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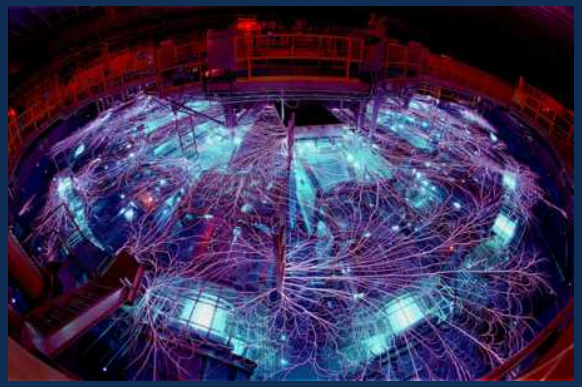
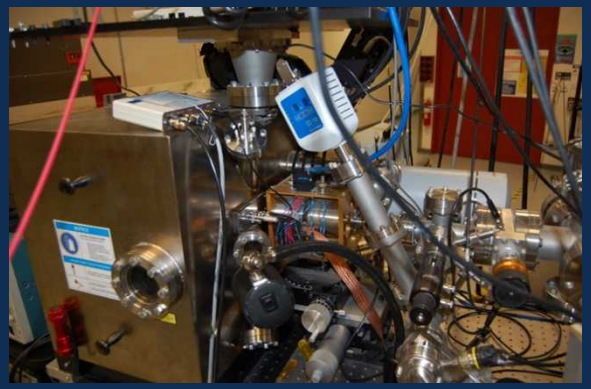




MaRIE Extreme Environments and Driver Technologies Workshop
Buffalo Thunder Resort
Pojoaque, New Mexico
August 28-29, 2017

Pulsed Power Driver Breakout Session
August 29th, 2017

Chairmen
Mike Cuneo, SNL
Chris Rousculp, LANL

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

One driver to rule them all?

- Several comments yesterday about the need/desire for multiple drivers (different timescales) (Barnes, and others)
- No one driver can access all regimes of materials dynamics (Brown)
- We only know what questions to ask at ~1 MBar. Don't want to be locked in at lower pressures than required for meaningful progress in 10 – 15 years. (Collins)
- 2 MBar would be disappointing in 2030 – aim for 10 – 20 MBar for MaRIE (Glenzer)
- Aim for up to 5 MBar IOC with upgrade path to higher pressures (McNabb)
- All drivers do not need to replicate all desired states, and can't do all things
  - Drivers should overlap in a meaningful way in part of the phase space
- Can't do high rep-rate and high pressure/energy at the same time?

Pulsed power driver design driven by requirements: peak pressure, pulse shape, shot rate

- The following are potential requirements for pulsed power driver at MaRIE:
  - 1 – 10 Hz at 10 – 100 kBar
  - Shot per hour at 2 MBar ramp
  - 20 shots per day at 2 MBar ramp
  - Few shots per day at ≥5 Mbar ramp
  - Shocks at 30-100 MBar
- For pulsed power, these are all different drivers
- MaRIE 1.0 Technical Requirements - Flow Down from Campaign Experiments to Specify Capabilities Required to Meet Mission Need (LA-UR-15-27974)
  - Up to 5 Mbar noted in six places in this document
  - 50 GPa to <= 200 Gpa (0.5 – 2 MBar) noted in several other places

Pulsed power driver requirements (before 8/28 breakouts)

- Kraus
  - Kinetics: 10 kBar – 5 MBar with ramp compression and quenching
  - Plasticity: 10 kBar – 5 MBar
  - Chemical kinetics: 10 MBar
- Jensen: Present status at DCS
  - 10 kBar – 3.5 Mbar
- Glenzer: Present status at LCLS
  - 10 kBar – 2 Mbar?
- Swift: 1 Mbar – 1 Gbar
- McNabb: up to 5 MBar IOC with upgrade path to higher pressures

Driver requirements (after 8/28 breakouts)

- Hemsley/Collins et al: **Metal Alloys**
  - 2 MBar up to 30-100 Mbar
  - Don't want to be locked in
- Specht et al: **HE and heterogeneous materials**
  - 5 MA Thor-class driver (0.5 MBar synchronous, 0.125 Mbar ramp)
- Hussein et al: **Turbulence and mix**
  - Cylindrical convergence with hypersonic flow
  - Multiple drivers
- Kraus et al: **HEDP**
  - 1 MBar – 1 GBar

