Overview of ACR Severe Accidents Analysis (for Level II PSA) and Mitigation Provisions

Raj Jaitly, Manager, PSA & Safety Design
Andrew White, Director, Reactor Safety Division

Presentation to US Nuclear Regulatory Commission

Washington DC

April 6-7, 2004

AECL
TECHNOLOGIES INC.

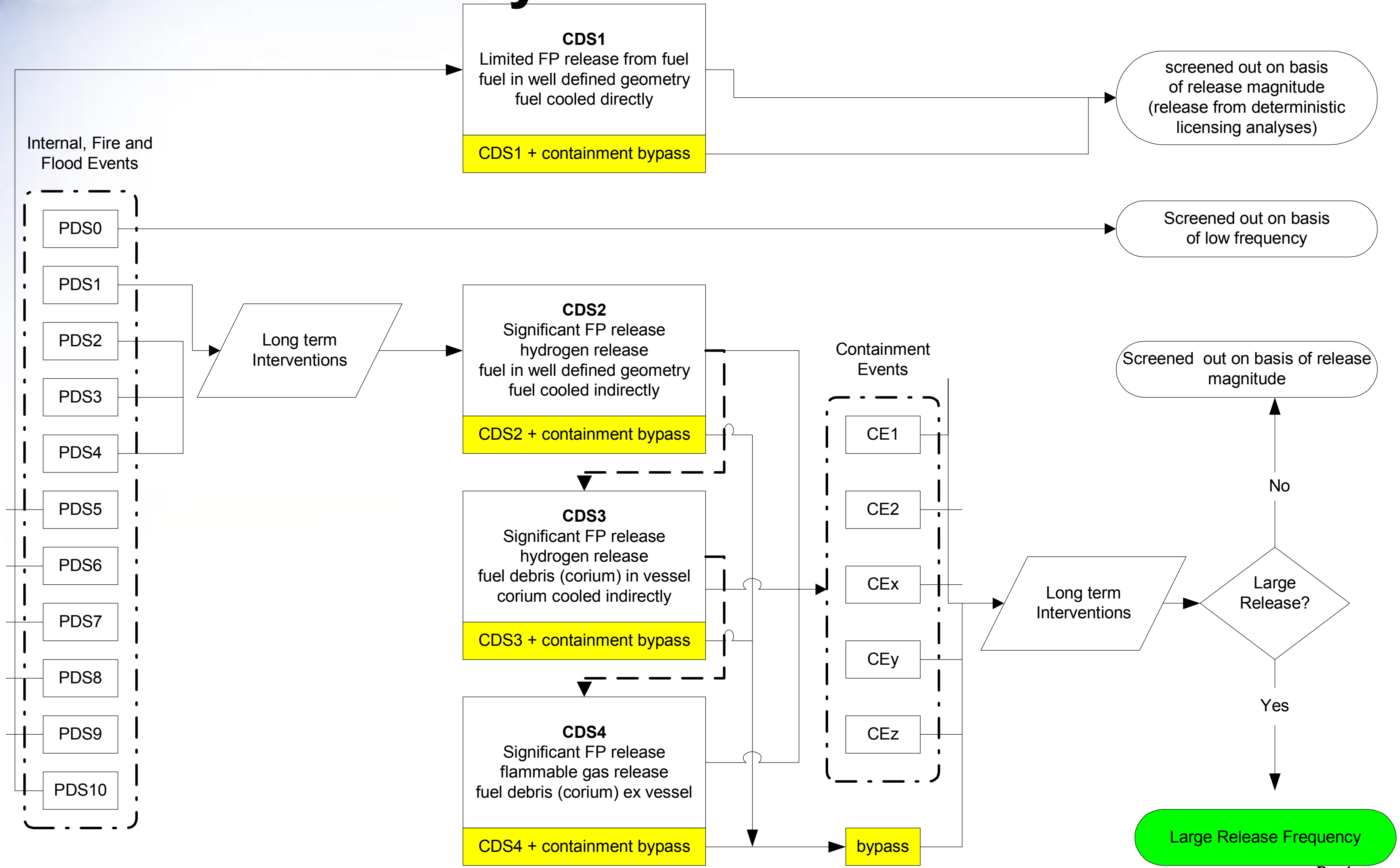
Outline

- Severe Accident Analysis overview
- Severe Accident Mitigation Design Assessment
- Severe Accident Mitigation Design Guidelines

