DISCLAIMER & COPYRIGHT NOTICE

DISCLAIMER

COPYRIGHT NOTICE

On the Kinetics Critical Excursions Pertinent to the ANS-8.3 Minimum Accident of Concern – a Focus on the *Rapid Transient*

Peter L. Angelo, J. McCall, T. Nore
B&W Y-12 LLC
Y-12 National Security Complex

NCSD 2013
Wilmington NC
Sept 28-Oct 4 2013

The Main Ideas

1. **Divide** Rapid Transient (RT) into two excursion categories

2. **Quantify near field risks** for instantaneous poorly moderated/unmoderated **0.2 Gy in air**

3. Level 1 Calculation method **verified** and to an extent **validated** for **reactivity insertions** for simple models extending from SR to RT

4. **Threshold fission rate** for ANS-8.3 Appendix B Rapid Transient using 1 msec duration - **peak power, FWHM**

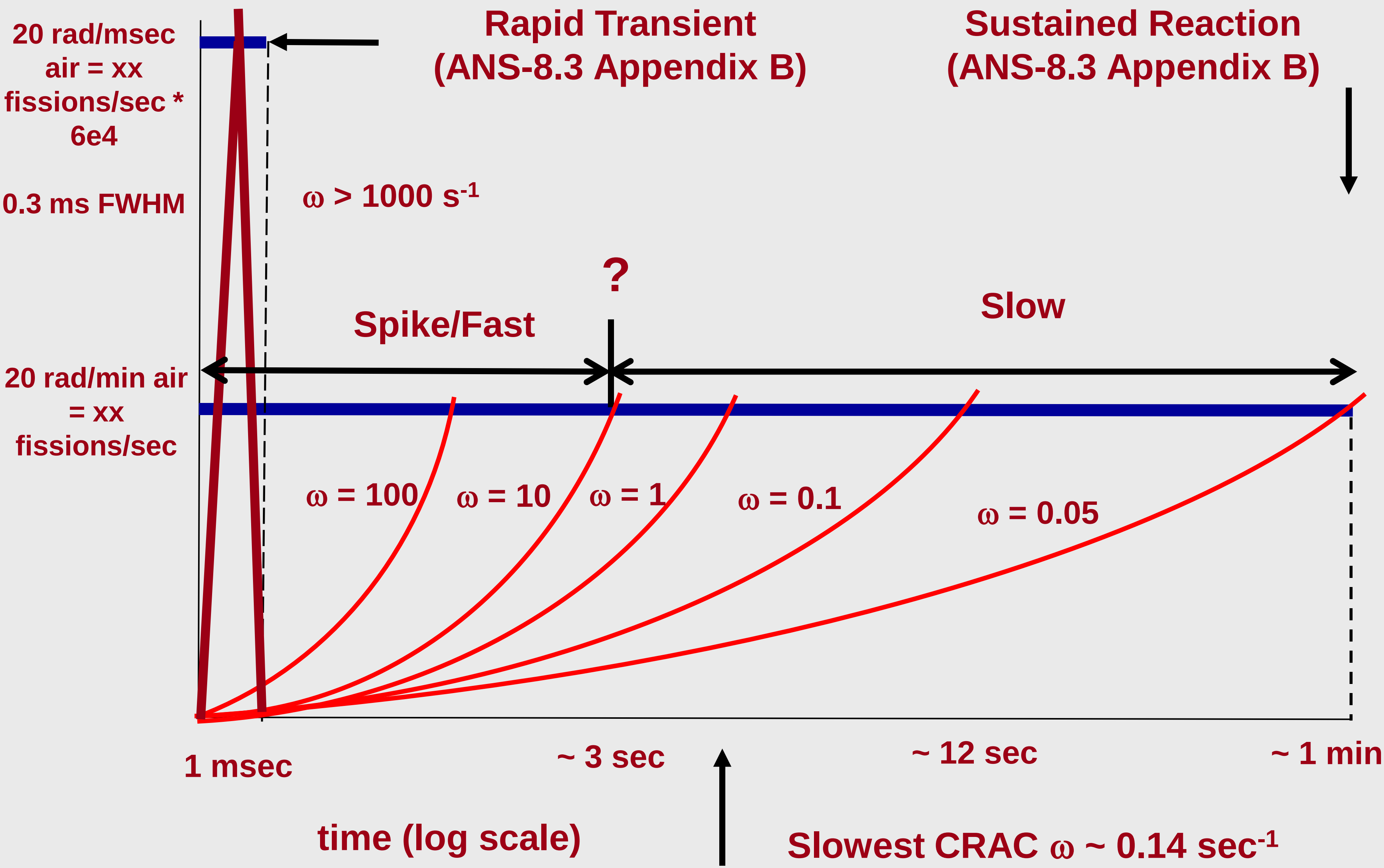
5. Use of excursions kinetics in CAAS is **holistic** across detector response /emergency planning

RT as "Fast Excursion" or "Spike Excursion"

fast excursion *(lower case) – A credible excursion presenting a significant risk within a minimum time at a minimal distance from the reacting assembly.*

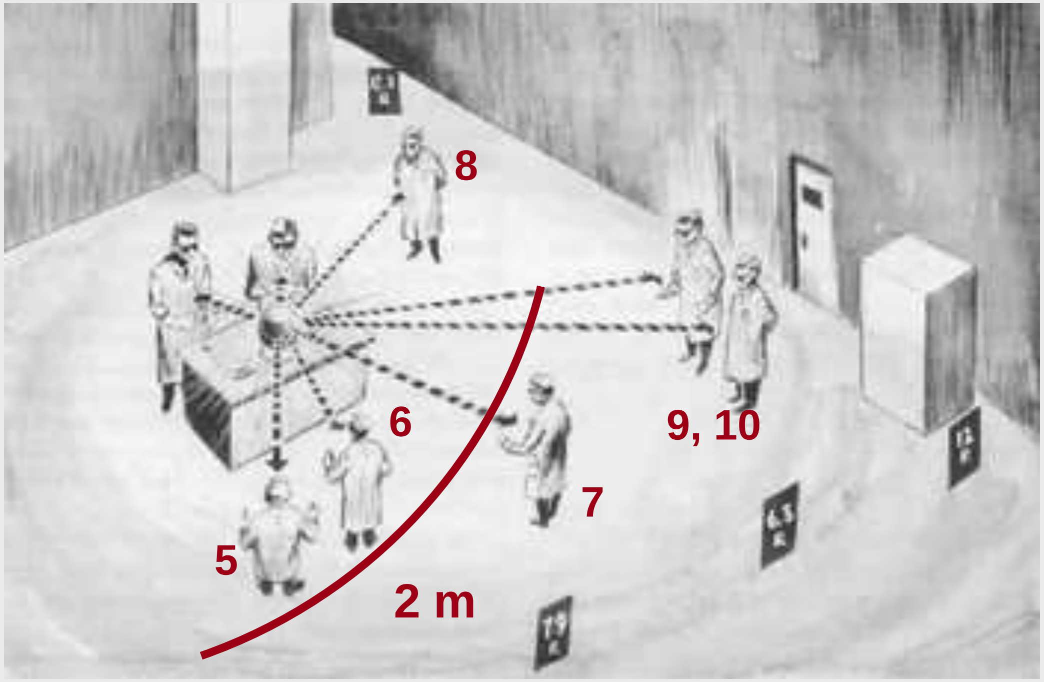
spike excursion *(lower case) – A credible excursion representing an initial prompt critical condition*

