Tokamaks

History and Future

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November 24th, 2009

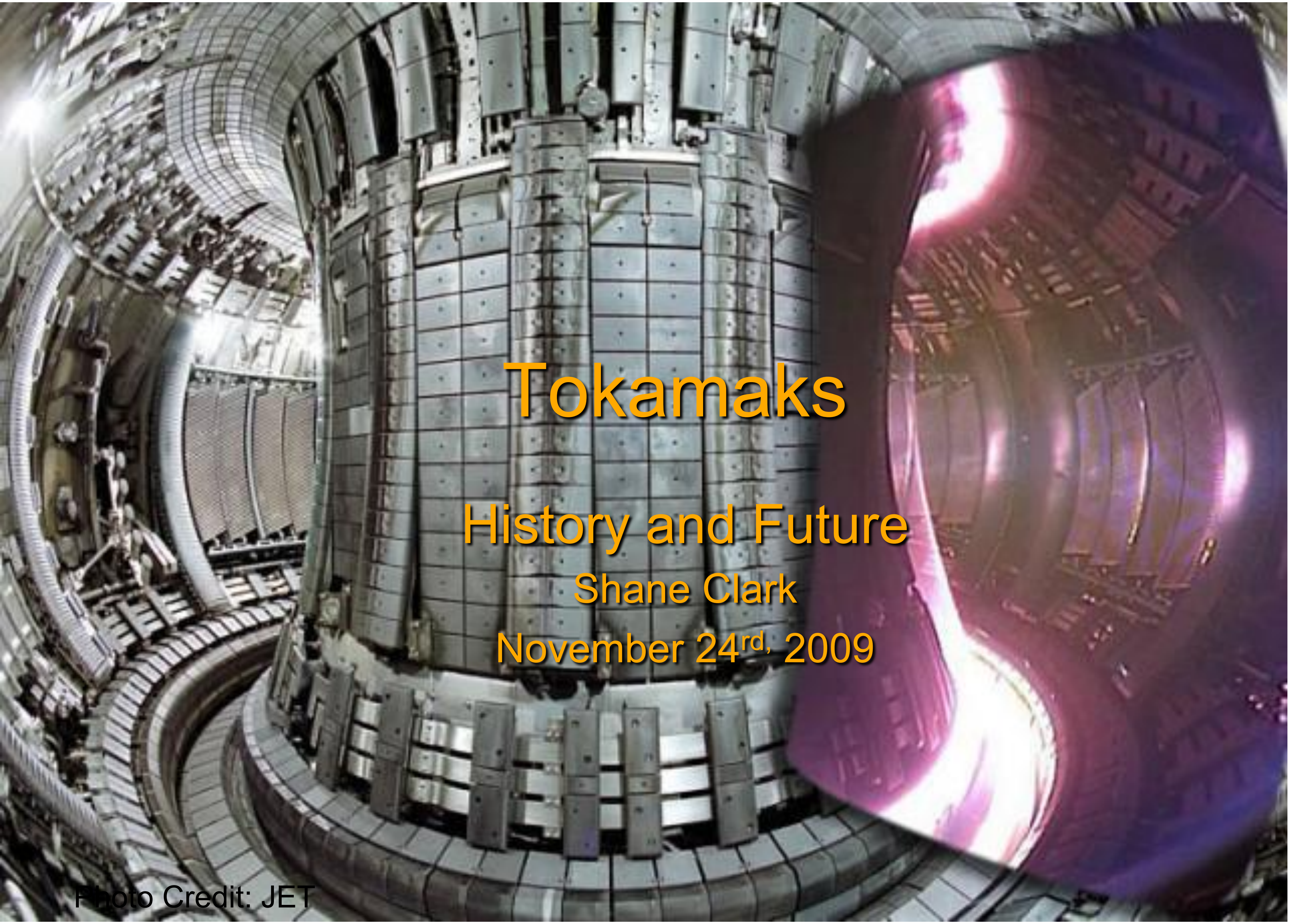


Photo Credit: JET

Overview

- What is a Tokamak?
- Fusion Reactions
- Fusion in Tokamaks
- Challenges
- Current Standings
- Competitors
- Future Prospects