Analysis Objectives

- To confirm that
  - the summed Severed Core Damage Frequency is ≤ 1E-5 per year and
  - the Large Release Frequency (LRF) is ≤ 1E-6

Main Elements of Severe Accident Analysis for Level II PSA



Summary of Analysis Tasks

- Accidents are grouped into categories of similar potential for airborne radioactivity content within the plant and similar containment integrity challenges (4 Core Damage States)
- Core Damage State frequencies are summed
- Containment event tree analysis
- Deterministic analyses to enumerate the radioactivity source terms outside the containment for all combinations of Core Damage States and containment end states
- Derive a profile of source terms vs. frequency
- Enumerate large release frequency
- (Severe Accident Analysis code – MAAP4 CANDU)

Main Elements of Containment Performance Assessment

- Local Air coolers
- Airlocks
- Containment Isolation
- Passive Autocatalytic Hydrogen Recombiners
- Bypass:
  - Steam generator tube rupture
  - Bleed cooler tube rupture
  - Interfacing LOCA

CANDU SAMG Overview

- Based on Westinghouse Owner's Group (WOG) approach:
  - 2 volumes Technical Basis Documents
  - Diagnostic Flow Chart and Severe Challenge Status Tree
  - Severe Accident Control Room Guideline 1 – Initial Response
  - Severe Accident Control Room Guideline 2 – After Technical Support Center is Functional

- Severe Accident Guidelines (SAGs):
  - SAG1 – Control Calandria Vault Conditions
  - SAG2 – Control Moderator Conditions
  - SAG3 – Inject into the RCS
  - SAG4 – Reduce Fission Product Releases
  - SAG5 – Control Containment Conditions
  - SAG6 – Reduce Containment Hydrogen
  - SAG7 – Inject into Containment

SAMG Overview (Cont'd)

- 4 Severe Challenge Guidelines (SCGs):
  - SCG1 – Mitigate Fission Product Releases
  - SCG2 – Reduce Containment Pressure
  - SCG3 – Control Containment Atmosphere Flammability
  - SCG4 – Control Containment Vacuum

- Computational Aids – exact numbers to be determined

Review of ACR Design Features for Severe Accident Management

- For new Reactor designs, regulators require evaluation of design alternatives to reduce the radiological risk from a severe accident by preventing substantial core damage or by limiting releases from the plant in the event of substantial core damage
- The purpose of such evaluation is to establish whether there are any cost-effective severe accident mitigation design alternatives (SAMDAs) that should be added to the facility
- SAMDA screening assessment for ACR 700 has been performed and a number of design alternatives identified

Severe Accident Management

Actions that are taken by the plant staff during the course of an accident to:

- **prevent core damage,**
- **terminate progress of core damage,**
- **retain the core within the vessel,**
- **maintain containment integrity, and**
- **minimize off-site releases.**

ACR Severe Accident Prevention and Mitigation Features

- **Inherent CANDU features:**
  - three shutdown methods: one control and two independent, diverse shutdown systems
  - presence of two large sources of water in or near the core
  - potential to stop or slow down the accident at two points:
    - channel boundary (moderator)
    - calandria boundary (calandria vault)
  - long time scales allow for severe accident counter-measures and emergency planning

ACR Severe Accident Prevention and Mitigation Features (Cont'd)

- **Inherent CANDU features:**
  - Two front line SA mitigation systems normally in operation, so need not worry about their failure to start on demand;
    - emphasis should be on the recovery of support services (e.g., class III power, class IV power, cooling water, instrument air)
- **HT depressurization occurs before formation of core melt:**
  - High pressure melt ejection need not be a concern for CANDUs
  - large containment volume further assures no concern for early containment failure
- **Large surface area for melt relocation and large pool on containment floor following SA → no significant concrete/core interaction**

Key SAMDA Candidates

- Emergency Cross-Connections - to connect alternate services by manual field actions, spool pieces, jumpers, etc.
- Calandria Head Tank – Compensation for Liquid Expulsion
- Reserve Water System (RWS) Valves – Emergency Connection to Alternate Power Supply
- Long Term Cooling System (LTCS) – Emergency Connections to Alternate Services
- Reserve Water System – Emergency Connection for Water Recirculation with containment water
- Local Air Coolers – Emergency Connections to Alternates Services
- Containment Sprays
- Hydrogen Control (mixtures of igniters and recombiners)
- Off-Site Release Control – Containment Venting