Rapid Transient – The Unheralded MAC



Rapid Transient – Near Field Risk

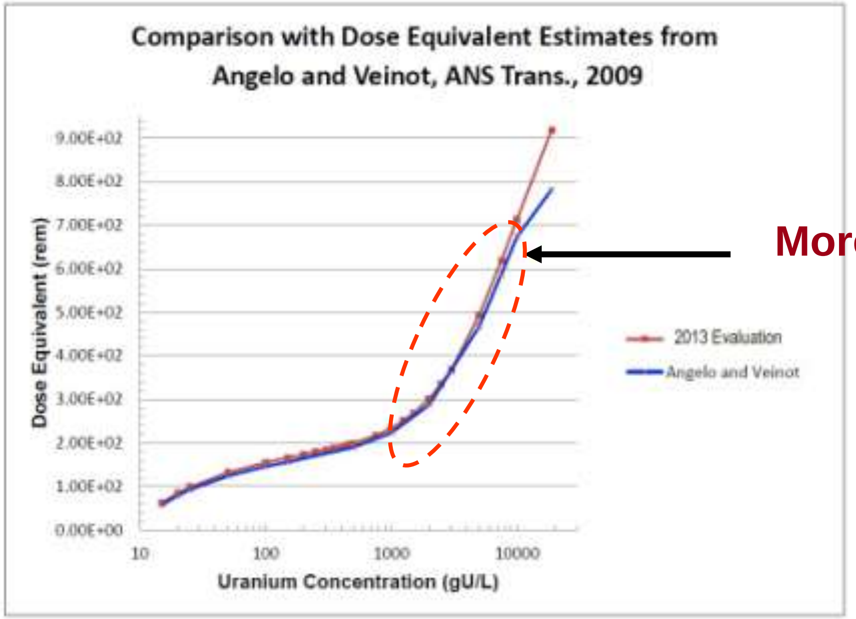
1946 Los Alamos Accident



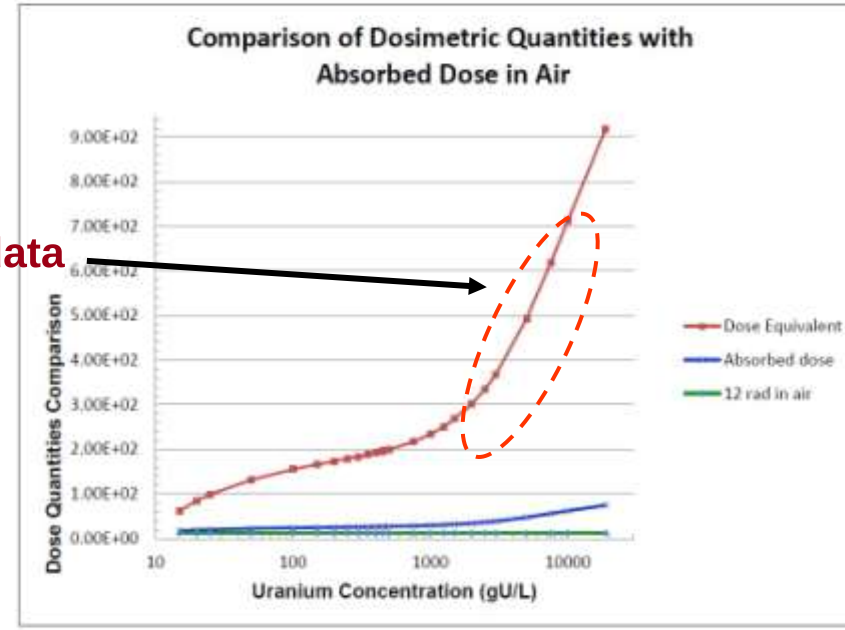
Person	Dist.(m)	Gray (abs)
5	1.5	0.9
6	1.8	0.6
7	2.4	0.2
9,10	5.0	0.1

- **LA-13638** – Pu/Be refl **3e15 fissions** ~ **3 sec, ~ $1.10**
- **ANS-8.3 Appendix A** "**Represents a reasonable lower bound** for accidents terminated by inherent shutdown"
- Hankins, Hansen **LA-3861** (1968) **initial dose construction**
- Hempleman, Lushbaugh – **LA-UR-79-2802**- **survivor history**
- **Absorbed dose at 2 m** ~ **0.4 Gy - half that is 0.2 Gy**

Risks for Instantaneous Dose of 0.2 Gy air @ 2m



More data



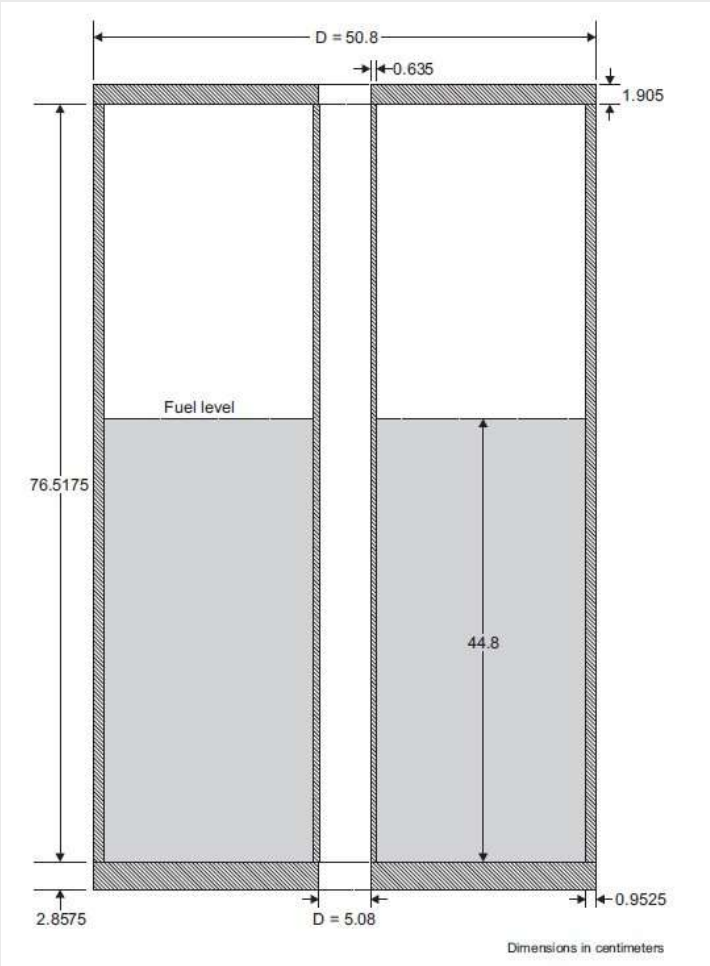
Type	D* (10) Gy	H*(10) Sv
Solution (H/X 500)	0.4	2.2
Poorly Mod (H/X 10)	0.6	**5.6**
Unmod (H/X 0)	1.3	**15.3**