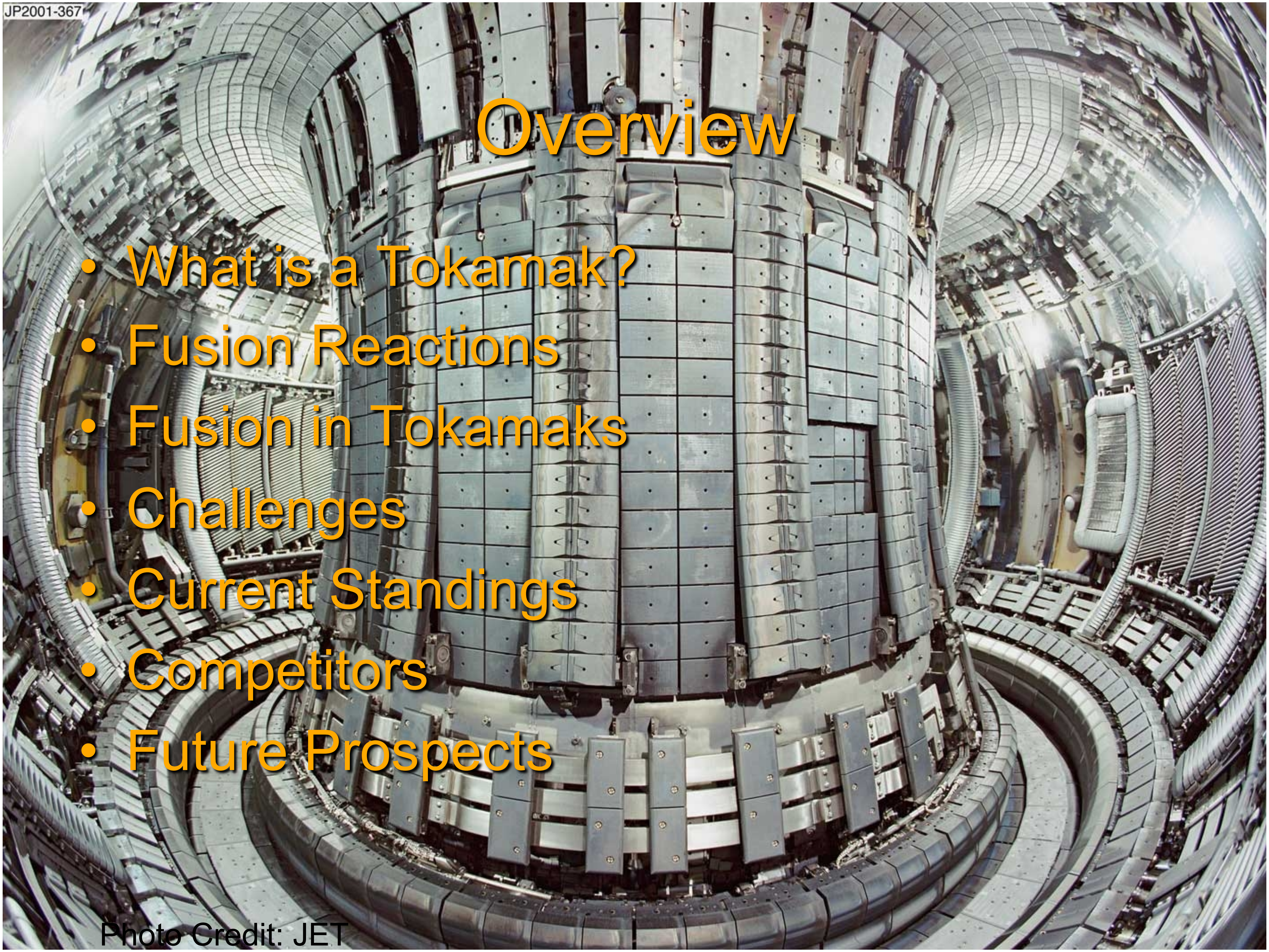
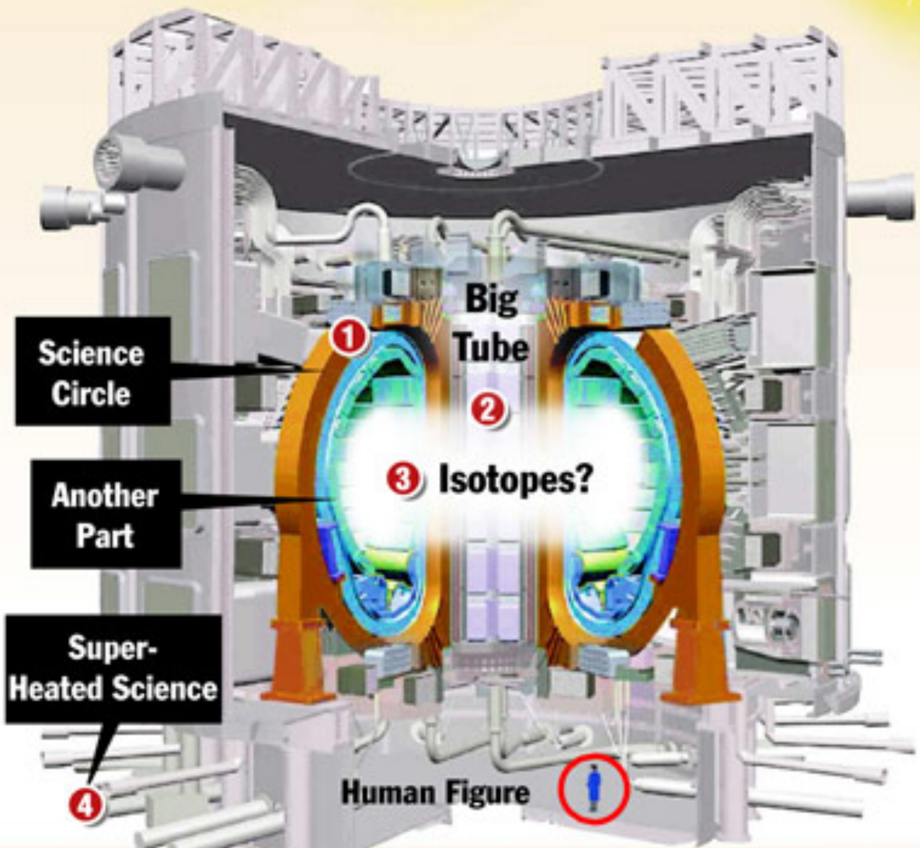


Photo Credit: JET

Onion Science Thursday

Giant Machine Creates Science

The Onion explains the inner workings of the complex, expensive science thing.