Present pulsed power driver benefits and characteristics

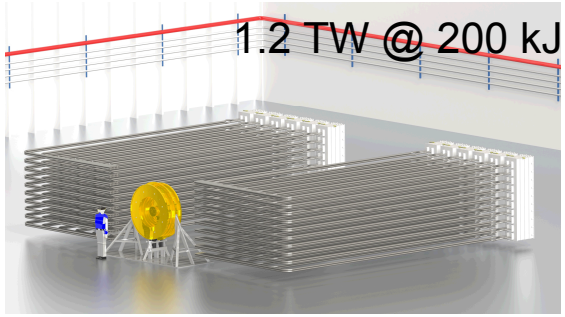
- Large samples ~1 mm thick
- Relevant and relatively low strain rates (10^4 – 10^7 s^{-1}) and time scales (~0.4 – 1 μs) with modest cost
- Arbitrary loading history, with repeatability, accuracy, and precision (1-2%)
  - Ramp compression without shock, ramp and hold, quenching?
  - Provide a capability that exceeds our present grasp and meet requirements of 10-15 years hence
- Ability to generate shear waves (with static transverse field)
- One shot per hour at pressures up to 2 MBar at 0.5 to 1 μs (~$10 – 15 M)
- 2-4(?) shots per day at pressures of 10-30 Mbar at 0.5 to 1 μs (~$100 – 150 M)
- Can deliver energy to planar targets at 10-40% efficiency
- Potential for converging targets (Cr ~ 2-5?)

Technology to system requirements breakout

- Define [technical functional] requirements of the system that would meet scientific requirements of the mission
  - 0.1 µs - 1 µs shock and ramp loading with arbitrary pulse shaping
  - Thor-class: 2 to 5 Mbar (TRL = 7, 5 to 10 MA peak, planar drive)
  - Neptune-class: >5 Mbar, (TRL = 2, development required)
  - PHELIX-class: 3 - 6 µs, cylindrical implosion, 0.5 Mbar in Sn, 5 MA peak

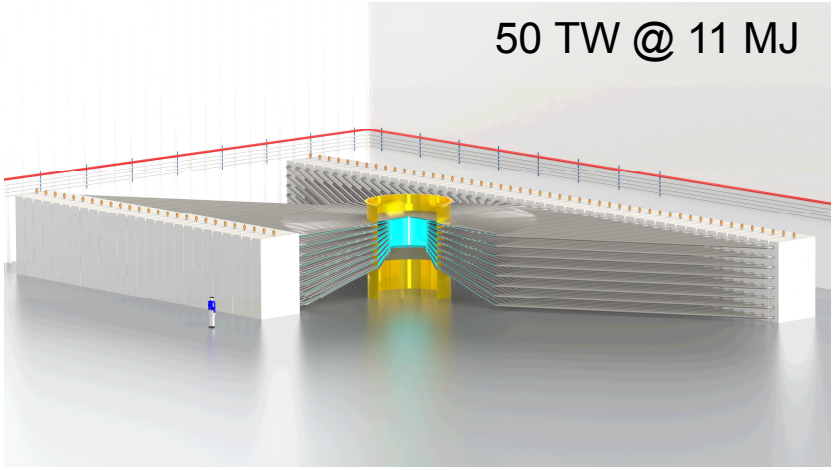
"Off the shelf"

Thor (0.5 – 2 Mbar)



PHELIX (0.5 Mbar)

