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

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NCSD 2013

Wilmington NC

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The Main Ideas

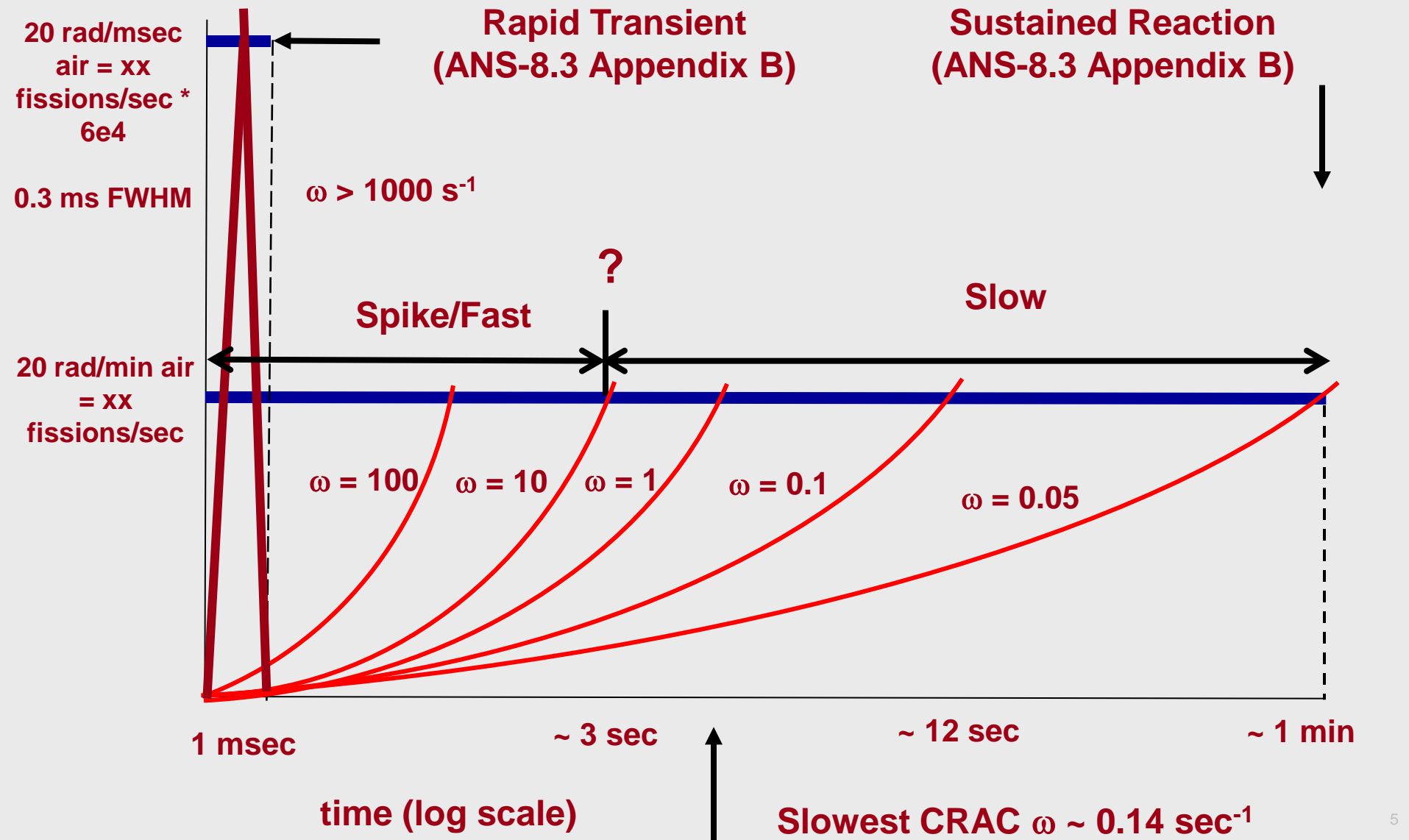
1. **Divide** Rapid Transient (RT) into two excursion categories
2. **Quantify near field risks** for instantaneous poorly moderated/unmoderated **0.2 Gy in air**
3. Level 1 Calculation method **verified** and to an extent **validated** for **reactivity insertions** for simple models extending from SR 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.

