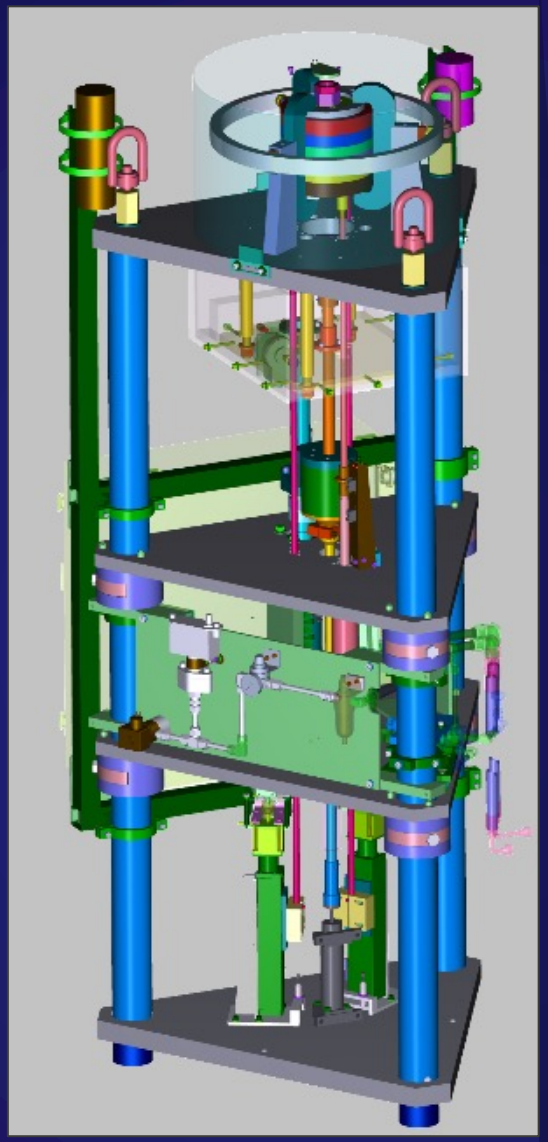

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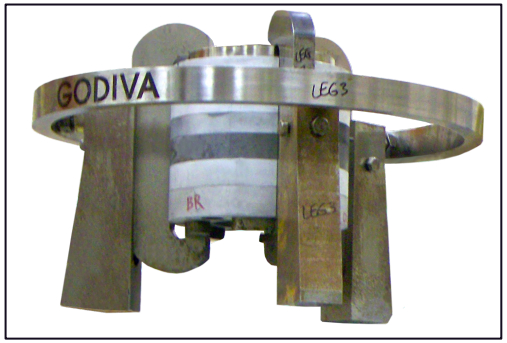
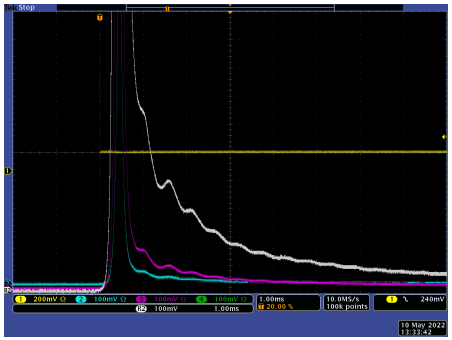
Godiva IV Radiation Signature Ringing





Robert Weldon, Joetta Goda,
Travis Grove, Robert Kimpland

Nuclear Engineering and
Nonproliferation Advanced
Nuclear Technology (NEN-2)
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2/22/2023

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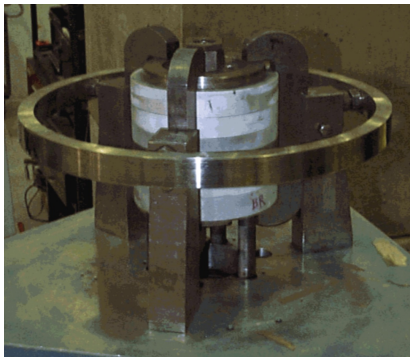
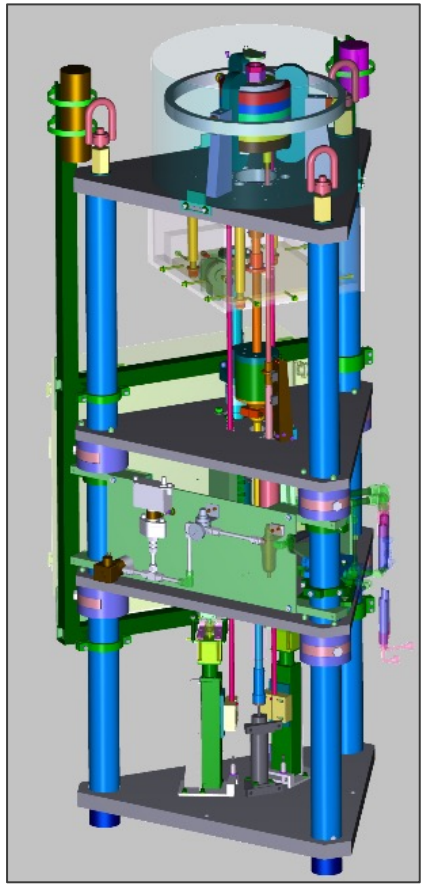
Godiva IV

