOURCE
  - fuel failure time
  - the extent of clad oxidation for input to SOURCE

Fission Product Analysis Tools - 1

SOURCE

- Calculates the amount and type of fission product released from fuel
- Some of the phenomena modeled:
  - Diffusion, grain boundary sweeping, vapor transport, gap transport, fuel/zircaloy interaction, temperature transients, grain boundary separation, etc.

Fission Product Analysis Tools - 2

SOURCE

- **Inputs:**
  - fuel temperature transients from ELOCA
  - fuel boundary conditions (pressure, temperature, and fuel-to-coolant heat transfer coefficient) from CATHENA
  - power transient from RFSP-CERBERUS calculations
- **Outputs:**
  - fission product release transient – amounts and species

Fission Product Analysis Tools - 3

SOPHAEROS

- Calculates the fission product deposition and transport through the heat transport system components and piping
- The code employs a pseudo-kinetic thermochemical-equilibrium numerical solution scheme using deviation from the equilibrium state as driving force to calculate fission-product specification and volatility

Fission Product Analysis Tools - 4

SOPHAEROS

- **Inputs:**
  - fission product release transients from SOURCE
  - RCS boundary conditions (steam pressure and temperature, materials and temperatures) from CATHENA
- **Outputs:**
  - fission product retention within the RCS, and deposition on the RCS materials
  - the amount and species of the fission products released into containment

Moderator Analysis Tools - 1

MODTURC-CLAS

- General purpose CFD code used to assesses the moderator velocity and temperature distribution
- Consists of coupling ACR moderator related specific modules with the general purpose CFD code
- Calculation of poison concentration distributions after Shut Down System 2 (SDS2) initiation

Moderator Analysis Tools - 2

MODTURC-CLAS

- **Inputs:**
  - Moderator circuit geometry and conditions
  - Heat load to the moderator during normal operation and accidents conditions obtained from CATHENA
- **Outputs:**
  - Moderator subcooling margin
  - Distribution of moderator poison after SDS2 initiation

In-Core Damage Analysis Tools - 1

TUBRUPT

- A code used to determine the pressure transients within the calandria vessel caused by an in-core LOCA (channel rupture)
- Assesses the damage to in-core components as a result of an in-core LOCA

In-Core Damage Analysis Tools - 2

TUBRUPT

- **Inputs:**
  - fuel channel conditions at the time of channel failure (pressure and temperature) from CATHENA
  - core and channel geometry
- **Outputs:**
  - assessment of in-core damage (calandria vessel integrity, adjacent channel integrity, and shut-off rod guide tube integrity)

Containment Analysis Tools - 1

GOTHIC

- **3-D 2-fluid thermal-hydraulic code to determine the transient conditions inside the reactor building**
- **Track hydrogen as a non-condensable gas within containment**
- **Lumped parameter model for peak pressure assessment**
- **Lumped parameter model in combination with 3-D model (in the vicinity of the discharge) for hydrogen assessment**

Containment Analysis Tools - 2

GOTHIC

- **Inputs:**
  - break discharge and hydrogen release transients from CATHENA
  - containment geometry and heat sinks
- **Outputs:**
  - Thermal-hydraulic conditions to SMART
  - Peak containment pressure
  - Hydrogen distribution within containment

Containment Analysis Tools - 3

SMART

- Calculates the radionuclide behavior inside the reactor building and calculates the radionuclide release to the outside atmosphere via various release paths
- An aerosol general dynamics equation is solved to calculate aerosol size distribution as a function of space and time
- Calculates the speciation of iodine within containment

Containment Analysis Tools - 4

SMART

- **Inputs:**
  - Thermal-hydraulic conditions from GOTHIC
  - Fission product releases from SOPHAEROS
- **Outputs:**
  - Fission product releases to atmosphere to be used in dose assessment by ADDAM

Dose Assessment Tools - 1

ADDAM

- **Uses Gaussian dispersion model to calculate dispersion factors**
- **Applies corrections due to nearby buildings, release height, and deposition**

Dose Assessment Tools - 2

- **ADDAM:**
- **Inputs:**
  - **Fission product releases from SMART**
  - **Thermal-hydraulic conditions from GOTHIC**
- **Outputs:**
  - **Internal dose due to inhalation and skin absorption of radioactive material from the cloud**
  - **External dose from exposure to radioactive material in the cloud (cloud shine)**
  - **External dose due to exposure to radioactive material from ground deposition (ground shine)**

Summary

- ACR-700 safety analysis methodology is based on computer codes that have been developed and used for several decades in CANDU safety analysis at AECL and across the Canadian industry
- The AECL computer codes cover the full scope of the ACR safety analysis needs

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