MATERION

BERYLLIUM REFLECTOR MATERIALS FOR RESEARCH & TEST REACTOR APPLICATIONS

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Presentation Outline

- Introduction
  - Materion Corporation Overview
  - Relevant Beryllium Physical Properties
- Fission Test Reactors
  - Programs: Past, Present & Future
  - Replacement Cycle
  - Relevant Beryllium Mechanical Properties
- Spallation Neutron Source Programs
- Return of Molten Salt Reactors?
- Fusion Test Reactors
  - Programs: Past, Present & Future
- Summary & Conclusion

Global Footprint

2400
Employees serving our customers

50
In more than 50 countries

30
From more than 30 facilities

10
In 10 countries around the world

Corporate Office
Mayfield Heights, Ohio

Manufacturing Facilities
Albuquerque, New Mexico
Bloomfield, Connecticut
Brewster, New York
Buellton, California
Buffalo, New York
Delta, Utah
Elmore, Ohio
Fremont, California
Limerick, Ireland
Lincoln, Rhode Island
Lorain, Ohio
Louny, Czech Republic
Milwaukee, Wisconsin
Newburyport, Massachusetts
Reading, Pennsylvania
Santa Clara, California
Singapore
Subic Bay, Philippines
Suzhou, China
Taipei, Taiwan
Tucson, Arizona
Tyngsboro, Massachusetts
Westford, Massachusetts
Wheatfield, New York
Windsor, Connecticut

Service Centers
Elmhurst, Illinois
Warren, Michigan
Singapore
Stuttgart, Germany
Theale, England
Tokyo, Japan

Materion Product Portfolio

- Precious & Non-Precious Specialty Metals
- Precision Optical Filters
- Inorganic Chemicals & Powders
- Specialty Coatings
- High-Performance Engineered Alloys
  - Beryllium-Containing
  - Non-Beryllium
- Beryllium & Metal Matrix Composites
- Engineered Clad & Plated Metal Strip

Copper-Beryllium Alloy Strip Coil

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Elmore, Ohio Beryllium & Composites Production Facility

Why Beryllium? – Relevant Physical Properties for Nuclear Uses

- Nuclear Properties
  - Low Atomic Number "Z"
  - Low Mass Absorption Coefficient
  - Neutron Reflection, Moderation, Donation & Multiplication
- Thermal Conductivity
- Melting Point

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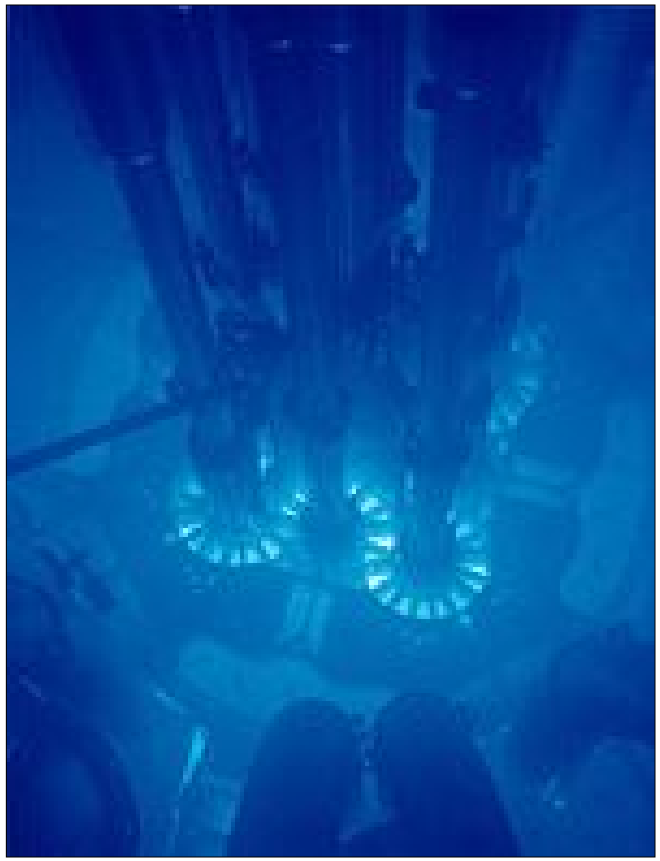

Core of the
Advanced Test Reactor

Fission Test Reactors

- Traditional Functions
  - Materials Research
  - Accelerated Life-Testing
  - Fuel Production & Research
  - Weapons Research
- New Functions
  - Medical Radioisotope Production
  - Other Nuclear Medical Uses (BNCT, etc.)

