4. ELESTRES Workshop

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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

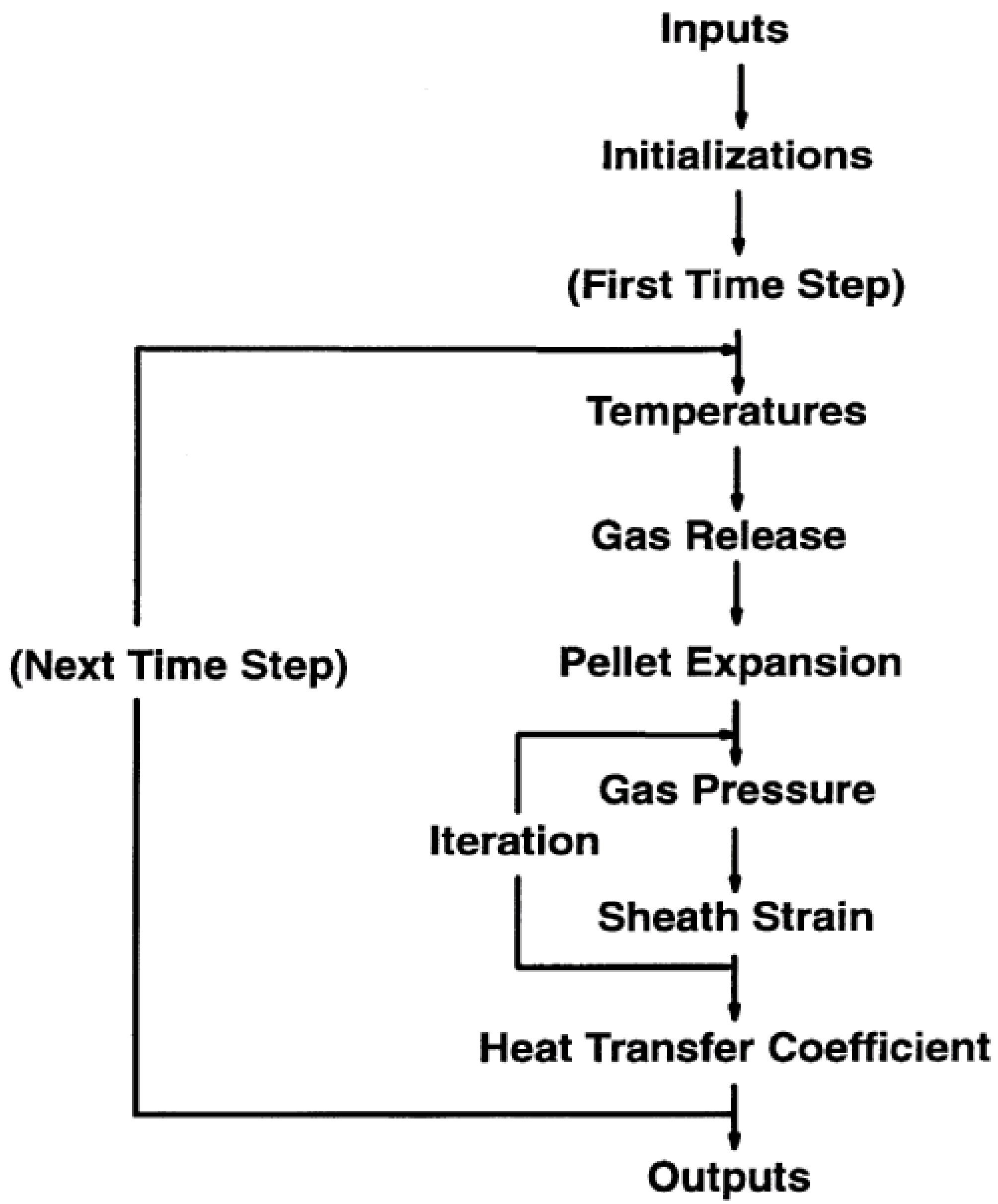
Validation: Output Parameters vs. Phenomena

