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# Fluid Fuel PRKEs in MELCOR for MSRs

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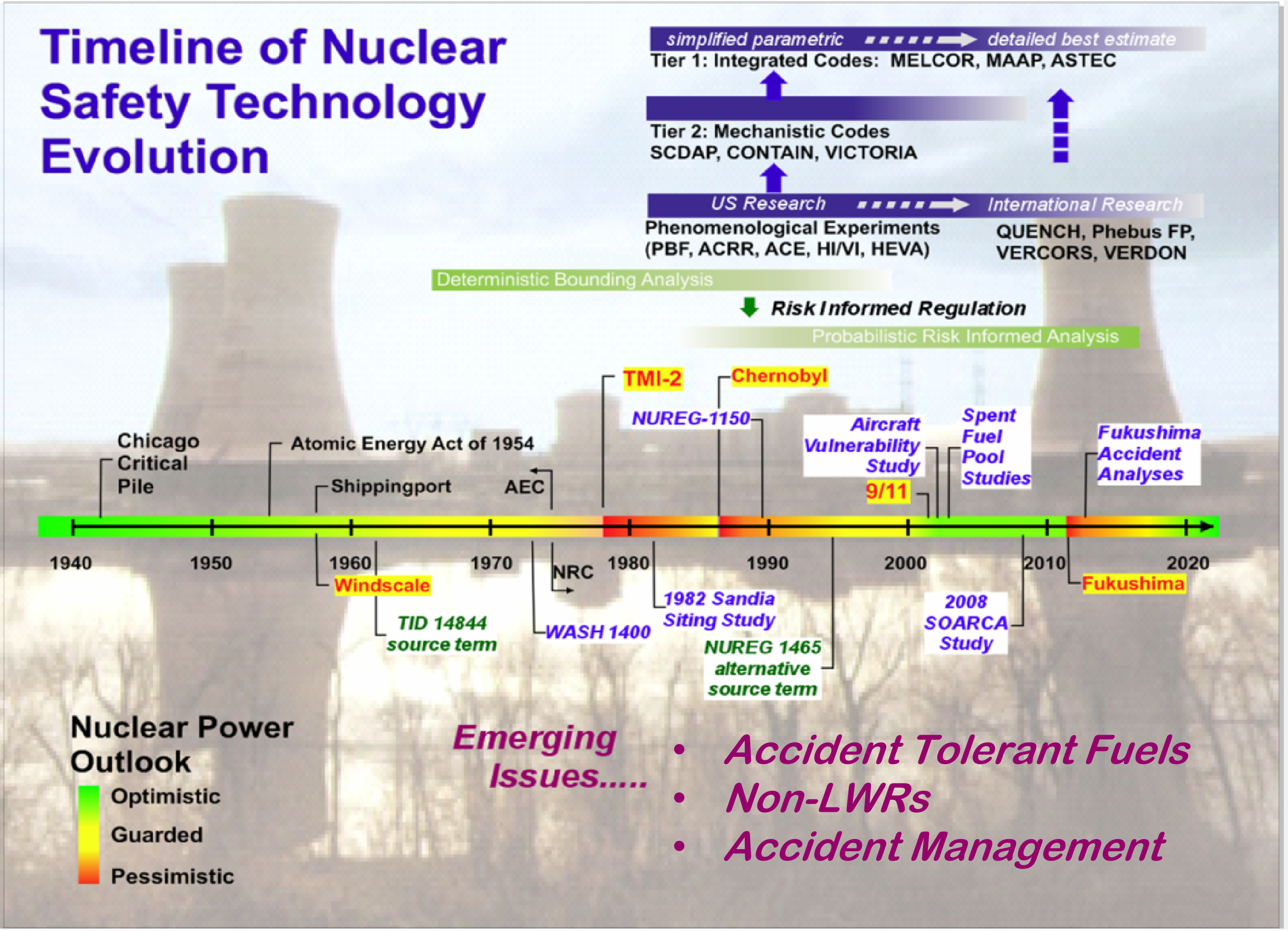
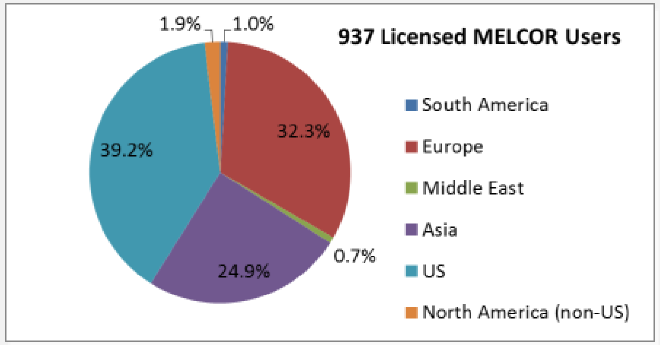
# Outline