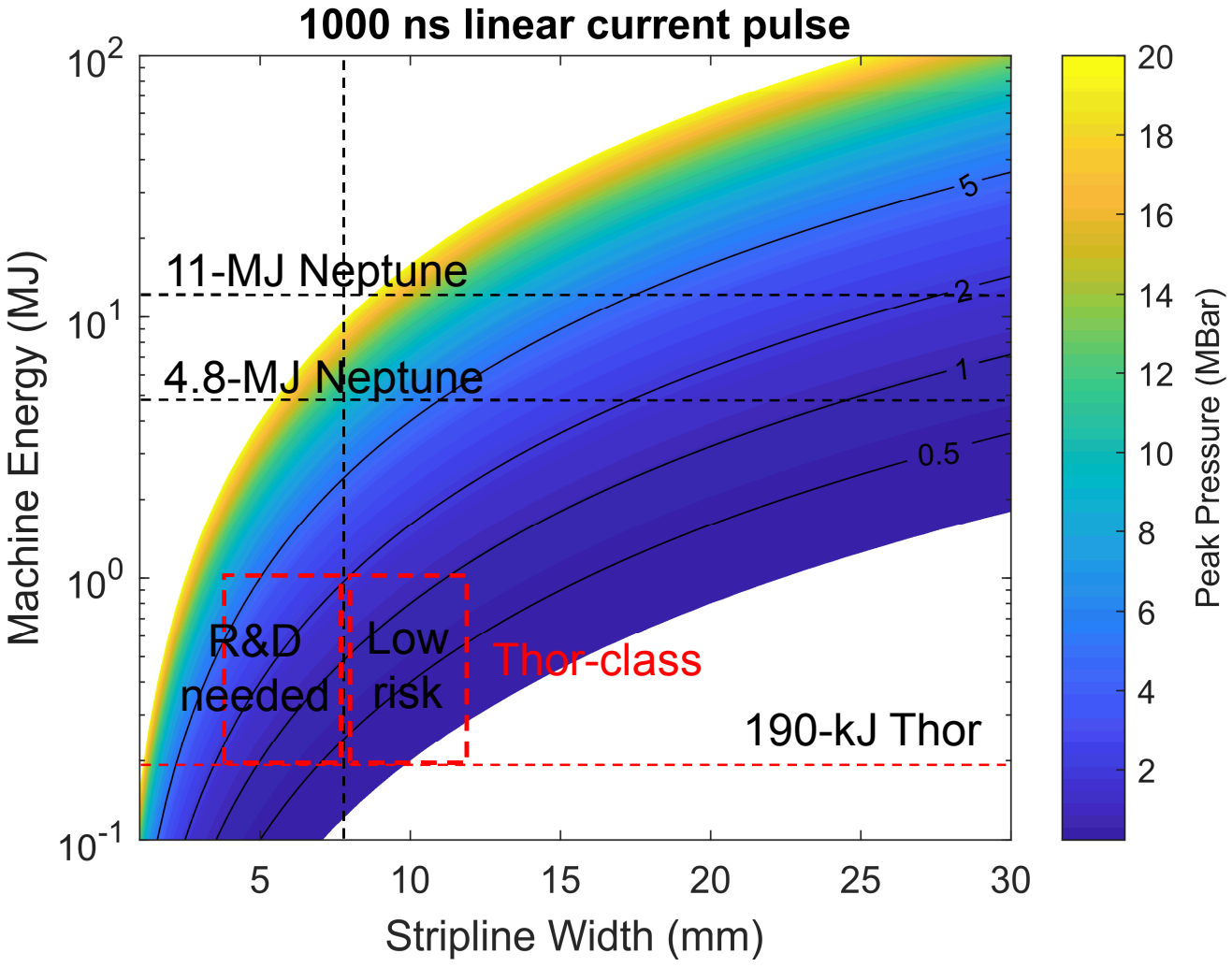
Neptune (>5 – 20 Mbar)



