



4. ELESTRES Workshop

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Chalk River Laboratories
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Purpose

- Provide ELESTRES overview, e.g., validation strategy, thermo-mechanical models, applicability of the code, input/out, data transfer to safety code
- Demonstration



Outline

Background

Overview of the code

Validation: phenomena, output parameters, relevant models

Verification and validation for fuel performance models

Range of applicability in the modelling aspect

Domain of applicability of the code to ACR fuel

Data flow diagram

Input parameters

Key outputs

Links between output files and other codes

Concluding remarks

Demonstration



Background

- In use since 1975
- Used in all safety assessments at AECL since Wolsong
- Much validation and documentation over the years
 - experimental data
 - other independent results
- Selected as industry standard toolset (IST) fuel design and performance code, validated in 2001
- ACR version (2.0) under improvement based on IST version and qualification
 - validation by 2004 December
- Configuration management
 - strict, rigorous, consistent



ELESTRES 2.0 - Overview

- **Axisymmetric thermal mechanical behaviour of an ACR fuel element under NOC**
 - safety during NOC: design assessment
 - safety during pre-trans. conditions: accident analysis
 - FGR
 - thermal energy (i.e., temperature)
 - fuel deformation
- **ELESTRES (IST version) + ACR features**
 - effects of extended burnup
 - effects of high temperature and pressure of coolant
 - effects of pellet design



Validation: Phenomena

- **Phenomena that are ranked as primary for initial condition of various accident scenarios; described in Technical Basis Document (DBD)**
- **Two VMs that link selected phenomena to data sets**
 - **FC1** **Fission and decay heating**
 - **FC2** **Diffusion of heat in fuel**
 - **FC3** **Fuel-to-sheath heat transfer**
 - **FC6** **Fuel sheath deformation**
 - **FC8** **Fuel pellet deformation**
 - **FC5** **Fission gas release and internal pressurization
(Combination of FPR2 through FPR4 and FPR6)**
 - **FPR2** **Diffusion**
 - **FPR3** **Grain boundary sweeping**
 - **FPR4** **Grain boundary coalescence and tunnel interlinkage**
 - **FPR6** **Fuel cracking**