- MELCOR code introduction
- Delayed neutrons and reactor kinetics
- Standard and fluid-fuel point kinetics equations in MELCOR
- Validation against ORNL MSRE zero-power flow coast-down experiment
- Conclusions

# MELCOR – History and Introduction




- Began in 1982 shortly after TMI-2
- Replaced Source Term Code Package
- Systems-level approach to modeling
- Emphasis on “best-estimate”
- Repository of knowledge
- Global standard (used by 31+ nations)
  - Users’ groups (AMUG & EMUG)
  - Annual CSARP/MCAP meetings

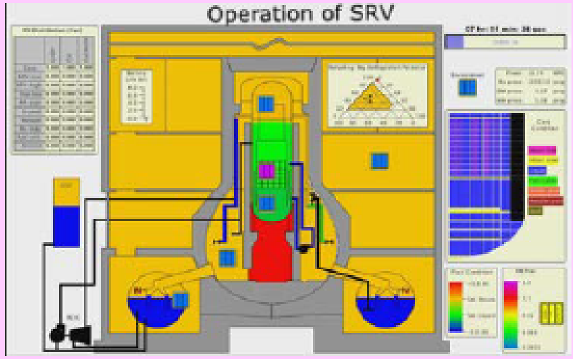



- Used by USNRC, USDOE & US industry
- Used for naval reactors (US/UK)
- Evolves to meet regulatory needs

# MELCOR – History and Introduction

- Fully integrated, multi-physics engineering-level code
  - Thermal-hydraulic response in the reactor coolant system, reactor cavity, containment, and confinement buildings
  - Core heat-up, degradation, and relocation
  - Core-concrete attack
  - Hydrogen production, transport, and combustion
  - Fission product release and transport behavior
- Diverse application
  - Multiple core designs
  - Models built from basic code constructs
  - Adaptability to new or non-traditional reactor designs (ATR, Naval, VVER)
- Validated physics models (ISP's, benchmarks, experiments, accidents)
- Uncertainty analysis & dynamic PRA (fast-running, reliable, access to parameters)
- User convenience
  - Windows/Linux versions
  - User utilities and post-processing/visualization capabilities
  - Extensive code documentation

Multi- Physics

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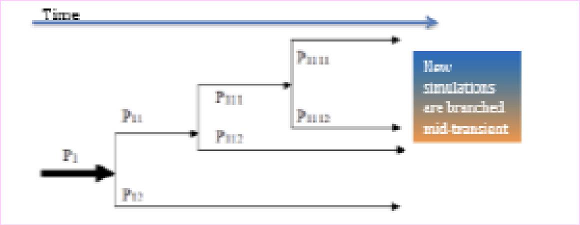
Diverse Application