Scale 0.12 Gy air by 5/3

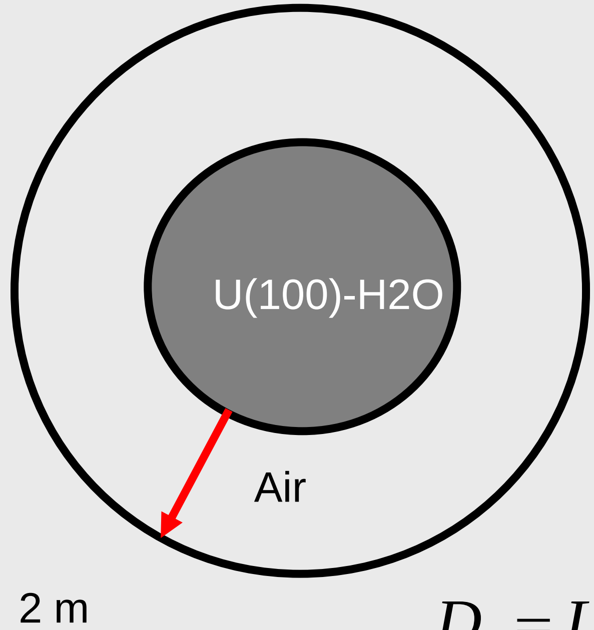
Risk = $5e^{-2}$/Sv

1 Sv threshold for near field considered “adequate protection”

Level 1 Application Cases – Continued from ICNC 2011



LEU-SOL-THERM-001 (SHEBA-II)



$$D_n = L_n * \nu * \Phi_n * dcf_n$$

$$D_\gamma = L_\gamma * \nu * \Phi_\gamma * dcf_\gamma$$

$$F = 20/[D_n + D_\gamma]$$

HEU MOD-METAL-WATER H/X ~ 10, 2500 gU/L

Kinetics, Feedback and Power/Energy Expressions

$$\frac{dP(t)}{dt} = \frac{[\beta - \rho(t)]}{\Lambda} \cdot P(t) - \sum_i \lambda_i \cdot C_i(t) + S(t)$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda} \cdot P(t) - \lambda_i \cdot C_i(t)$$

$$\frac{dT(t,z)}{dt} = f(K_C, P(t), T(t,z))$$

$$\frac{dV(t,z)}{dt} = f(G, P(t), V(t,z))$$

$$\rho(t) = \rho_{ext}(t) + \rho_T(t) + \rho_V(t)$$

Neutronics in 0-D

Temp and Void in 1-D (axial)

$$P(t) = P(0)e^{\omega \cdot t}$$

$$E(t) = \int P(t)dt = \frac{P(t)}{\omega}$$

$$\omega(t) = \frac{P(t)}{E(t)} = \frac{1}{\tau}$$

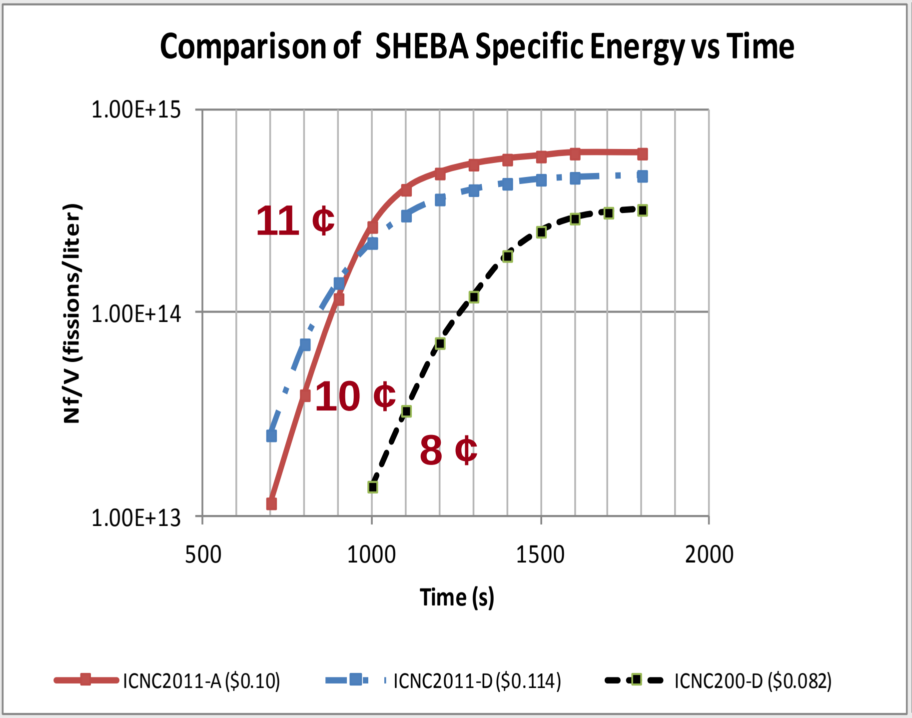
$$\tau \approx \frac{(\beta - \rho)}{\lambda \cdot \rho}$$