Validation: Output Parameters vs. Phenomena

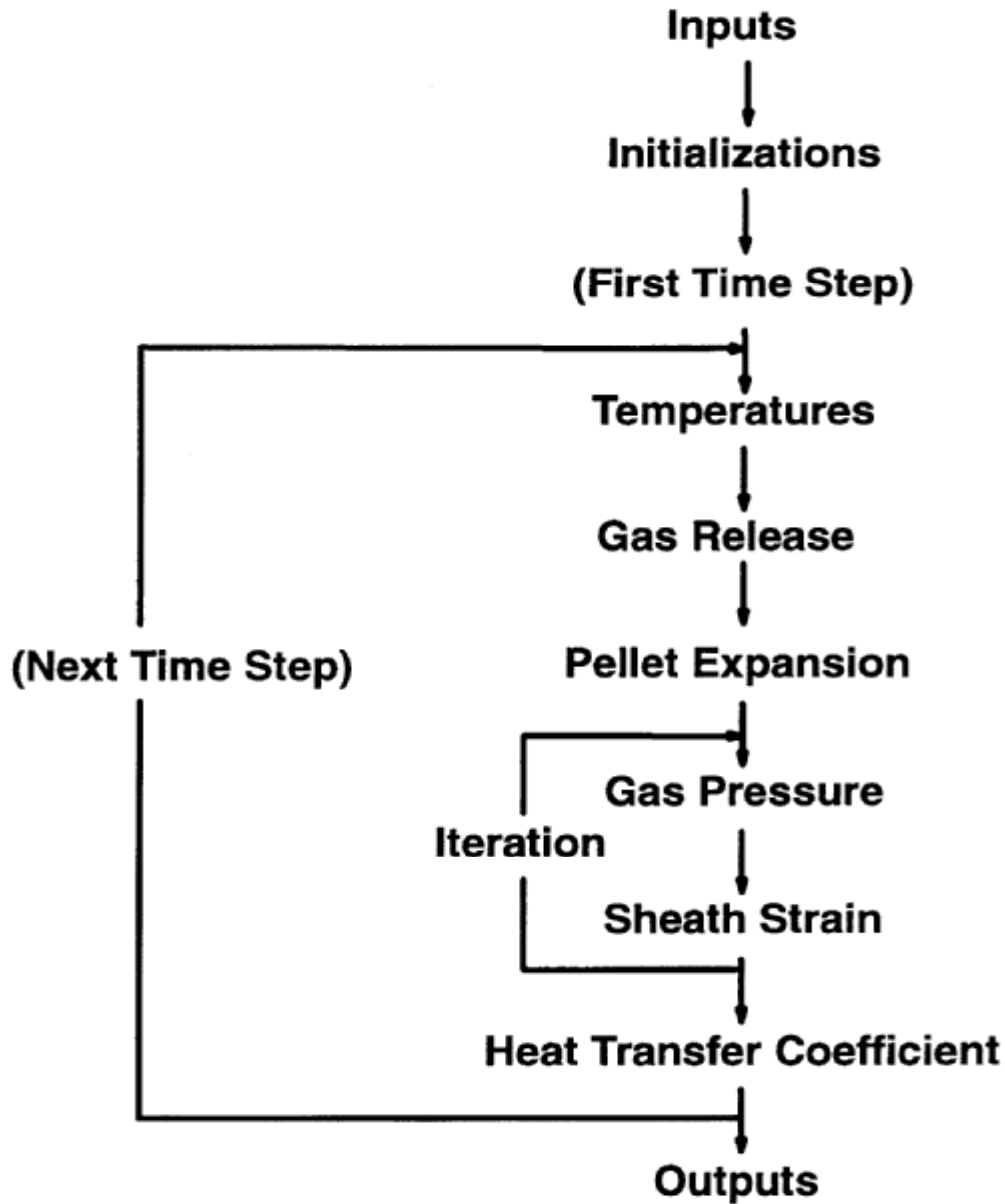
| Key Output Parameter | Output Parameter | Phenomena Identified in VM |
|-------------------------|--|--|
| Fuel temperature | Sheath temperature Pellet temperature | Fission & decay heating (FC1) Diffusion of heat in fuel (FC2) Fuel-to-sheath heat transfer (FC3) |
| Fission product release | Fission gas volume | Diffusion (FPR2) GB sweeping (FPR3) |
| | Internal gas pressure | GB coalescence and tunnel inter. (FPR4) Fuel cracking (FPR6) |
| Fuel deformation | Sheath strain | Sheath deformation (FC6) Pellet deformation (FC8) |



Validation: Output Parameters and Relevant Models

- **Fuel temperature**
 - heat generation, flux depression, heat conduction, thermal conductivity, gap/contact, gap conductance
 - finite difference, 2-dimensional; 100 radial annuli
- **Fission product release**
 - gas atom generation, microstructure-dependent models for grain boundary sweep and migration, recoil/knockout, bubble interlinkage
- **Fuel deformation**
 - densification, fission product swelling, thermal expansion, cracking, elastic- plastic-creep (for both pellet and clad)
 - radial and axial gaps
 - finite element (for pellet); 2-dimensional

Flow Diagram





V&V for Fuel Performance Models

- **Verification**
 - line-by-line inspections
 - spot checks
 - hand calculations
 - unit testing
 - static testing
 - coverage testing
 - stress testing
 - regression testing
 - detailed impact assessment



V&V for Fuel Performance Models

| Thermo-mechanical models identified by US NRC | ELESTRES Models | FRAPCON-3 Models | Validation Strategy/Remarks |
|---|---|---|---|
| Pellet radial power /temperature /burnup distribution | TUBRNP for heat generation, 1D conduction with an improved k based on MATPRO database | TUBRNP for heat generation, 1D conduction with the MATPRO k model | Compare with independent solutions and pellet temperature measurements |
| Pellet densification | Model developed by Assmann and Sthele | MATPRO model | Compare with measurements |
| Pellet thermal expansion | MATPRO model | MATPRO model | |
| Pellet relocation | - | G2TR2 model | Unlikely to occur in CANDU fuel due to collapsible feature; will continue to investigate its effect |