Development required

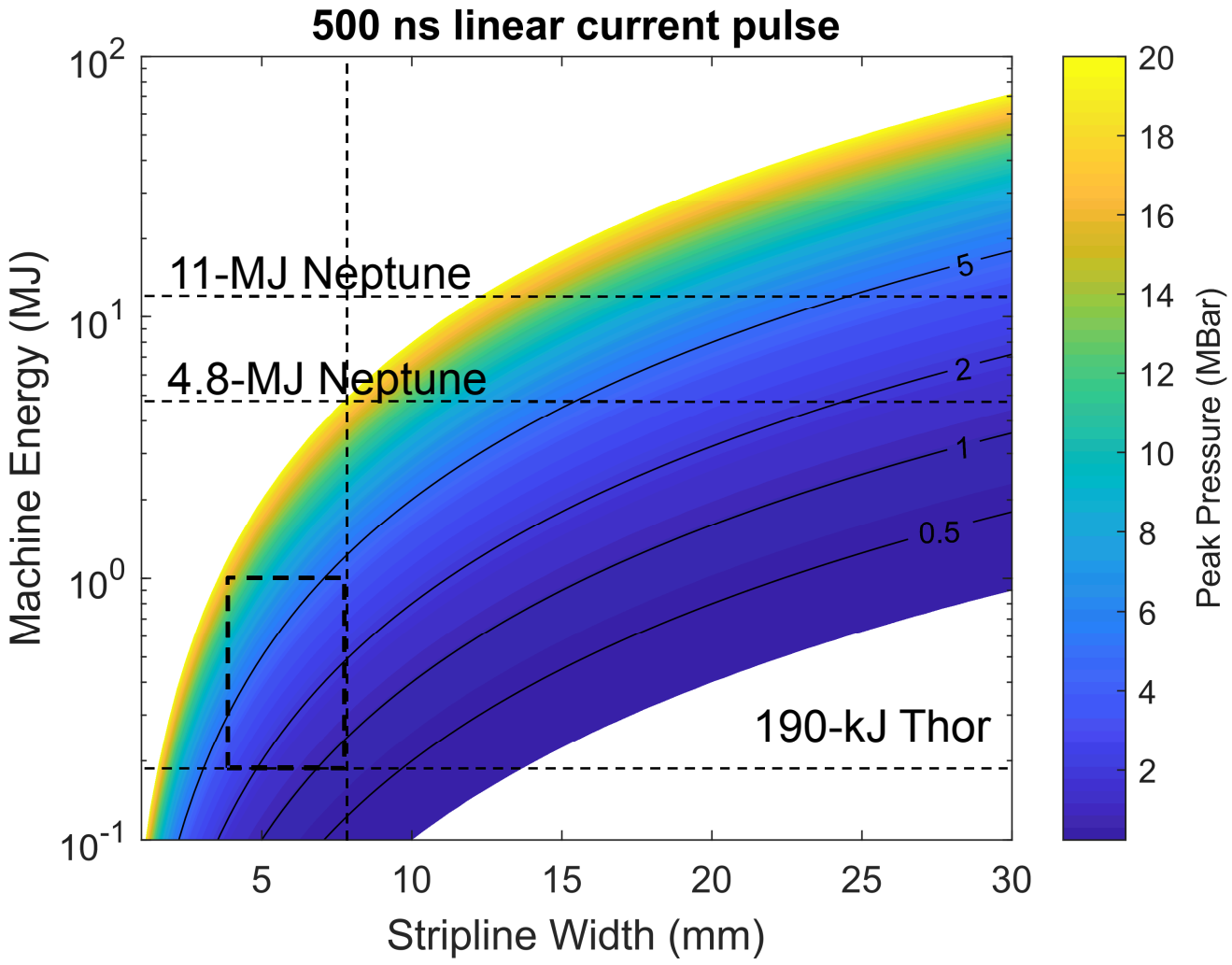
Overview of pulsed power driven material properties driver conditions in planar geometry

Justin Brown
Bill Stygar



Electrical efficiency of pulses
Synchronous – 25%
Ramp – 20%
Square – 40%

Higher pressures (>2X) available for shorter ramps



Thor 48 is a TRL-7 demonstration of a new pulsed power architecture (current adders) being commissioned for DMP experiments