- Godiva IV is NCERC's baseline HEU system
- Composed of several HEU pieces (65 kg)
  - 6 cylindrical, stacked, interlocking rings
  - Safety block
  - Two control rods
  - Burst rod
- Standard burst sizes at NCERC by temperature rise: 70, 150, 250 °C
- IER-557: provided an opportunity to deploy new detectors around Godiva
  - More sensitive detectors → measurements of "ringing" in the radiation signal
  - Burst physics need to be studied in more detail

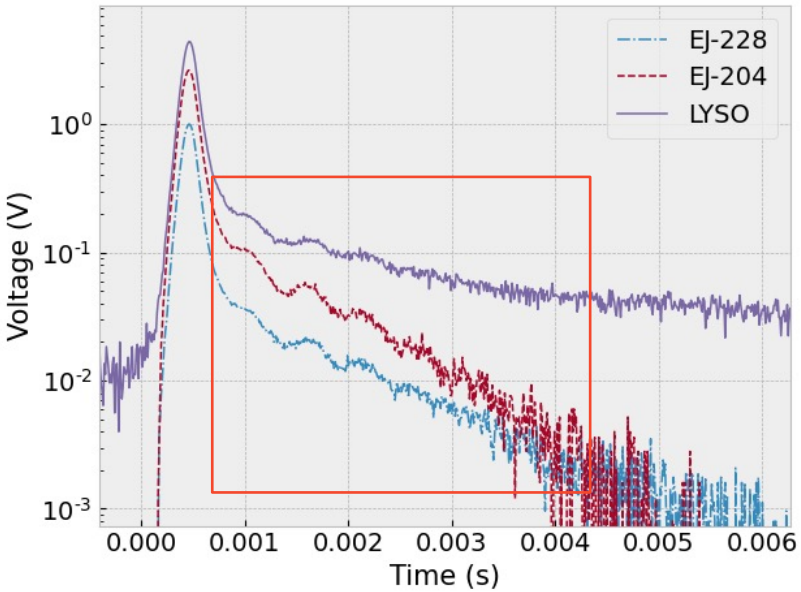
Safety block, control rods and burst rod

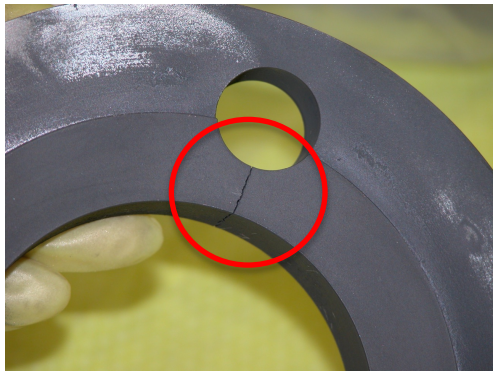




Thermo-mechanical ringing in FBRs

- < 70 μs FWHM bursts → extremely fast temperature rise
- Material expansion lags temperature rise due to mechanical inertia
- Thermal energy is converted into mechanical
  - Mechanical stresses are superimposed on thermal stresses
  - Thermo-mechanical ringing
  - Note: possible for total system stresses to surpass tensile strength leading to fractures and damage to the reactor
- Godiva IV was designed to minimize thermo-mechanical shock
  - C-clamps
    - Secure fuel to support structure at central horizontal plane (limits oscillations due to symmetry)
    - Act as "springs" to reduce impact of oscillations
  - Central cavity
  - Alloyed with 1.5% Mo for strength

