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Conceptual designs of 300-TW and 800-TW pulsed-power accelerators

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Developing the conceptual designs is a large team effort.

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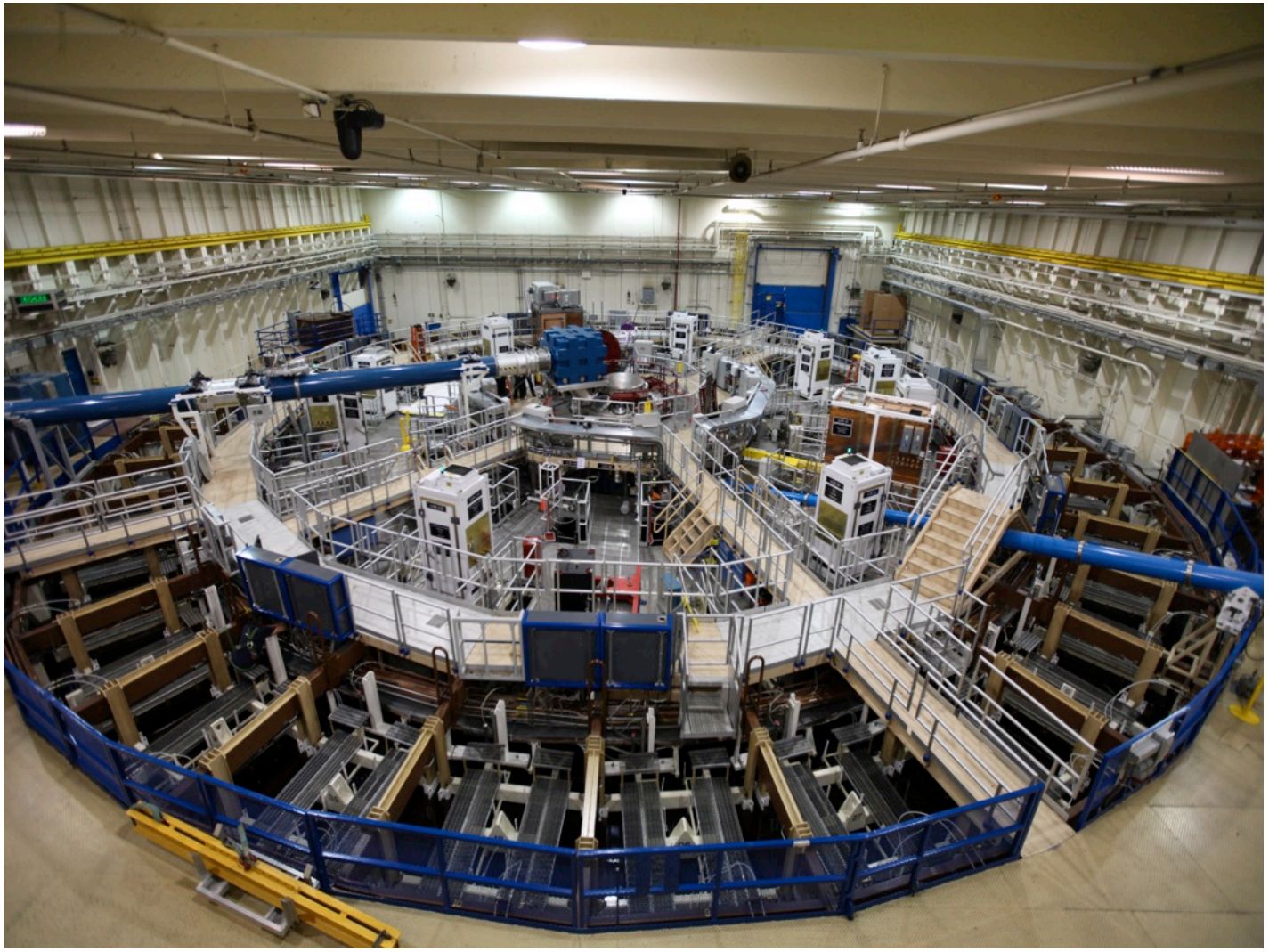
Sandia's Z accelerator is presently the world's largest and most powerful pulsed-power machine.