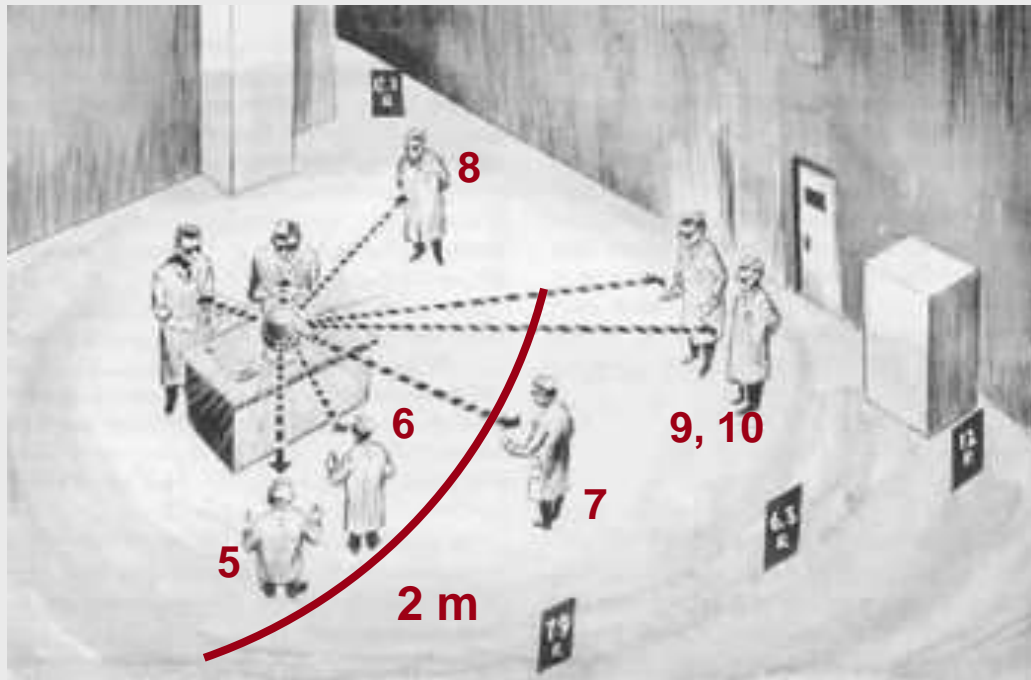
spike excursion (lower case) – A credible excursion representing an initial prompt critical condition

Rapid Transient – The Unheralded MAC



Rapid Transient – Near Field Risk

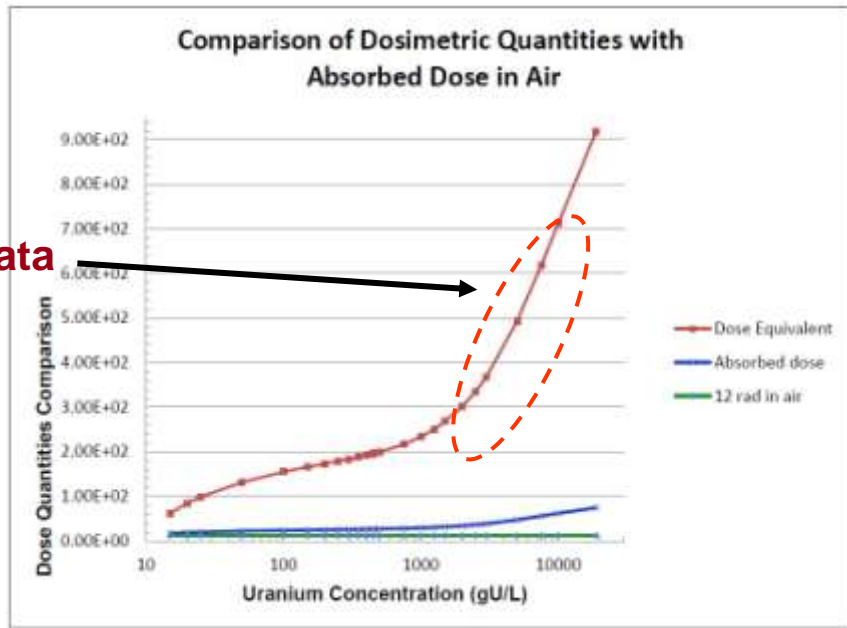
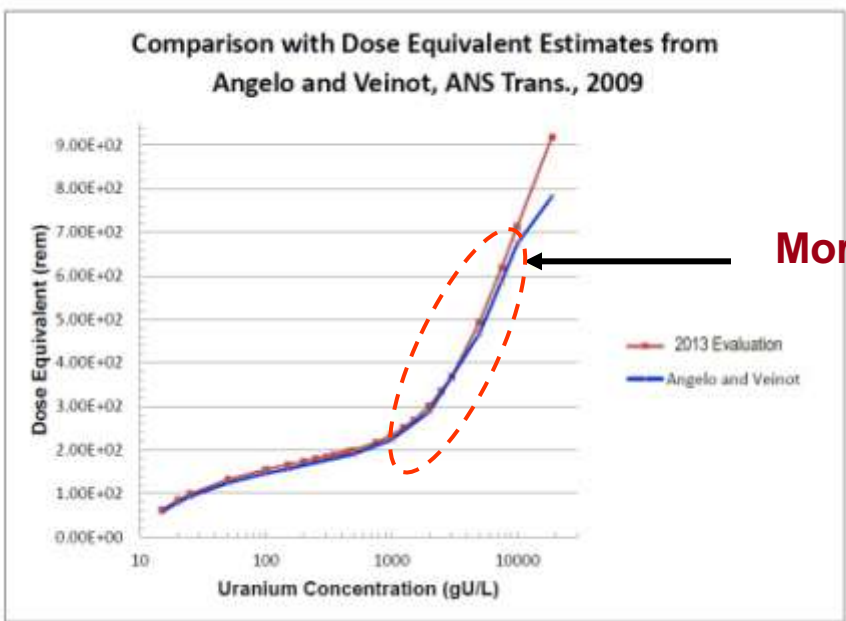
1946 Los Alamos Accident