Advanced Test Reactor

Uncertainty & Dynamic PRA




Dynamic Event Tree

# Reactor Kinetics & Dynamics

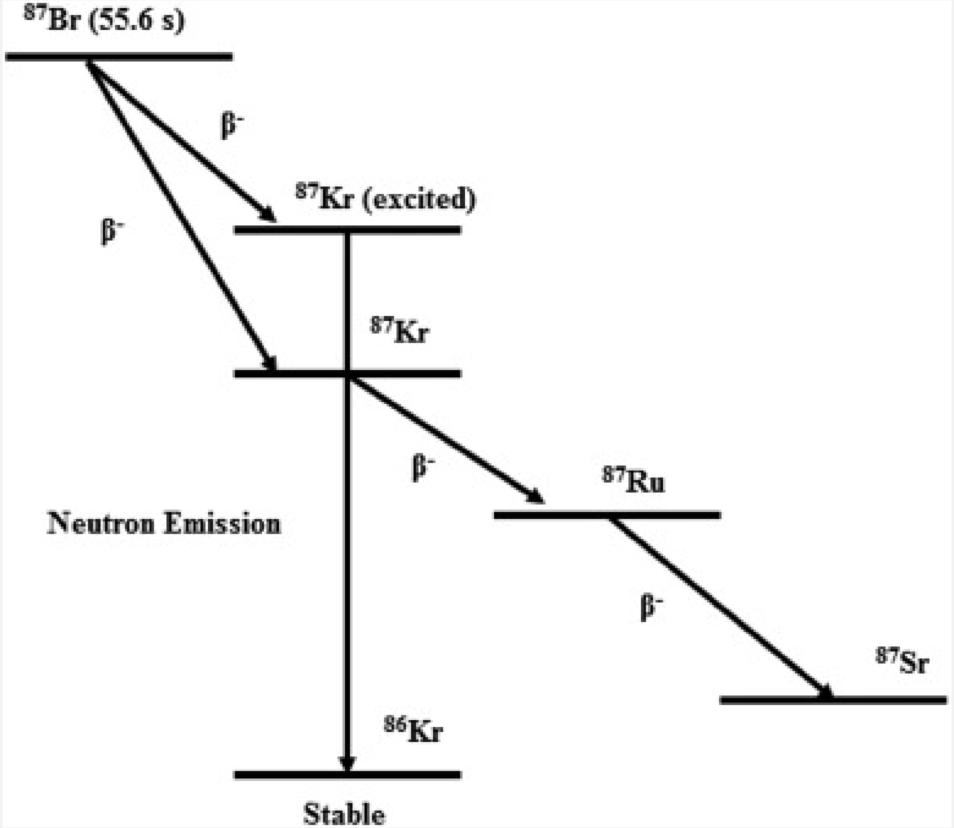
- Time-dependent neutron population (kinetics) plus system feedback mechanisms (dynamics)

- Delayed neutron (DN) emission from delayed neutron precursor (DNP) decay a primary governor of dynamic response
  - Solid fuel –DNP's stay and hence DN's contribute to economy
  - Fluid fuel – DNP's move (ex-core) and lost DN's impact economy

- DNP grouping help with analyses (group decay, abundance)

- Process of DNP advection with flowing fuel -> DNP "drift"

- Cannot neglect the kinetic/dynamic implications of DNP "drift"