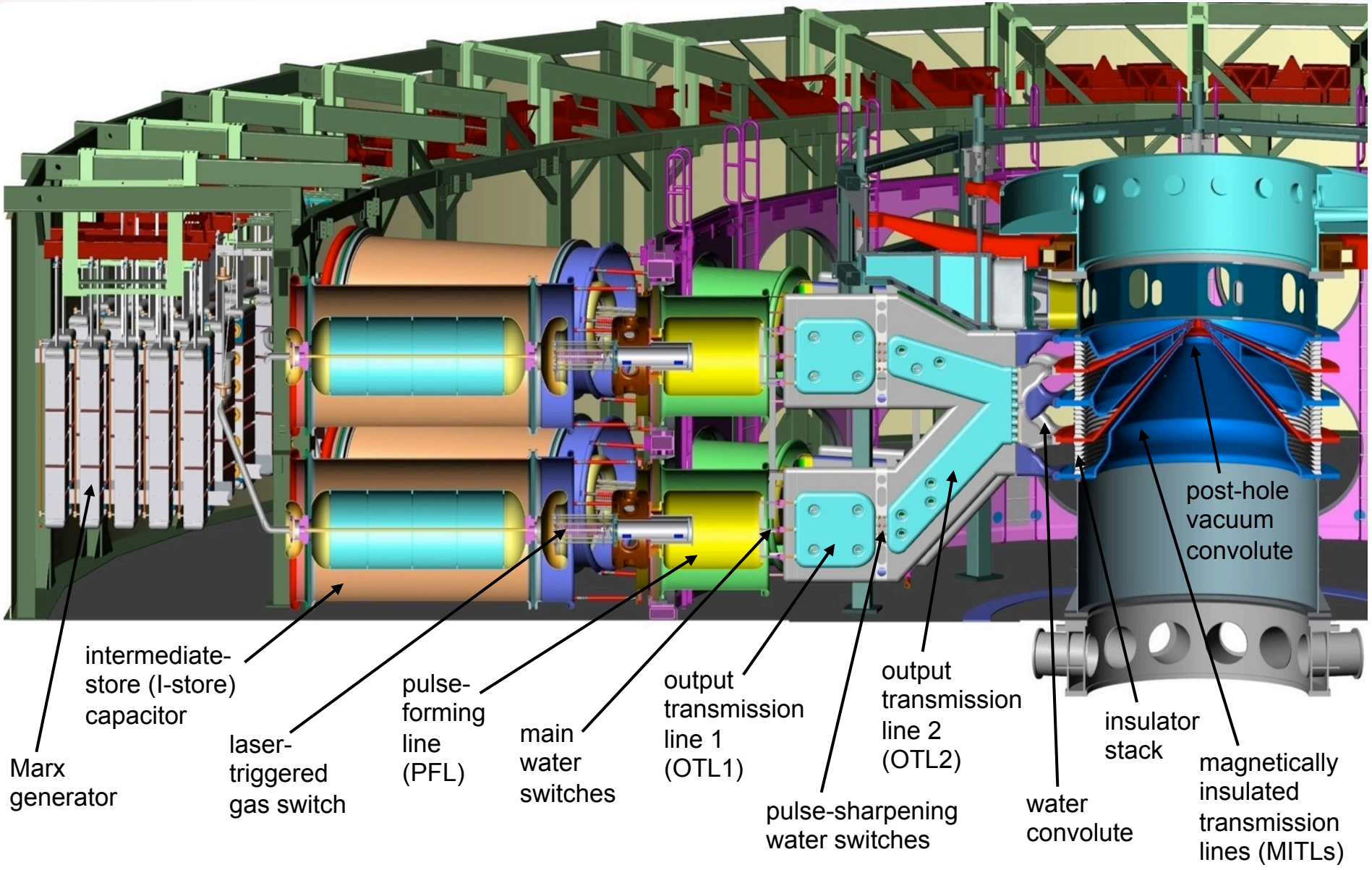
E_{stored} = 20 MJ	V_{stack} = 4 MV	I_{load} = 27 MA	$E_{radiated}$ = 3 MJ
$P_{electrical}$ = 80 TW	L_{vacuum} = 14 nH	$\tau_{implosion}$ = 130 ns	diameter = 33 m

Z drives a large variety of high-energy-density-physics experiments in support of U.S. Department of Energy programs.

To advance such experiments to the next level, we propose to build even higher-power accelerators.



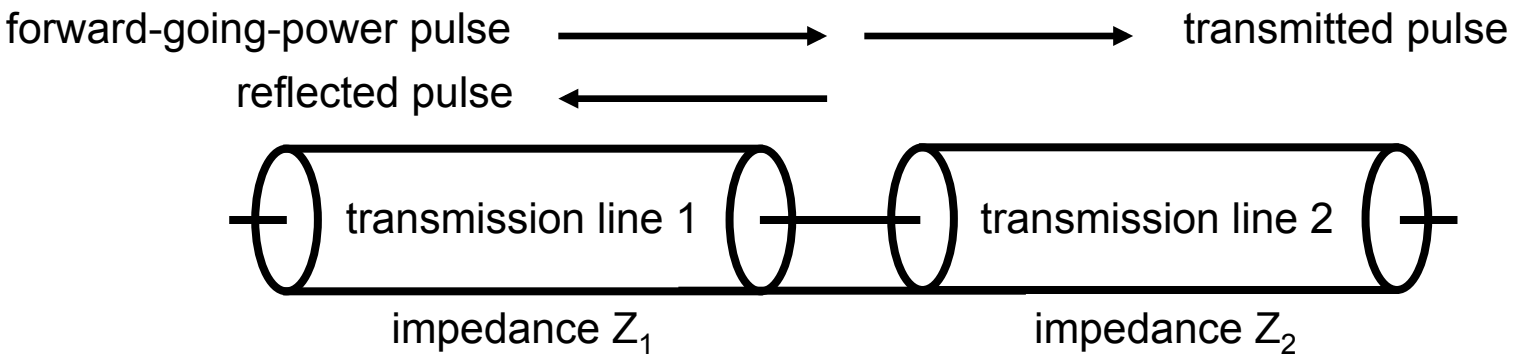
Each of Z's 36 modules performs several stages of pulse compression.