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”

Technical drawing of a rectangular container with dimensions in centimeters. The drawing shows a cross-section of a container with a central vertical divider. The total width is $D = 50.8$. The width of the central divider is $D = 5.08$. The width of each side chamber is 2.8575 . The total height is 76.5175 . The height of the fuel level is 44.8 . The thickness of the top and bottom plates is 1.905 . The thickness of the central divider is 0.635 . The thickness of the side walls is 0.9525 . The fuel level is indicated by a horizontal line in the left chamber.



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

HEU MOD-METAL-WATER

H/X ~ 10, 2500 gU/L

Kinetics, Feedback and Power/Energy Expressions

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

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

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

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

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

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

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

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

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

Neutronics in 0-D

Temp and Void in 1-D (axial)

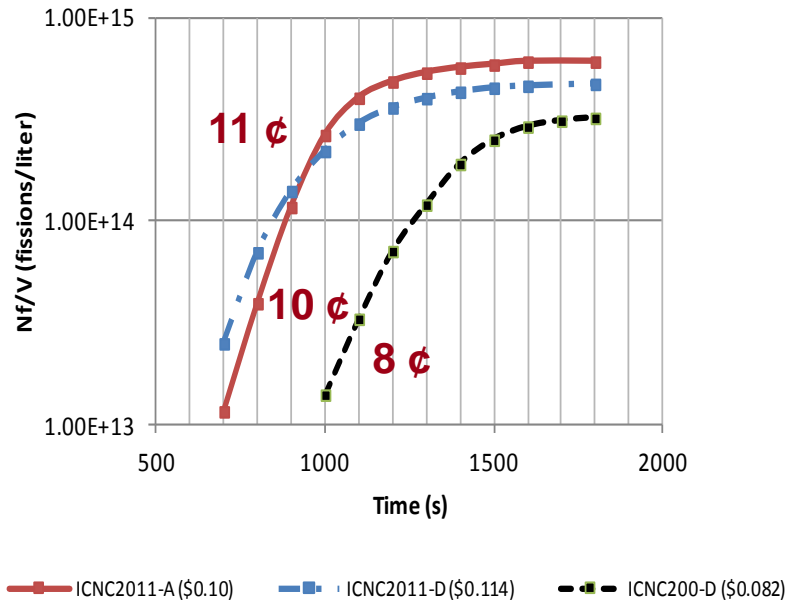
**Power and Energy over
small Δt**

Kinetics and Feedback Parameters w MCNP 5-1.6

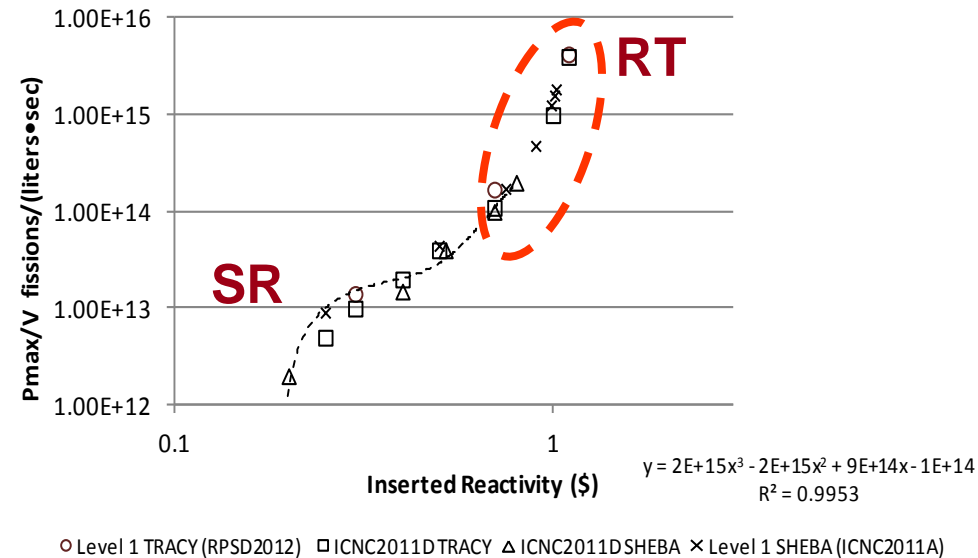
Parameter	Name	LEU Solution	HEU Moderated Metal-Water
β	Delayed neutron fraction	7.11e-3 3.60e-3, 1.30e-3, 1.07e-3, 3.17e-3, 9.6e-4, 3.4e-4	8.17e-3 2.40e-4, 1.22e-3, 1.28e-3, 3.97e-3, 1.04e-3, 4.2e-4
λ	Delayed neutron decay constants sec ⁻¹	2.03e-2 1.29e-2, 3.18e-2, 1.10e-1, 3.18e-1, 1.35e-0, 8.70e-0	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)