Related Reports Issued to Date

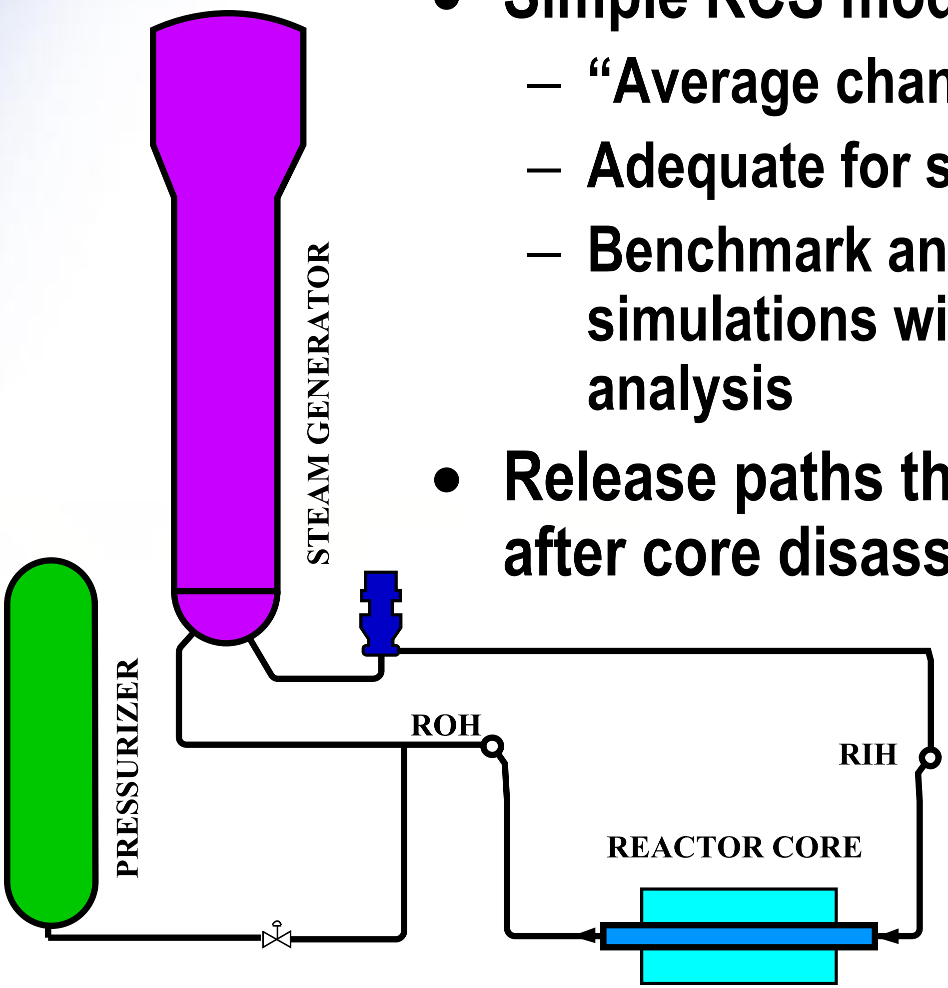
- 10810-03660-ASD-005, Rev 0, January 2004, "Review of Design Features for Severe Accident Management"
- 10810-03660-AB-001, Rev 0, July 2004, "Probabilistic Safety Assessment Methodology"
- 10810-03660-LS-001, Rev 0, September 2003, "Phenomenology for Limited and Severe Core Damage Accidents in an ACR"
- 10810-03660-LS-002, Rev 0, November 2003, "ACR Limited and Severe Core Damage Accidents: Supporting R&D"
- 10810-03660-AR-001, Rev 1, January 2004, "Preliminary Design Assist PSA Level 1 - Selected Full Power Event Trees"

MAAP CANDU

- **Development started in 1988**
  - **Post-Chernobyl recommendation by Ontario Safety Review Commission that severe accidents be analysed**
  - **Joined effort by FAI and Ontario Hydro (now Ontario Power Generation, OPG)**
- **Modular structure is amenable to modeling of different reactor designs**
  - **CANDU-specific models for core disassembly (until terminal debris bed is formed)**
  - **Remaining models same as for LWR's**
- **Current version is MAAP-CANDU 4.0.4**