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 Internal gas pressure	Diffusion (FPR2) GB sweeping (FPR3) 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	-

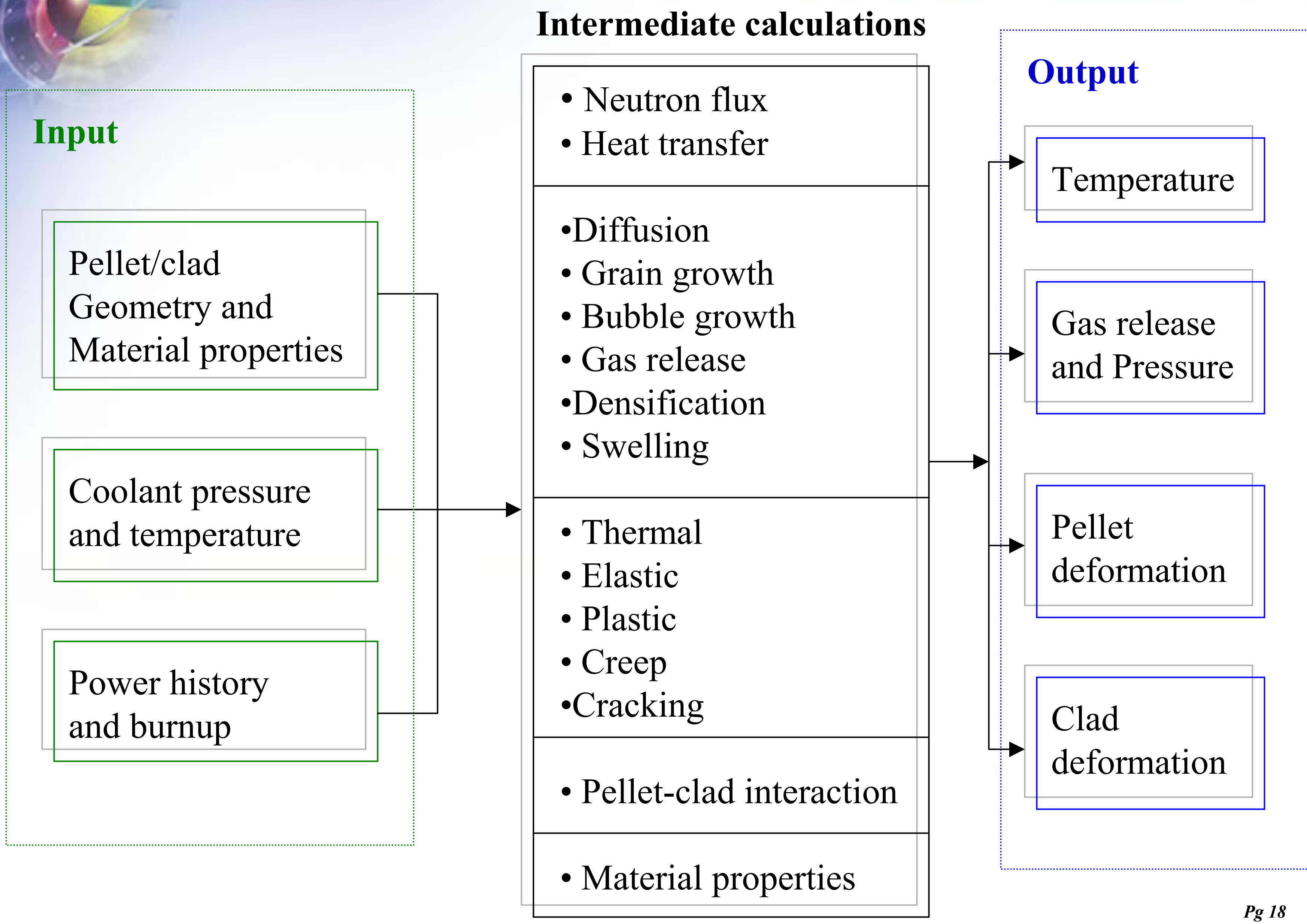
Thermo-mechanical models identified by US NRC	ELESTRES Models	FRAPCON-3 Models	Validation Strategy/Remarks
Rod bow	No	No	Not required
Rod void volume	Volume calculation	Volume calculation	Compare with measurements
Rod internal pressure	Ideal gas law	Ideal gas law	Compare with measurements
Power-ramp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