Comparison of SHEBA Specific Energy vs Time

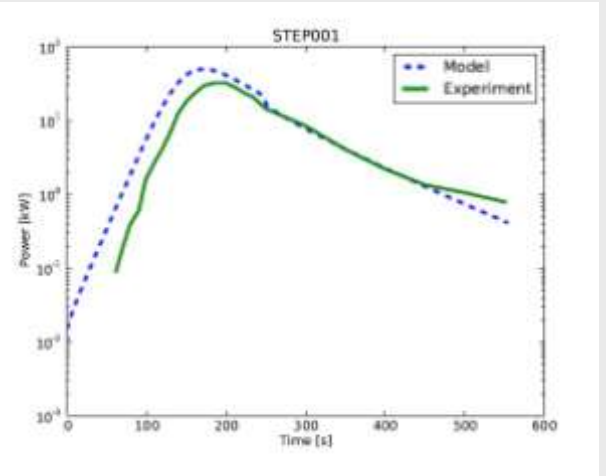


Maximum Specific Power vs. Inserted Reactivity
(Level 1 vs. TRACY and SHEBA Solution Experiments)

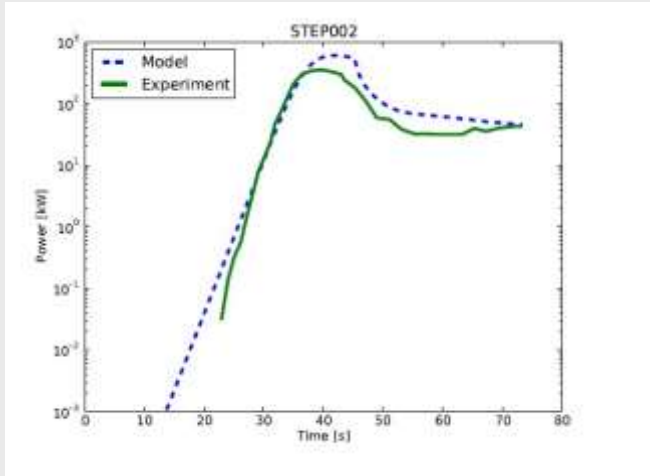


The Level 1 method compares
over the range of solution experiment through
Rapid Transient
 N_f/V and P_{max}/V (M. Duluc ICNC2011)