A Science Machine

The expensive device will test and execute more science than ever before

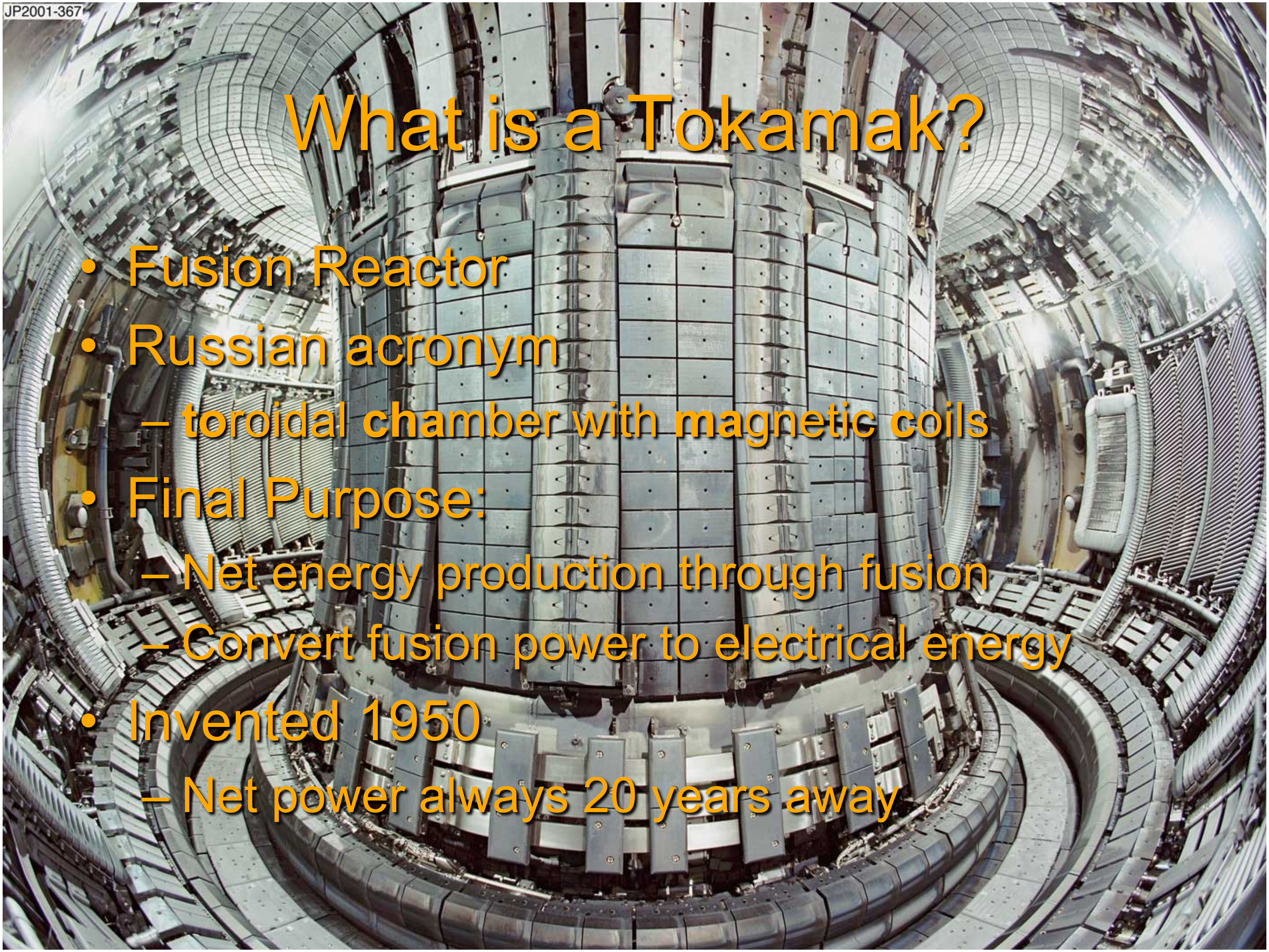
1 Scientists make sure machine's On/Off button is switched to On

2 Parts of the machine begin to move, at first slowly, and then rapidly

3 A lot of science begins to generate

4 Many things light up and sounds of thunder happen

5 Science ends



What is a Tokamak?

- Fusion Reactor
- Russian acronym
  - **to**roidal **cha**mber with **ma**gnetic **c**oils
- Final Purpose:
  - Net energy production through fusion
  - Convert fusion power to electrical energy
- Invented 1950
  - Net power always 20 years away

Fusion Reactions

- Combining two nuclei into one
  - Strong force is attractive
  - Coulomb barrier
- Two needs:
  - High energy (high temp)
  - Density, Time
- Q
  - P_{fusion}/P_{heat}
  - Q=1 Breakeven
  - Q>5 Power production

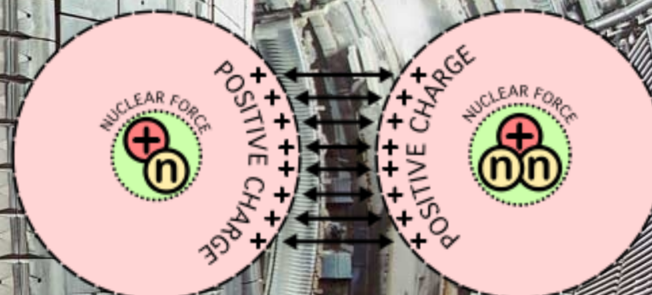


Diagram: wikipedia.org/wiki/Nuclear_fusion

Fusion Reactions

- D-D: 15-30 keV, 12MeV
  - Naturally occurring
  - No fast neutrons, 2.45 MeV
- D-T: 4keV, 17MeV
  - Easier to ignite
  - T would have to be manufactured
  - Fast neutrons 14.1 MeV
- Lawson Criteria
  - $n_e T \tau_E$
  - 10^{21} keV s/m^3