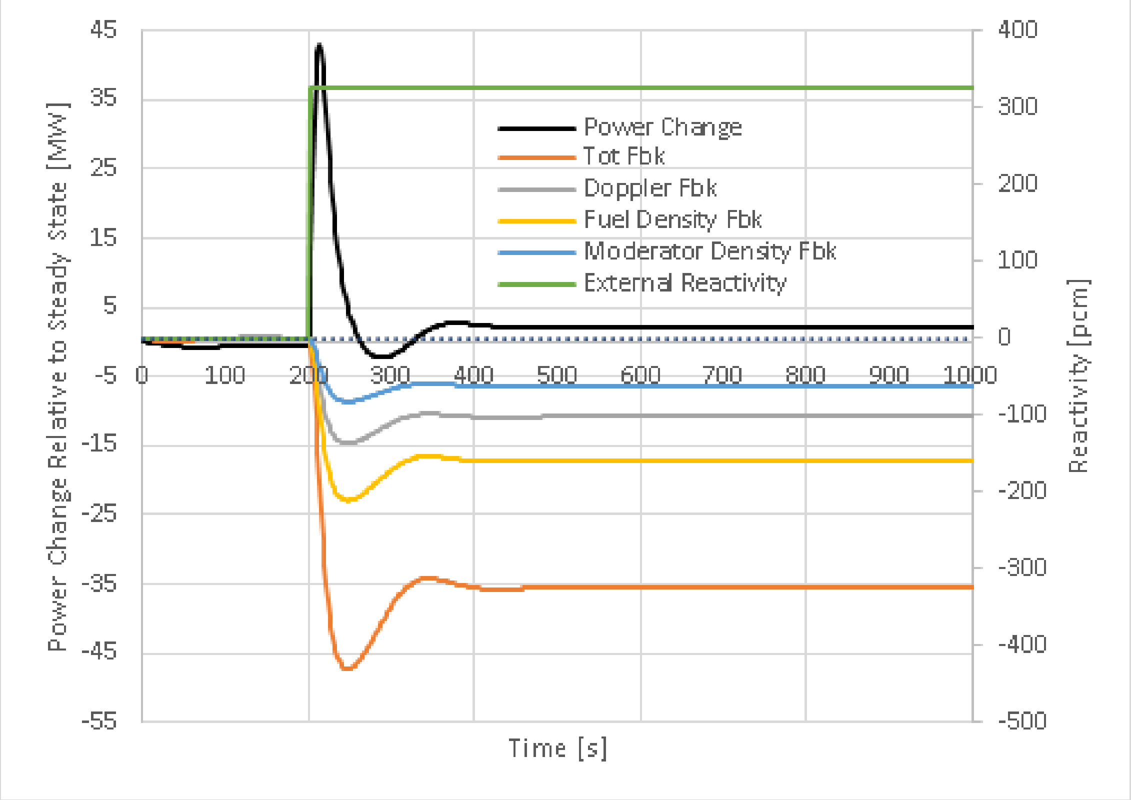


# Standard Point Reactor Kinetics Equations

- Textbook Six DNP group PRKE's

$$\frac{dP}{dt} = \left(\frac{\rho - \beta}{\Lambda}\right) P + \sum_{i=1}^{6} \lambda_i Y_i + S_0$$

$$\frac{dY_i}{dt} = \left(\frac{\beta_i}{\Lambda}\right) P - \lambda_i C_i, \qquad for\ i = 1 \dots 6$$




- DNP drift
  - Leads to lower effective DN fraction,
  - Looks like negative reactivity insertion, and
  - Introduces a "reactivity bias" barrier to criticality for a given flow
- Relatively lower DN emission in core as core DNP inventory decreases
- Relatively higher DN emission in core as core DNP inventory increases
- Fuel flow has direct reactivity implications (e.g. pump coast-down increases reactivity, pump ramp-up decreases reactivity)

# Fluid Fuel Point Reactor Kinetics Equation Model

$$\frac{dP(t)}{dt} = \left(\frac{\rho(t) - \bar{\beta}}{\Lambda}\right)P(t) + \sum_{i=1}^{6} \lambda_i C_i^C + S_0$$

$$\frac{dC_i^C(t)}{dt} = \overset{A}{\left(\frac{\beta_i}{\Lambda}\right)P(t)} - \overset{B}{\left(\lambda_i + {}^{1}/_{\tau_C}\right)C_i^C(t)} + \overset{C}{\left(\frac{V_L}{\tau_L V_C}\right)C_i^L(t - \tau_L)}, \qquad for\ i = 1 \ldots 6$$

$$\frac{dC_i^L(t)}{dt} = \overset{D}{\left(\frac{V_C}{\tau_C V_L}\right)C_i^C(t)} - \overset{E}{\left(\lambda_i + {}^{1}/_{\tau_L}\right)C_i^L(t)}, \qquad for\ i = 1 \ldots 6$$

$$\bar{\beta} = \beta - \left(\frac{\Lambda}{P(t)}\right)\sum_{i=1}^{6} \lambda_i C_i^L(t)$$

A – In-Vessel DNP gain by fission
B – In-Vessel DNP loss by decay, flow
C – In-Vessel DNP gain by Ex-Vessel DNP flow
D – Ex-Vessel DNP gain by In-Vessel DNP flow
E – Ex-Vessel DNP loss by decay, flow

Where:

$P(t)$= Thermal power due to fission 0

$C_i^C$= delayed neutron precursor group $i$ inventory/concentration in-core

$C_i^L$= delayed neutron precursor group $i$ inventory/concentration ex-core

$S_0$= Thermal power generation rate due to neutron source

$\rho(t) = \frac{k-1}{k}$= Reactivity for $k$ the effective multiplication factor