Level 1 Peak Power Comparisons with Benchmarks

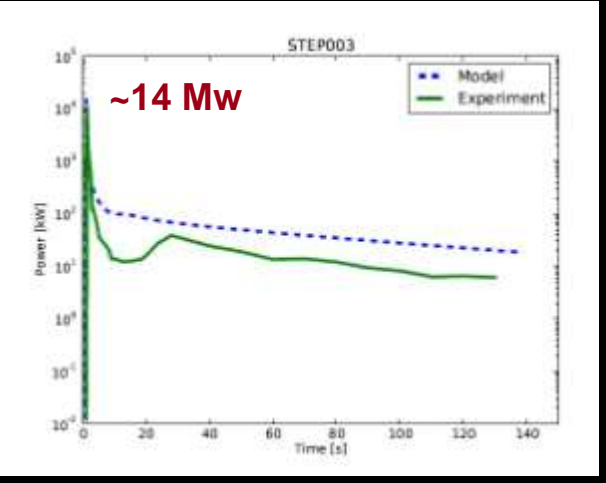


STEP001

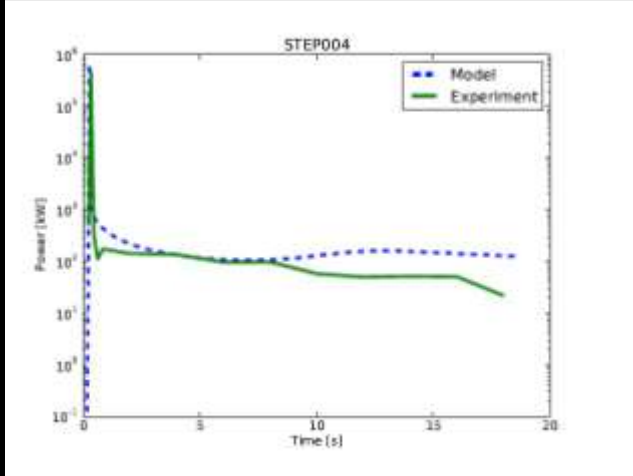


STEP002

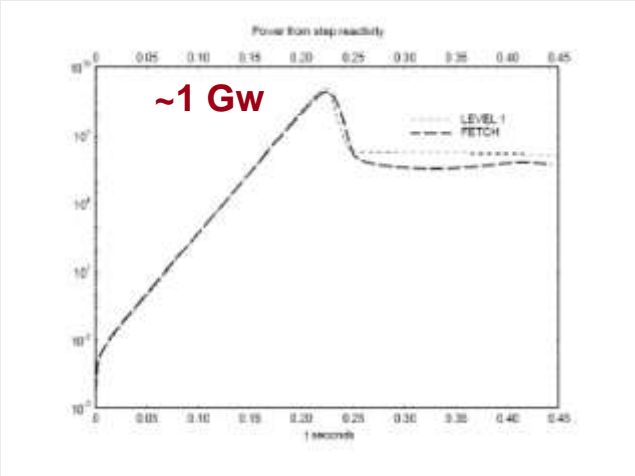
TRACY Benchmark	Step (\$)	C/E
STEP001	0.3	1.59
STEP002	0.7	1.63
STEP003	1.1	1.07
STEP004	2.97	1.21



STEP003



STEP004



“Level 2” FETCH

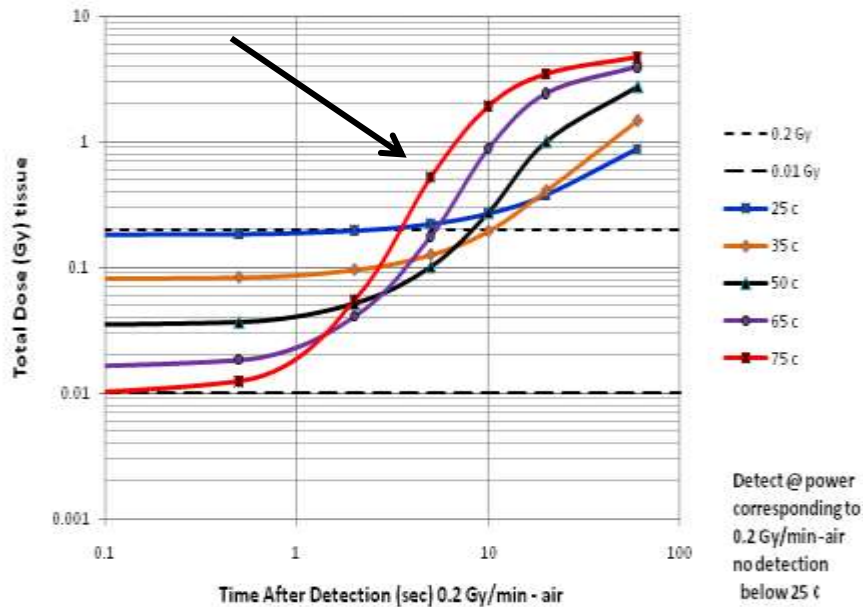
RT Total Fissions, Energy, Fission Rate, Power

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

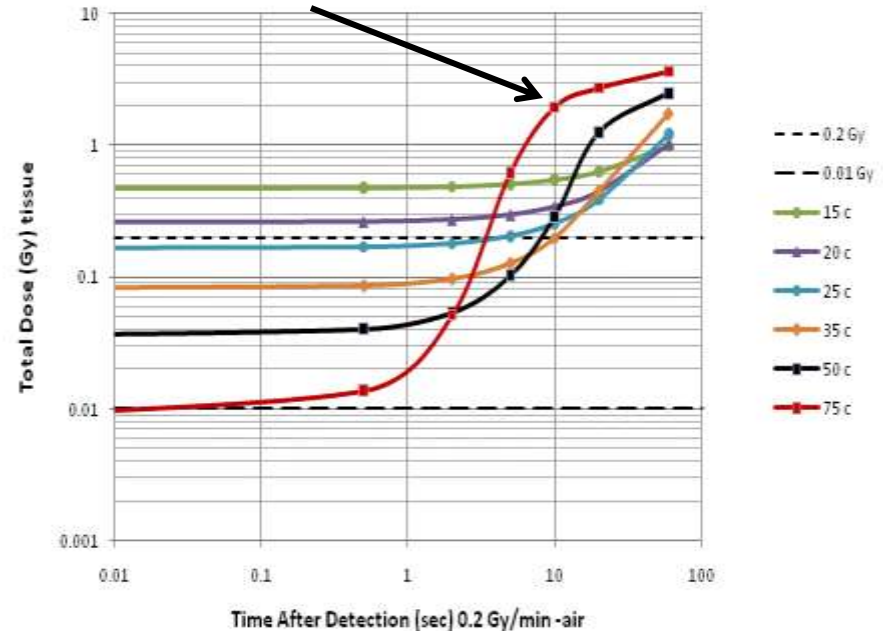
Question becomes: What are the fast excursion peak fission rates in relation to the *Rapid Transient* thresholds?