| Thermo-mechanical models identified by US NRC | ELESTRES Models | FRAPCON-3 Models | Validation Strategy/Remarks |
|--|---|---|--------------------------------------|
| Fission gas release | Booth release with Massih diffusivity, GB tunnelling | ANS 5.4 with Massih diffusivity, GB tunnelling | Compare with measurements |
| Clad temperature distribution | 1-D conduction, MATPRO thermal conductivity | The same as ELESTRES | Compare with measurements |
| Clad creep | AECL | MATPRO | Compare with measurements |
| Clad ballooning/rupture | - | - | Not required for steady state |
| Clad corrosion | Input | MATPRO | Not required |
| Clad hydrogen pickup | - | - | Not required |



| Thermo-mechanical models identified by US NRC | ELESTRES Models | FRAPCON-3 Models | Validation Strategy/Remarks |
|--|---|---|--|
| Clad heat transfer | Input (film heat transfer coefficient), 1D conduction across oxide layer | Dittus-Boelter for film heat transfer coefficient., 1D conduction across oxide layer | Included in the validation for clad temperature |
| Pellet-clad gap heat transfer | AECL (based on Ross-Stoute model) | Mikic-Todreas model for contact conductance; GT2 model for gas conductance | Included in the validation for pellet temperature |
| Rod growth | No model for irradiation induced growth | MATPRO | - |



| Thermo-mechanical models identified by US NRC | ELESTRES Models | FRAPCON-3 Models | Validation Strategy/Remarks |
|--|---------------------------|---------------------------|---|
| Rod bow | No | No | Not required |
| Rod void volume | Volume calculation | Volume calculation | Compare with measurements |
| Rod internal pressure | Ideal gas law | Ideal gas law | Compare with measurements |
| Power-ramp behaviour | No | No | Empirical correlations available |



Range of Applicability in the Modelling Aspects

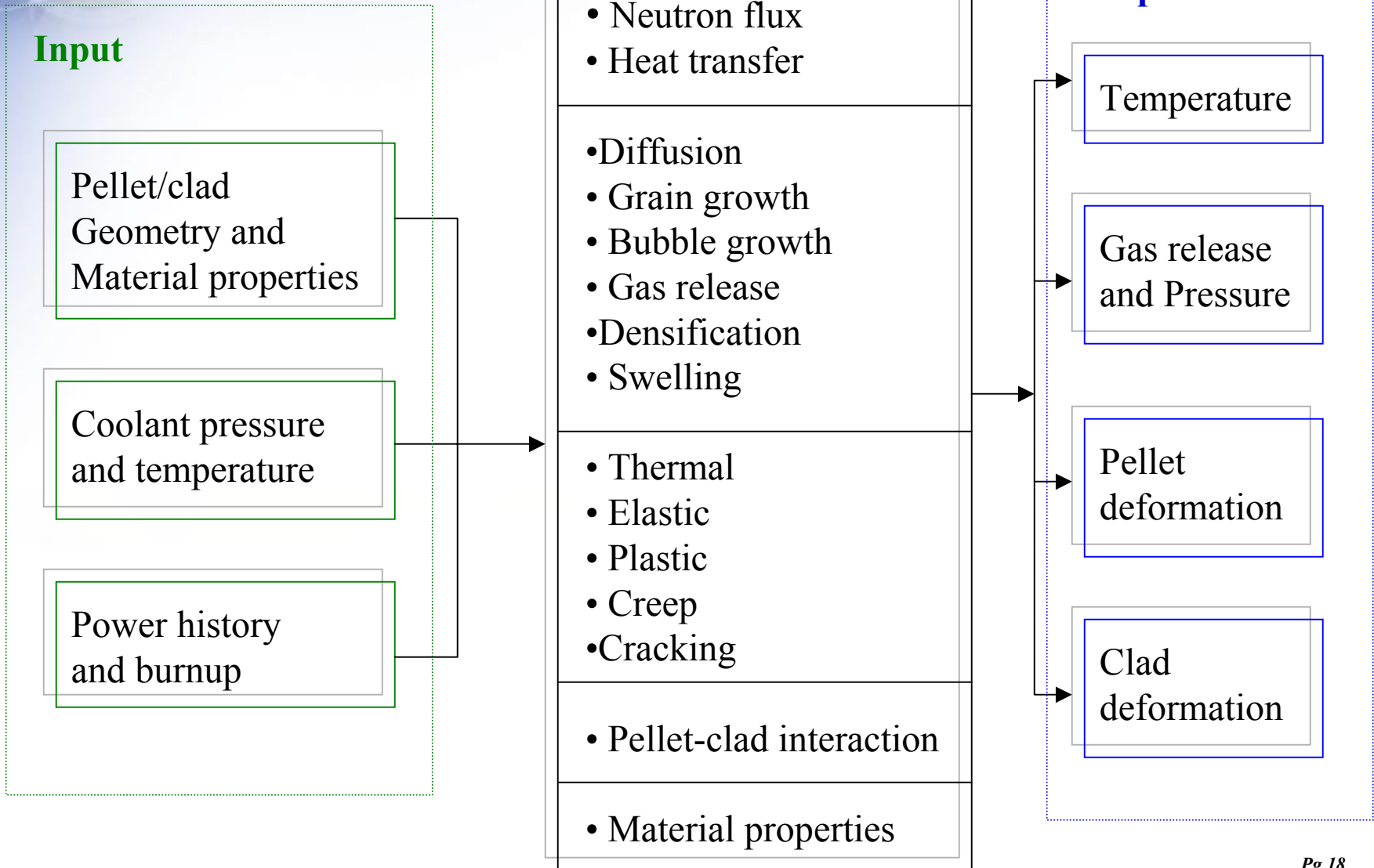
- **CANDU fuel under NOC**
- **Stoichiometric UO₂**
- **Peak ratings less than 83 kW/m to prevent UO₂ melting**
- **Clad temperatures less than 400°C to be consistent with clad creep correlation**