$\bar{\beta}$= Effective delayed neutron fraction

$\beta$= Delayed neutron fraction (static, in absence of drift effects)

$\Lambda = {}^{1}/_{\nu V \Sigma_f}$ = Neutron generation time

$\tau_{C/L} = {}^{M_{C/L}}/_{\dot{m}}$ = Residence time of precursors (core, loop, respectively)

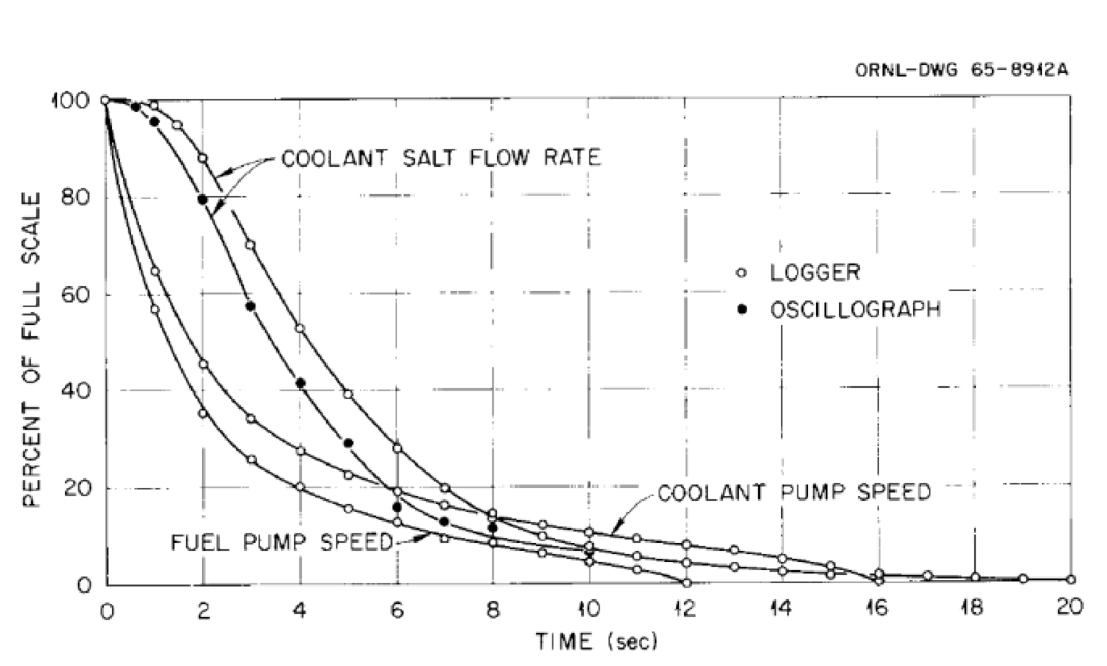
$V_{C/L}$= Fluid volume (core, loop, respectively)

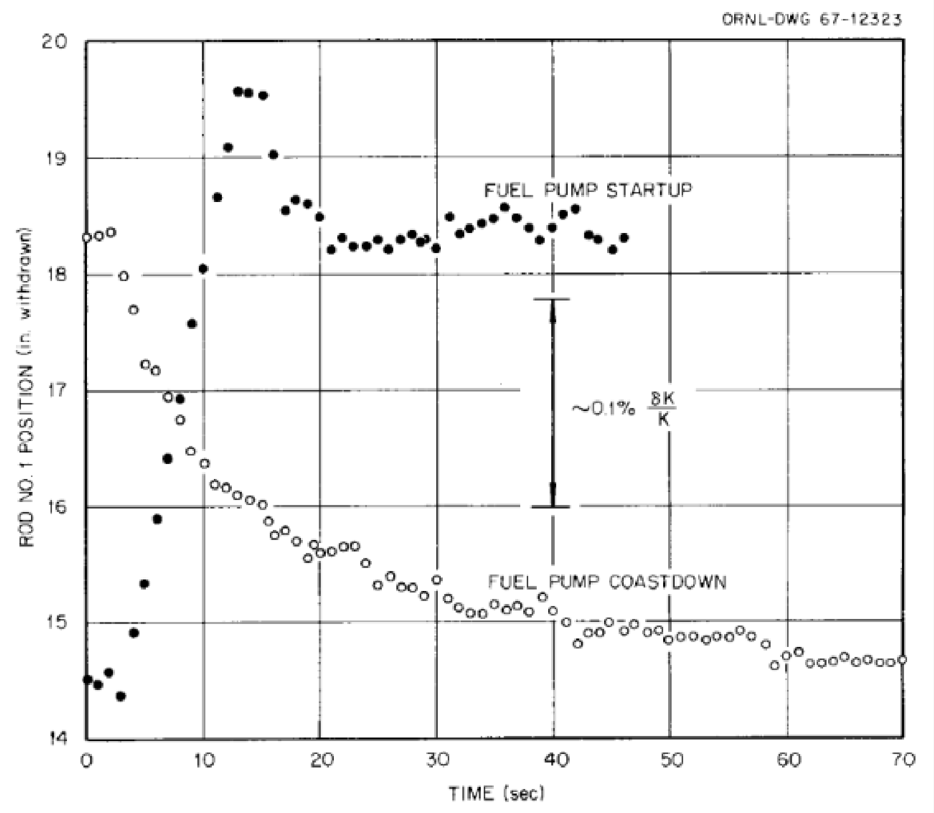
$\lambda_i$= Decay constant of delayed neutron precursor group $i$