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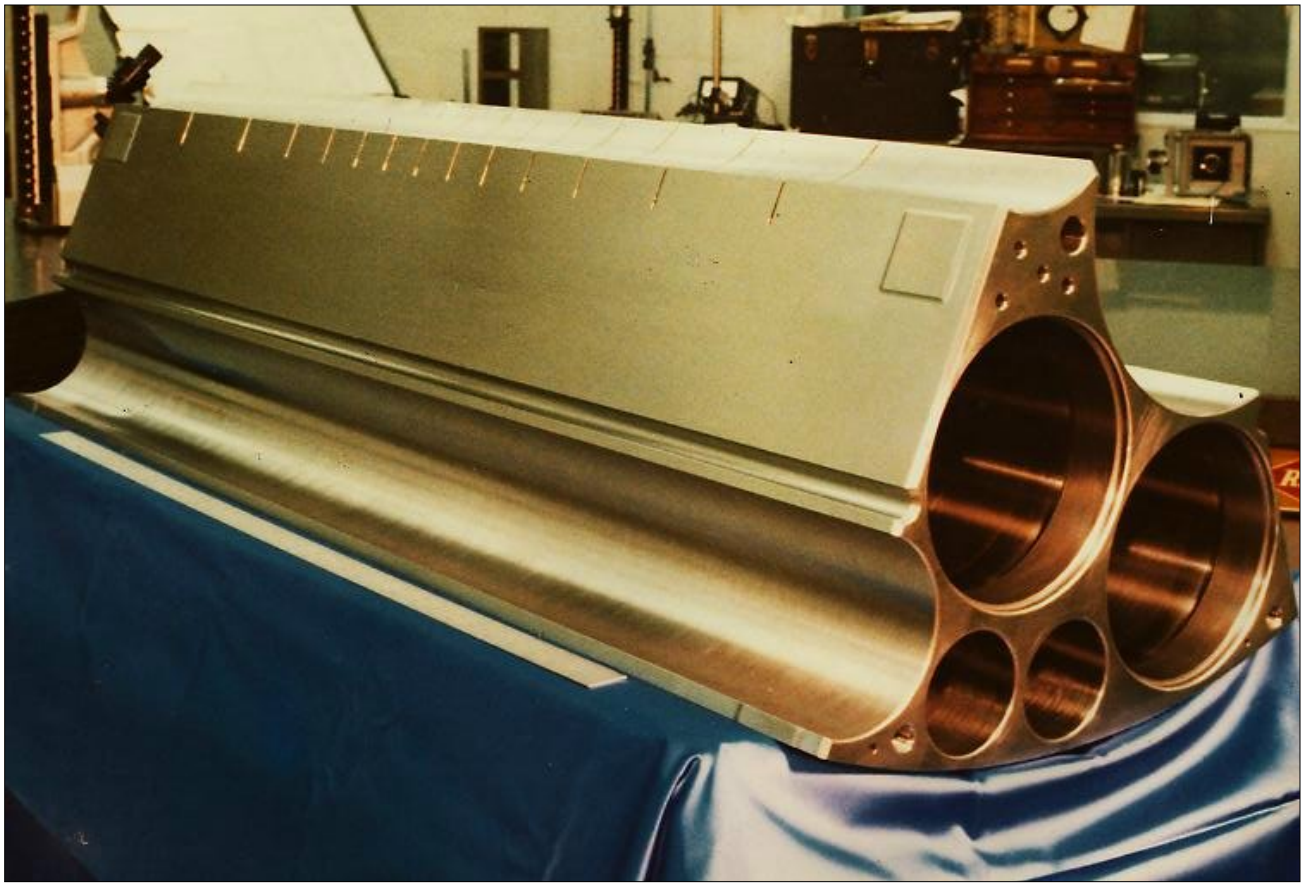
Fission Test Reactor Programs (Current & New)