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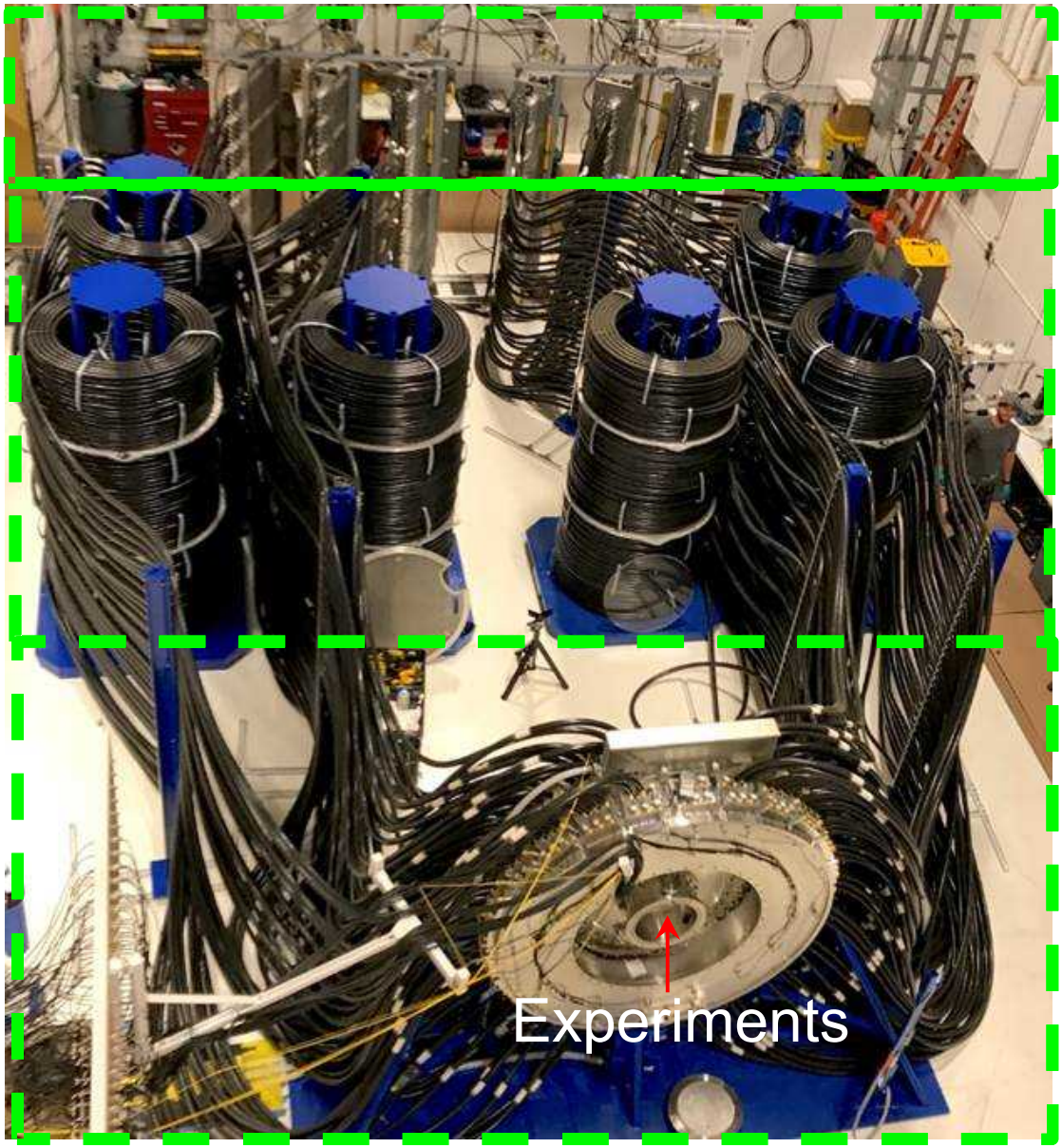
Energy storage
• 6 brick towers

Coupling
• 6 cable towers

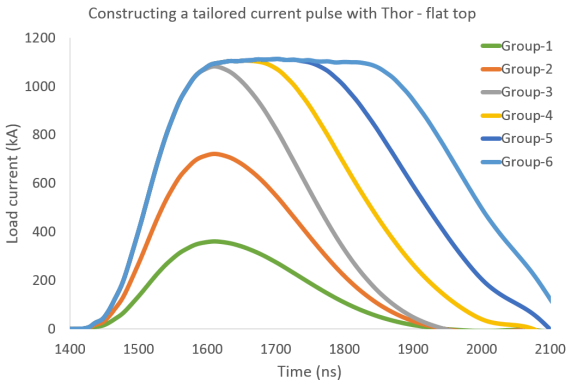
Coupling
• Central Power Flow Section



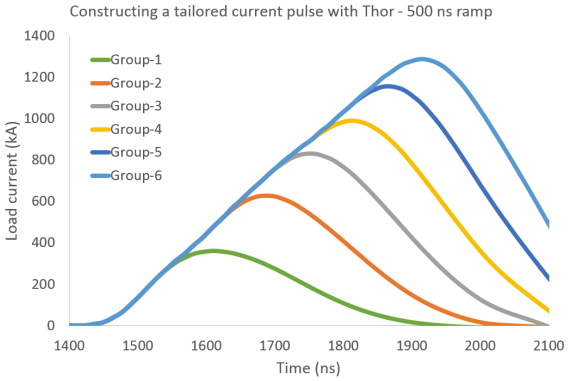
Developed over 2015-17
Thor 72 provides 600 kBar in FY2018