# ORNL MSRE Zero-Power Flow Reactivity Experiments

- Null transient was checked
  - Steady-state MSRE model, fluid-fuel PRKE's start at some time with an initial power
  - Verify steady power level (no Δρ) and a bias reactivity due to steady flow
  - Good test of input structures and data read/write capabilities
- Zero-power fuel pump coast-down

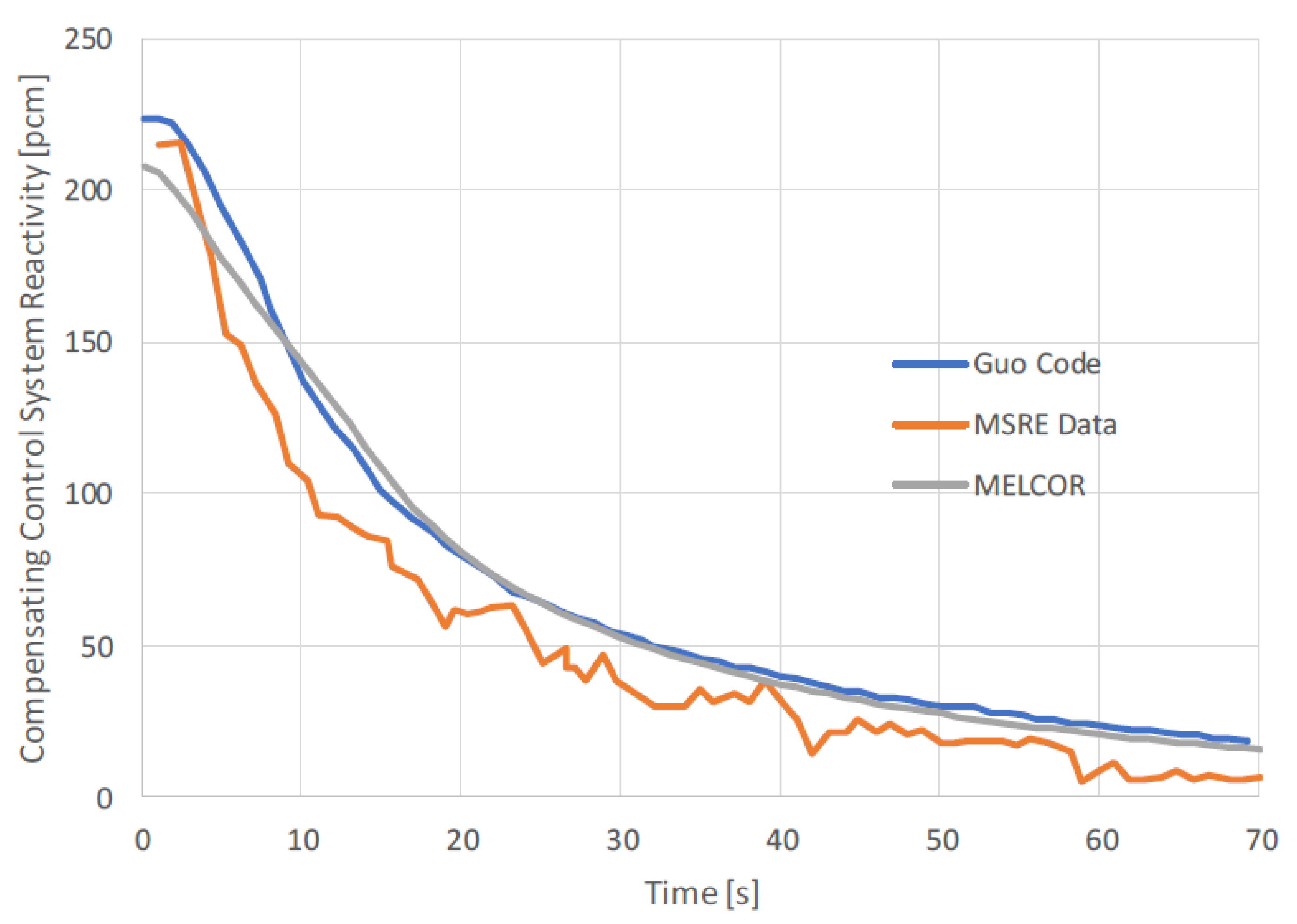
*Fuel circulation worth is: 0.212 +/- 0.004 δK/K