- ATR – Advanced Test Reactor (Idaho, U.S.A.)
- HFIR – High Flux Isotope Reactor (Tennessee, U.S.A.)
- MURR – Missouri University Research Reactor (U.S.A.)
- JMTR – Japan Materials Testing Reactor (Japan)
- JRR-3 – Japan Research Reactor (Japan)
- HFR – High Flux Reactor (Netherlands)
- BR2 – SCK-CEN Test Reactor (Belgium)
- SAFARI-1 – NECSA Test Reactor (South Africa)
- OPAL – ANSTO Test Reactor (Australia)
- JRTR – Jordan Research & Training Reactor (Jordan)
- RJH – Jules Horowitz Reactor (France)
- KJRR – Kwang-Ju Research Reactor (Korea)

ATR Machined S-200F Beryllium Reflector Element



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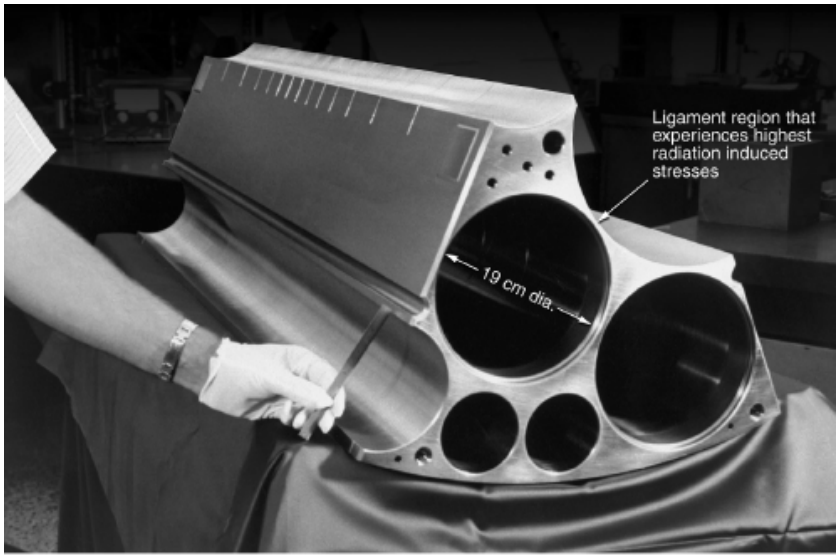
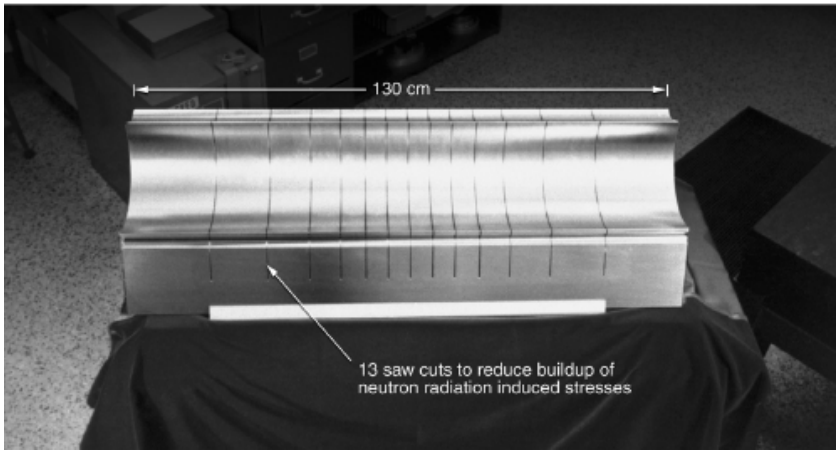
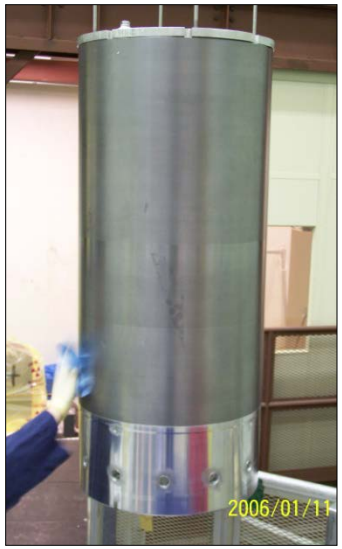