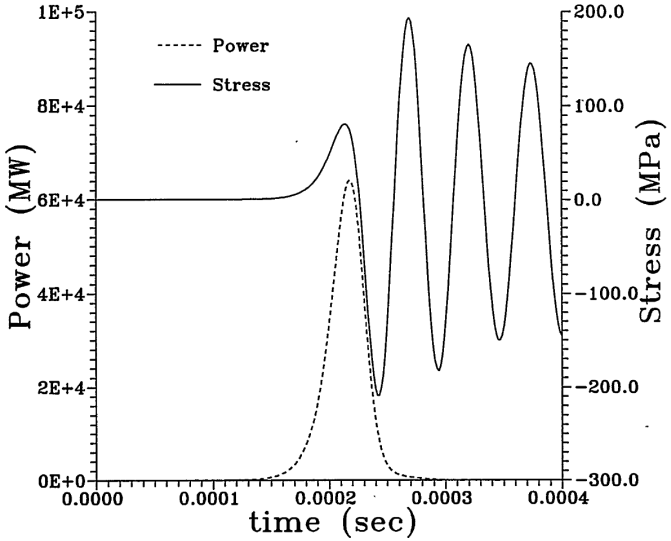


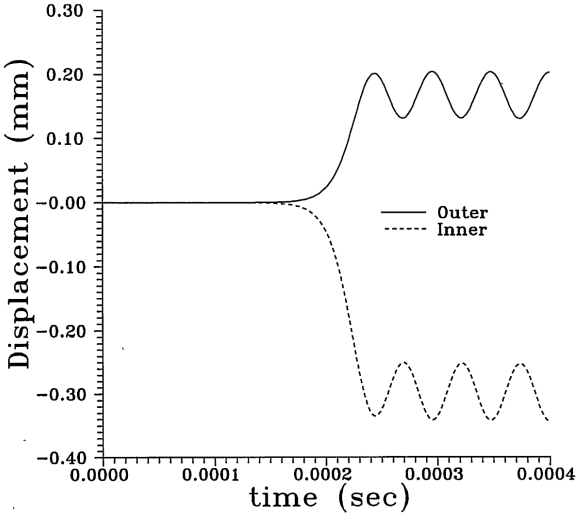


Previous studies of thermo-mechanical ringing

Thermo-mechanical modeling for Godiva IV

- Thermo-mechanical Godiva IV model used to study basic prompt burst physics
- Model combines neutronic and hydrodynamic models
- Stresses produce asymmetric pulse
  - Rise is slower than fall
  - Heating → acceleration of fuel material → rapid expansion → large negative reactivity feedback → rapid power decrease after maximum
- Plots (1996): $1.10, ~ 295 °C
- Ringing frequency = 19.4 kHz
- Updated results (report in progress)
  - Updates made to model following measured data (next slide)
  - $1.05, $1.07, $1.10: 11 kHz

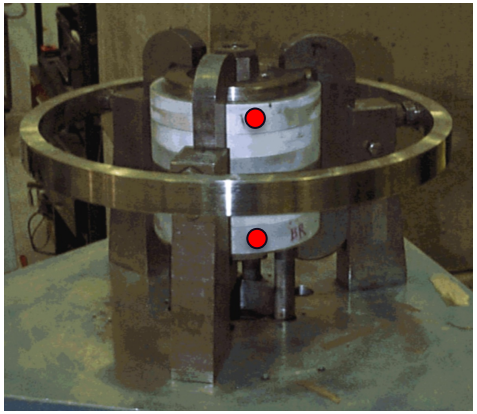




R. KIMPLAND, "Preliminary results of GODIVA-IV prompt burst modeling," Tech. rep., Los Alamos National Lab.(LANL), Los Alamos, NM (United States) (1996).

PDV measurements at 123 °C and 201 °C

- Photonic doppler velocimetry (PDV) system from LLNL
  - Doppler shift of laser used to precisely determine velocity
  - Lasers were focused on the top and bottom fuel cylinders
- 70 °C, 123 °C, and 201 °C bursts performed
  - Thermo-mechanical ringing was not resolvable at 70 °C