MAAP CANDU RCS

- Simple RCS model
  - "Average channel" in single loop
  - Adequate for scoping analyses
  - Benchmark and tune up to front-end simulations with CATHENA for final analysis
- Release paths through RCS during and after core disassembly
  - Interconnected volumes are represented
  - FP interactions are modeled



MAAP CANDU Channels

- Lumped channel model for boil-off
- Segmented model for heat-up of voided channel
  - Axial node = bundle length
- User defined ΔP for steam flow
  - From separate assessments
- Ring model for fuel rods
  - Fuel and PT deformations can be represented
  - Deformations triggered by predefined criteria

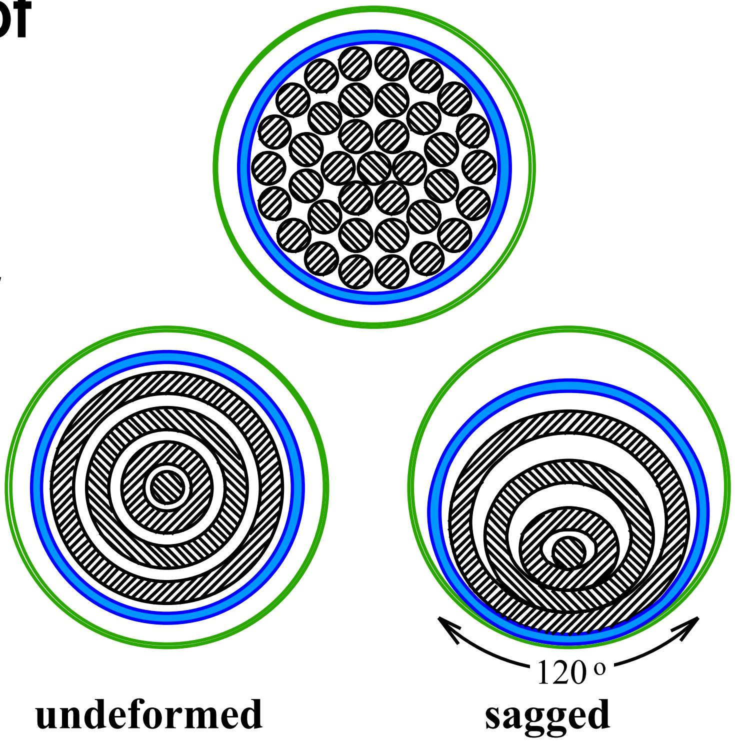
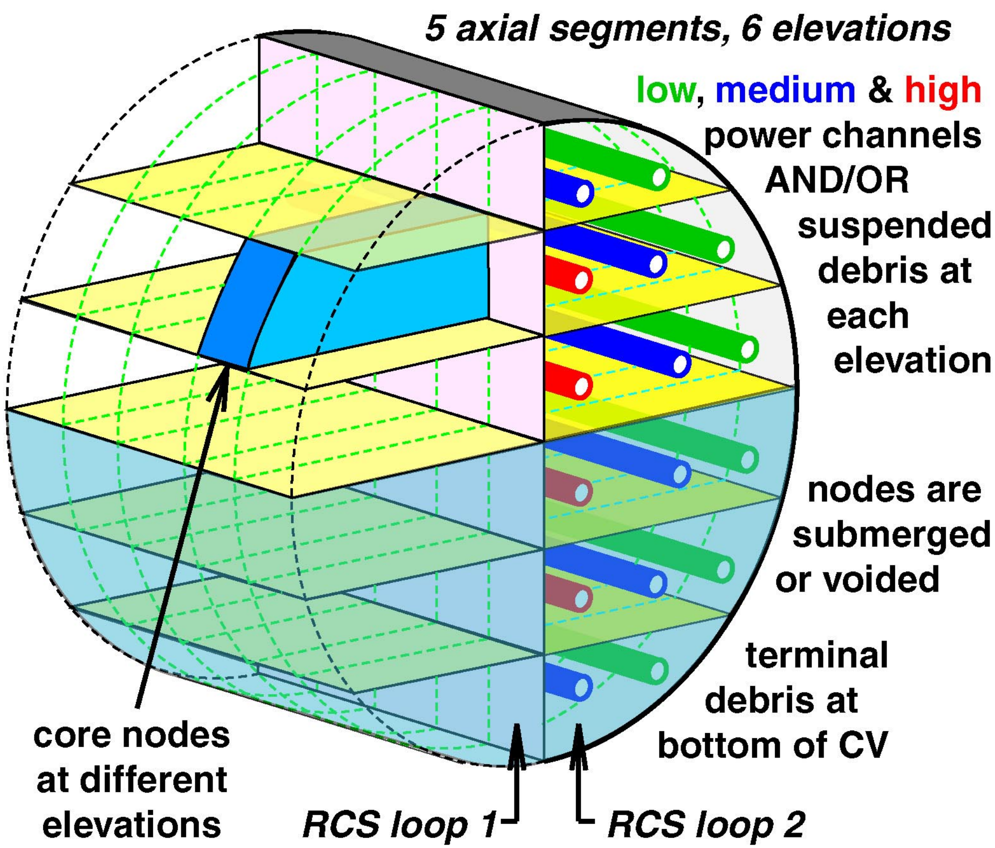