Domain of Applicability of ELESTRES 2.0 to ACR Fuel



Data Flow Diagram



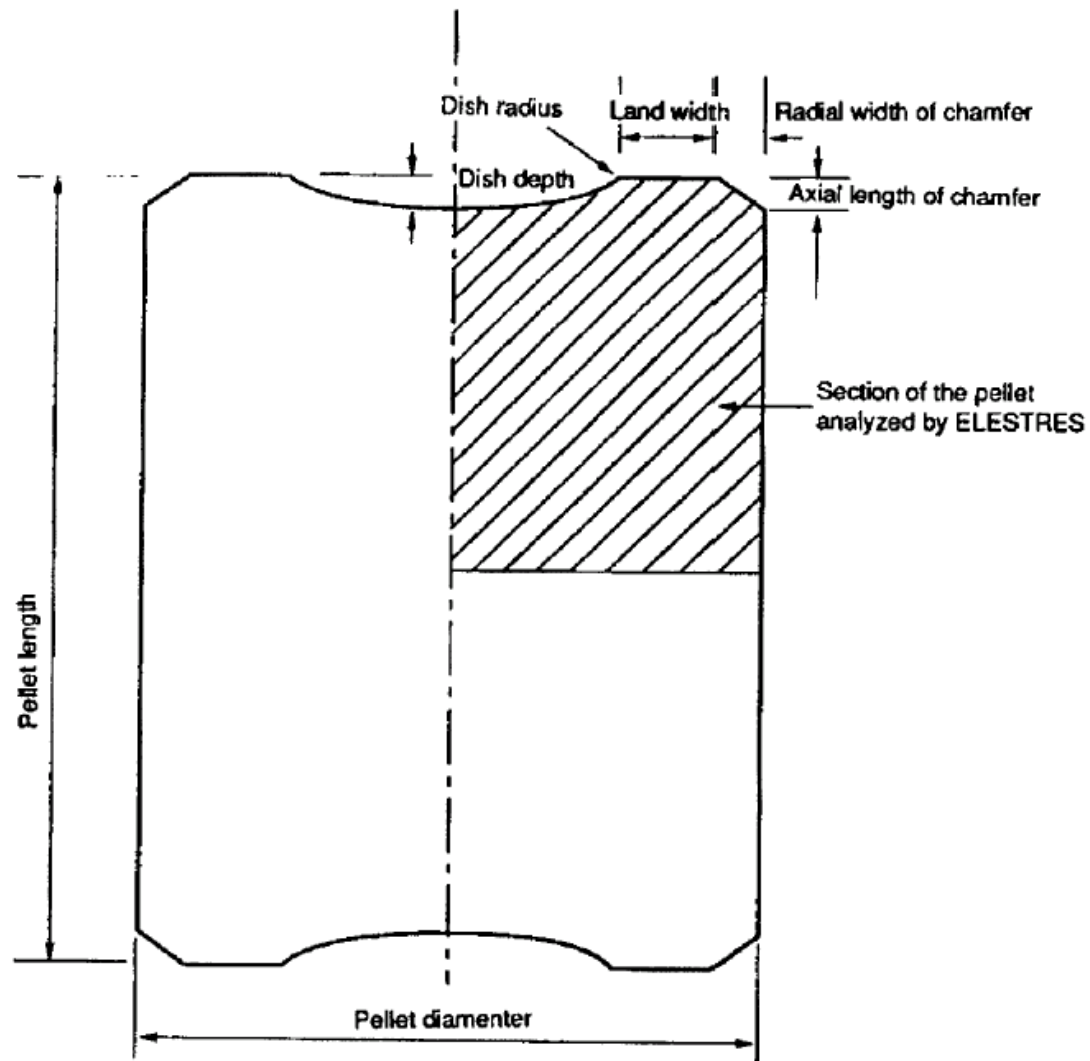


Input Parameters

- **Group 1: pellet data**
 - no per element, OD, dish depth, ID, density, stack length
- **Group 2: rod data**
 - no per bundle, axial gap, diametral gap, clad wall thickness, filling gas volume (or pressure), He fraction
- **Group 3: clad properties (recommend default values)**
 - Young's modulus, yield stress, coefficient of thermal expansion, friction coefficient, sheath and pellet ovality
- **Group 4: heat transfer data**
 - CANLUB (yes, no), film heat transfer coefficient, clad and pellet surface roughness, clad oxidation layer thickness, crud thickness
- **Group 5: operational parameters**
 - coolant temperature/pressure, neutron inverse diffusion length, thermal-to-fission power ratio, pellet grain size, enrichment