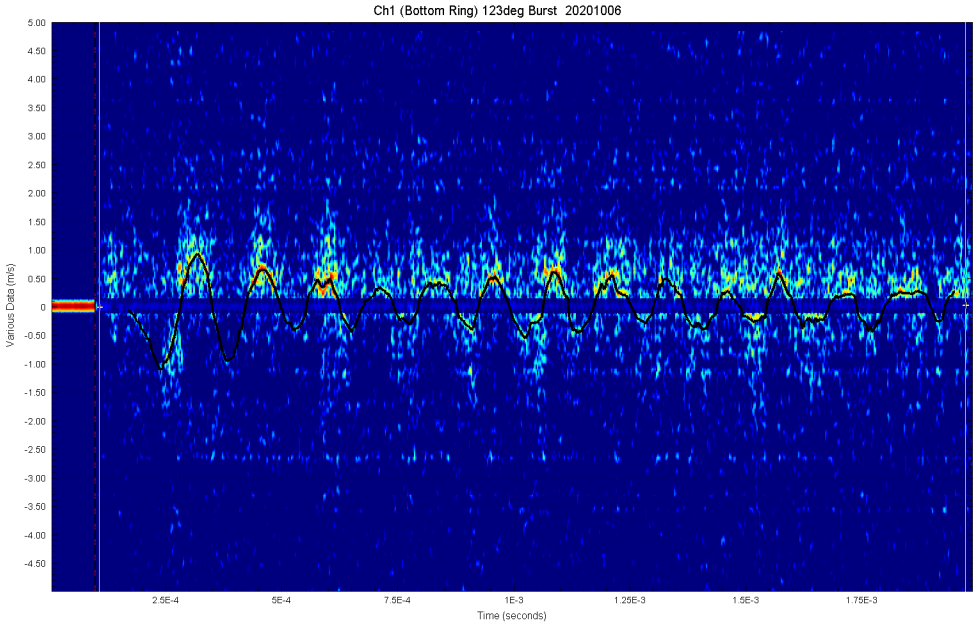
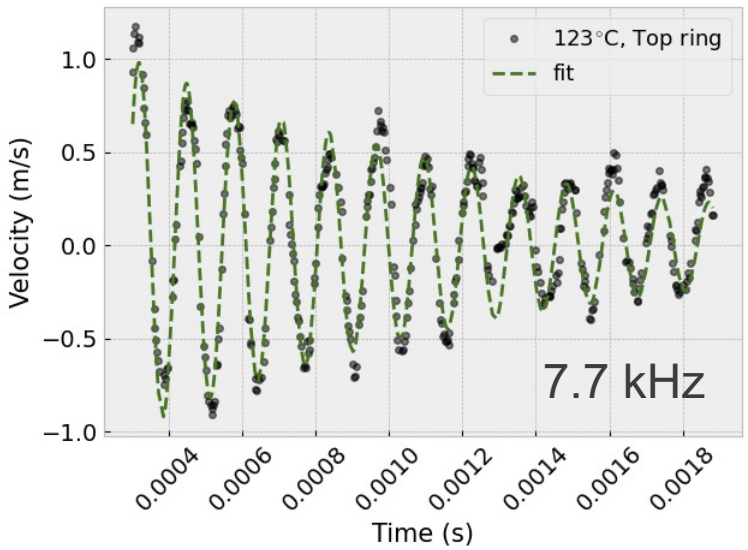
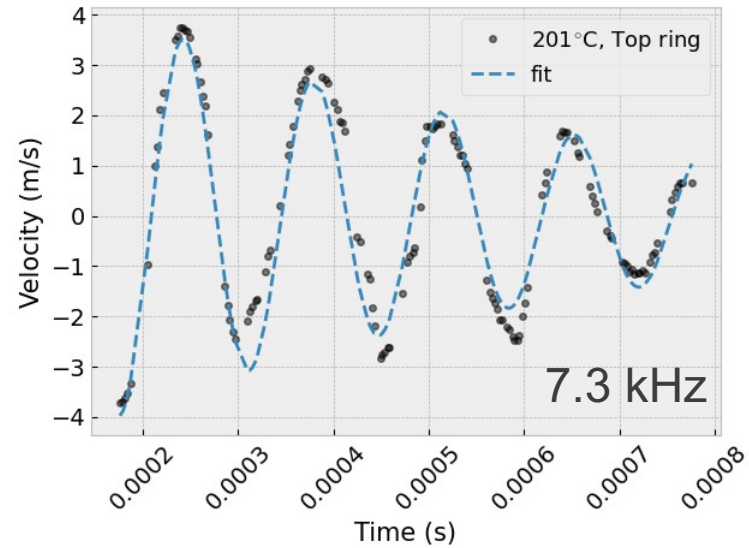
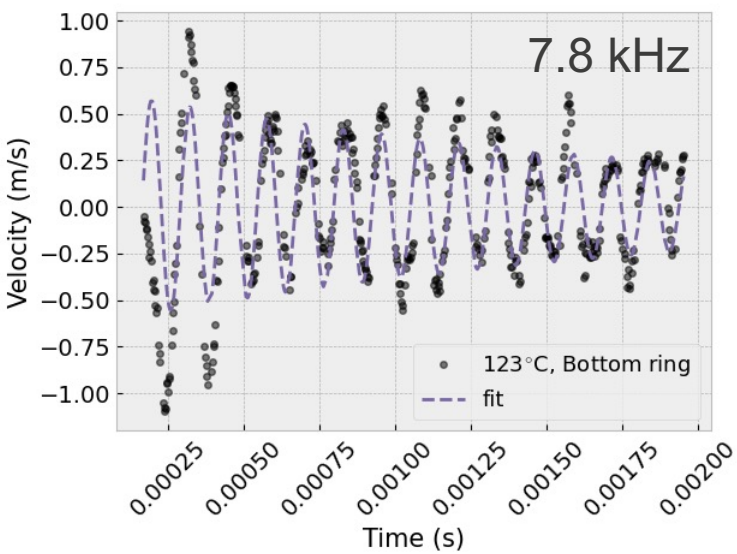