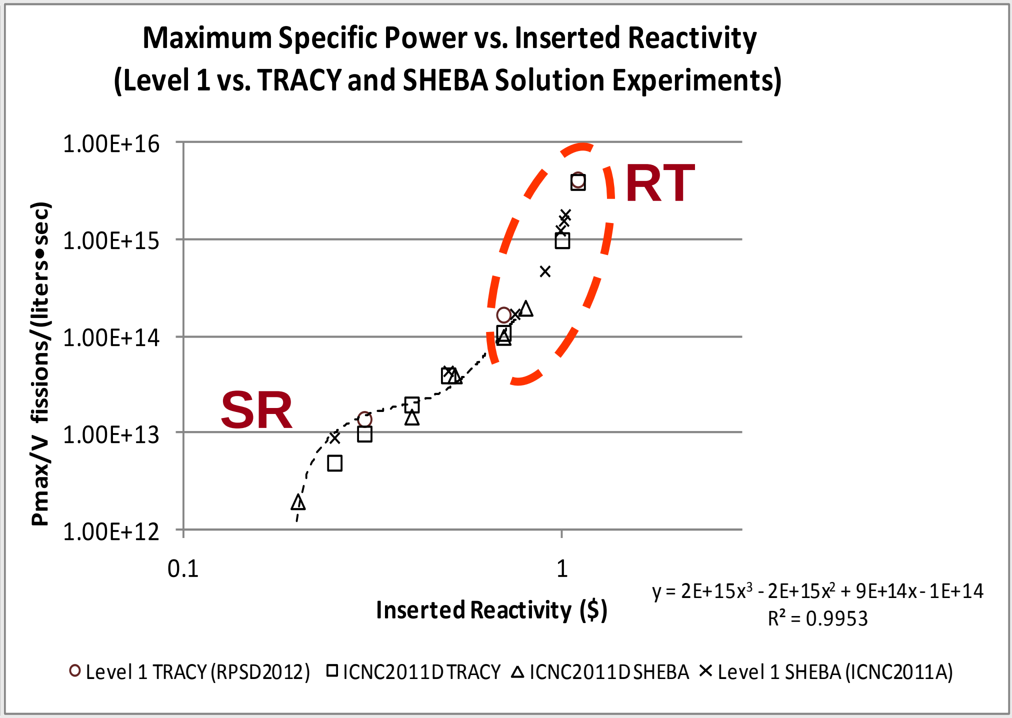
Power and Energy over small Δt

Kinetics and Feedback Parameters w MCNP 5-1.6

Parameter	Name	LEU Solution	HEU Moderated Metal-Water
β	Delayed neutron fraction	**7.11e-3** 3.60e-3, 1.30e-3, 1.07e-3,3.17e-3, 9.6e-4, 3.4e-4	**8.17e-3** 2.40e-4,1.22e 3, 1.28e-3,3.97e-3, 1.04e-3,4.2e-4
λ	Delayed neutron decay constants sec^{-1}	**2.03e-2** 1.29e-2, 3.18e-2, 1.10e-1, 3.18e-1, 1.35e-0, 8.70e-0	**3.23e-2** 1.29e-2, 3.18e-2, 1.10e-1, 3.17e-1, 1.35e-0, 8.64e-0
Λ	Neutron Generation Time	**4.01e-05**	**7.40e-07**
β/Λ	Rossi alpha	**1.77e+2**	**1.1e+4**
α_T	Temperature feedback ($/deg K)	-3.7e-2	-2.0e-2
α_V	Void feedback $/cc	-9.0e-4	-9.0e-4
K_c	Heat Capacity (J/kg-K)	2.16	1.17
G	Gas generation rate cc/kJ	0.67	------------

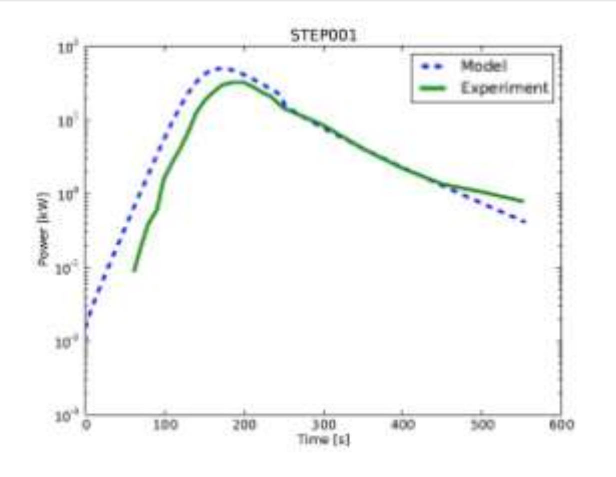
Level 1 Results Compare with Experiments (ICNC 2011)



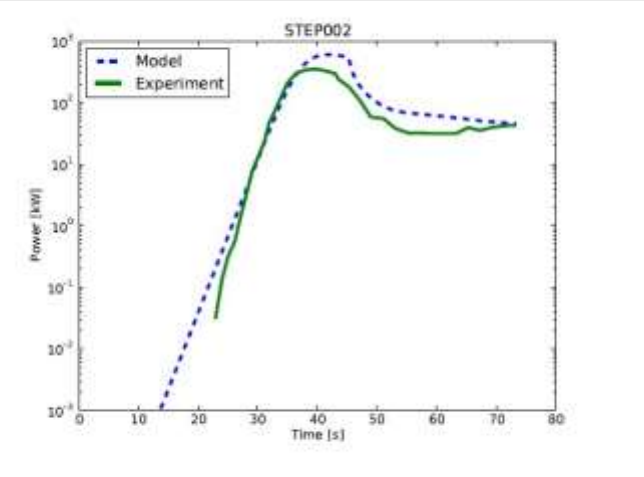


The Level 1 method compares over the range of solution experiment through *Rapid Transient* N_f/V and P_{max}/V (M. Duluc ICNC2011)