We propose to base the designs of next-generation machines on a *new* architecture.

The architecture is based on two concepts: Single-stage pulse compression and impedance matching.

- We propose to go from DC-charged capacitors to the requisite 100-ns power pulse in a single step.
  - This eliminates the need for pulse-compression hardware.
  - This in turn simplifies the machine design, increases efficiency, improves component lifetime, and facilities simulations of an accelerator shot.
- We propose to use impedance matching throughout.
  - When power flows from one transmission line to another, the reflected power is zero (and the power-coupling efficiency is maximized) when $Z_1 = Z_2$.



We have used the architecture to design two new machines: Z 300 and Z 800.

Z 300 will deliver 50 MA to physics-package loads, and fit within the existing Z building.

P_{LTDs} = 300 TW
E_{LTDs} = 47 MJ

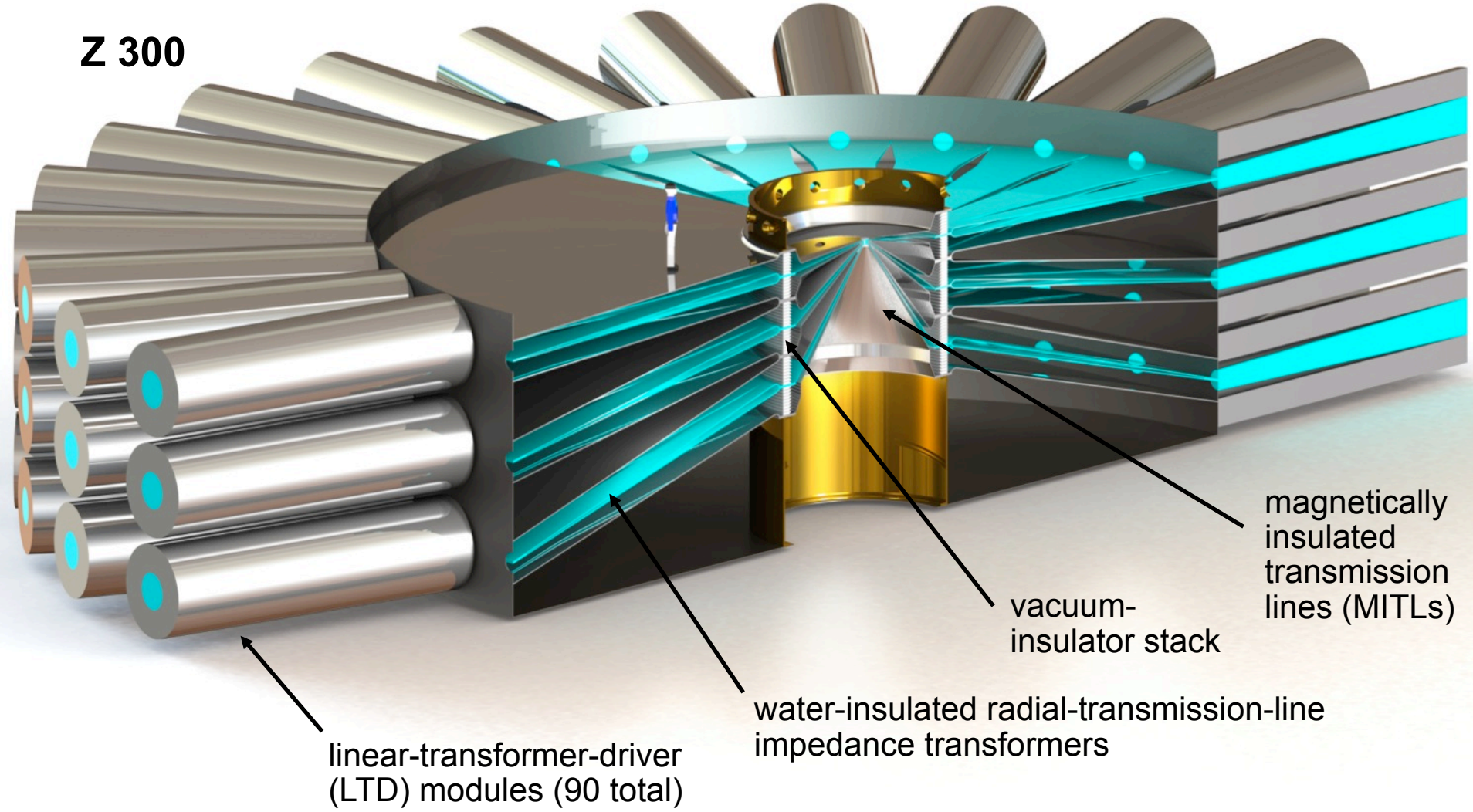
V_{stack} = 8 MV
L_{vacuum} = 15 nH

I_{load} = 50 MA
$\tau_{implosion}$ = 130 ns

$E_{radiated}$ = 11 MJ
diameter = 35 m

η_{x-ray} = 23%

Z 300



The conceptual design of Z 300 is supported by 50 peer-reviewed journal articles and a U.S. patent.

