



# **Overview of Fuel and Fission Product Methodology and R&D**

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**Presentation to U.S. Nuclear Regulatory Commission Staff**

**Chalk River Laboratories**

**July 20-22, 2004**

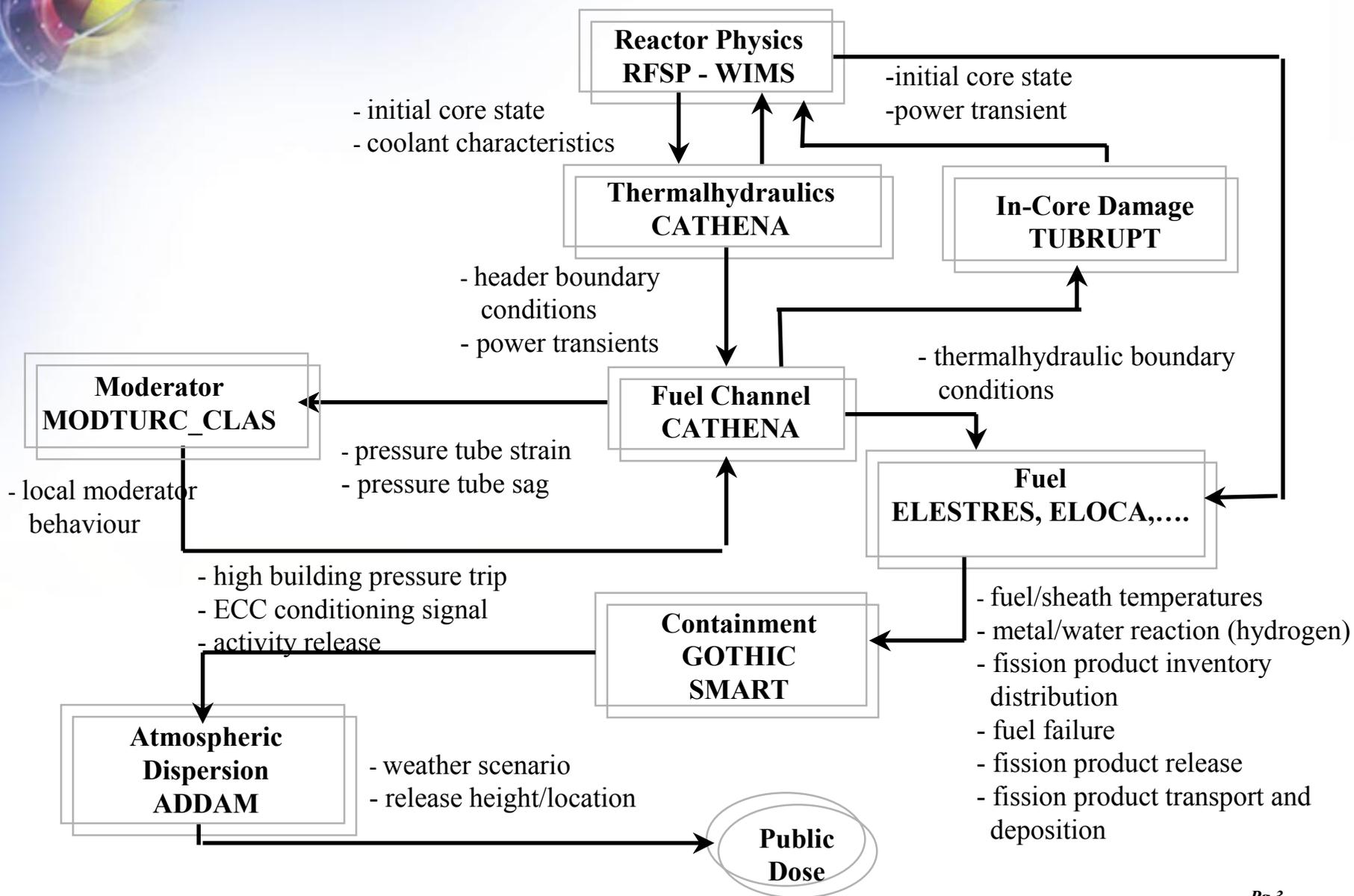




# Outline

- **Fuel and fission product methodology and codes**
- **CANDU experimental database**
- **Additional R&D for ACR**

# Computer Code Connections





# Thermalhydraulic Analysis Tools

## CATHENA

- Non-equilibrium two fluid system thermalhydraulics code;
- Full network defined by user in the input files;
- Has D<sub>2</sub>O and H<sub>2</sub>O properties;
- Generalized heat transfer package:
  - Multiple surfaces per thermalhydraulic node;
  - Models heat transfer in and between fuel pins;
  - Has built-in temperature dependent properties (has options for user input properties).



# Fuel NOC Analysis Tool

## ELESTRES

- ELESTRES computer code models the thermal and mechanical behaviour of an individual fuel element during its irradiation life under normal operating conditions.
- ELESTRES is composed of two models:
  - one-dimensional fuel performance models:
    - thermal model for temperature calculations; and
    - 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.