Pellet



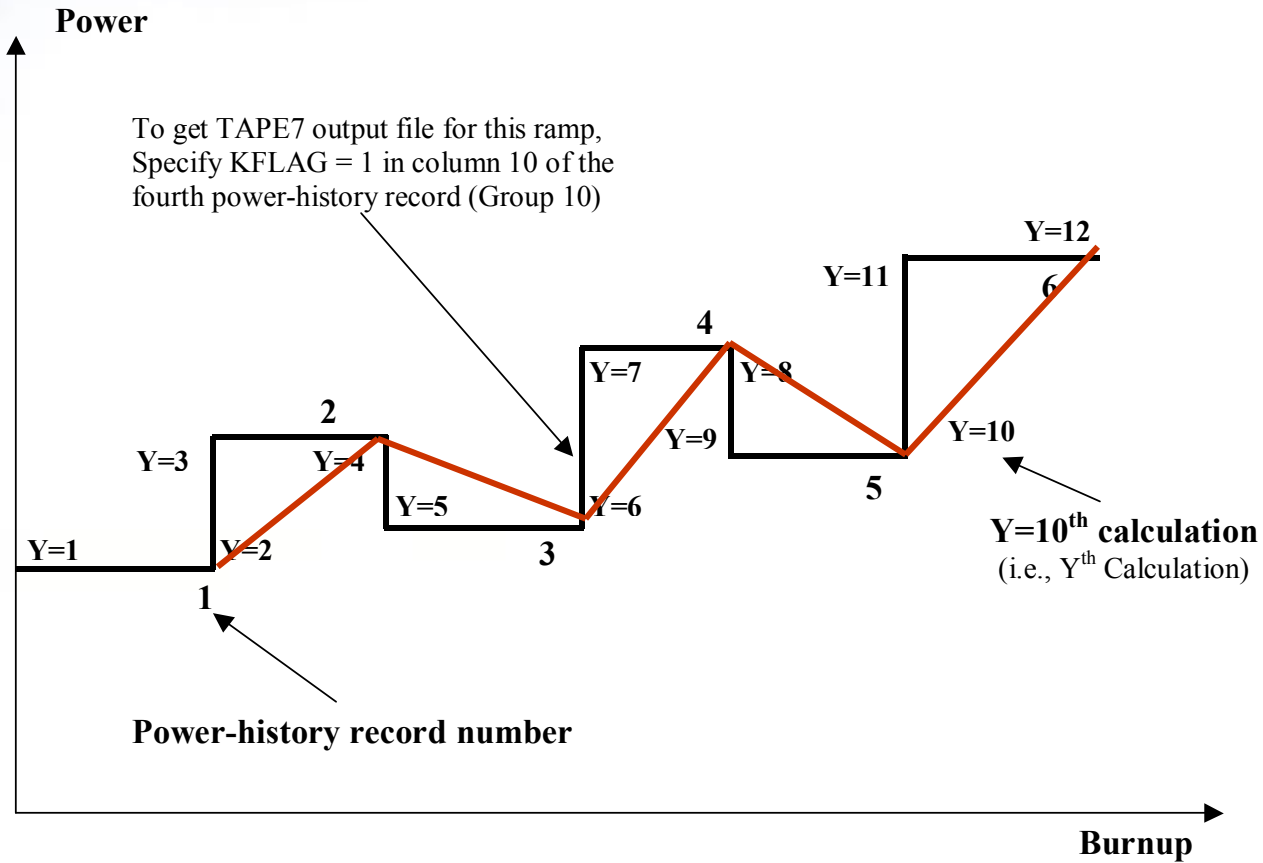


Input Parameters

- **Group 7: groove data (usually do not use)**
 - total number, width, depth, flux detector size
- **Group 8: input title**
- **Group 9: print option**
- **Group 10: power-burnup history data**
 - total number, linear power, burnup, coolant temperature/pressure, film heat transfer coefficient, ramp rate, clad oxidation thickness



Power-Burnup History





Input Parameters

- **Group 11: finite element and operational data**
 - no of dishes/pellet, chamfer width and height, axial yield stress of clad
- **Group 12: UO_2 mechanical properties (recommend default values)**
 - cracking option, Young's modulus, Poisson's ratio, coefficient of thermal expansion, coefficients for a creep equation
- **Group 13: UO_2 yield function (recommend default values)**
 - yield stresses versus temperatures
- **Group 14: creep stress exponents for UO_2 (recommend default values)**
 - exponents of stress terms in a creep equation
- **Group 15: pellet finite element mesh data**
 - number of radial and axial FE meshes



Sample Input

| 1 to 5 | 6 to 10 | 11 to 20 | 21 to 30 | 31 to 40 | 41 to 50 | 51 to 60 | 61 to 70 | 71 to 80 |
|-------------------|---------|----------|----------|----------|----------|----------|----------|----------|
| Sample run | | | | | | | | |
| 1 | 30 | 12.160 | 0.300 | | | 10.600 | | 495.30 |
| 2 | 37 | 3.00 | 0.038 | 0.380 | -0.1013 | | | 0.8 |
| 3 | 0 | | | | | | | |
| 4 | 1 | | 50.0 | 0.5 | 0.81 | | | |
| 5 | 0 | 524.00 | 10.3 | | | 10.0 | 0.71 | |
| 9 | 2 | | | | | | | |
| 11 | 2 | | | | | | | |
| 10 | 25 | | | | | | | |
| | | 54.45 | 10.00 | | | | | |
| | | 55.75 | 20.00 | | | | | |
| | | ... | ... | | | | | |
| 0 | | | | | | | | |



Key Outputs

- **Fuel temperature**
 - gap heat transfer coefficient
 - pellet centreline temperature; average pellet temperature
 - pellet surface temperature
 - clad inside surface temperature
 - average clad temperature
- **Fission product release**
 - percentage FGR
 - volume FGR; grain growth
 - FP concentration on clad surface
 - internal gas pressure