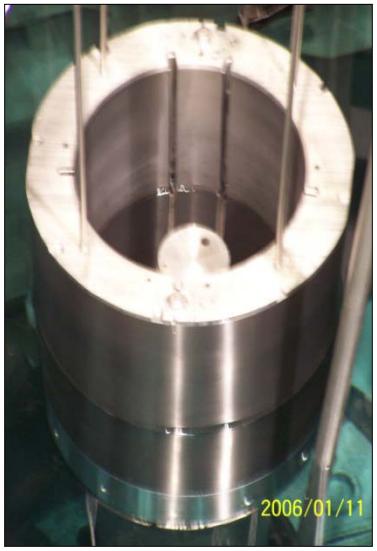


Advanced Test Reactor

- Built in 1967
- Highest Power Test Reactor in the World
- Major Bore: 190mm ID
- Length: 1300mm
- Saw-cuts to Reduce Stress
- Core Internals Change-out (CIC) on 7-10 year cycle, including several beryllium parts, now S-200F

MURR Machined S-200F-H Beryllium Reflector Assembly



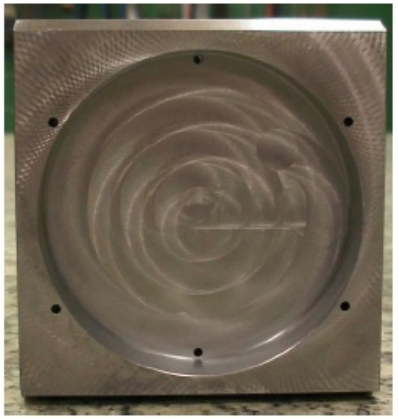


Photos Courtesy of University of Missouri at Columbia

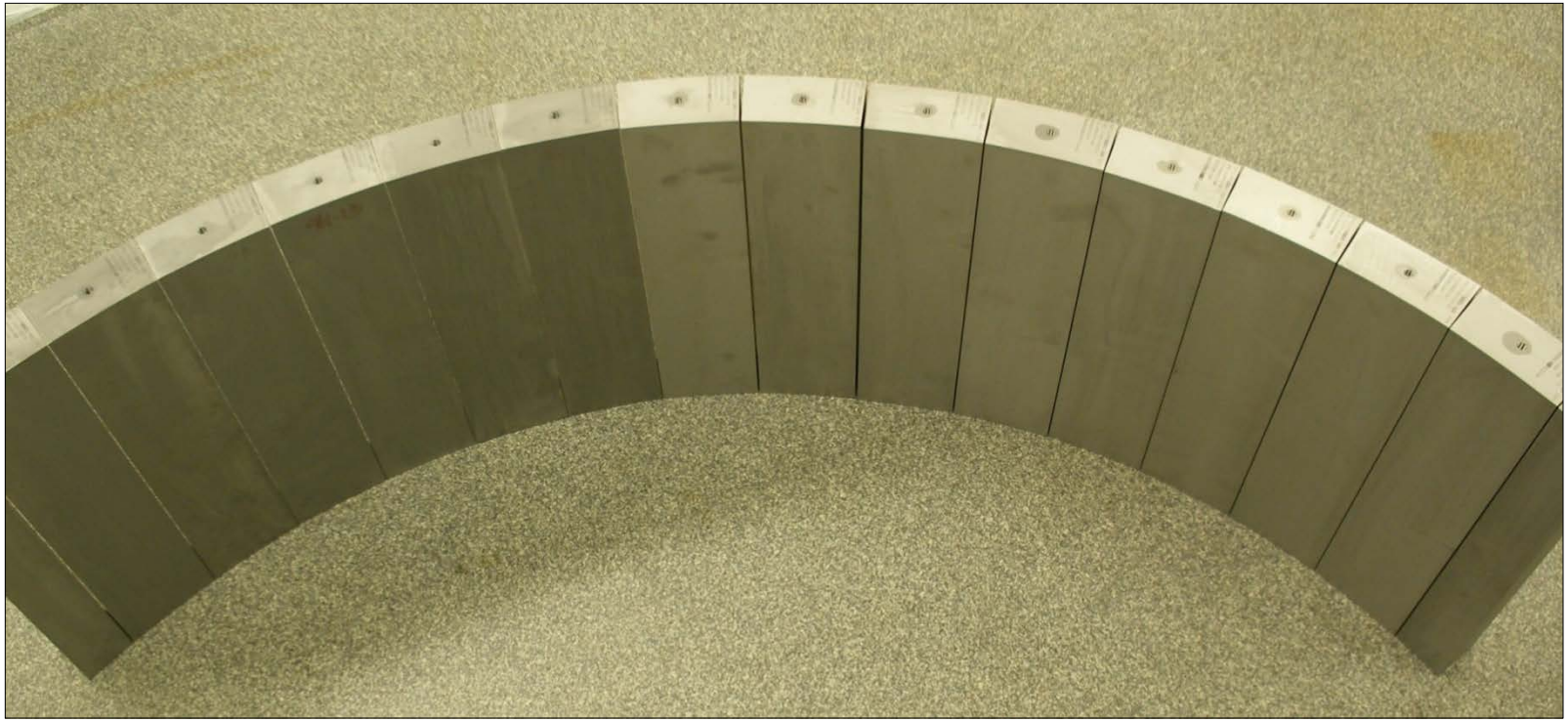
HFR Machined S-200F Beryllium Reflector Assemblies