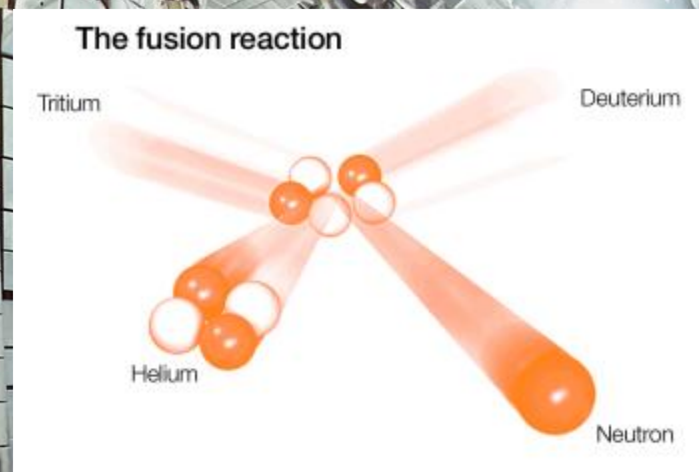


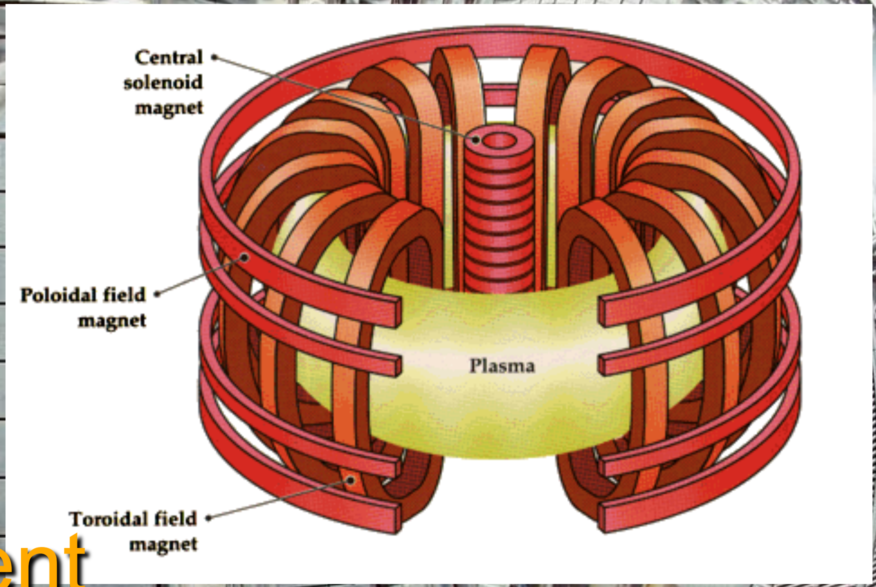
Diagram: ITER.org

Methods for Fusion

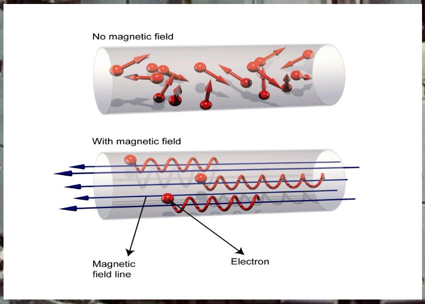
- Gravity
  - Stars
- Inertial Confinement
  - Laser
  - Electrostatic
  - Pyroelectric
- Magnetic Confinement
  - Z-Pinch
  - ZaP
  - Stellerator
  - Spheromak

Picture credit: NIF, MAST, http://fusion.wsyntax.com/

Fusion in Tokamaks



- Heating
  - Ohmic
  - ECR
  - Particle beam
- Magnetic Confinement
  - Poloidal
  - Toroidal
  - Pinch
  - Bootstrap



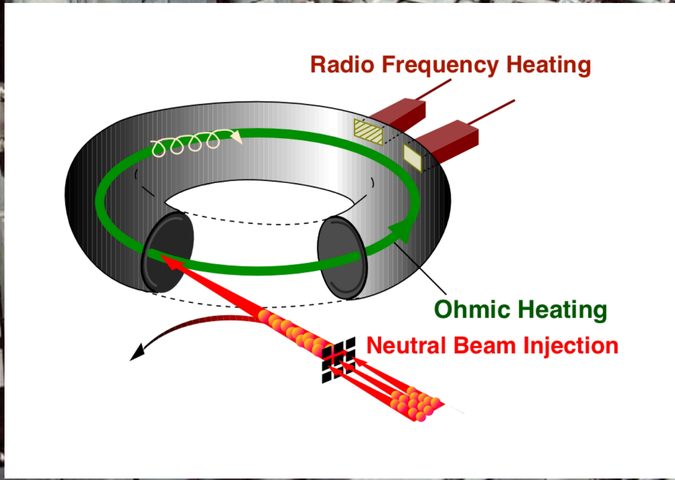


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Diagram: Lawrence Livermore Lab

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Fusion in Tokamaks

- Power production from Fusion
  - Neutron capture
  - Liquid metal jacket
  - Heat exchanger
  - Steam, turbine
- Stable Operation
  - Constant power
  - Maintenance

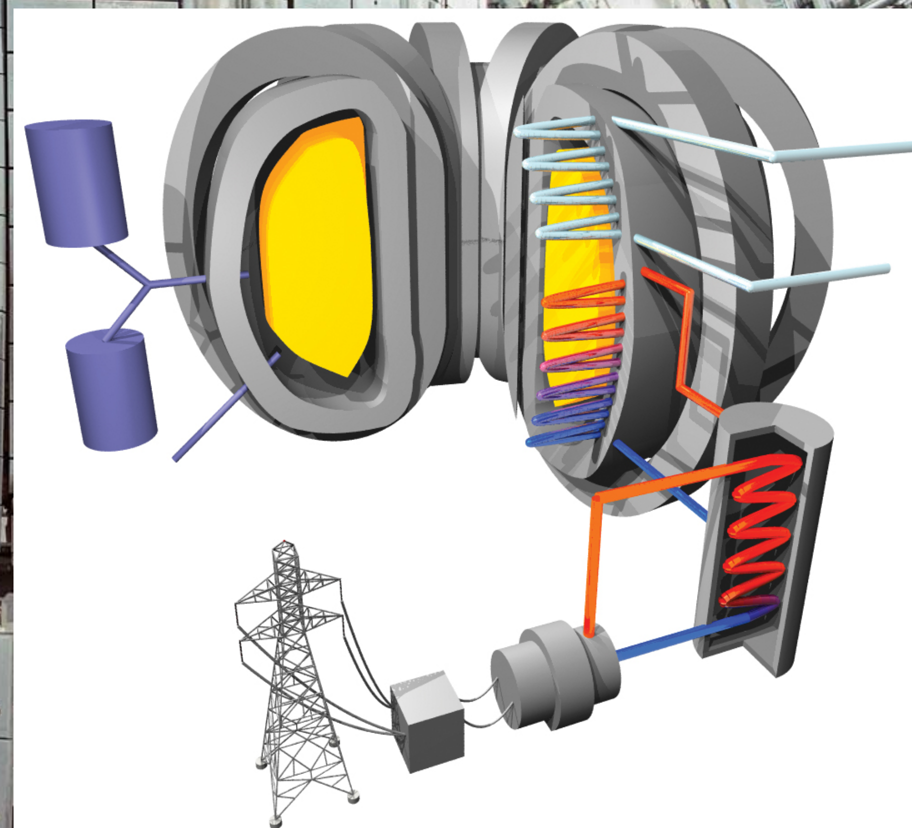
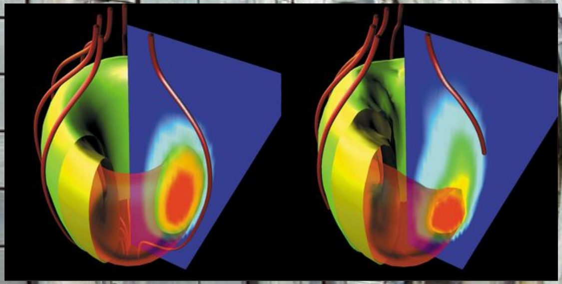
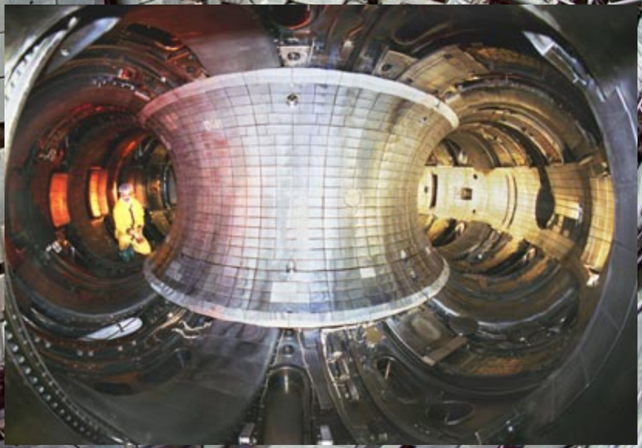