Transition from Slow to Fast Excursion

Total Dose vs Time After Detection
Step Insertion - HEU Moderated Metal H/X ~10

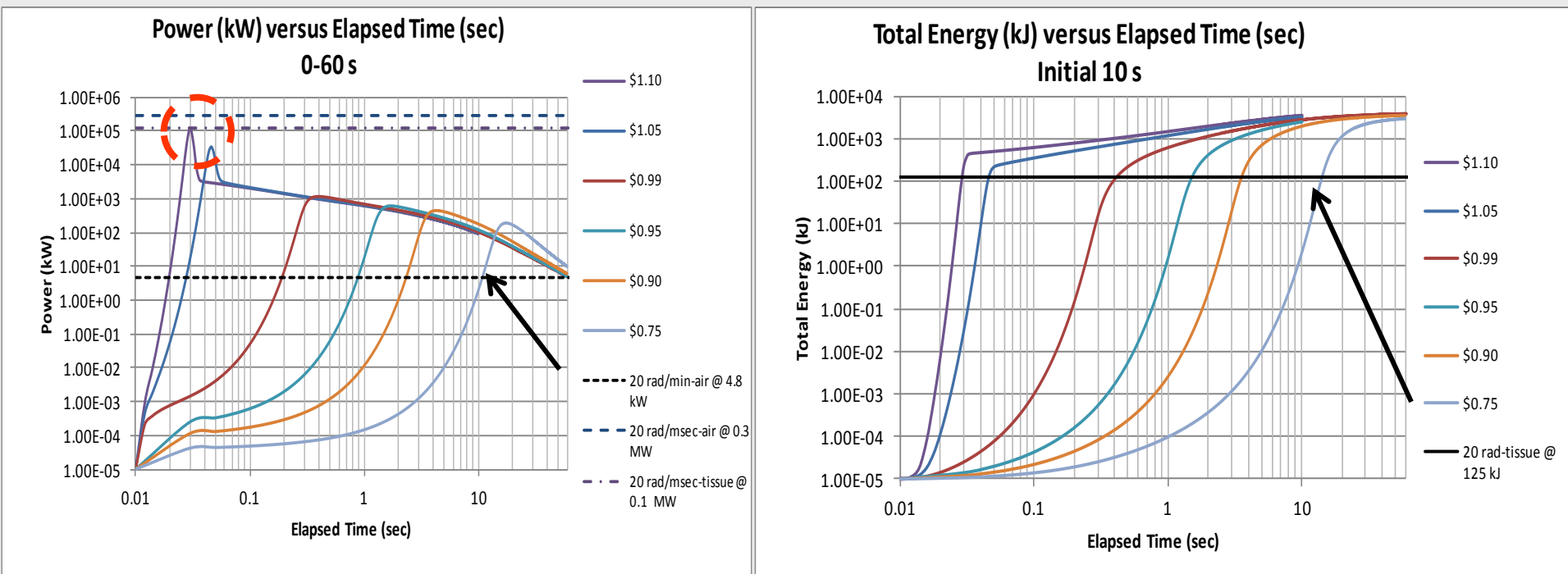


Total Dose versus Time After Detection
Step Insertion - LEU Solution



The transition to a fast excursion occurs ~ \$0.75