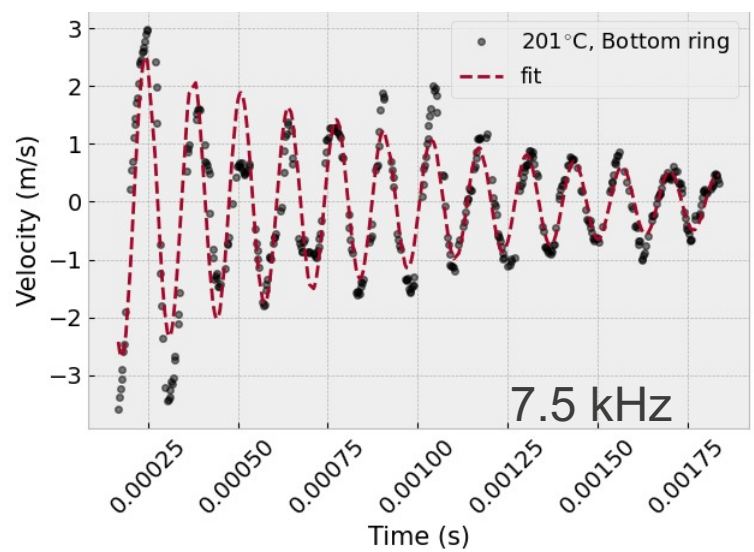
Photo-Doppler Velocimetry response on fuel surface during 123 °C Godiva burst.

PDV results


123°C, Top ring
fit
7.7 kHz
Velocity (m/s)
Time (s)


201°C, Top ring
fit
7.3 kHz
Velocity (m/s)
Time (s)

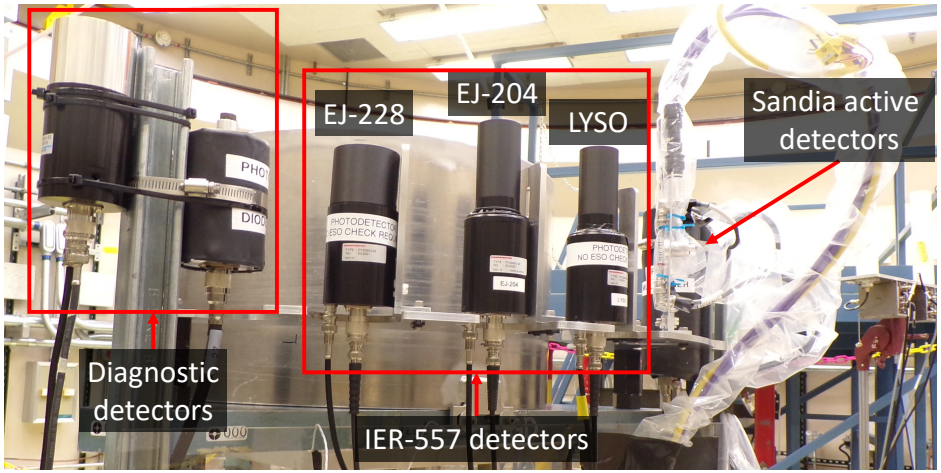

7.8 kHz
123°C, Bottom ring
fit
Velocity (m/s)
Time (s)

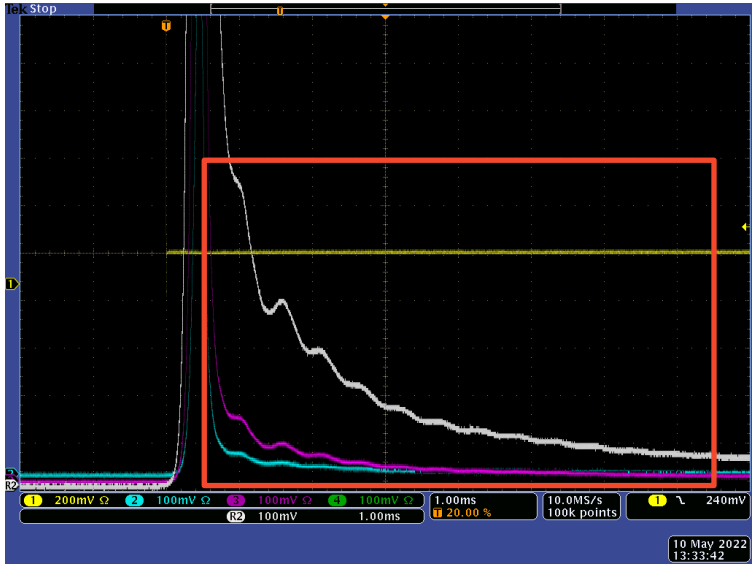

201°C, Bottom ring
fit
7.5 kHz
Velocity (m/s)
Time (s)