Thor is capable of many different loading histories which allows greater flexibility in accessing the materials temperature-density phase space

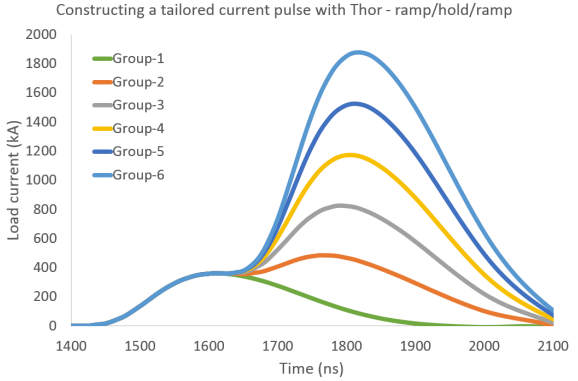
ramp-hold-release



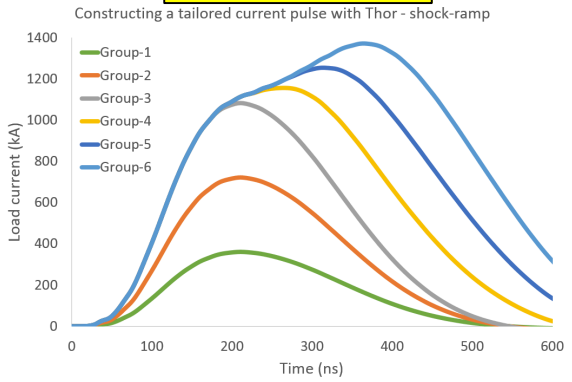
ramp



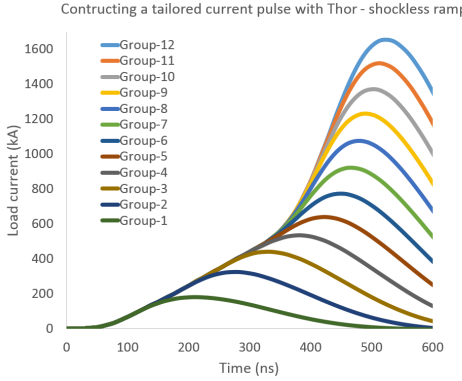
ramp-hold-ramp



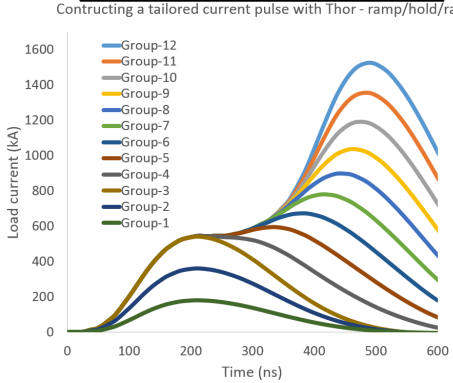
shock-ramp



shockless ramp



ramp-hold-ramp



Technology to system requirements breakout

- What are the critical technology elements that should be addressed by R & D to raise the TRL to >3 by CD-1 and >6 by CD-2

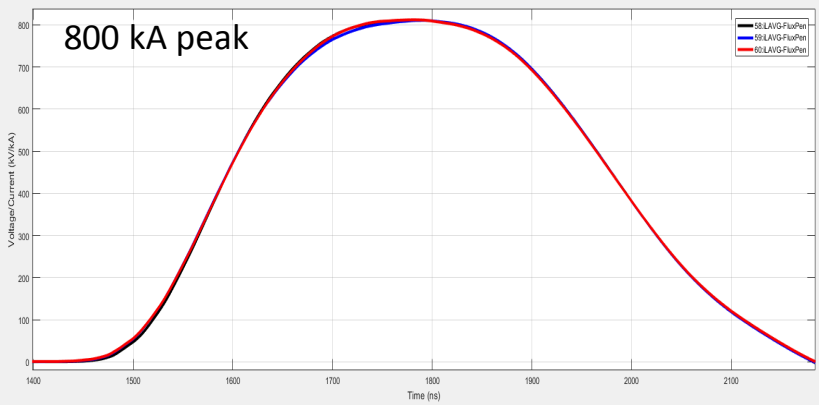
  - Physics and engineering limits of stripline physics (2 Mbar low risk)
  - Diagnostic access (small angle scattering, imaging, spectroscopy)
  - Alternate load configurations (working fluid approaches) to reach higher pressures
  - Cylindrical implosions (Cr ~2-5) to increase pressure
  - Explore transmissive low angle diagnostics with a Thor at DCS!
  - Design of targets to allow multi-probe diagnostic access
  - Compatibility of prad with B-fields in planar targets
  - Concepts/engineering of precision target alignment to the beam
  - We haven't thought about high rep-rate applications. Is there an application that requires this?