Mod Met Fast Excursion Power and Energy

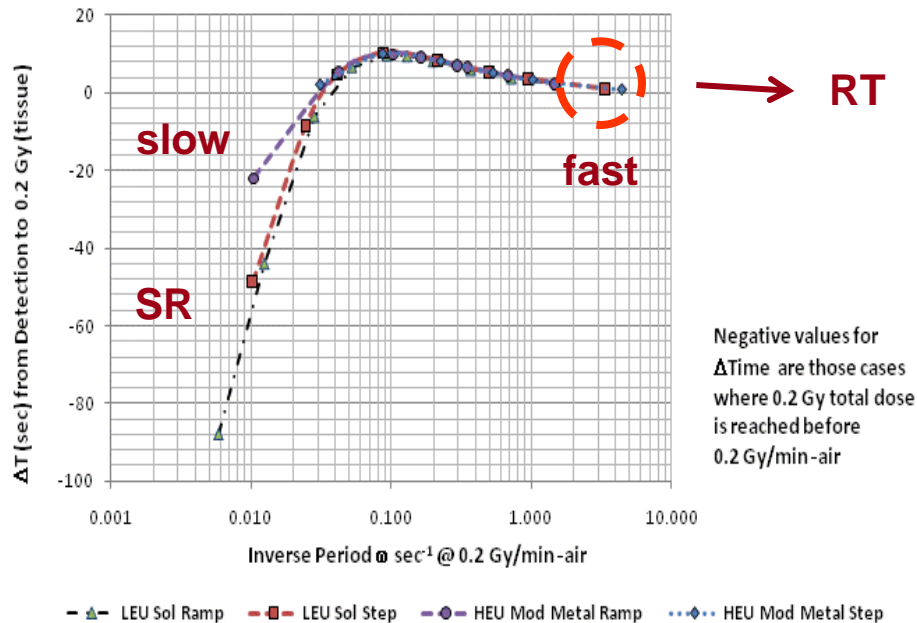


The Δ time between 0.2 Gy/min in air and 0.2 Gy tissue decreases as reactivity insertion increases - \$0.75 is ~3 s

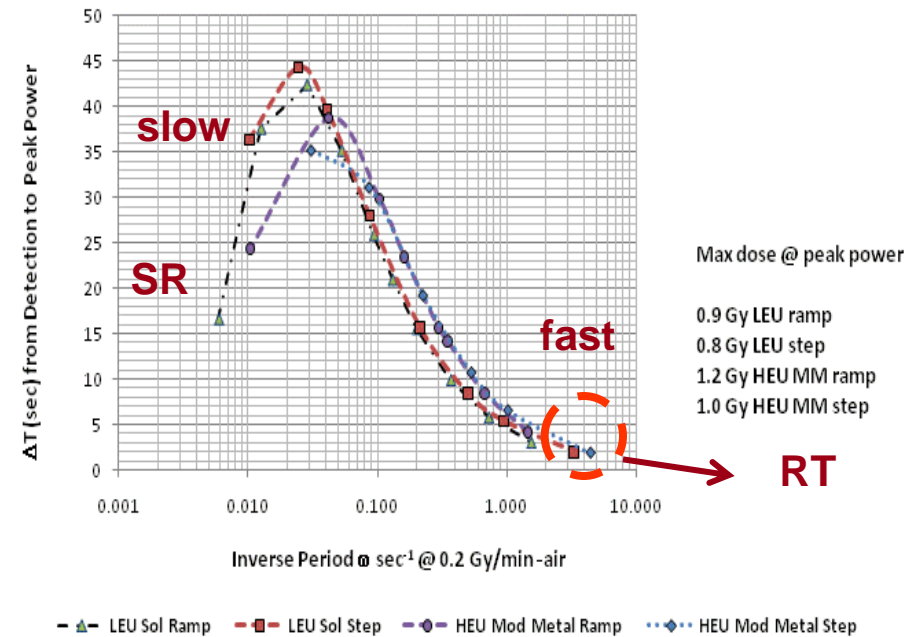
Spike excursion power are less than that for 0.2 Gy/msec in air or tissue