Range of Applicability in the Modelling Aspects

- CANDU fuel under NOC
- Stoichiometric UO_2
- Peak ratings less than 83 kW/m to prevent UO_2 melting
- Clad temperatures less than 400°C to be consistent with clad creep correlation

Domain of Applicability of ELESTRES 2.0 to ACR Fuel

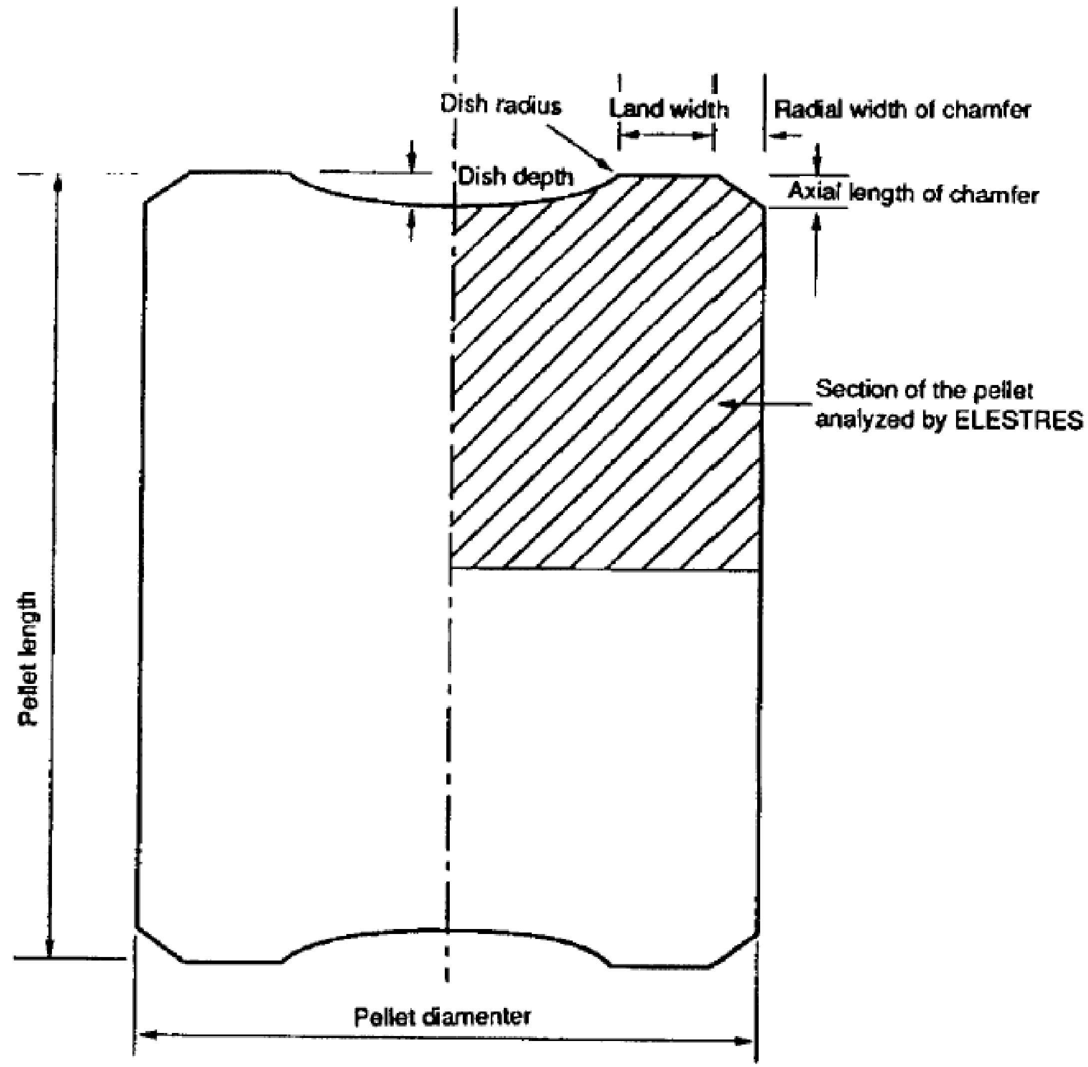
Data Flow Diagram



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

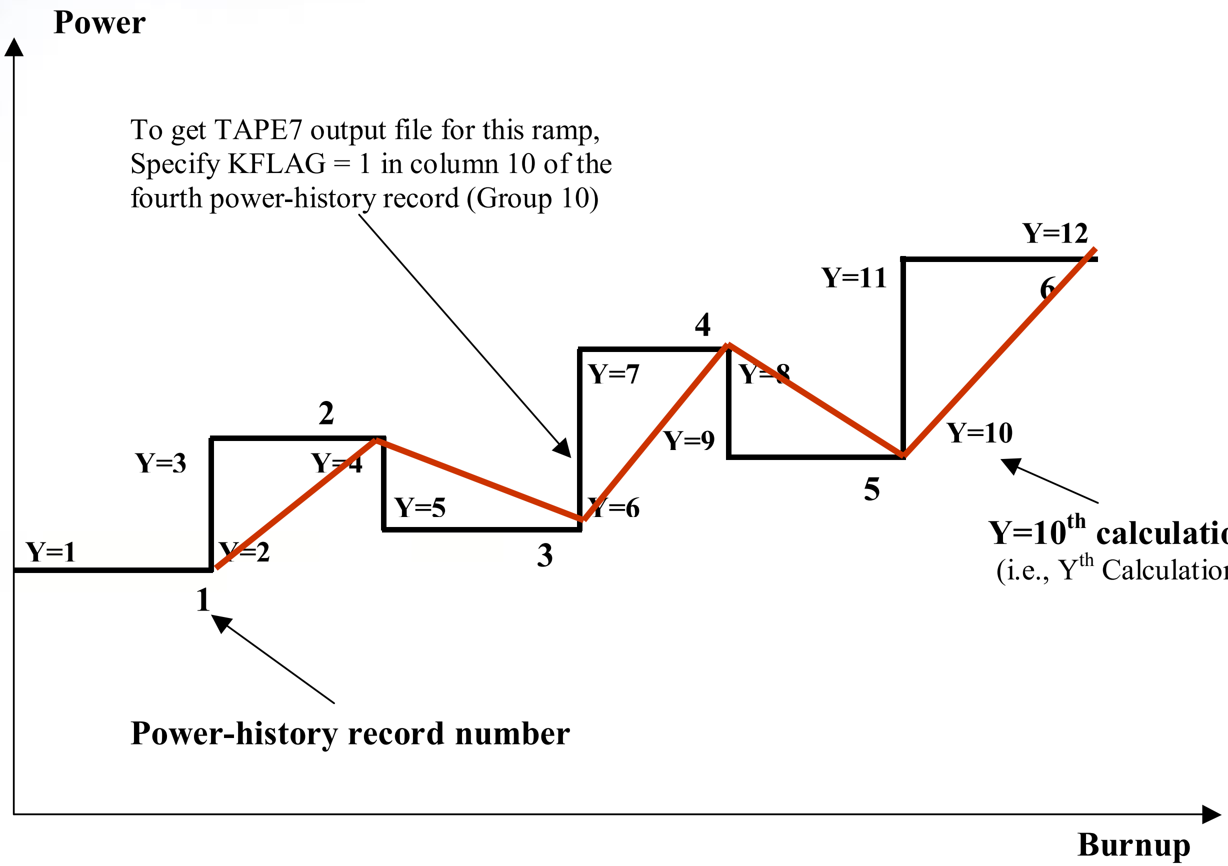


Dish radius
Land width
Radial width of chamfer
Dish depth
Axial length of chamfer
Section of the pellet analyzed by ELESTRES
Pellet length
Pellet diamenter