IER-557 radiation measurements (2022)

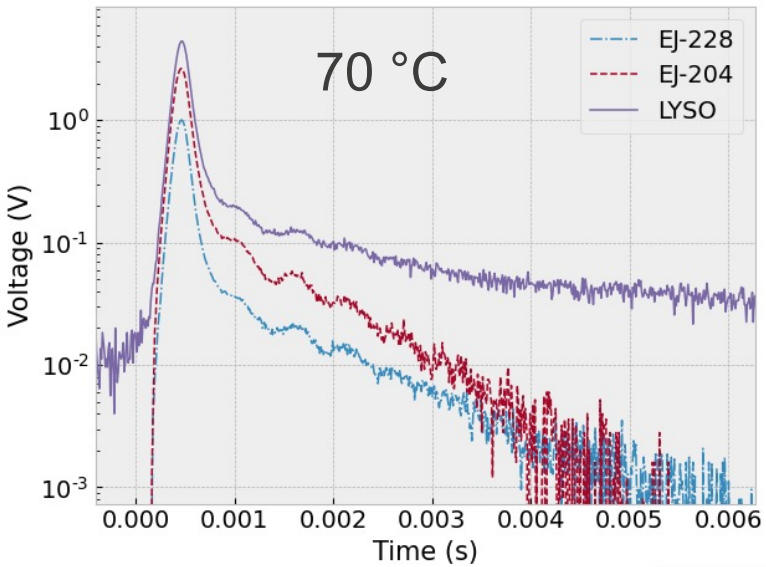
Ringing measured by radiation emission

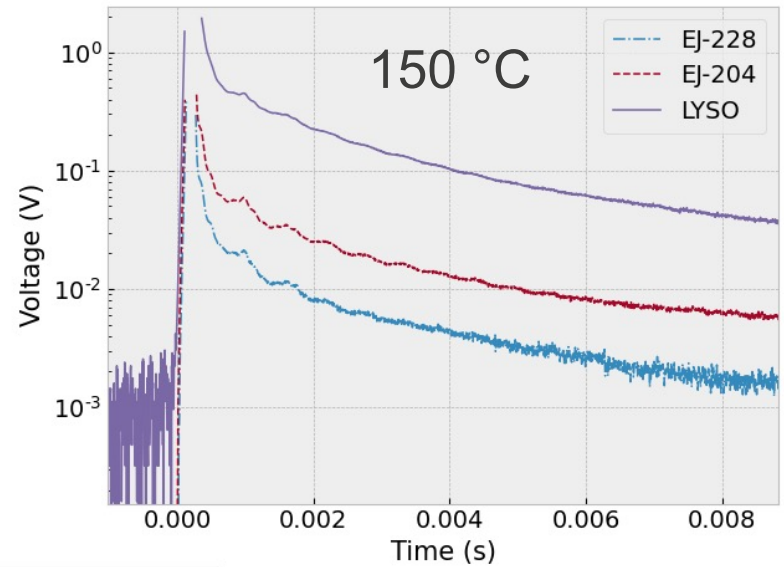
- New photodiode (PD) based detectors for IER-557
  - Used to determine precision of relative changes in source emission between bursts
  - Two geometries
    - 5.08 cm x 5.08 cm (same geometry as detector diagnostic deployed on Godiva for over 10 years)
    - 3.5 cm x 10 cm (mounted directly to photocathode, significant increase in light collection efficiency)
- Fast plastic scintillators – neutron and gamma sensitive
- LYSO – inorganic scintillator, high light yield and sensitivity to gamma radiation
- Placed ~14 cm from center of Godiva
- Combination of proximity, high scintillation light production, and high light collection efficiency – measure “ringing” in the tail of the pulse