Rapid Transient vs. Sustained Reaction Δ Time

Inverse Period ω vs Δ Time to 0.2 Gy



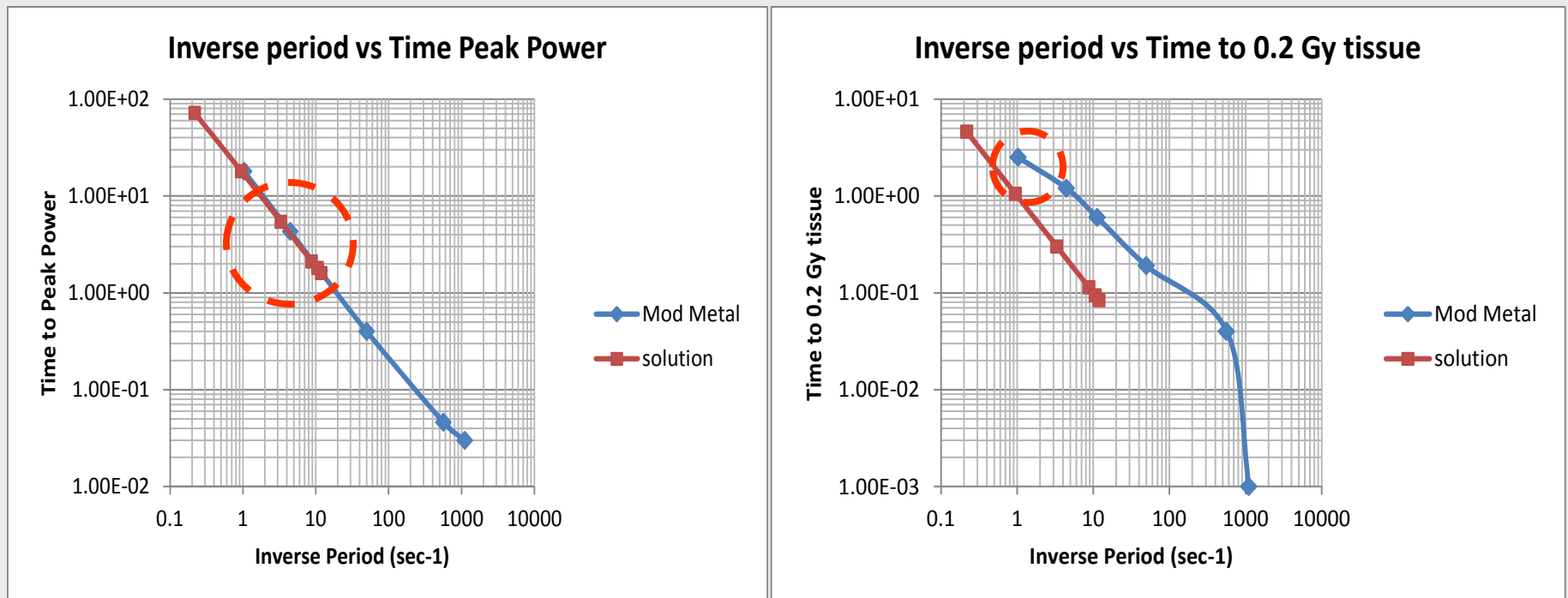
Inverse Period ω vs Δ Time to Peak Power



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

Independent of material form, type, reactivity insertion modality

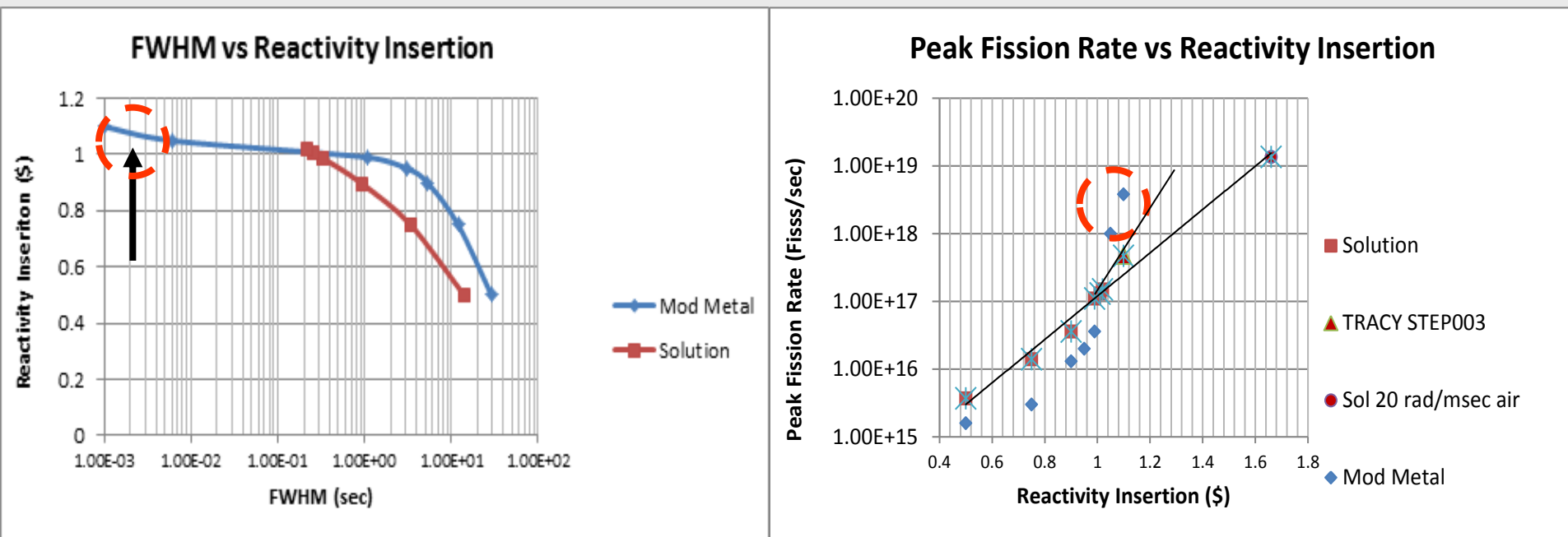
Fast Excursion Inverse Periods



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” $1-2 \times 10^{15}$ 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”