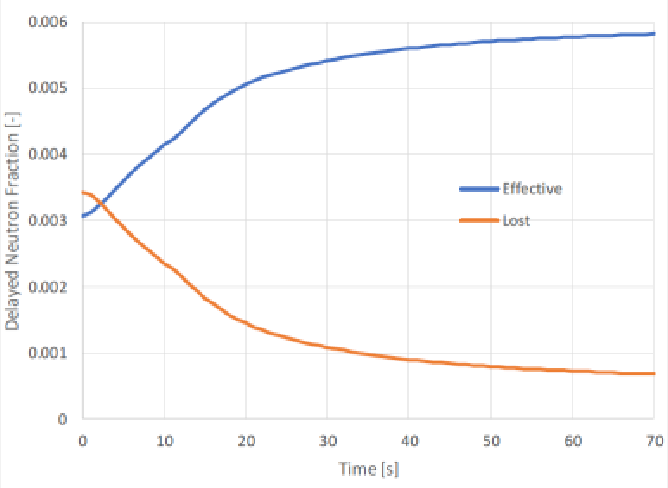


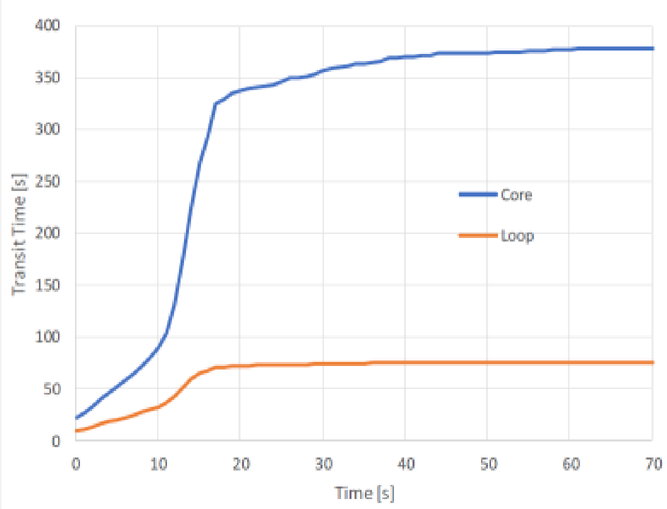



# ORNL MSRE Zero-Power Flow Reactivity Experiments

- Validation of MELCOR FFPRKE predictions against experimental data and a separate computer code



# Conclusions

- To facilitate MELCOR modeling of MSRs, a fluid fuel point reactor kinetics equation model was developed and integrated
- An approach consistent with the systems-level modeling philosophy of MELCOR was taken
- Validation was performed against experimental data from the ORNL MSRE zero-power flow reactivity experiments