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Architecture of petawatt-class *z*-pinch accelerators

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(12) **United States Patent**
Stygar et al.

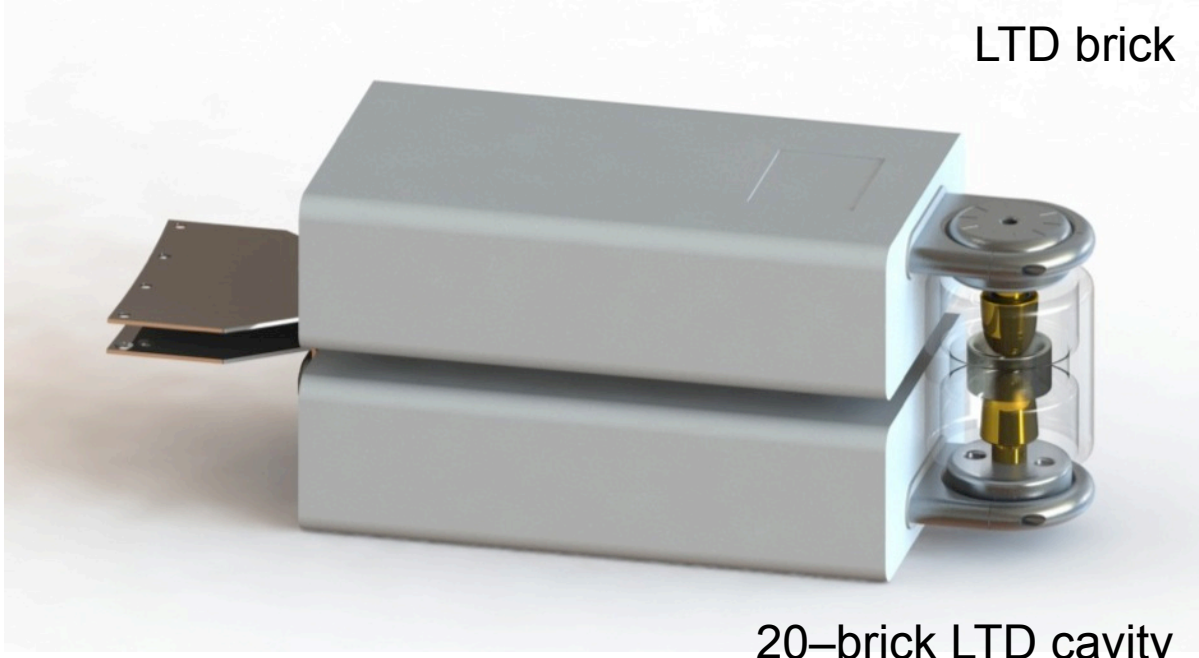
(10) **Patent No.: US 7,679,297 B1**
(45) **Date of Patent: Mar. 16, 2010**

(54) **PETAWATT PULSED-POWER ACCELERATOR**

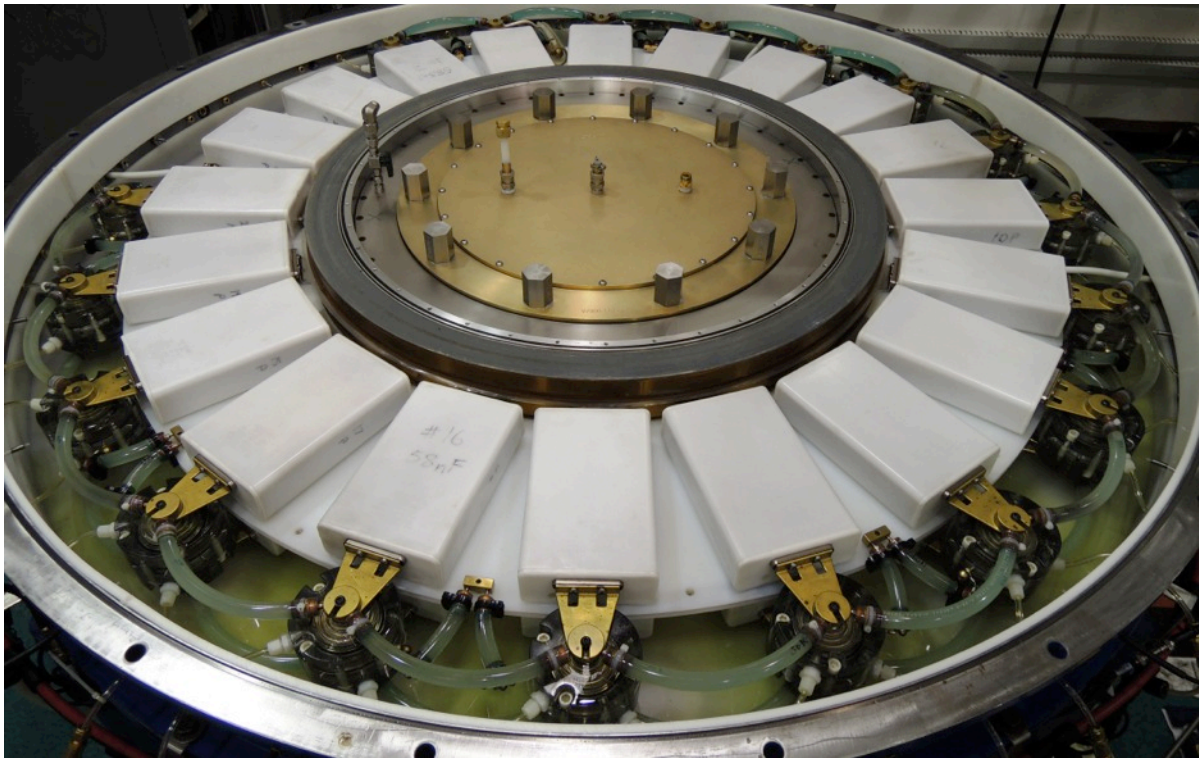
5,326,970 A * 7/1994 Bayless 250/269.1
6,278,239 B1 * 8/2001 Caporaso et al. 315/5.41