Level 1 Peak Power Comparisons with Benchmarks

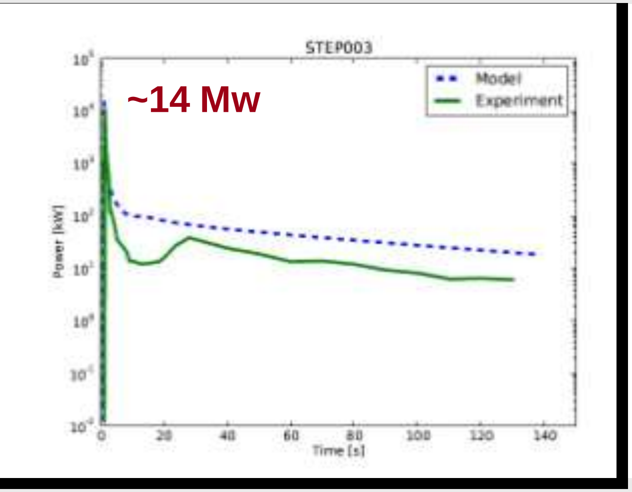


STEP001

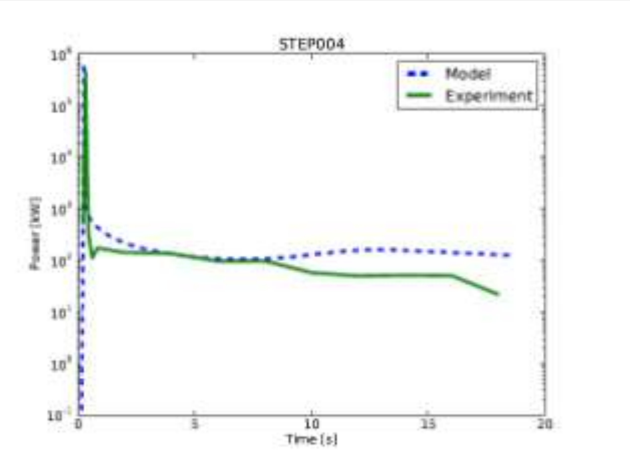


STEP002

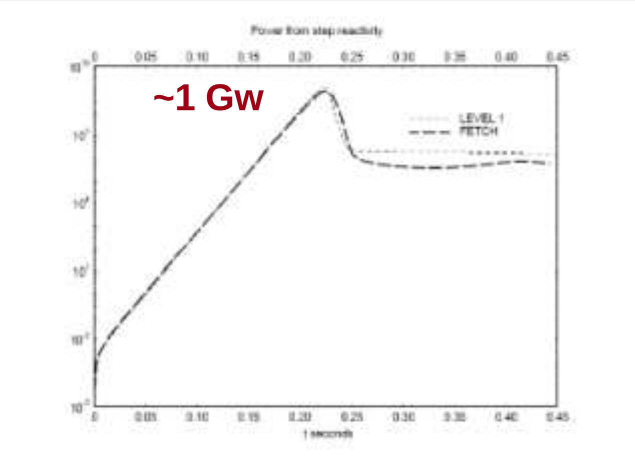
TRACY Benchmark	Step ($)	C/E
STEP001	0.3	1.59
STEP002	0.7	1.63
STEP003	**1.1**	**1.07**
STEP004	2.97	1.21



STEP003



STEP004



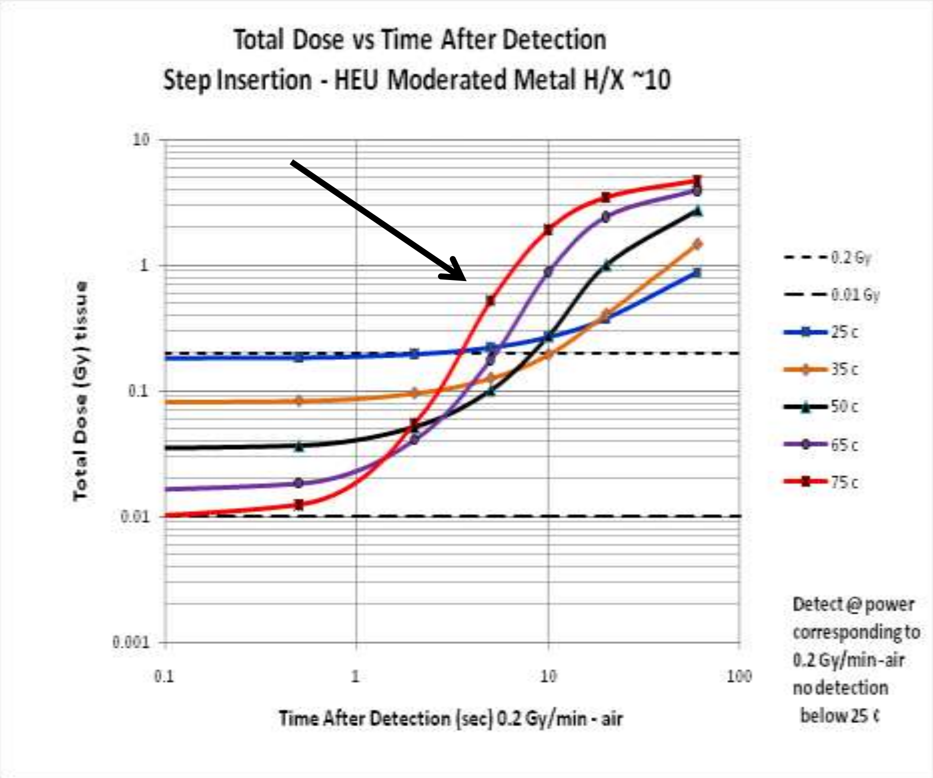
"Level 2" FETCH

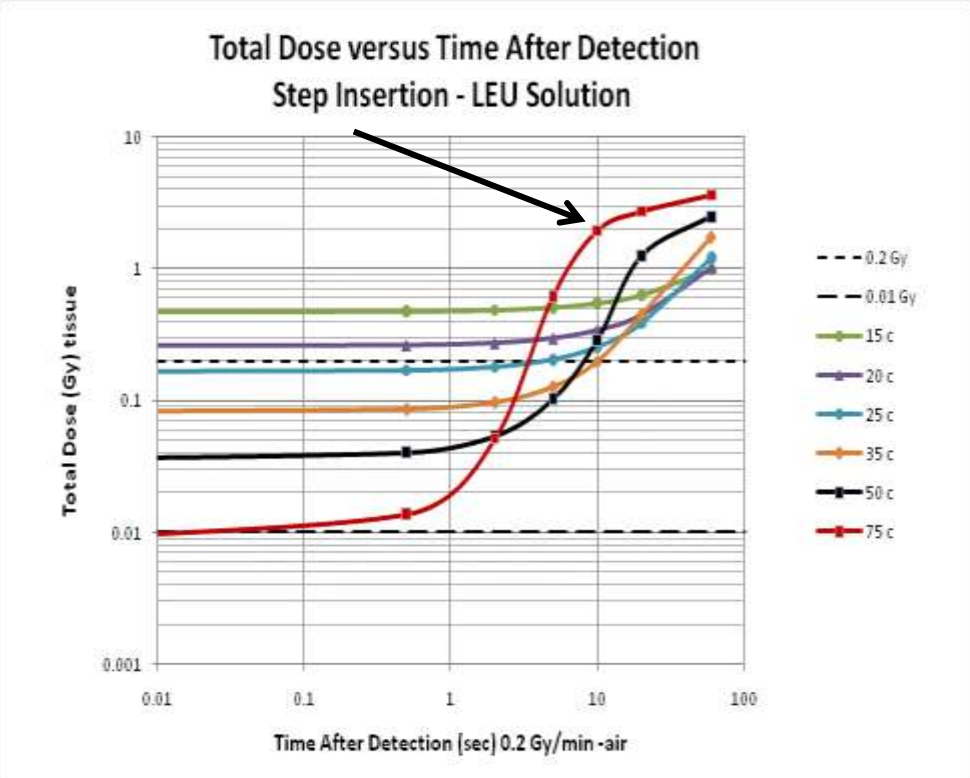
RT Total Fissions, Energy, Fission Rate, Power

Dose response	Total Fissions 0.2 Gy	Total Energy (kJ)	Fission Rate (fissions/sec)	Power (kW)
LEU Solution				
Air (SR)	1.36E+16	4.35E+02	2.26E+14	7.25E+00
Air (RT)			**1.36E+19**	**4.36E+05**
Tissue (SR)	6.15E+15	1.97E+02	1.03E+14	3.28E+00
Tissue (RT)			**6.18E+18**	**1.97E+05**
HEU Mod Metal				
Air (SR)	8.90E+15	2.85E+02	1.48E+14	4.75E+00
Air (RT)			**8.90E+18**	**2.85E+05**
Tissue (SR)	3.90E+15	1.25E+02	6.50E+13	2.08E+00
Tissue (RT)			**3.90E+18**	**1.25E+05**

Question becomes: What are the fast excursion peak fission rates in relation to the *Rapid Transient* thresholds?