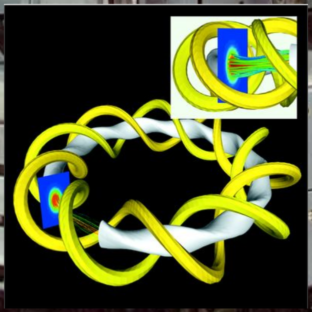
Diagram: Lawrence Livermore Lab

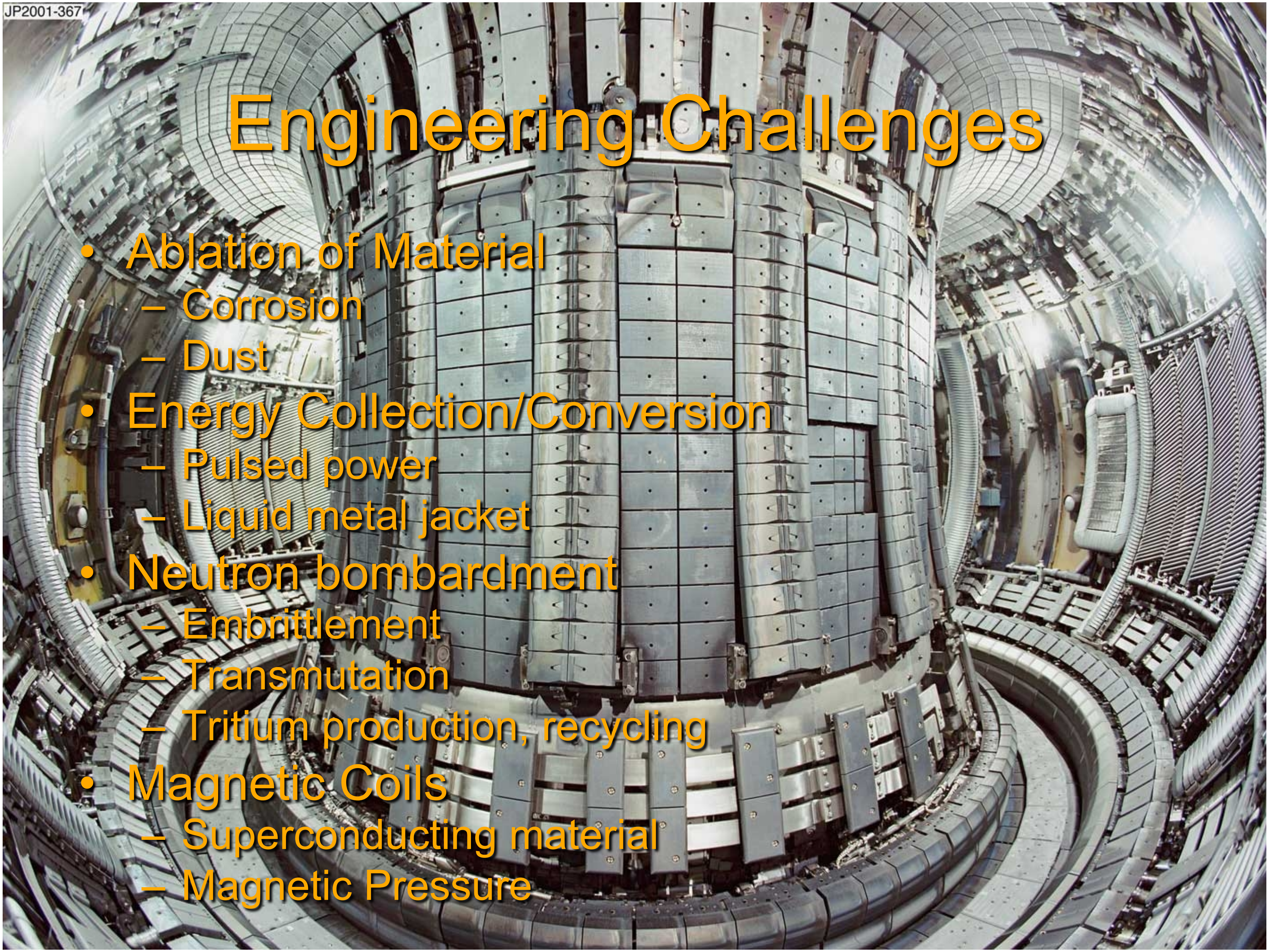
Physical Challenges

- Magnetic field non-uniformity
  - Plasma breaks confinement
  - Expands and cools, rate drops
- Heat
  - 100,000,000 K
- Stability
  - Pinch
  - Kelvin-Helmholtz
- Modeling
  - Alfvén waves
  - Toroidal DOF
  - Dust