The quantum of an LTD is a “brick.”

- An LTD brick consists of a single switch and two capacitors connected electrically in series.
- An LTD cavity consists of a number of bricks connected electrically in parallel.
- The 2-meter-diameter cavity shown here includes 20 bricks.

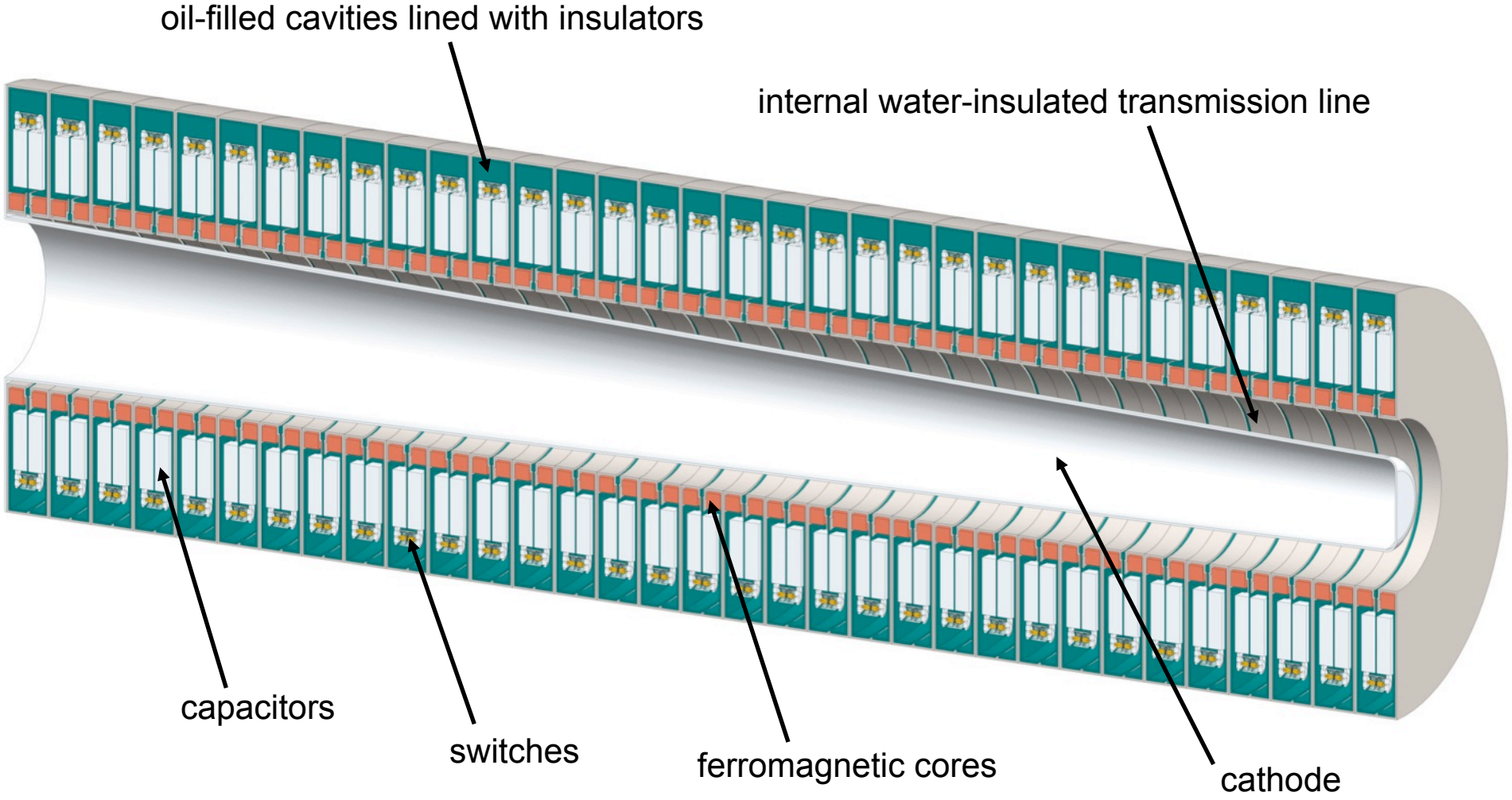


20–brick LTD cavity



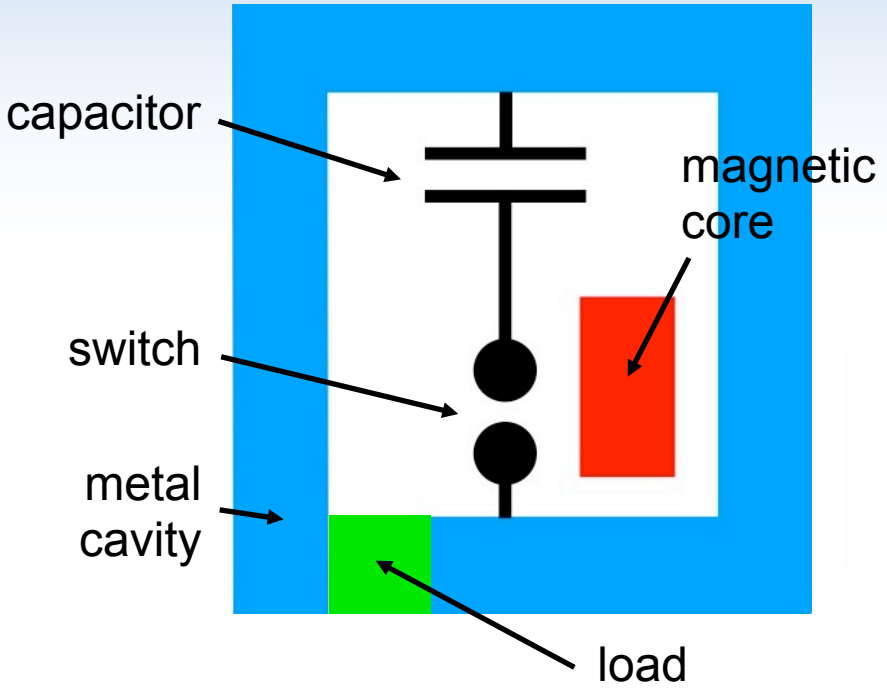
An LTD module consists of a number of LTD cavities connected electrically in series.

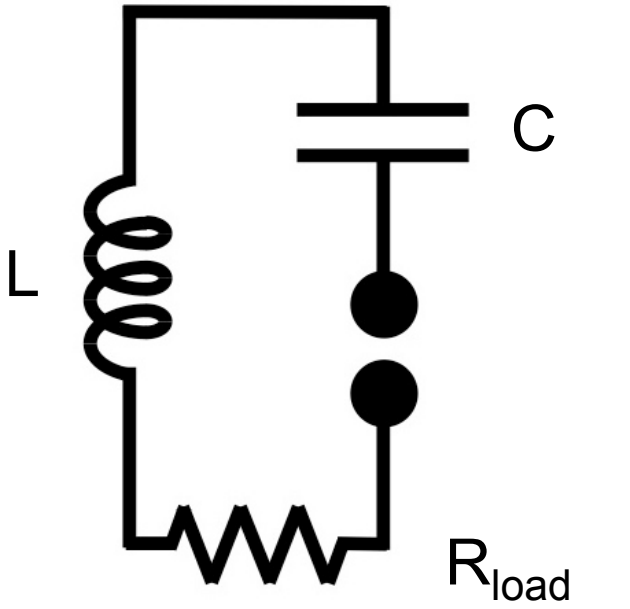
33–cavity LTD module



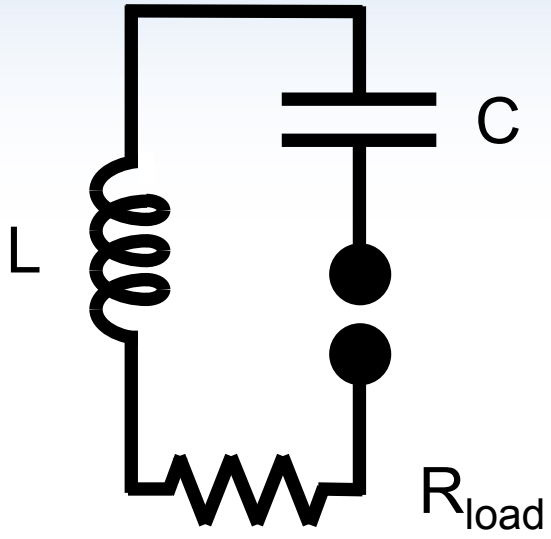
An entire system of LTD modules can be *approximately* modeled as a single RLC circuit.

- The energy is stored in the LTD capacitors.
- The inductance is due to the LTD switches, capacitors, and connections.
- The capacitors and switches are packed in metal cavities to reduce system inductance.
- The magnetic cores prevent most of the LTD current from flowing inside the cavity walls.
- The electrical power generated by the LTDs is delivered to the load.
- The peak power delivered to the load is maximized when the impedance of the LTD system is matched to that of the load; i.e., $R_{load} \sim 1.10(L/C)^{1/2}$.