Technology to system requirements breakout

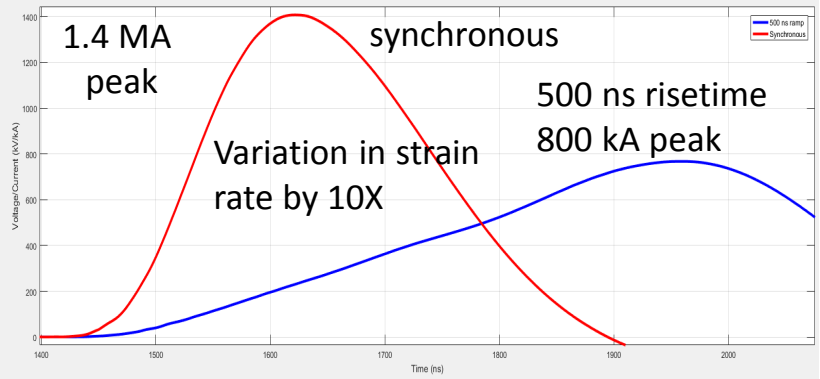
- What scientific requirements might drive costs or risks?
  - High rep-rate requires extremely low pressures/energies
  - Higher pressure requirements (>5 Mbar) could greatly increase the costs/risks

Thor provides a multi-MA arbitrary waveform generator with unprecedented precision in achieving a desired loading history

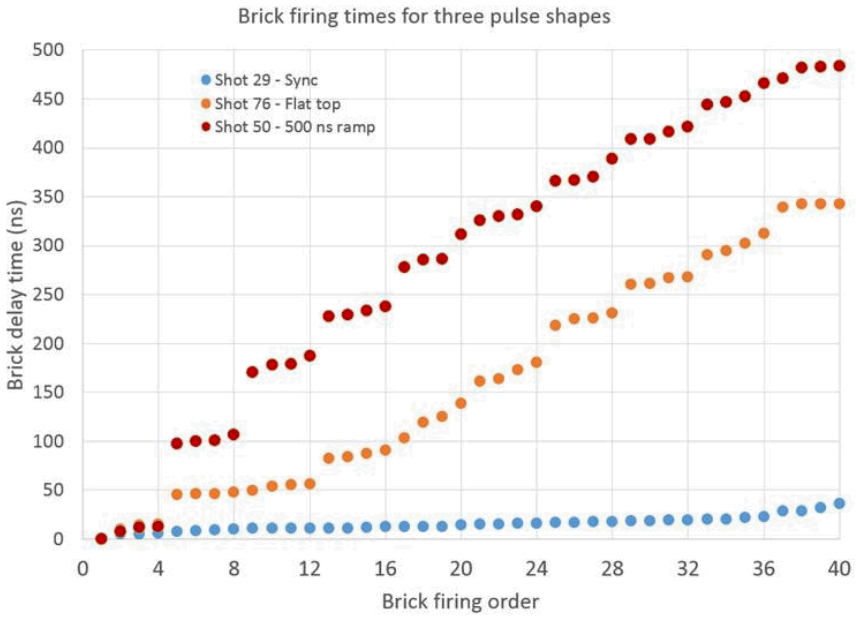
*Pulse shape for resistance to deformation