SAFARI-1 Machined S-65-H Beryllium Reflector Elements





OPAL Machined S-200F Beryllium Filters



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Beryllium Reflector Element Replacement Cycles

- Radiation-induced Swelling
- Common Cycle 5-10 years
  - Neutron Fluence
  - Operation Schedule
- Empirical Replacement Criteria
  - Various "Go-No Go" Indicators
  - Projects to Optimize Lifetime
    - KAERI in Korea
    - JAEA with Kazakhstan & U.S.A.
    - Restart in Japan in 2015?

SAFARI-1 Original Beryllium Reflector Elements Photo Courtesy of NECSA, South Africa

Comparison of Typical Physical & Mechanical Properties

Property	Beryllium S-200F AMS7906	AlBeMet® AM162H AMS7911	SupremEX® S640XA (Non-Be)	E-Material E-60	Magnesium AZ80A T6	Aluminum 6061 T6	Titanium Grade 4
Density (g/cm³)	1.85	2.10	2.90	2.51	1.80	2.70	4.50
Modulus (GPa)	303	193	140	331	45	69	105
UTS (MPa)	380	305	570	273	340	310	660
YS (MPa)	260	226	480	N/A	250	275	590
Elongation (%)	3.0	4.7	2.5	<0.05	5.0	12.0	20.0
Fatigue Strength (MPa)	261	138	271	N/A	100	95	N/A
Thermal Cond. (W/m-°K)	216	210	130	210	76	180	16.9
Heat Capacity (J/g-°C)	1.95	1.56	N/A	1.26	1.05	0.896	0.54
CTE (ppm/°C)	11.3	13.9	13.4	6.1	26	24	8.6
Elec. Resistivity (ohm-cm)	4.2 E-06	3.5 E-06	N/A	N/A	14.5 E-06	4 E-06	60 E-06

Materion Beryllium Reflector Materials Specification vs. Typical

Factor	Grade	Be Assay		YS		UTS		Elongation		GS
		min	typ	min	typ	min	typ	min	typ	max
		(%)		(MPa)		(MPa)		(%)		(µm)
Reference	S-200F	98.5	99.1	241	260	324	380	2.0	3.0	20
Purity	S-65	99.2	99.4	206	230	289	386	3.0	5.2	20
Isotropy	S-65-H	99.0	99.4	206	280	345	450	2.0	5.1	15
	I-70-H	99.0	99.4	207	290	345	460	2.0	5.4	12
	O-30-H	99.0	99.5	297	302	400	425	3.0	3.1	15
Strength	S-200F-H	98.5	99.1	296	336	414	450	3.0	4.6	12
	I-220-H	98.0	98.6	345	498	448	577	2.0	3.2	15

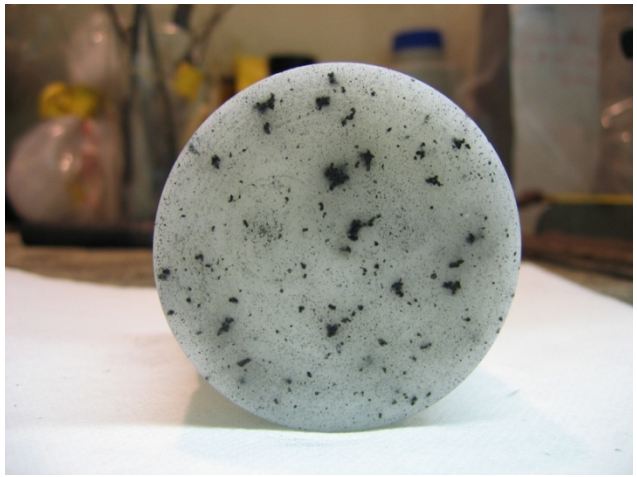
Spallation Neutron Source Programs (Current & New)