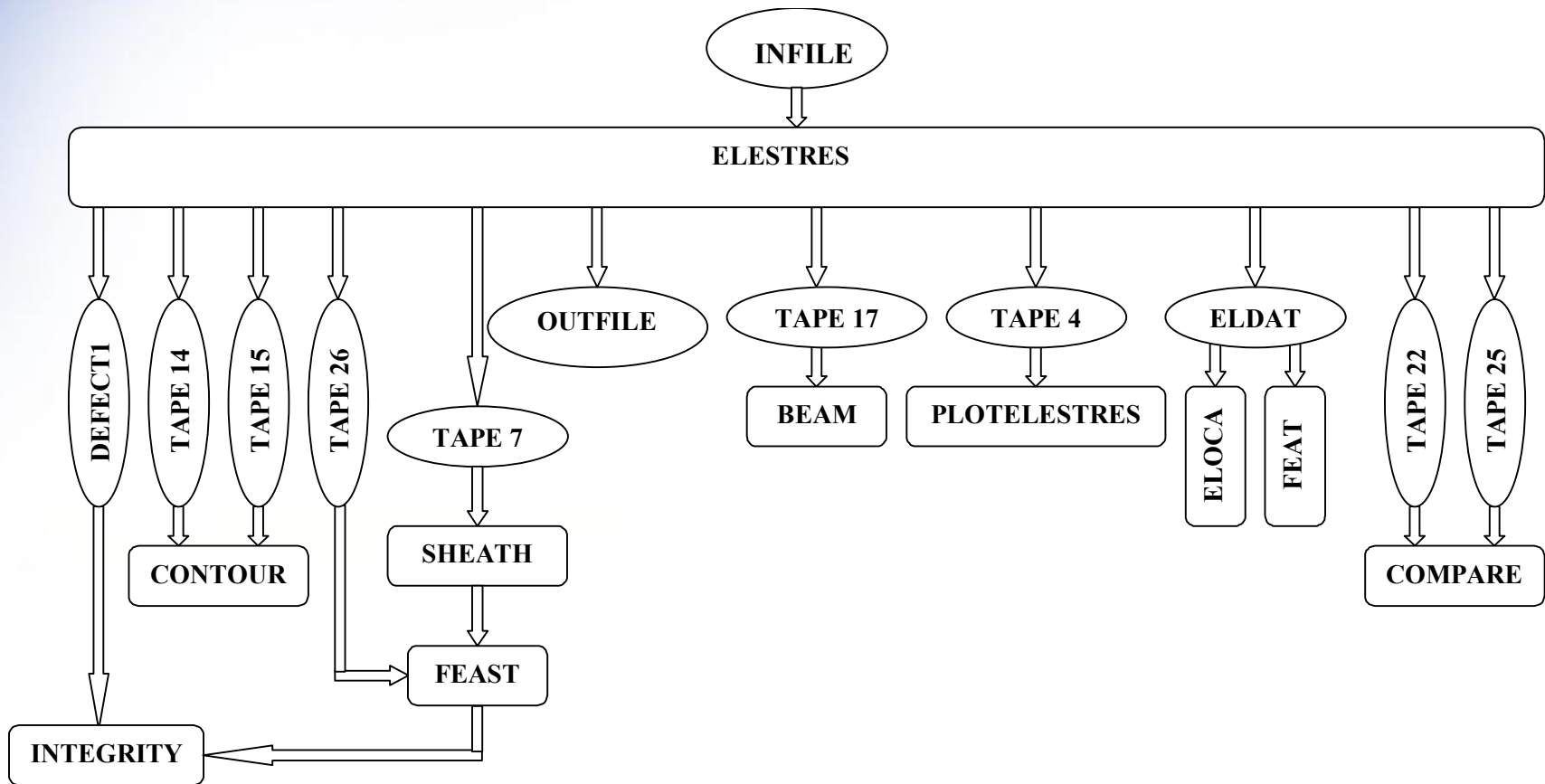


Key Outputs

- **Fuel deformation**
 - clad hoop strain at midplane (elastic, plastic, thermal and total)
 - clad hoop strain at pellet end (elastic, plastic, thermal and total)
 - clad hoop stress at pellet end
 - radial and axial deformations of the pellet
 - pellet-to-clad interfacial pressure at pellet end
 - voidage
 - diametral gap at midplane
 - probability of clad failure due to SCC