# **ELOCA-IST 2.1**

- **ELOCA models the thermo-mechanical behavior of the fuel and fuel cladding under the transient conditions of an accident**
- **The model was first developed in the mid 1970s and has undergone continuous development since this time**
- **The model was chosen as part of the Industry Standard Tool Set (IST) in 1998**
- **The current version, ELOCA-IST 2.1, completed validation in 2001 and was released for use in 2002**



# **ELOCA – Phenomena Modeled**

- **Expansion, contraction, and melting of the fuel**
- **Variations in the element internal gas pressure**
- **Deformation of the cladding**
- **Changes in the fuel/cladding heat transfer**
- **Zircaloy/coolant chemical reaction (oxidation)**
- **Cladding failure by over strain, oxidation, and beryllium-assisted cracking**



# **Fission Product Release and Transport**

- **Fission product release from fuel and transport in the reactor coolant system and containment are assessed to determine FP release into the environment under accident conditions**
- **FP release and transport calculations are part of the source term analysis methodology**
- **FP release and transport simulations are used in estimating doses to the public, station staff and plant equipment**



# **SOURCE IST 2.0**

- **SOURCE IST 2.0 is the Canadian Industry Standard Toolset (IST) code for calculating fission-product release from fuel**
- **SOURCE IST 2.0 simulates all of the primary phenomena affecting FP release from CANDU fuel under accident conditions**
- **Release fraction is the key output of SOURCE**



# SOURCE IST 2.0

- **Inventory partitions:**
  - **Grain Matrix**
  - **Grain Boundary**
  - **Fuel Surface**
  - **Gap**
  - **Released**



# SOPHAEROS-IST 2.0

- **SOPHAEROS initially developed by IRSN (France) to simulate fission-product transport and retention in the RCS under LWR severe accident conditions**
- **SOPHAEROS-IST 2.0 adopted as Canadian Industry Standard Toolset code for calculating fission-product transport and retention in the RCS**
- **When development is complete, SOPHAEROS will simulate all of the primary phenomena affecting FP transport and retention in CANDU RCS under accident conditions**
- **Fractional retention is the key output of SOPHAEROS**



# **SMART-IST VER-0.300 Code**

- **Predicts fission product / aerosol behavior in CANDU reactor containments**
- **Predicts nuclide releases to the outside atmosphere**
- **Provides nuclide release data to other codes for public dose calculations**



# SMART – Phenomena

- **Calculates transport of radionuclides**
  - Contained / dissolved in water droplets
  - Existing in gas phase
- **Simulates**
  - Aerosol formation, agglomeration and deposition
  - Radionuclide decay and buildup
  - Iodine chemistry (IMOD)
  - Radionuclide transport between containment rooms
  - Radionuclide release from containment



# Fuel Experimental Database (1)

- **Laboratory separate-effects tests**
  - Fuel cladding ballooning tests
  - Cladding oxidation tests
  - $\text{UO}_2$  – Zircaloy interaction and dissolution tests
  - Cladding embrittlement tests
- **In-reactor tests under normal operating conditions**
  - Fuel-centerline temperature measurements
  - Fuel rod internal gas pressure measurements
  - Defected fuel rod behavior tests



# Fuel Experimental Database (2)

- **In-reactor tests under accident conditions**
  - Canadian in-reactor blowdown tests (X-2)
  - Canadian severe-fuel-damage tests (BTF)
  - International severe accident tests (PBF SFD, FLHT, Phebus)



# FPR&T Experimental Database

- **Laboratory separate-effects tests**
  - Fission-product thermochemistry (Knudsen cell – mass spec.)
  - Aerosol deposition in CANDU fuel channel end fitting
- **Hot-cell fission-product release tests**
  - FP release and transport from clad and unclad fuel samples under accident conditions (Canadian, ORNL VI, Vercors)
  - Grain boundary inventory measurements
  - Direct-electric-heating tests
- **In-reactor NOC tests (sweep gas, defected fuel)**
- **In-reactor tests under accident conditions**
  - Canadian severe-fuel-damage tests (BTF)
  - International severe accident tests (ACRR ST, Phébus FP)



# Containment FP Experiments

- **Canadian aerosol tests**
  - Flashing jet aerosol characterization tests (jet fragmentation)
  - Stern Labs Water Aerosol Leakage Experiments (WALE) (jet impingement)
  - Aerosol leakage tests (leakage through airlock door seals, concrete penetrations, etc.)
- **International aerosol tests**
  - PITEAS tests (diffusiophoresis)
  - Forney and Spielman tests (turbulent deposition)
  - Liu and Agarwal tests (turbulent deposition)



# Planned ACR Fuel and FP R&D

- Existing fuel and fission product experimental database applies to ACR
- Confirmatory R&D for ACR
  - ACR sheath ballooning tests
  - Additional validation of ELOCA code
    - Thermal properties at higher burnup
    - ACR sheath ballooning test data



# Summary and Conclusions

- **Good technology base for understanding of fission-product release and transport behavior in CANDU reactor accidents**
  - Phenomena
  - Experimental database
- **Extension to ACR is straightforward**



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