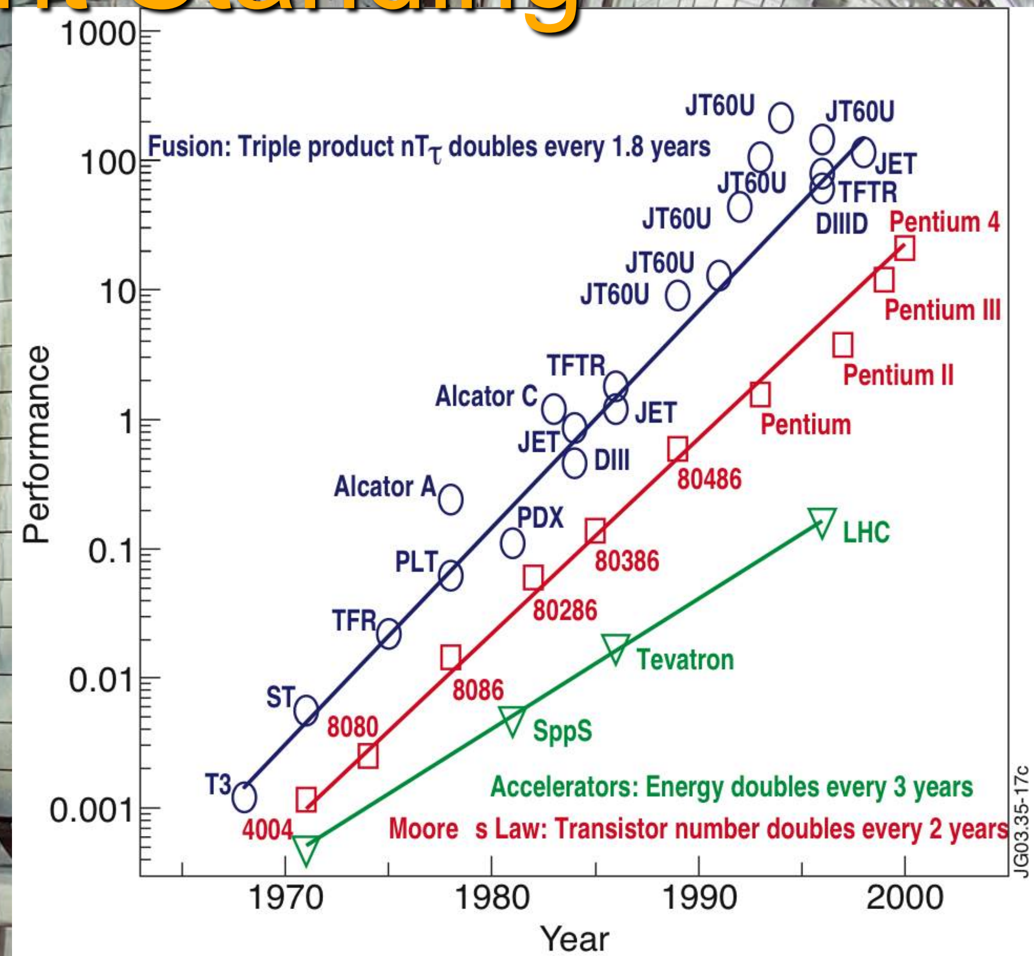


Engineering Challenges

- Ablation of Material
  - Corrosion
  - Dust
- Energy Collection/Conversion
  - Pulsed power
  - Liquid metal jacket
- Neutron bombardment
  - Embrittlement
  - Transmutation
  - Tritium production, recycling
- Magnetic Coils
  - Superconducting material
  - Magnetic Pressure

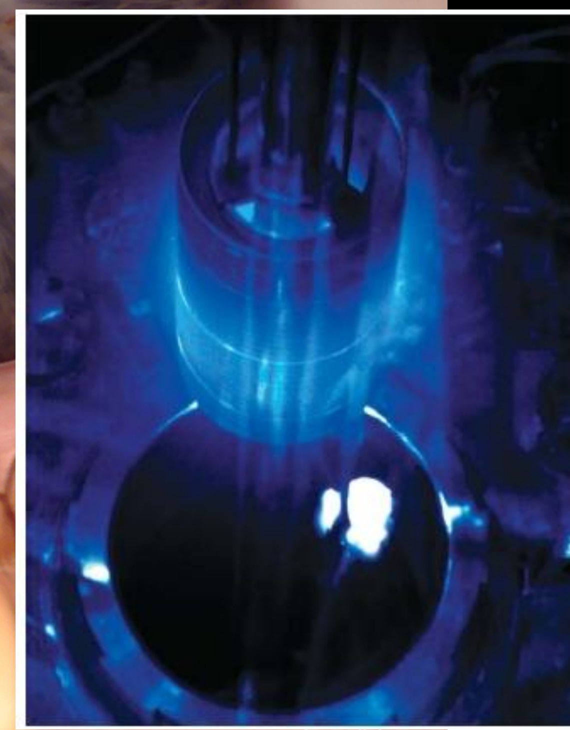
Current Standing

- JET
  - Q=.7
- Tore Supra
  - 390 second
- JT-60
  - $n_e T_\tau E$=1.53x10^{21}
  - Q=1.25 with D-T
- EAST
  - Superconducting coils