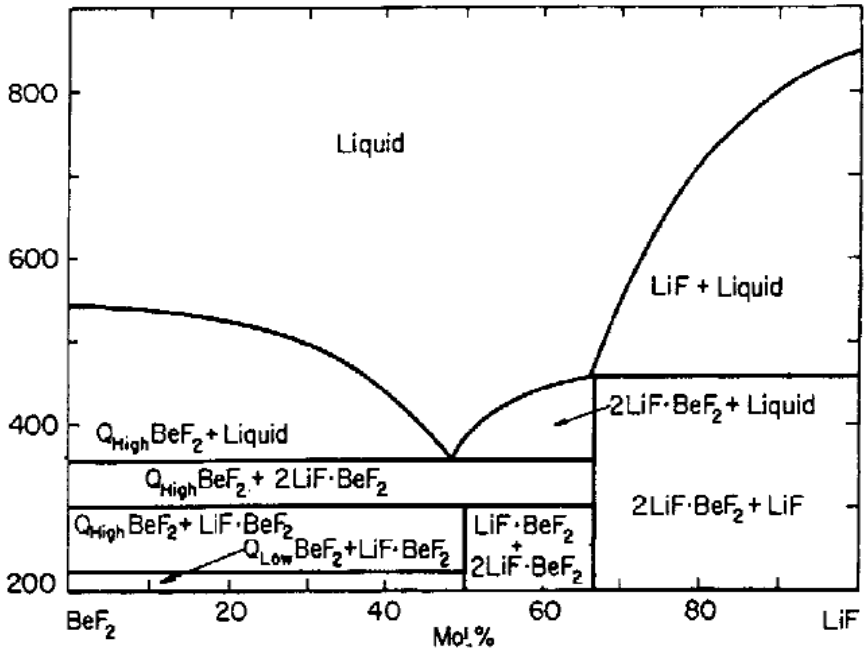
- SNS – Spallation Neutron Source
  - Oak Ridge National Laboratory
  - Tennessee, U.S.A.
- JSNS – Japan Spallation Neutron Source
  - Japan Proton Accelerator Research Complex (J-PARC)
  - Tokai, Ibaraki Prefecture, Japan
- CSNS – China Spallation Neutron Source
  - Institute of High Energy Physics (IHEP)
  - Dong-Guan City, Guang-Dong Province, China
- ESS – European Spallation Source
  - Site Construction Started in Lund, Sweden
  - 17 European Partners Contributing

Historical Use of Beryllium in Molten Salt Reactors

- FLiBe – First Major Nuclear Use
  - 8-MWth Molten Salt Reactor Experiment (MSRE)
  - Oak Ridge National Laboratory
- MSRE Operation History & Parameters
  - Time Period: June 1965 – May 1969
  - Composition: 66 mole% LiF and 34 mole% BeF_2
  - Temperature: 545 – 650 degrees C
  - Pressure: 34.4kPa
  - Circulation Rate: 54L/sec (intermediate coolant)
- MSRE Safety Record
  - 17,655 hours critical with no major safety events

FLiBe Production at Materion in Elmore, Ohio, U.S.A.





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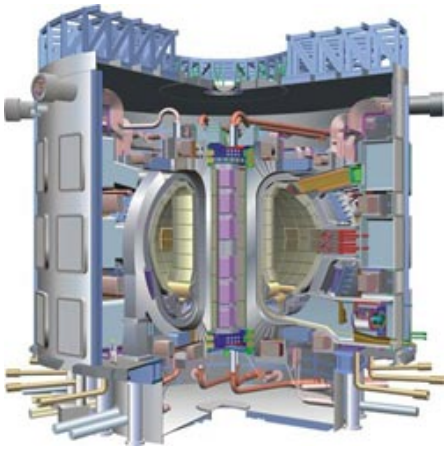
Fusion Test Reactors