Pulse shapes for multi-phase kinetics



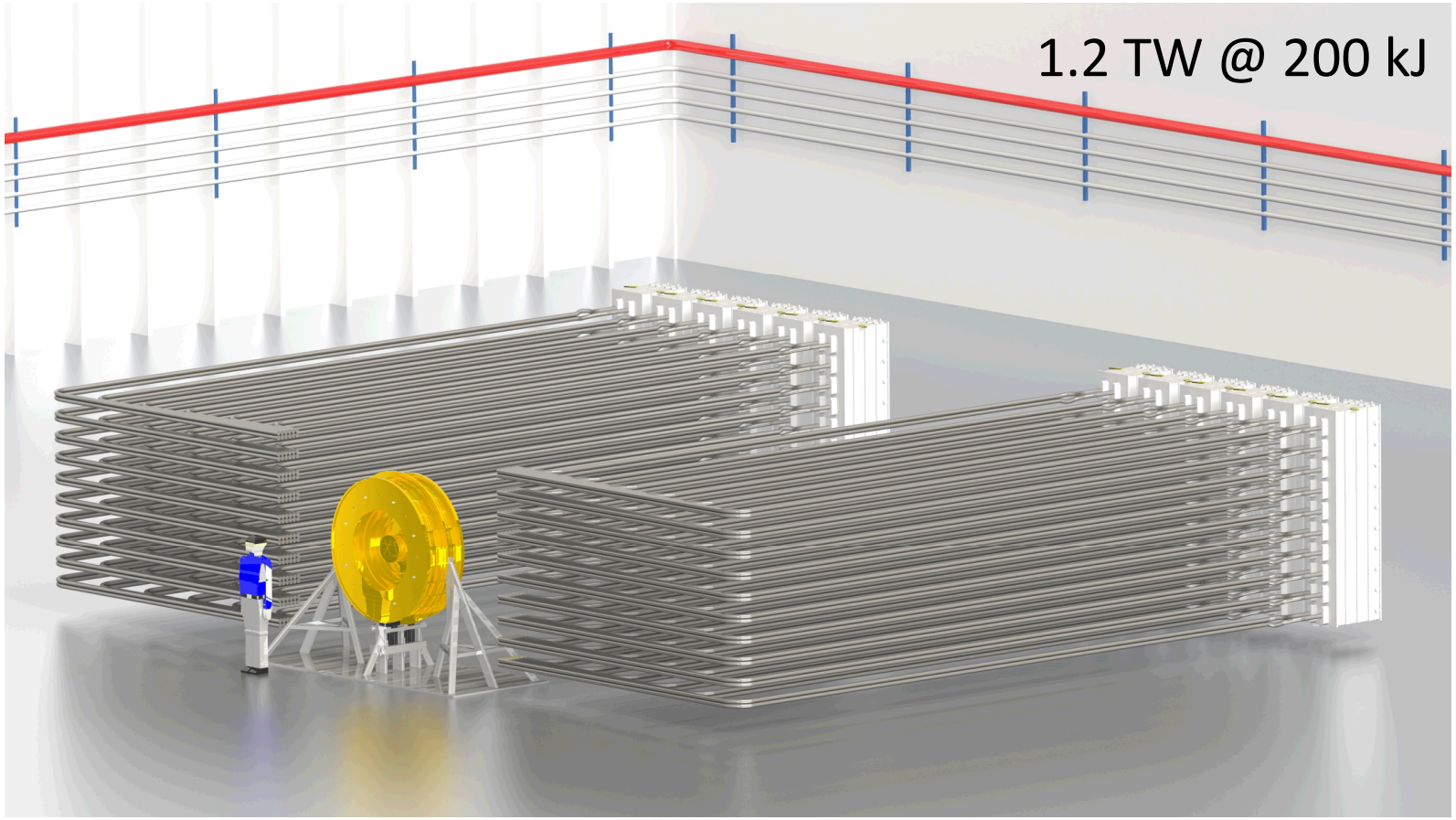
Brick timing



Capability addresses advanced manufacturing, multi-phase kinetics, strength

We are planning a Ga refreeze experiment in FY18, using variable strain rates
We are planning to measure Cu strength at variable strain in FY18

A Thor-240 utilizing water lines rather than dielectric cables provides 9 MA peak current, 2 Mbar peak pressures and could be built for $10 – 15 M



- Technology development is needed and could be demonstrated on Thor-72
- Doesn’t include costs of integration with facility

Current addition for arbitrary loading is a new idea that has been developed over 2015-2017