illustration of 37-element fuel in existing CANDU

MAAP CANDU Core

Complex Nodalization for Core Disassembly

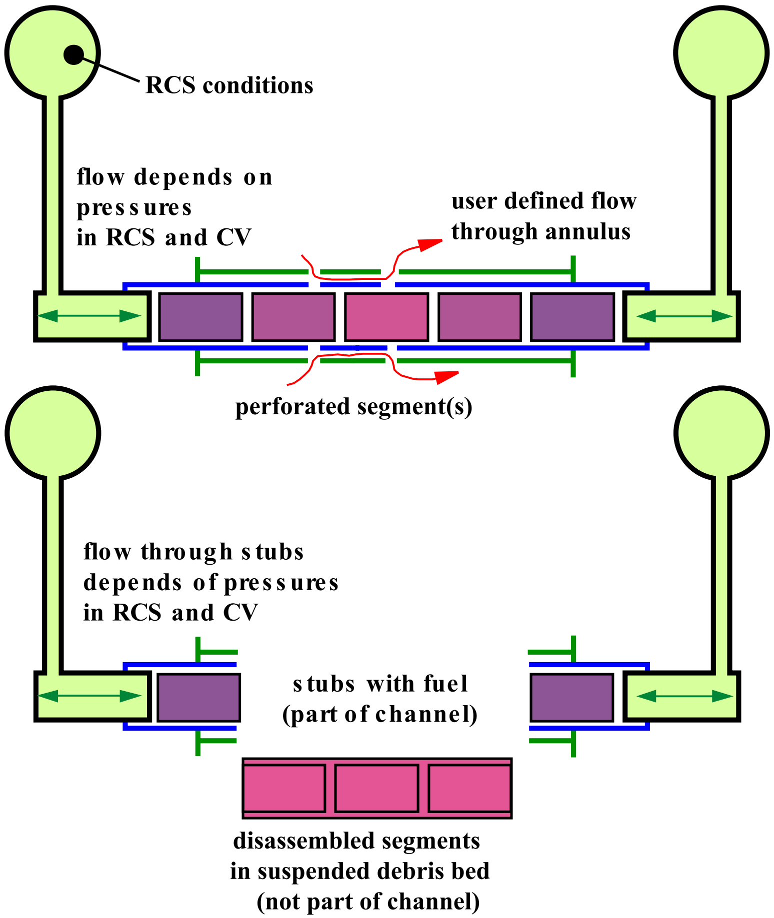
- **Channels heat up and break up at different rates**
- **Intact channels and debris coexist**
- **Same CV water level in all axial nodes**
- **Suspended debris mass differs in axial nodes**