- Fusion Technologies
  - Origin
  - Magnetic Confinement
  - Inertial Confinement (also called Laser)
- Potential Benefits
  - No CO_2 Emissions
  - Unlimited Fuel Supply
  - Minimal Waste Products

the way to new energy

iter

china eu india japan korea russia usa

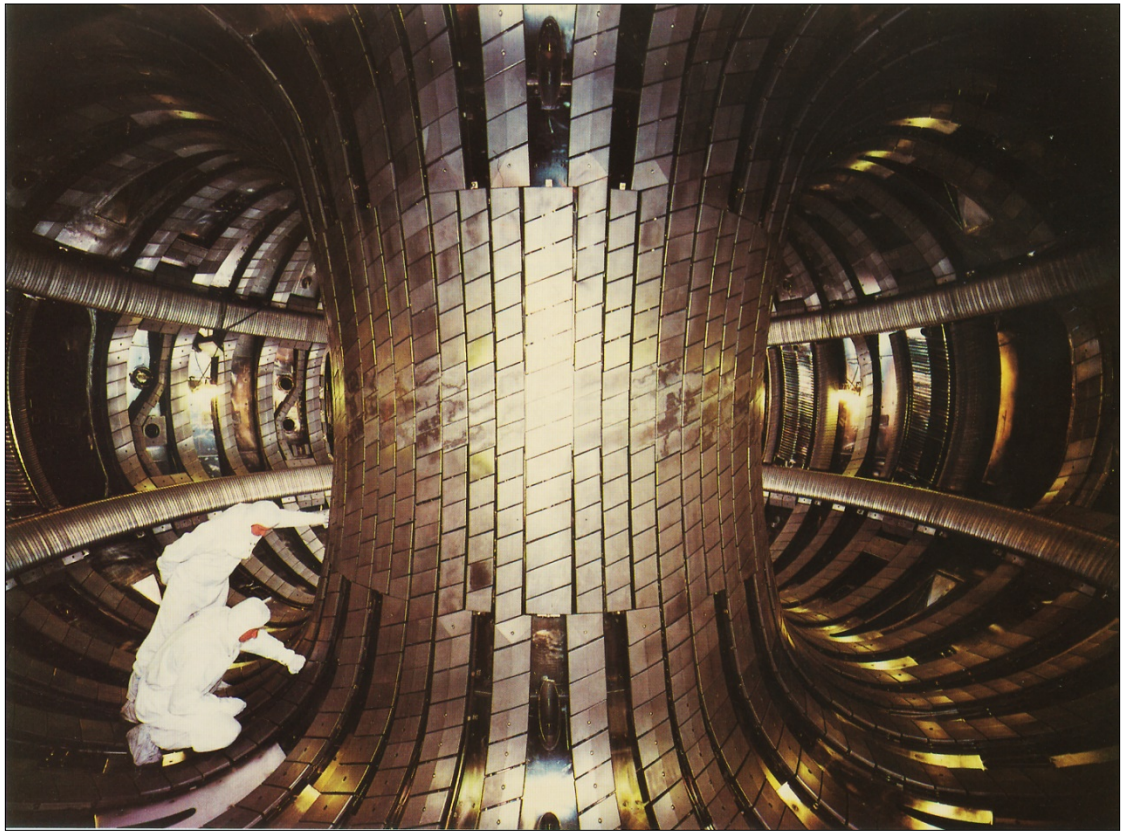


ITER Fusion Reactor Schematic

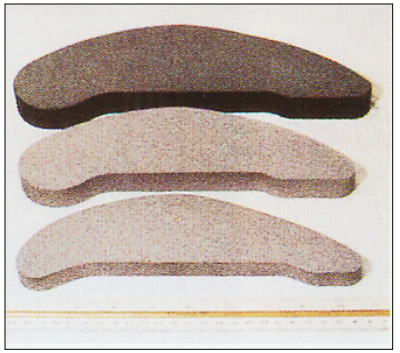
Fusion Test Reactor Programs

- JET – Joint European Torus (England)
  - RF Antenna & Belt Limiter Tiles; ITER-Like Wall Project
- ITER – Int'l Thermonuclear Experimental Reactor (France)
  - First Wall Tiles & TBM Neutron Multiplier Option
- DEMO – Demonstration Fusion Reactor (Future)
  - High-Temperature Neutron Multiplier Material
- NIF – National Ignition Facility (California, U.S.A.)
- LIFE – Laser Inertial Fusion Energy (Future)
  - Molten-Salt Coolant & Neutron Multiplier Possibilities