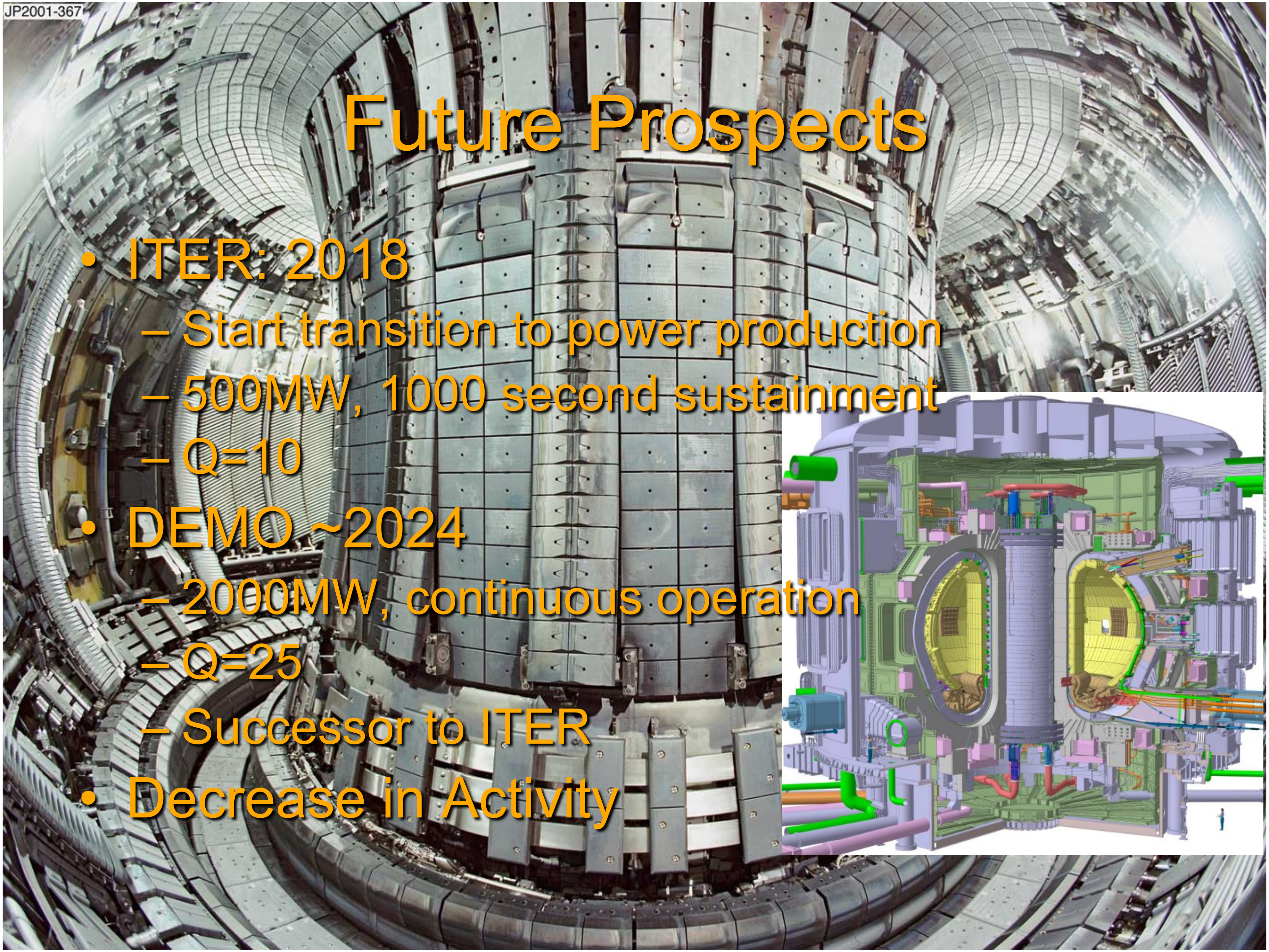


Competitive Technologies

- National Ignition Facility
  - Long cycle time
  - Costly
- LDX
  - D-D
  - Promising Stabilities
- Fission
  - Cheap
  - Well known technology
  - Waste Storage