Links Between Output Files and Other Codes



ELESTRES input and output files



Computer codes

Key ACR Computer Codes



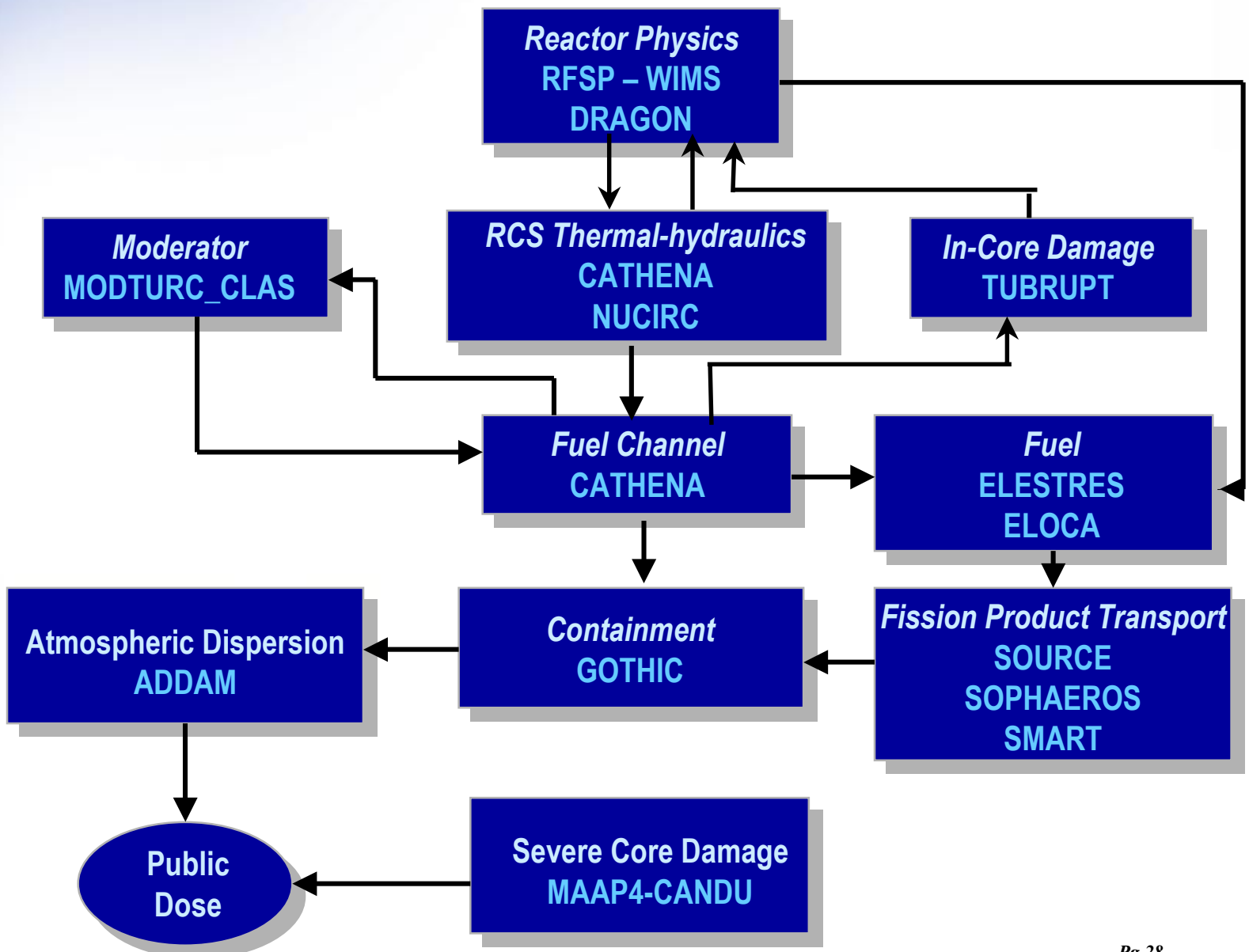
Physics

Thermal-Hydraulics

Fuel & Channel

Containment & Fission Trans.

Severer Core Damage





Data Transfer to ELOCA

- **Hot pellet geometry**
 - volume from diametral gap
 - dish
 - axial gap
 - clad radius
 - wall thickness and length, etc.
- **Performance parameters**
 - clad strains
 - gas pressure
 - interfacial pressure
 - remaining axial gap
 - clad temperature
 - fraction gas release
 - annulus temperature and heat generation rate
 - porosity, etc.



Concluding Remarks

- **ELESTRES 2.0 is capable of modelling steady-state, thermal mechanical behaviour of ACR fuel**
- **ELESTRES 2.0 is to be verified and validated according to Canadian standard CSA N-286.7**



Demonstration

- Please refer to User's Manual for ELESTRES 1.9.7.1.



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