At a high level, a system of LTDs can be defined by four equations.



These assume that the impedance of the load is matched to that of the LTD system.

peak load current: $$I = 0.52 \frac{N V_{charge}}{n} \sqrt{\frac{C}{L}}$$

width of the current pulse: $$\tau = 1.61 \sqrt{LC}$$

load impedance: $$R_{load} = 1.10 \frac{n^2}{N} \sqrt{\frac{L}{C}}$$

initial DC charge voltage: $$V_{charge} = 200 \text{ kV}$$

C = capacitance of a single LTD brick, which is almost entirely due to that of the two capacitors in series

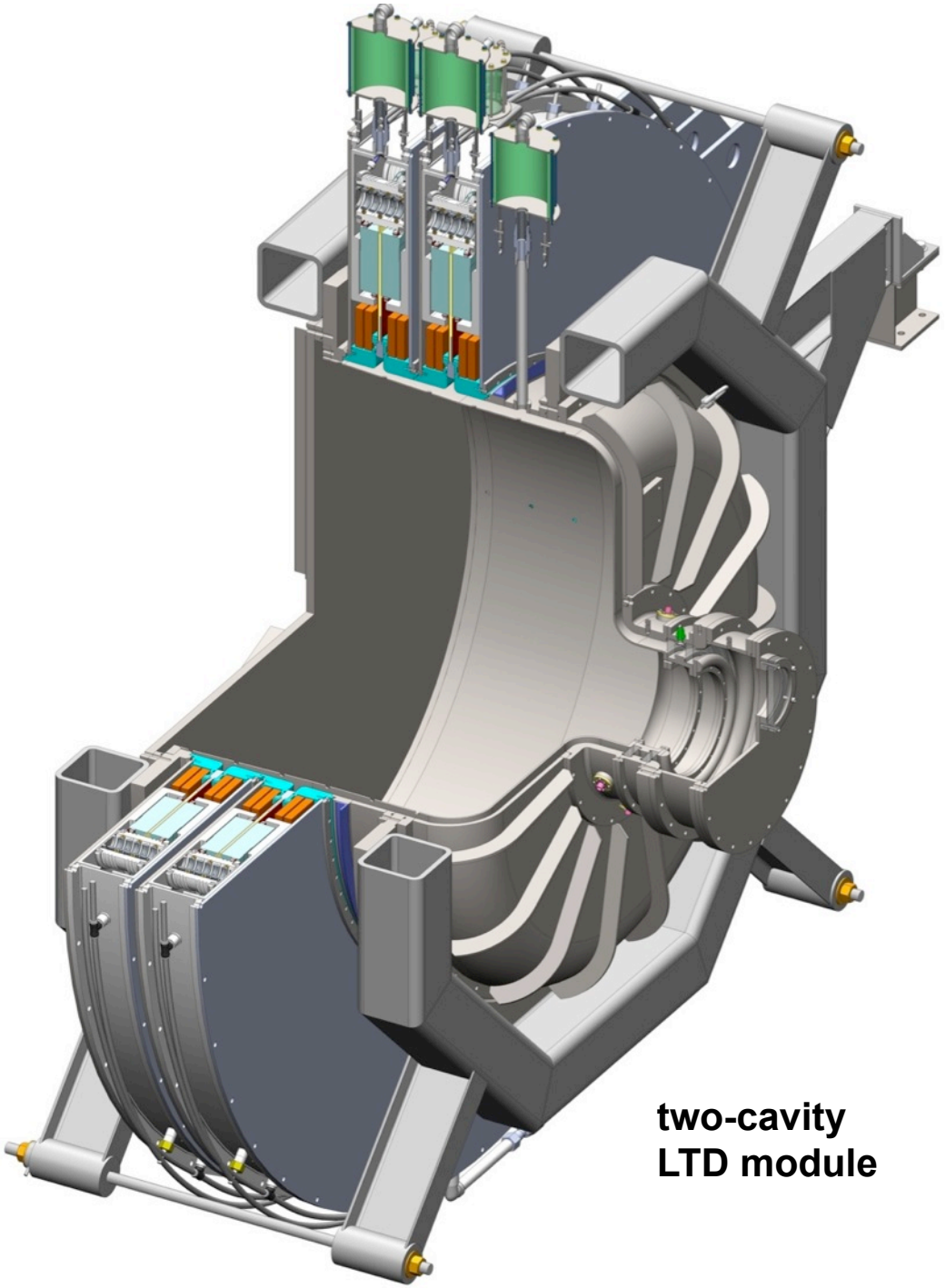
L = inductance of a single LTD brick, which is the sum of the switch, capacitor, and connection inductances

N = total number of LTD bricks

n = number of LTD cavities per module

We are developing the technology needed to build Z 300.

- We have developed the first 100-ns LTD brick that generates 5 GW of electrical power. We successfully tested the brick on 2000 shots.
- We have developed the highest-power-density LTD cavity, which is 2 meters in diameter and generates 79 GW. We successfully tested the cavity on 2000 shots.
- We have developed the highest-power megampere-class LTD module, which generates 160 GW. This module is also the first to drive an internal water-insulated transmission line. We successfully tested the two-cavity module on 2000 shots.



two-cavity LTD module

Z 800 will be a larger version of Z 300, and deliver as much as 63 MA to physics-package loads.