MAAP CANDU Debris Formation

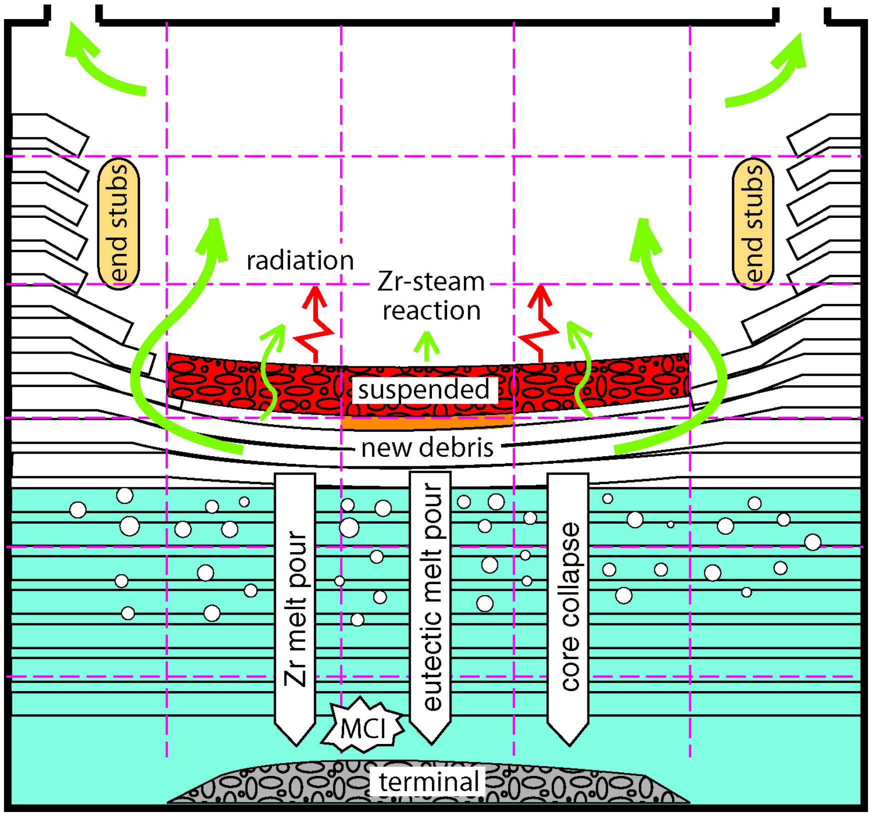
Failure by Deformation or by Melt-through

- Failure criteria developed by separate analyses
- Broken channel transient is evaluated by channel model
- Debris transient is evaluated by debris model
- Channel calculations stop when all fuel in debris beds
  - User can "spill" fuel remaining in channel end stubs (small amount) to expedite calculation



Suspended Debris Heat-up and Relocation

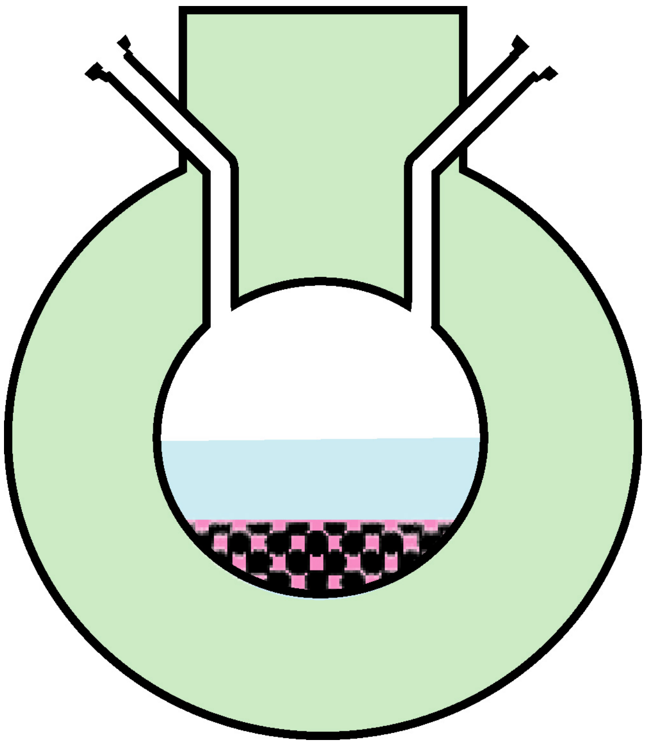
- Tracked in each axial node
  - Downward motion as new debris formed
  - Mass and energy balance in each node at each time step
- Relocation into common terminal debris bed
  - Only core collapse and Zr pours seen in past analyses
- steam access into debris uncertain ⇒ sensitivity analyses to define range of responses



Terminal Debris Bed

Generic MAAP models applicable for:

- Terminal debris bed
- Containment thermal hydraulics
- FP and aerosol transport



AECL

TECHNOLOGIES INC.