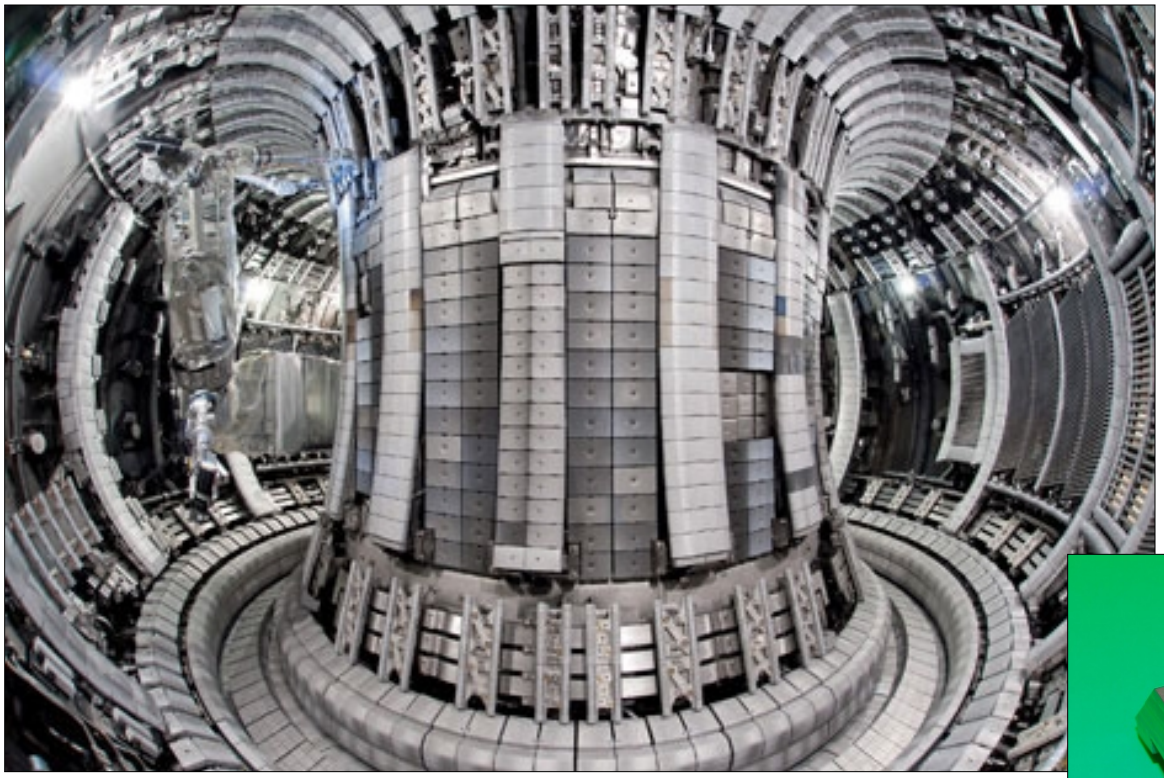
Joint European Torus – Historical Use of S-65 Be

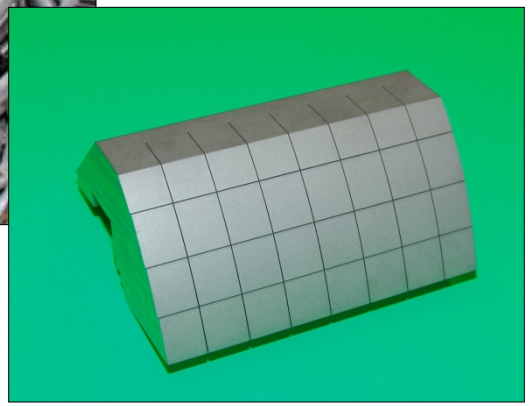


JET Reactor & Beryllium RF Antenna Tiles



ITER-Like Wall Project at JET – Current Be Fusion Application





Machined Be Tile for ITER-Like Wall Project
Photo Courtesy of Axsys Technologies PMP

Summary & Conclusion

- Beryllium Material Properties for Nuclear End-Uses
- Extensive Use in Fission Test Reactors & Continuing
  - Radioisotope Production & Nuclear Medicine
  - FLiBe Produced for Molten Salt Reactors
- Ongoing Fusion Reactor Development Programs
  - Both Magnetic & Laser Inertial Confinement
  - New Compact Fusion Reactor Materials?

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