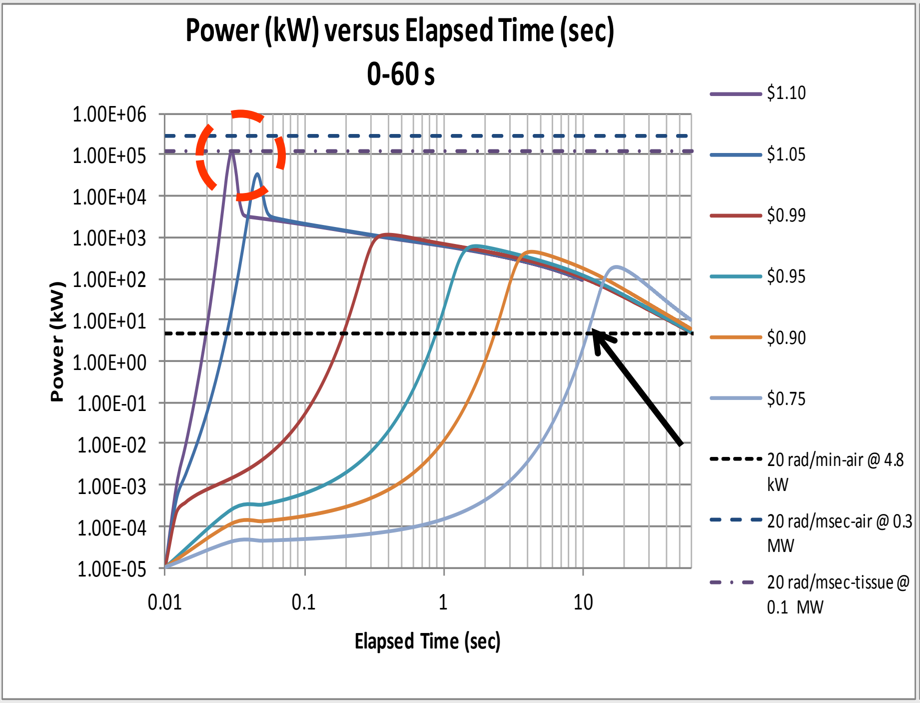
Transition from Slow to Fast Excursion

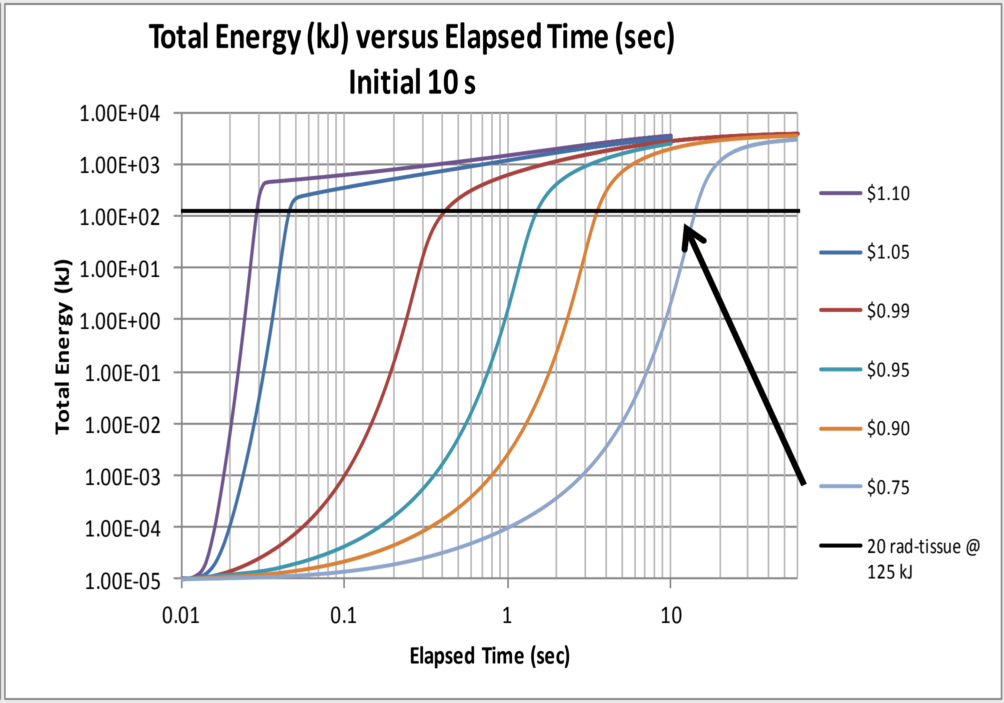




The transition to a fast excursion occurs ~ $0.75

Mod Met Fast Excursion Power and Energy

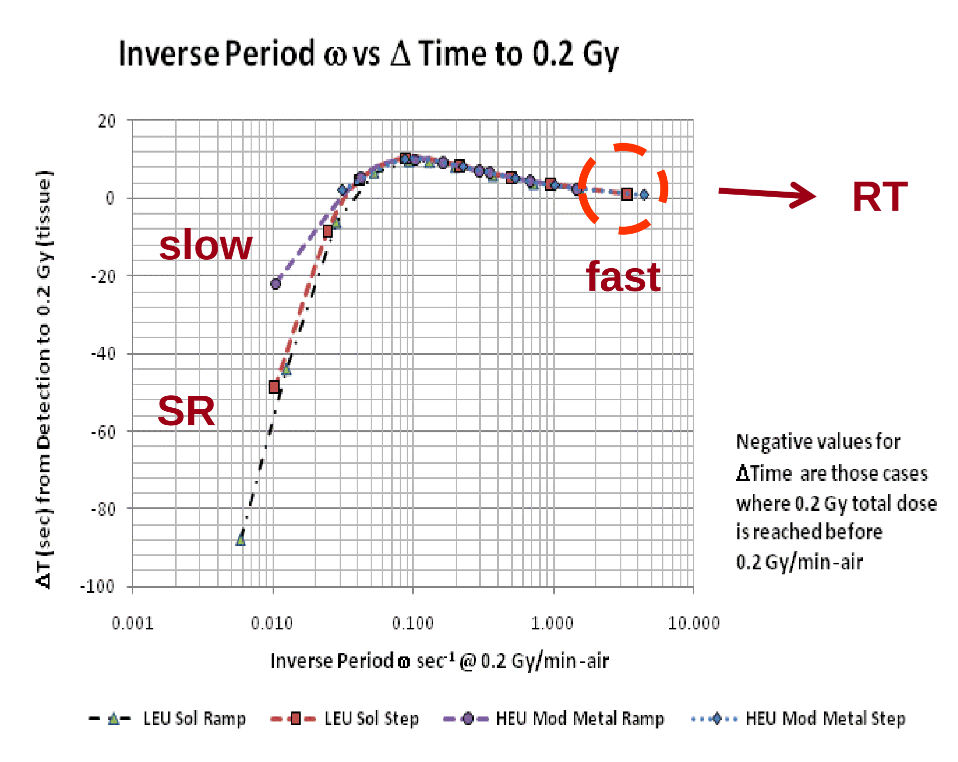


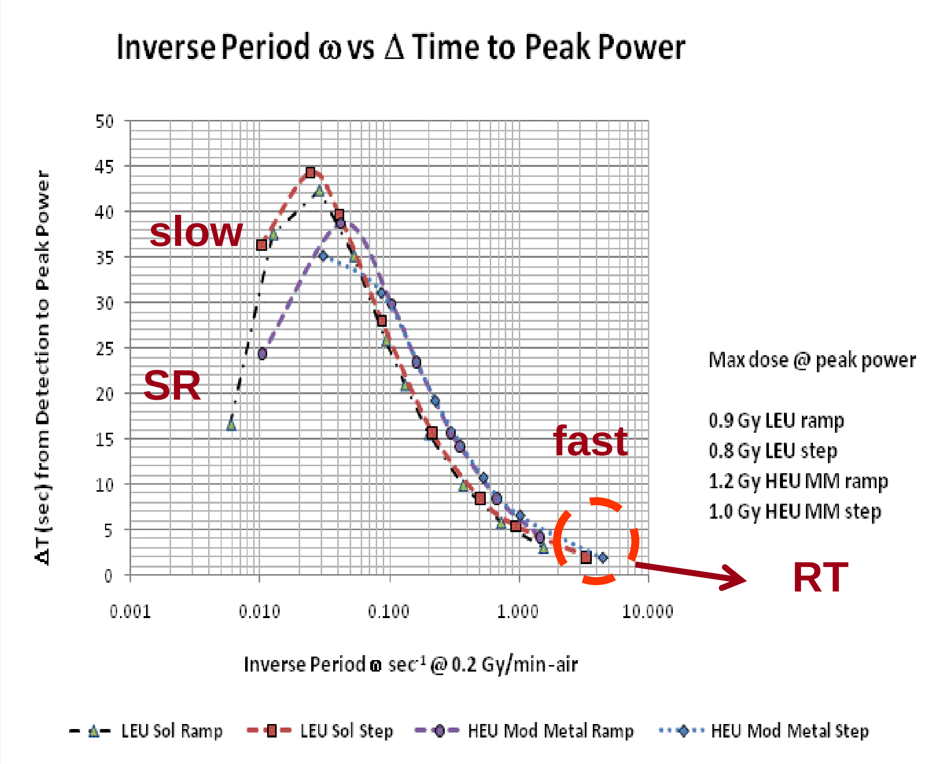


The Δ time between 0.2 Gy/min in air and 0.2 Gy tissue decreases as reactivity insertion increases - $0.75 is ~3 s