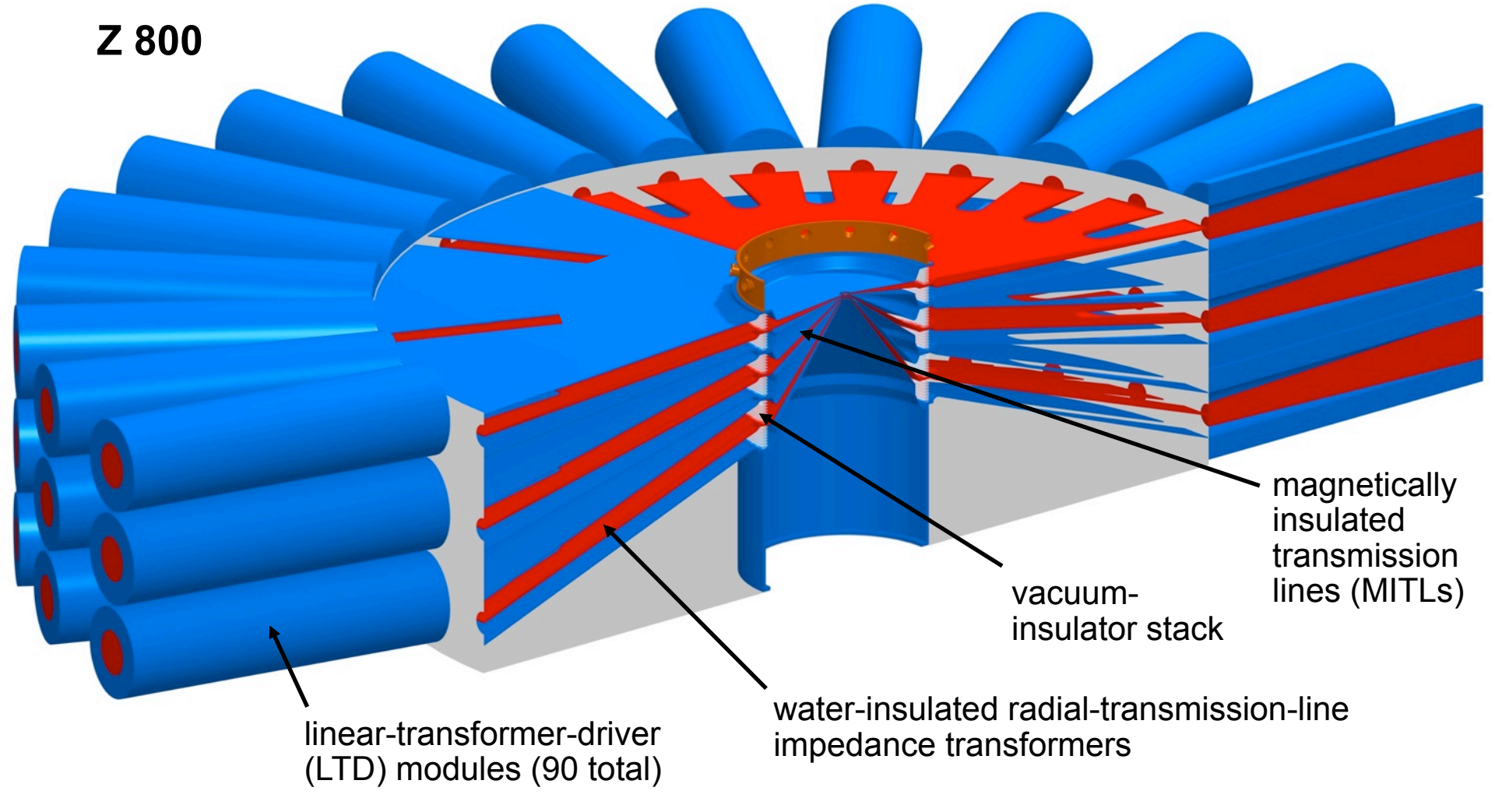
P = 830 TW
E = 130 MJ

V_{stack} = 16 MV
L_{vacuum} = 20 nH

I_{load} = 63 MA
$\tau_{implosion}$ = 110 ns

$E_{radiated}$ = 20 MJ
diameter = 50 m

η_{x-ray} = 15%



Summary

- We have developed *conceptual* designs of two next-generation pulsed-power accelerators: Z 300 and Z 800.
- The designs are based on two concepts: single-stage pulse compression and impedance matching. We accomplish both by using linear transformer drivers (LTDs) as the prime power source.
- The number of LTD bricks needed and the electrical parameters of each brick are determined by the peak load current, width of the current pulse, load impedance, and LTD-capacitor charge voltage.
- We are developing the technology needed to build the new machines.
  - We have developed the first 100-ns brick that generates 5 GW.
  - We have developed the highest-power-density LTD cavity.
  - We have developed the highest-power megampere-class LTD module.
- We will be ready soon to begin the *initial* design of Z 300.