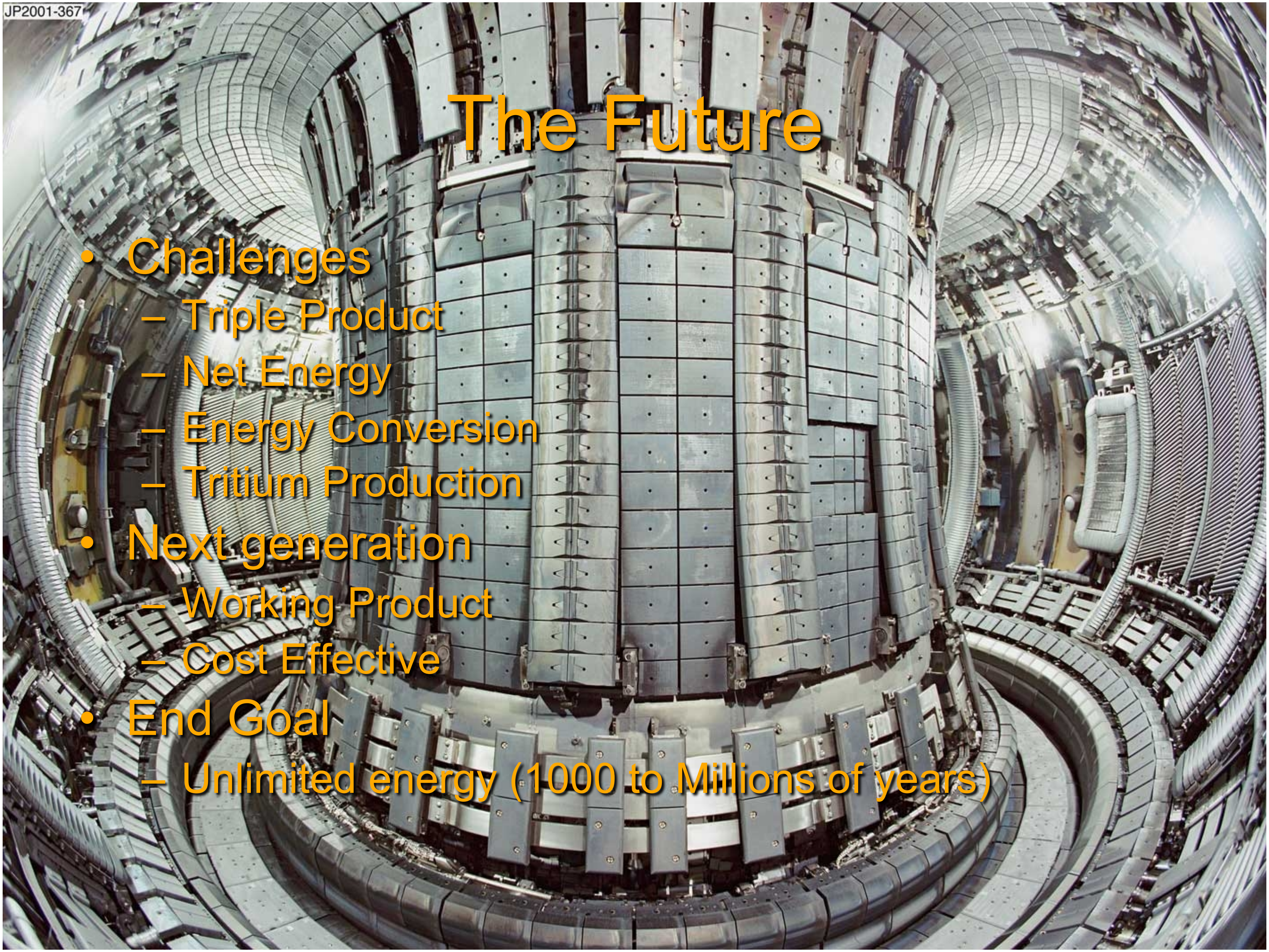
lasers.llnl.gov



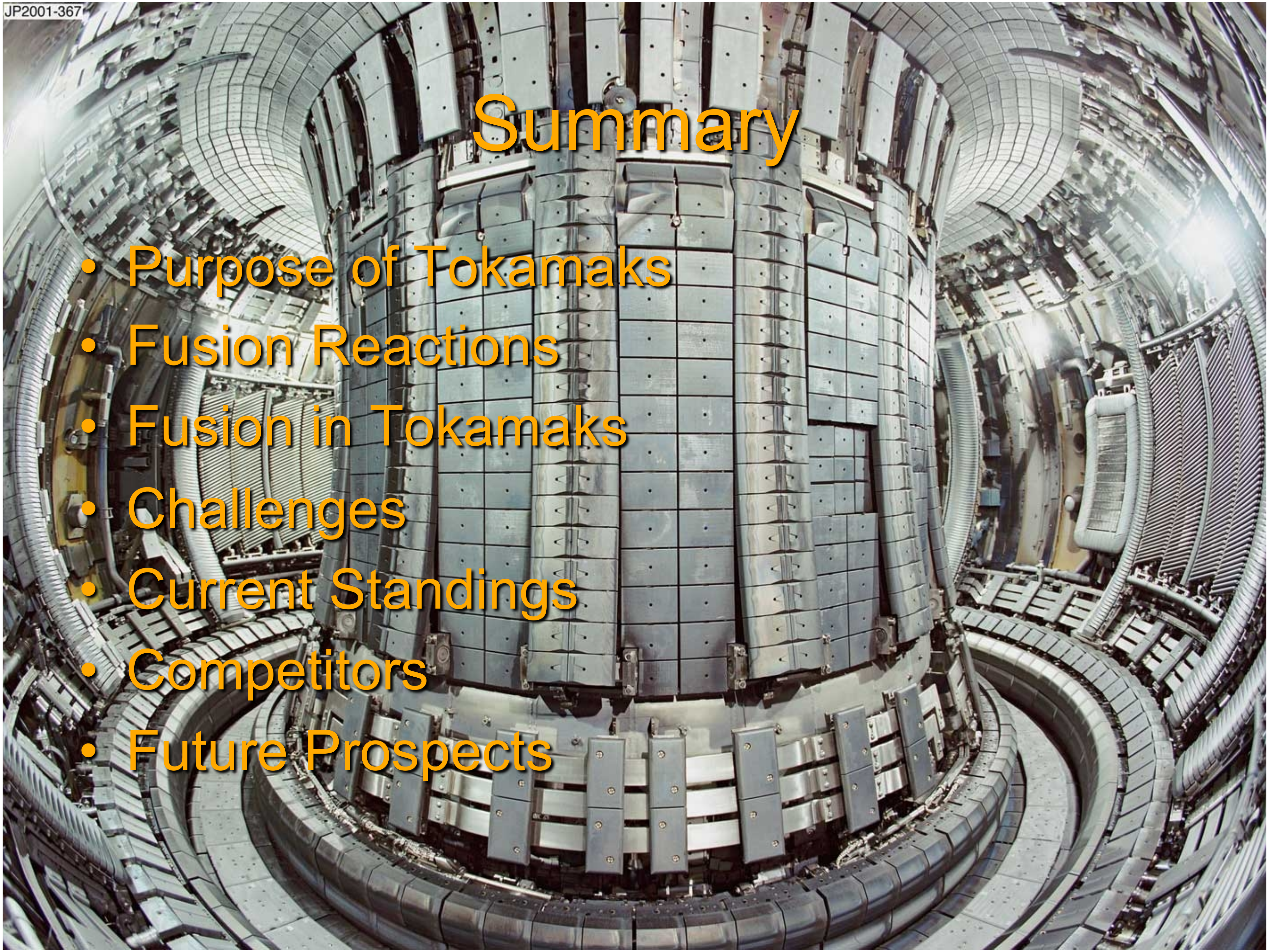
Future Prospects

- ITER: 2018
  - Start transition to power production
  - 500MW, 1000 second sustainment
  - Q=10
- DEMO ~2024
  - 2000MW, continuous operation
  - Q=25
  - Successor to ITER
- Decrease in Activity

The Future



- Challenges
  - Triple Product
  - Net Energy
  - Energy Conversion
  - Tritium Production
- Next generation
  - Working Product
  - Cost Effective
- End Goal
  - Unlimited energy (1000 to Millions of years)



Summary

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Sources

- ITER Project
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- Dust: A new challenge in nuclear fusion research? J. Wintera) ¨ ¨ Institut fur Experimentalphysik II, Ruhr-Universitat Bochum, D 44780 Bochum, Germany
- Levitated Dipole Experiment
  - http://psfcwww2.psfc.mit.edu/ldx/