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								

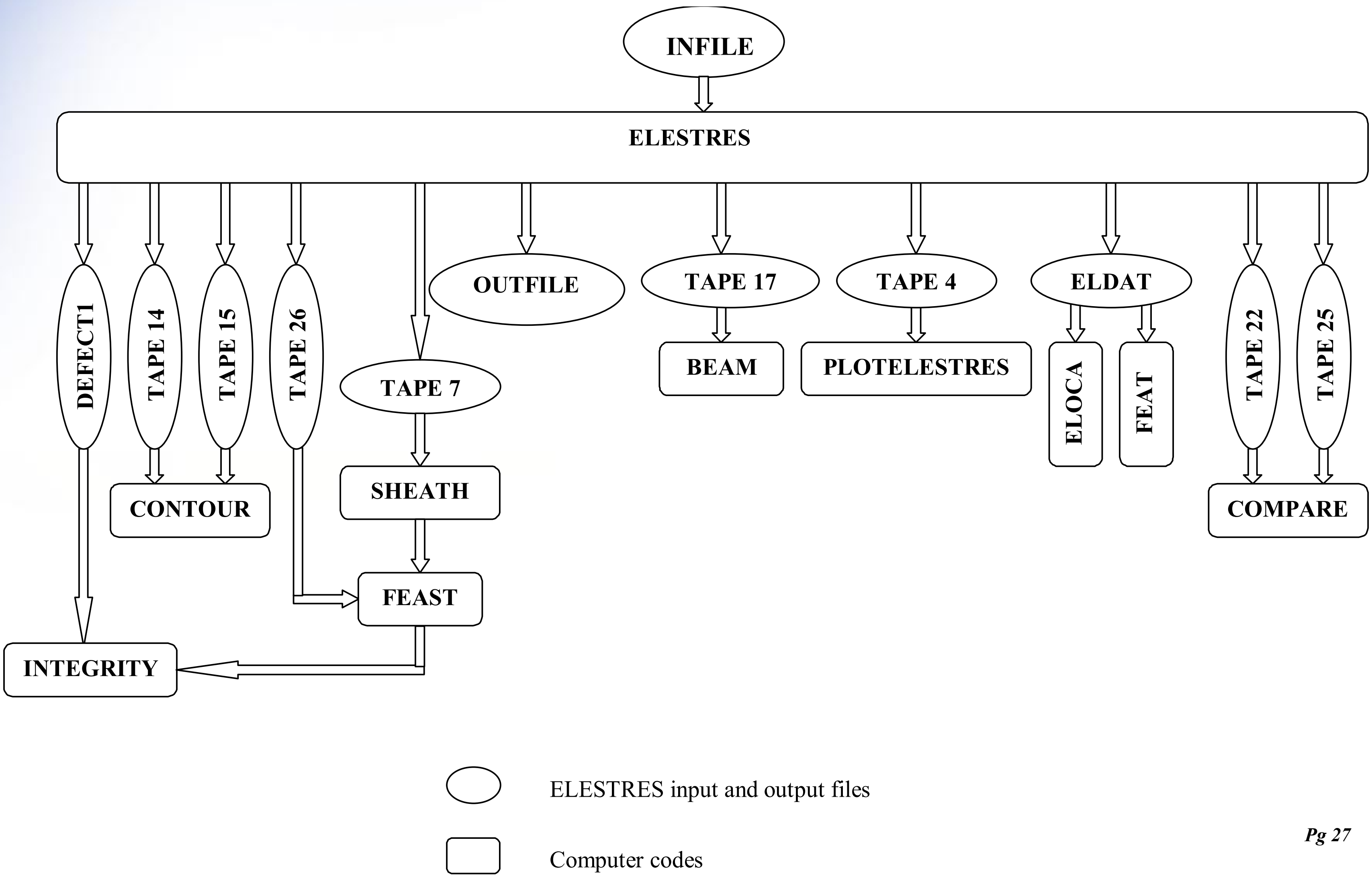
Key Outputs

- 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

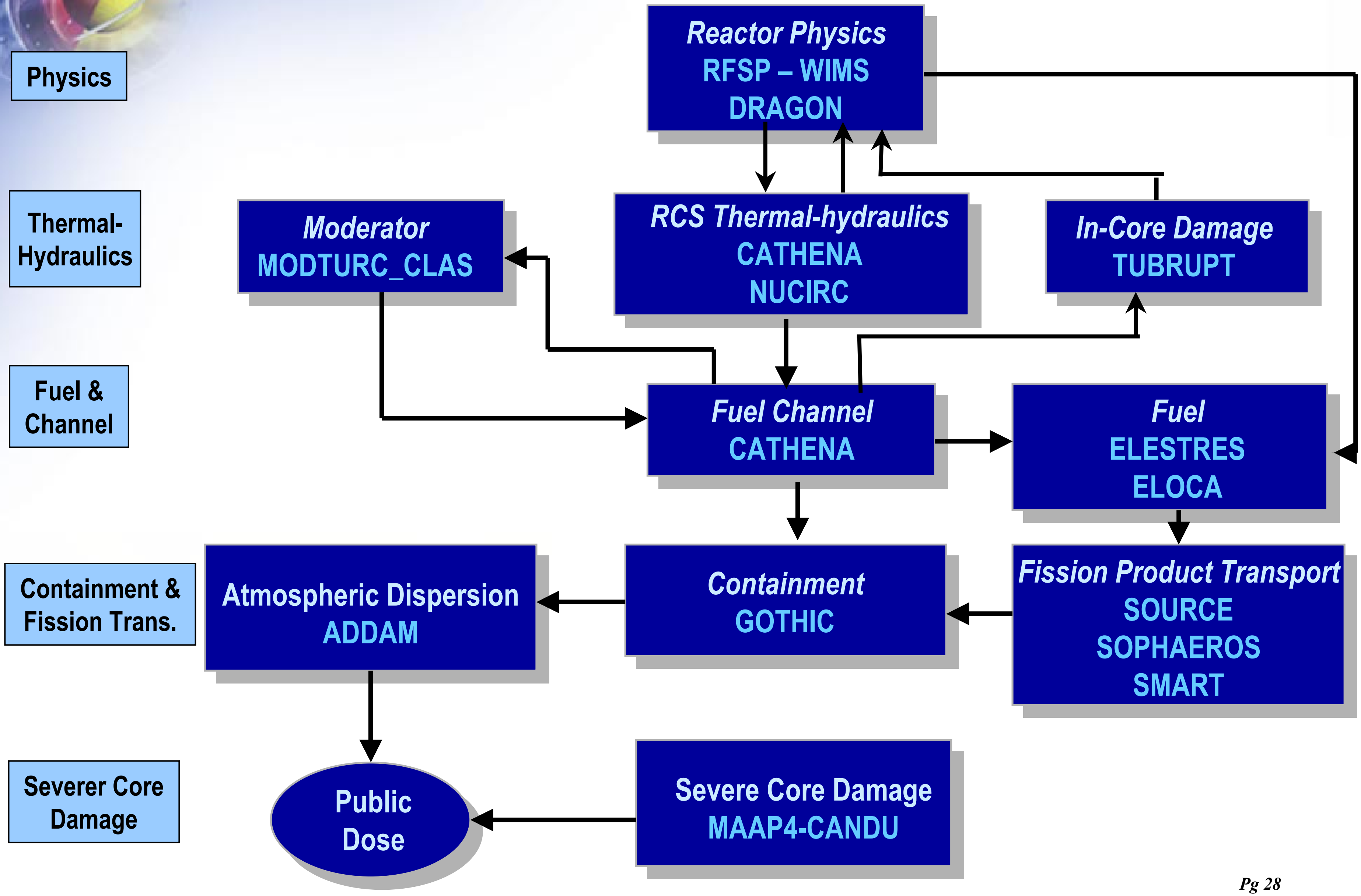
Key Outputs

- **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



Key ACR Computer Codes



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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