Spike excursion power are less than that for 0.2 Gy/msec in air or tissue

Rapid Transient vs. Sustained Reaction ΔTime

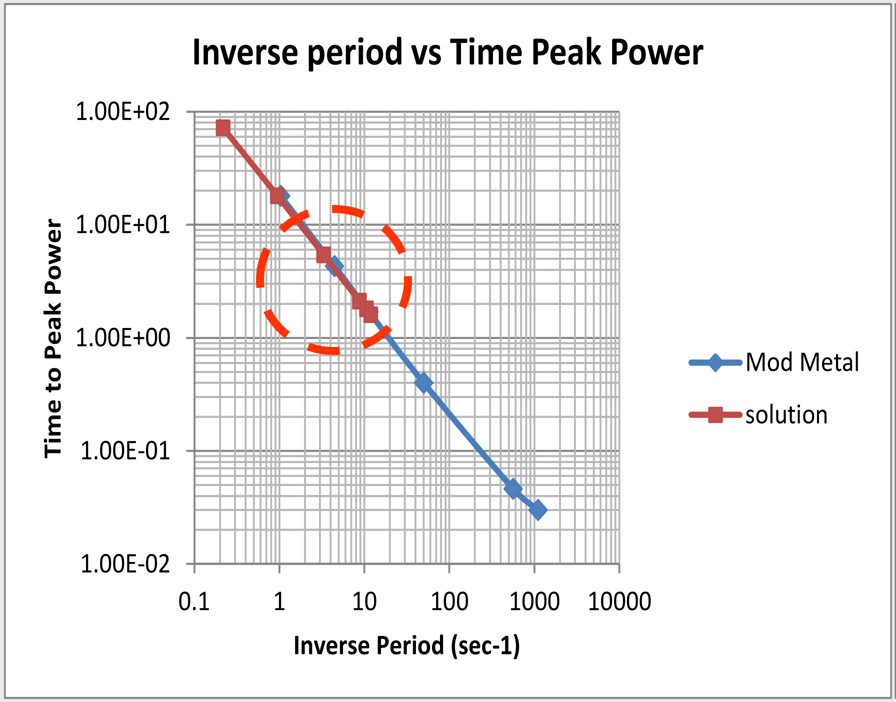


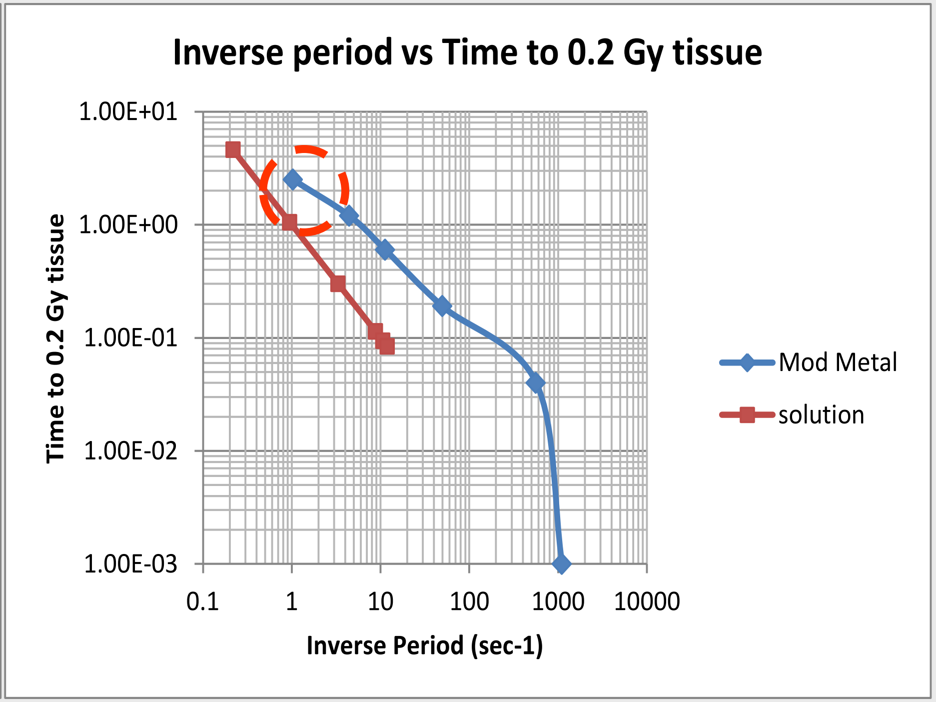


As inverse period increases (faster excursion), Δ Time decreases

Independent of material form, type, reactivity insertion modality

Fast Excursion Inverse Periods

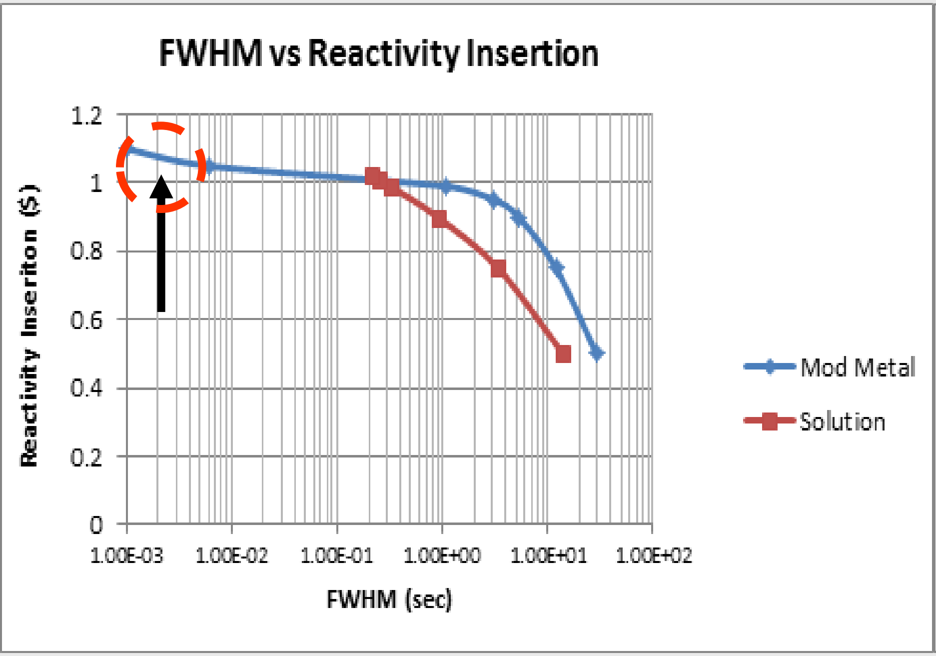


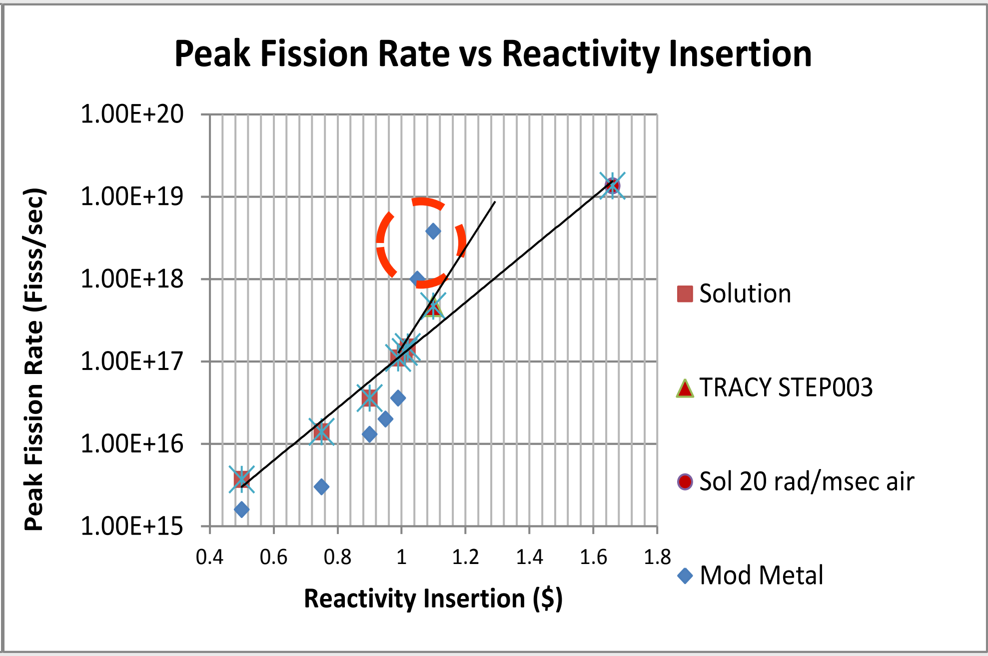


Inverse periods are model invariant from 1-1000 s^{-1}

"Time Period of Interest" for Fast Excursion ~ 3-5 s

FWHM, Peak Fission Rate vs. Reactivity Insertion





FWHM of 0.3 ms ~ $ 1.10 insertion Mod Metal < threshold RT
Thus CAAS set to ANS-8.3 RT min duration may not respond

Solution Excursion behavior "predictable"
0.2 Gy/min in air fission rate RT ~ $1.6 air, $1.3 tissue

Consequence and RT Kinetics Summary

- Stochastic risk associated with 0.2 Gy air/msec (ANS-8.3 App B) Rapid Transient increases as moderation decreases

- 1 Sv is “adequate protection” in near field (approx. 2 m)

- Transition from slow to fast excursion ~ $ 0.75 (3-5 s to get away)

- Excursion kinetics show that ANS-8.3 App **B RT fission rate higher** than fast excursions peak power < $ 1.3 solution (nonresponse)

- **Propose a “fast excursion” 1-2×10^{15} fissions** with inverse period of 1s^{-1} over a TPI 3-5 s

Applications of Fast Excursions Kinetics

Emergency Planning and Response (EP&R) Exercises

Conservative peak fission rate - CAAS, tail fissions - EP&R

$0.99 HEU Mod Met chosen for April 2013 exercise (critical on person reflection)

3 seconds to shutdown (walk away) – subsequent extended subcritical – 4e15 total fissions determined by kinetics

D*(10) doses for individuals (3 s) compares to Slide Rule (@ 1 min)

Transition to ANS-8.23 “predicted accident characteristics”