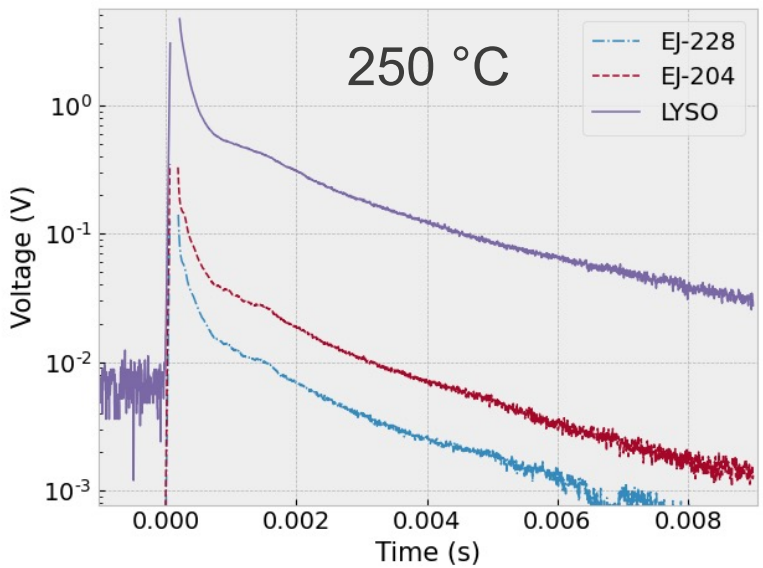




Godiva IV ringing traces

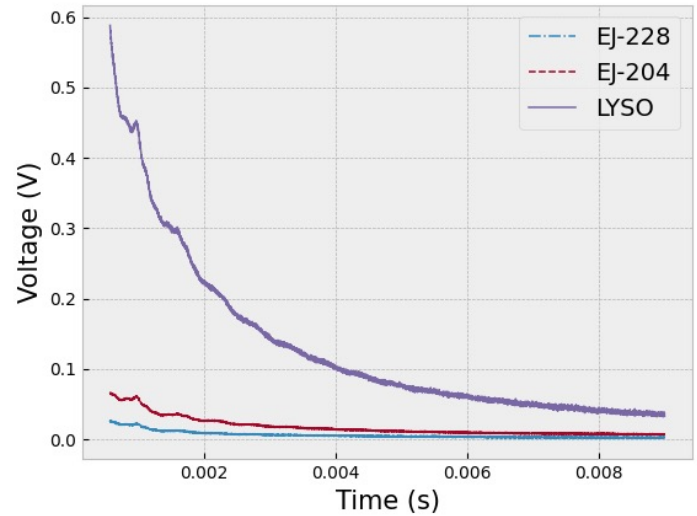


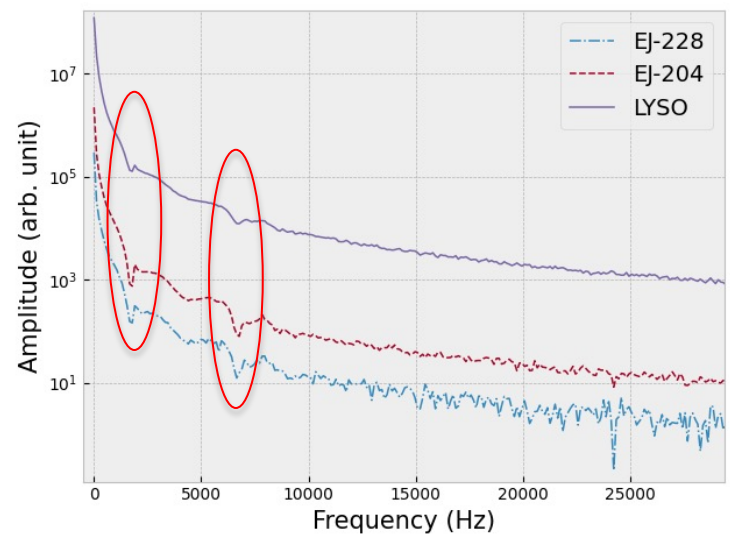




Radiation detector measurements of ringing at 115 °C, 130 °C and 154 °C

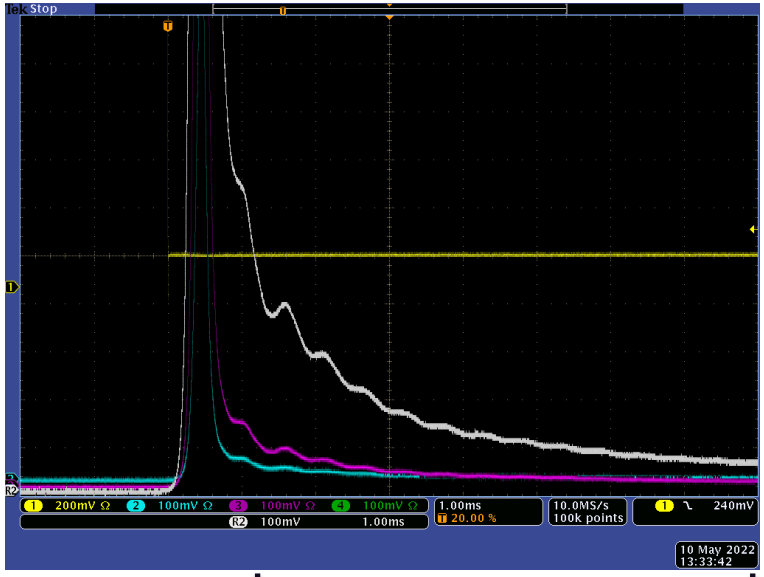
- Damped sinusoidal ringing is superimposed on the decaying pulse
- Future work – model/fit decay
- Frequencies estimated with FFT
  - –High uncertainty/bias
  - –Bin width ~100 Hz
  - –Additional bias due to use of FFT – spectral leakage
  - –Dual frequency components
    - 115 °C: 1.8 kHz, 6.3 kHz
    - 130 °C: 1.7 kHz, 6.7 kHz
    - 154 °C: 1.7 kHz, 7.0 kHz

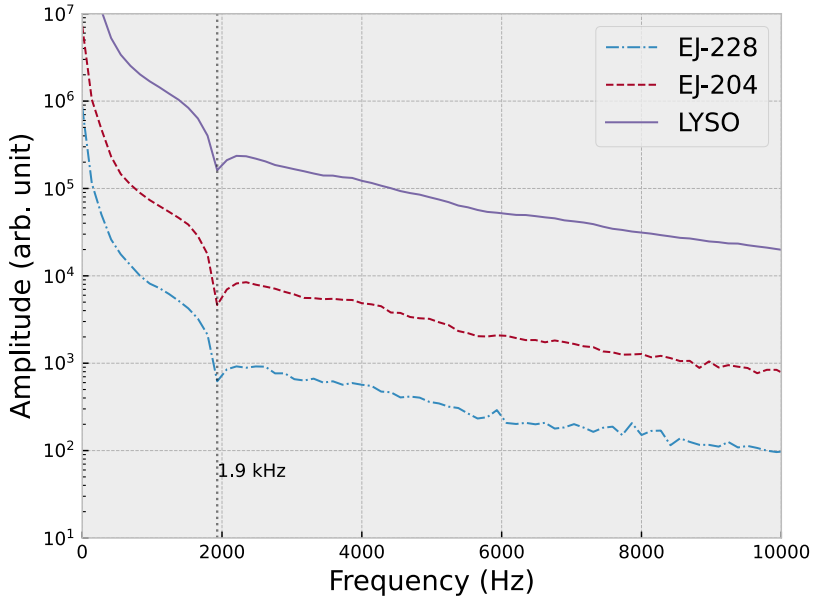


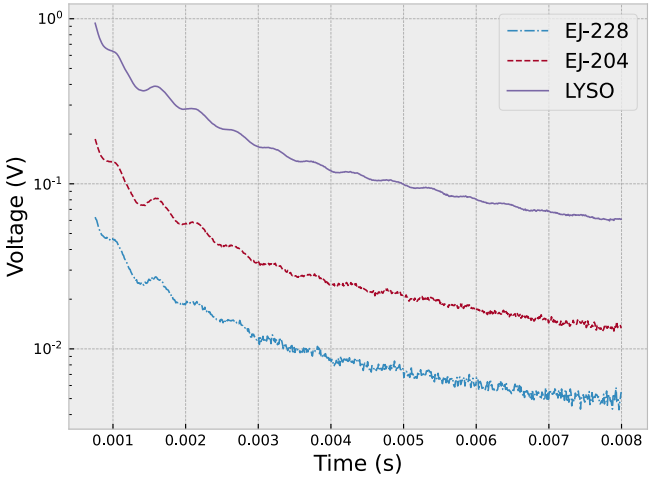


Radiation detector measurements of ringing at 76.8 °C

- Ringing frequency = 1.9 kHz
- Validated by 10 bursts
- Below theoretical limit for thermo-mechanical ringing
- Precursor to thermo-mechanical ringing
  - Heating → inertia → oscillatory change in density of HEU fuel → change in leakage







Summary

	70 °C (~$1.03)	115 °C (~$1.04)	150 °C (~$1.06)	250 °C (~$1.09)
Model	NA	11 kHz	11 kHz	11 kHz
Laser PDV	NA	NA	7.8 ± 0.1 kHz	7.4 ± 0.1 kHz
PD/radiation	1.9 kHz	1.8 kHz, 6.7 kHz	1.7 kHz, 7.0 kHz	NA

- Proposal to study Godiva burst physics
  - Suite of bursts in small reactivity steps from sub-prompt through 250 °C
  - Perform bursts in ~0.5 cent steps to study radiation emission characteristics
  - Multiple detectors
    - PDV measurements
    - Dosimetry
    - Scintillators
    - Radiation hard diamond detectors
  - Use data from bursts to inform new models of the Godiva IV burst physics
    - Thermo-mechanical modeling
    - Radiation and thermomechanical coupling

Acknowledgements

This work was supported by the DOE Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy