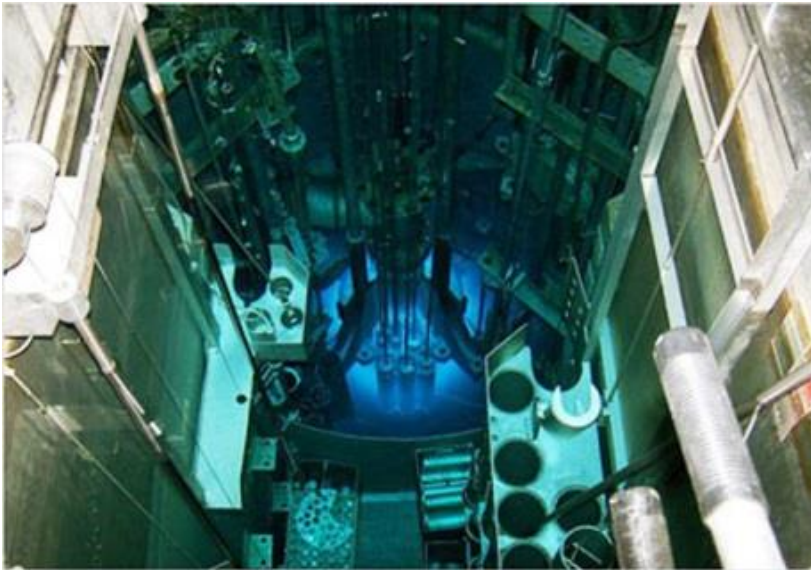


University of Missouri Research Reactor, Nordion and General Atomics Collaborating to Develop a New and Reliable Supply of Mo-99 for the Future



A Canadian-US partnership has been announced to create a "new, reliable supply" of medical isotopes for use worldwide.

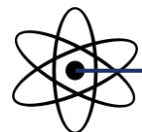
April 27, 2015



The MURR research reactor (Image: University of Missouri)

Today's meeting is to present and discuss the approach to NRC Licensing at MURR related to this project

Canada's Nordion and its US parent company Sterigenics International signed partnership agreements on 20 February with the USA's General Atomics (GA) and the University of Missouri Research Reactor Center (MURR).



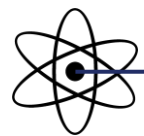
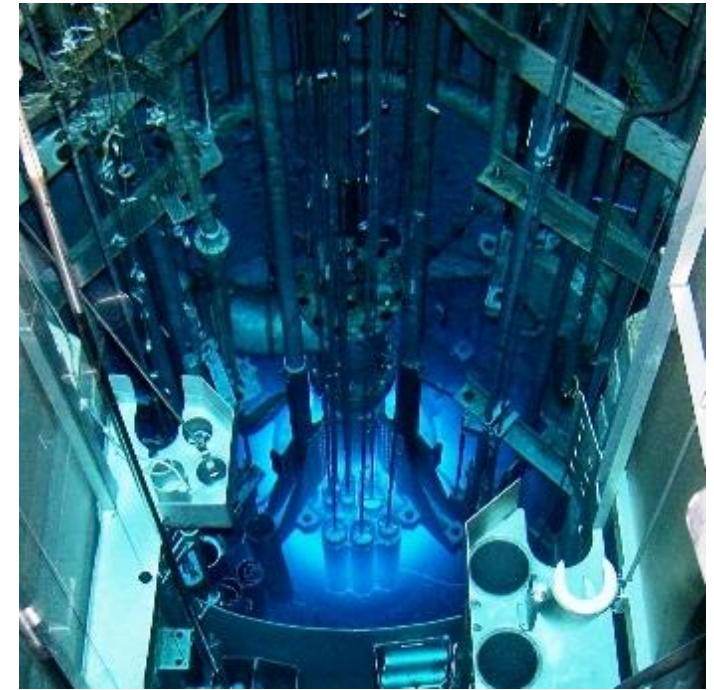
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Providing quality nuclear research, education and service to a global community

University of Missouri-Columbia Research Reactor



<http://www.murr.missouri.edu>



MURR[®]

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Improving the Quality of Life



**Research
&
Development**



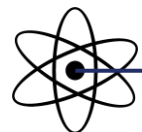
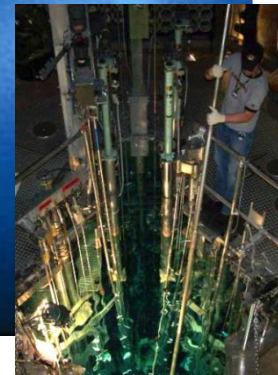
Education

**Products
&
Services**

Our core missions are Research & Education

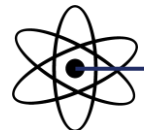


**Reactor
Operations**



Research and Development

- Life Sciences
 - ✓ Radiopharmaceutical Research
 - ✓ Trace Element Epidemiology
 - ✓ Boron Neutron Capture Therapy
 - ✓ Radioisotope Tracers
- Social Sciences
 - ✓ Archaeometry
- Material Sciences
 - ✓ Triple Axis Spectrometer
 - ✓ Neutron Reflectometer
 - ✓ Multi-detector Powder Diffractometer
 - ✓ High Resolution Powder Diffractometer



Archaeometry Research

Science

18 February 2005
Vol. 307, no. 5712, pp. 1068 - 1072
DOI: 10.1126/science.1107599



Research Articles: *Olmec Pottery Production and Export in Ancient Mexico Determined Through Elemental Analysis*
Jeffrey P. Blomster,¹ Hector Neff,² Michael D. Glascock³

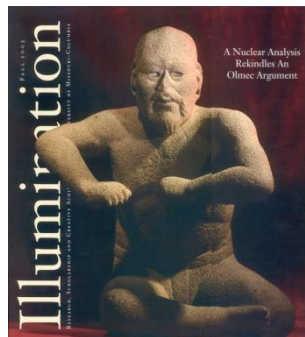
The first Mesoamerican civilization, the Gulf Coast Olmec, is associated with hierarchical society, monumental art, and an internally consistent ideology, expressed in a distinct style and salient iconography. Whether the Olmec style arose in just one area or emerged from interactions among scattered contemporaneous societies remains controversial. Using elemental analysis, we determined the regional clay sources of 725 archaeological ceramic samples from across Mesoamerica. Exported Olmec-style ceramics originated from the San Lorenzo region of the Gulf Coast, supporting Olmec priority in the creation and spread of the first unified style and iconographic system in Mesoamerica.

The New York Times

Mother Culture, or Only a Sister?

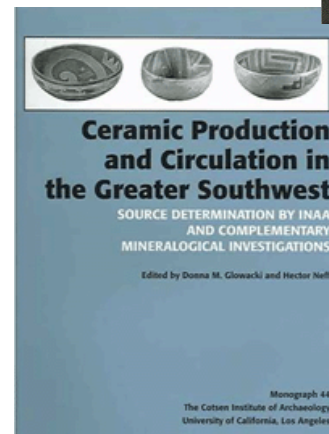
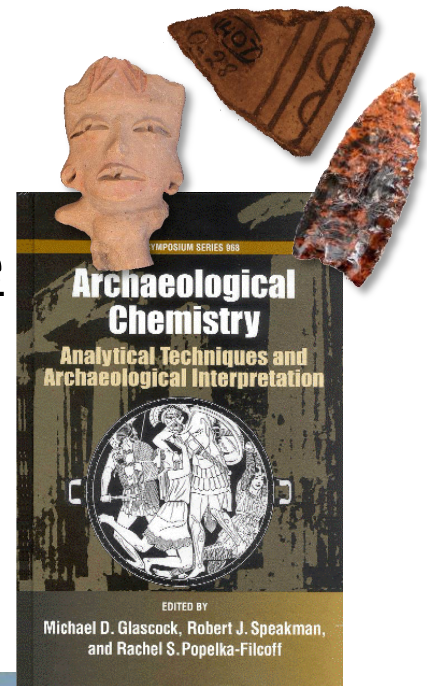
March 15, 2005, Tuesday
By JOHN NOBLE WILFORD (NYT); Science Desk
Late Edition - Final, Section F, Page 1, Column 2, 2204 words

Olmec civilization, Mesoamerican society that flourished 3,000 years ago near modern-day Veracruz, Mexico, is considered by many scholars to have been mother culture for later regional civilizations; recent report in journal *Science* by Dr Jeffrey P Blomster, George Washington University archaeologist, describes evidence of widespread export of Olmec pottery; export of goods, which Blomster asserts would spread Olmec culture, supports mother-culture theory; critics say that exportation of ceramics does not necessarily mean that other cultural aspects, like religion and politics, were also spread and influenced other groups...



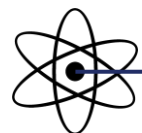
Ambasciata d'Italia
a Washington D.C.

Hidden Treasures of Rome



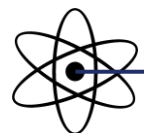
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Isotope Research Activities

- Carrier free lanthanides
 - ✓ Indirect production (Lu-177, Pm-149 and Ho-166)
 - DOE Advanced Nuclear Medicine Initiative
 - ✓ Electromagnetic isotope separation (Sm-153)
 - DOE SBIR
- Mo-99
 - ✓ n, gamma production for novel generator technologies
 - Industry partnership with NorthStar
 - ✓ Fission production with uranium recycle
 - Industry partnership with Northwest Medical Isotopes
- Rh-105
 - ✓ Carrier free from uranium fission using selective gas extraction
 - Subcontract with General Atomics/DOE Isotope Program
- Re-186
 - ✓ Accelerator production and separations for high specific activity
 - DOE Isotope Program
- As-72, As-77 and Cu-67
 - ✓ Production of high specific activity with target recycle
 - DOE Isotope Program



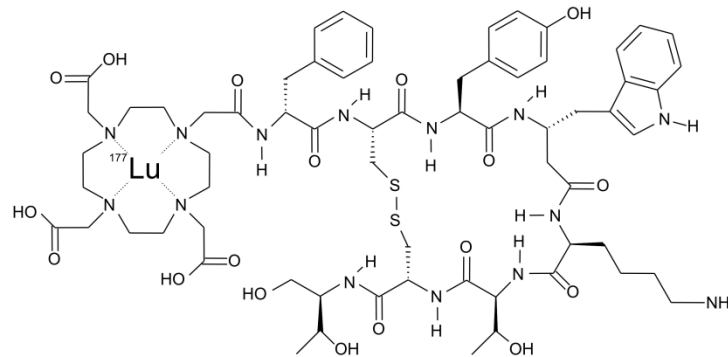
Nuclear Medicine Diagnostics AND Therapy

New Isotopes for Cancer Treatment

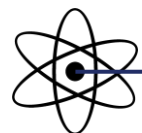
^{177}Lu from MURR is currently being evaluated in over 30 clinical applications for radiotherapy of cancer.

- Metastatic prostate cancer
- Non-hodgkins lymphoma
- Neuroendocrine tumors
- Ovarian cancer
- Metastatic bone cancer
- Colon cancer
- Lung cancer

Phase III Clinical Trials in Europe and U.S.
Metastatic gastro-entero-pancreatic
neuroendocrine tumors
Survival benefit of 40 to 72 months



Lutathera[®]



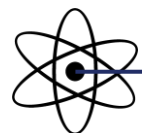
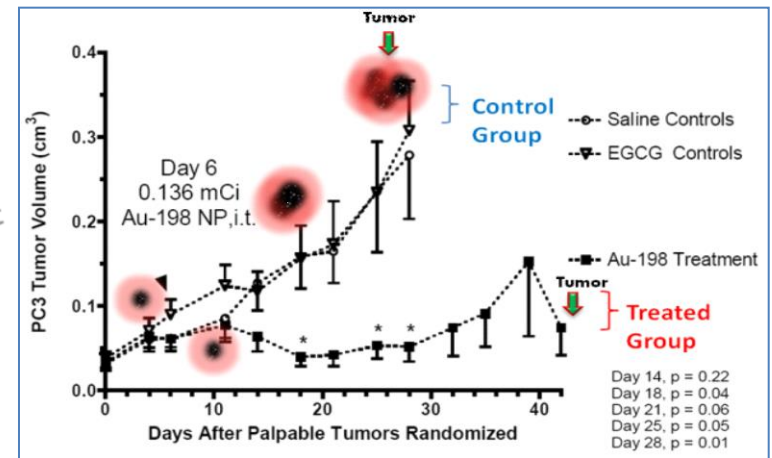
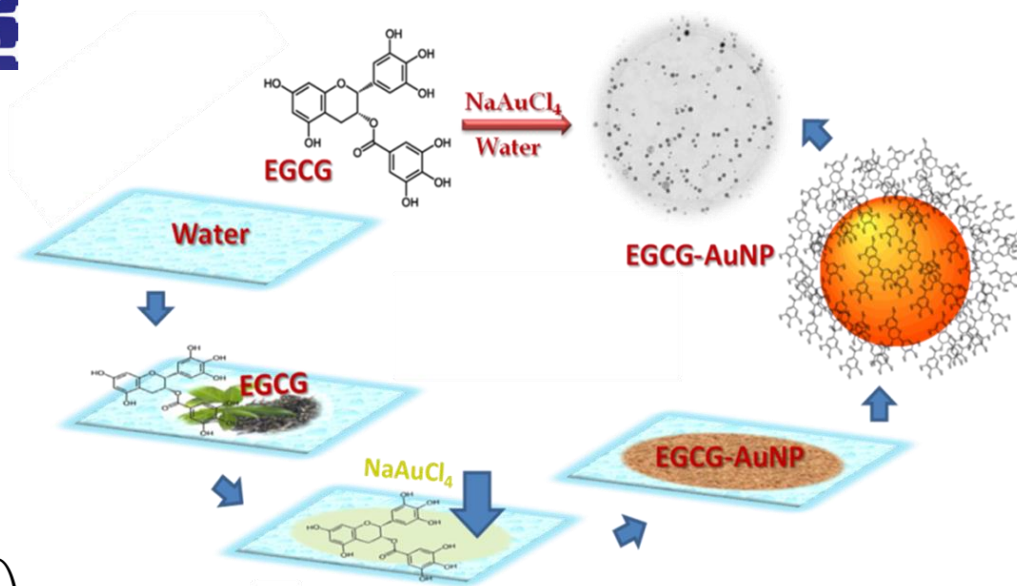
Nuclear Medicine Diagnostics AND Therapy

Radioactive Gold Nanoparticles

Epigallocatechin-gallate (EGCg) **functionalized** radioactive gold nanoparticles administered intratumorally resulted in 80% reduction of tumor volumes after 28 days.

Laminin receptor specific therapeutic gold nanoparticles ($^{198}\text{AuNP}$ -EGCg) show efficacy in treating prostate cancer

Ravi Shukla^a, Nripen Chanda^a, Ajit Zambre^a, Anandhi Upendran^{b,c}, Kavita Katti^a, Rajesh R. Kulkarni^{a,d}, Satish Kumar Nune^a, Stan W. Casteel^e, Charles Jeffrey Smith^{a,f,g}, Jatin Vimal^h, Evan Boote^a, J. David Robertson^{d,g,i}, Para Kanⁱ, Hendrik Engelbrecht^a, Lisa D. Watkinson^{a,f}, Terry L. Carmack^{a,f}, John R. Lever^{a,f,j}, Cathy S. Cutler^{d,g,i,1}, Charles Caldwell^{k,l,1}, Raghuraman Kannan^{a,c,1}, and Kattesh V. Katti^{a,b,c,g,1}

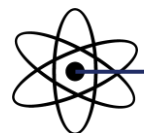


Isotope Activities

Isotopes Supplied by MURR in 2014		
Au-198	Ir-192	Sb-122
Au-199	Kr-79	Sb-124
Ba-131	Mo-99	Sc-46
Ca-45	Na-24	Se-75
Cd-115	P-32	Sm-153
Ce-141	P-33	Sn-117m
Co-60	Pd-109	Sr-89
Cr-51	Po-210	W-181
Cu-64	Rb-86	Y-90
Fe-59	Re-186	Yb-169
Lu-177	Ru-103	Zn-65
Hg-203	S-35	Zr-95

ATR Isotopes
Co-60

HFIR Isotopes
Se-75
Cf-252
W-188
Ra-223
Np-237



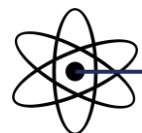
Preparing the Next Generation

Neutron Scattering for the Science and Engineering of the 21st Century \$3M National Science Foundation

Subtheme	5 Departments
Biological macromolecules and biomaterials	Biochemistry, Biology, Physics,
Strongly correlated electron systems: Oxides, superconductivity, magnetism, devices	Physics, Electrical Engineering
Nanomaterials: Energy storage materials Soft matter/polymers Thin films, surfaces, interfaces, and catalysts Nondestructive materials analysis	Physics, Mechanical and Aerospace Engineering



Università degli Studi di Roma "Tor Vergata"

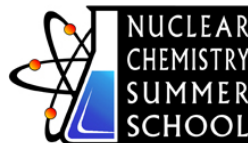


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Preparing the Next Generation

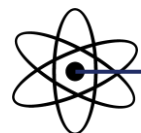
- **Introduction to Radiochemistry** lecture/lab course – the nation's largest
- Intensive **MU summer course for Missouri high school science teachers** (*3 graduate credits in nuclear engineering, 30 years running*)
- Host for **Nuclear Chemistry Summer School** for undergraduates, featuring lectures, labs and field trips covering aspects of nuclear science, medicine, particle physics and radiochemistry
- **Nuclear Workforce Development**



Radiation Protection Technician program – DOL grant to develop and disseminate curriculum to more than 20 technical colleges

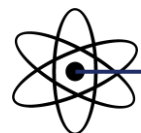


Nuclear Quality Control Technician program – NRC grant to develop QC curriculum for nuclear power industry



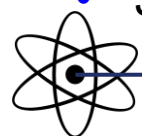
University-operated Research Reactors

Facility	Power Level	Facility	Power Level
University of Missouri, Columbia (MURR®)	10 MW	Kansas State University	250 kW
Massachusetts Institute of Technology	6 MW	Reed College	250 kW
University of California-Davis	2 MW	University of California-Irvine	250 kW
Rhode Island Nuclear Science Center	2 MW	University of Maryland	250 kW
Oregon State University	1 MW	Missouri University of Science and Technology (Rolla, MO)	200 kW
University of Texas, Austin	1 MW	University of Arizona	100 kW
North Carolina State University	1 MW	University of Florida	100 kW
Pennsylvania State University	1 MW	University of Utah	100 kW
Texas A&M University	1 MW	Purdue University	1 kW
University of Massachusetts-Lowell	1 MW	Idaho State University	5 W
University of Wisconsin	1 MW	University Of New Mexico	5 W
Washington State University	1 MW	Rensselaer Polytechnic Institute	100 W
Ohio State University	500 kW		



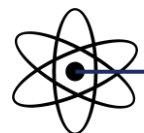
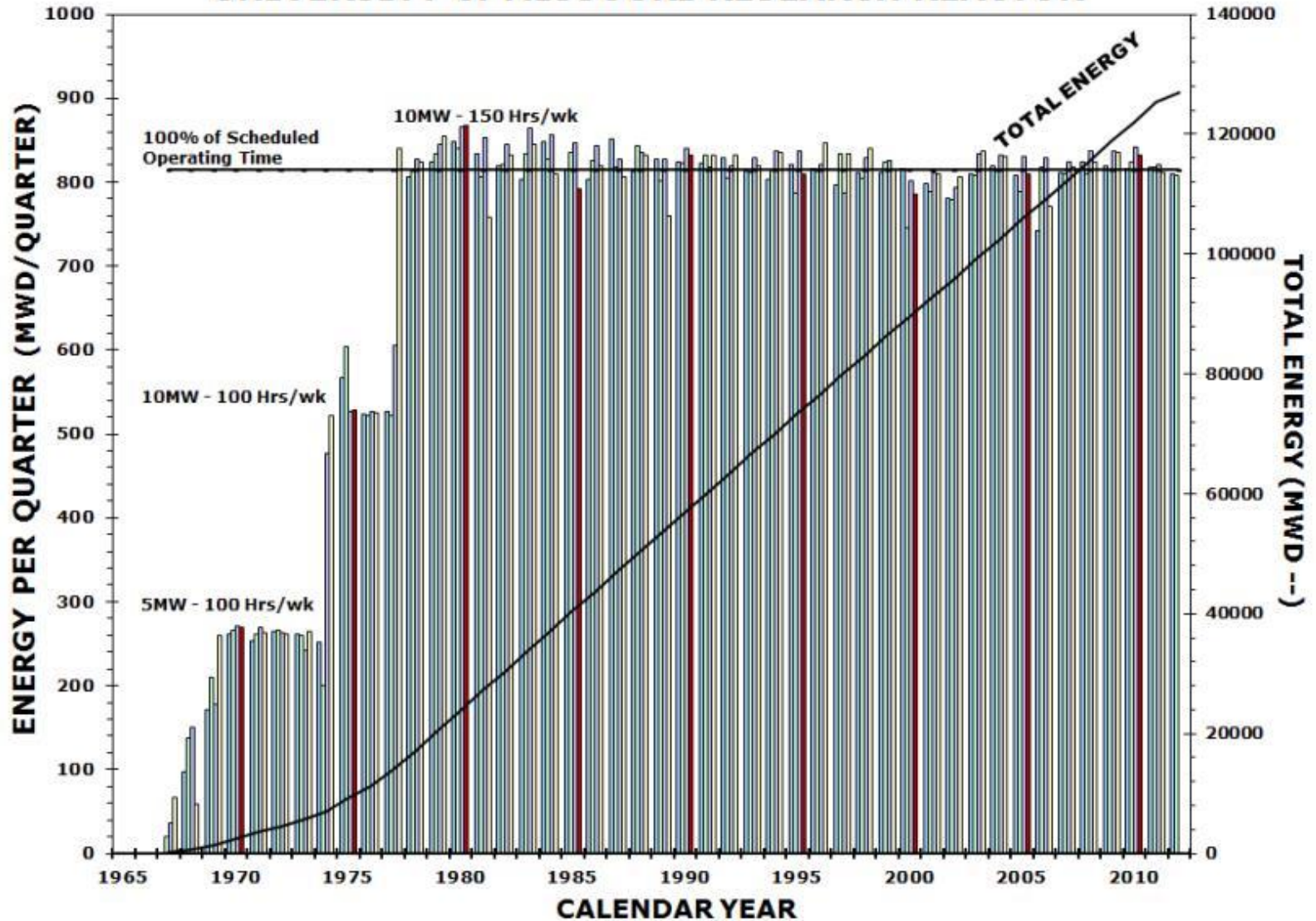
History

- July 1963 Ground broken at the reactor site
- **October 13, 1966** **MURR achieves initial criticality at 18:14 (5 MW license)**
- June 1967 Reactor reaches 5 MW
- July 1969 Reactor starts 5 MW, 100 hours per week operating schedule
- August 1971 Reactor upgraded to 6.2 kg uranium aluminide fuel core
- July 1974 Reactor upgraded and licensed to 10 MW
- September 1977 Reactor starts 10 MW, 100 hours per week operating schedule
- October 1981 First beryllium reflector replaced (occurs approximately every 8 years thereafter)
- April 1984 100,000 hours of operating time achieved
- August 2006 Facility relicensing application submitted to NRC
- December 2006 Primary and pool coolant heat exchangers replaced
- February 2010 300,000 hours of operating time achieved
- January 2012 Cooling tower replaced



OPERATING EXPERIENCE

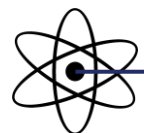
UNIVERSITY of MISSOURI RESEARCH REACTOR



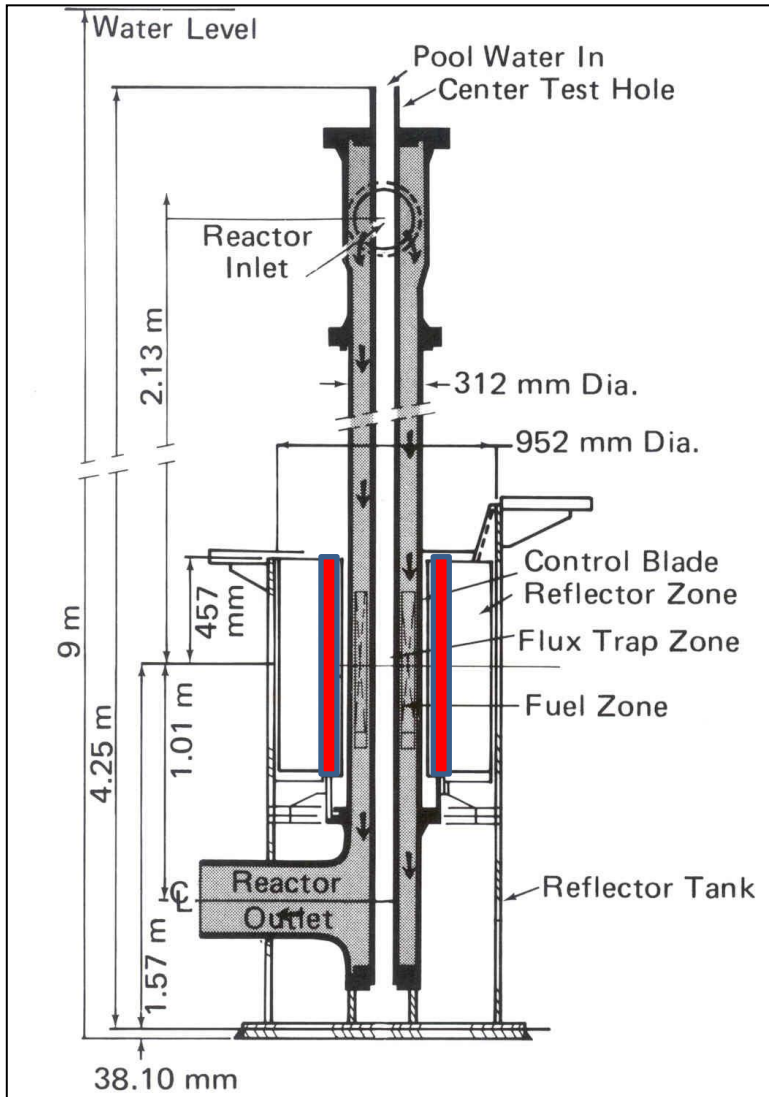
Key Reactor Parameters

MURR[®] is a pressurized, reflected, heterogeneous, open pool-type, which is light-water moderated and cooled:

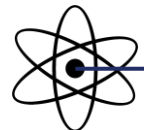
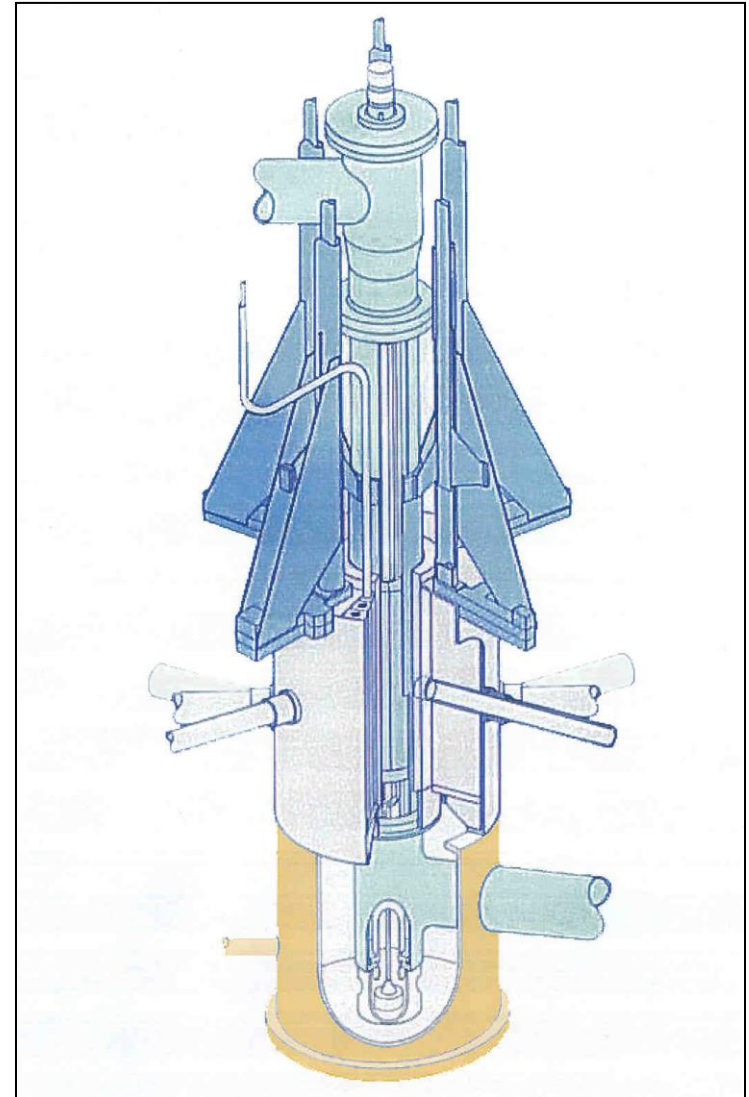
- Maximum power: **10 MW_{th}**
- Peak flux in center test hole: **6.0E14 n/cm²-s**
- Core: **8 fuel assemblies (775 grams of U-235/assembly)**
- Control blades: **5 total - 4 BORAL[®] shim-safety, 1 SS regulating**
- Reflectors: **beryllium and graphite**
- Forced primary coolant flow rate: **3,750 gpm (237 lps)**
- Primary coolant temps: **120 °F (49 °C) in, 136 °F (58 °C) out**
- Primary coolant system pressure: **85 psia (586 kPa)**
- Forced pool coolant flow rate: **1,200 gpm (76 lps)**
- Pool coolant temps: **100 °F (38 °C) in, 106 °F (41 °C) out**
- Beamports: **three 4-inch (10 cm), three 6-inch (15 cm)**



Reactor Core Assembly 2D View

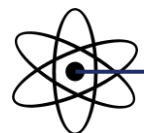


Reactor Core Assembly 3D View



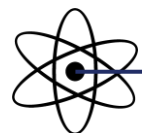
Reactor Design and Programs

- Reactor design is modular, where all components are replaceable, including the reactor pressure vessels.
- Spare reactor pressure vessel is on hand, including stock material to fabricate additional vessels, if needed.
- Beryllium reflector is replaced every 26,000 MWd (approximately 8 years); prior to the combined stresses [${}_1\text{H}^3$, ${}_2\text{He}^3$, and thermal] reaching the beryllium's yield point.
- Reactor pool is designed such that the entire reactor pool and pool liner are above the elevation of the beamport floor and not in contact with any soil. With the exception of the base, all areas of the reactor pool are visible and accessible.



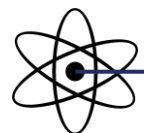
Renewal and Relicensing Projects

- Replacement of Graphite Reflector Elements
 - ✓ All 12 graphite reflector elements were replaced with new ones
- Radioactive Liquid Waste System Modification
 - ✓ System was modified such that all radioactive drain piping is accessible for inspection, monitoring and maintenance
- Installation of a Fire Protection System
 - ✓ A Detection System that consists of heat, smoke, and remote manual devices, and a Suppression System that incorporates a normal sprinkler system with a pre-action system used in areas with sensitive electrical equipment
- Replacement of the Primary & Pool Coolant System Heat Exchangers
 - ✓ Shell and tube-type heat exchangers were replaced with plate-type heat exchangers and flow measurement instrumentation upgraded



Renewal and Relicensing Projects

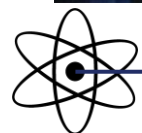
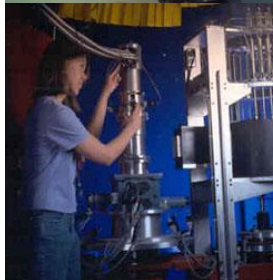
- Replacement of the Reactor Plant Make-up Water Tanks
 - ✓ Replaced two 7,000 gallon phenolic-lined carbon steel demineralized water storage tanks with two stainless steel tanks of the same capacities
- Replacement of major facility Electrical Distribution Transformers and Motor Control Centers
 - ✓ Installed two new 300-kVA transformers and distribution panels to increase the facility's 120/208V load capacity
 - ✓ Replaced and upgraded the facility's main 1000-kVA transformer with a new 2000-kVA transformer
 - ✓ Replaced and upgraded the cooling tower 500-kVA transformer with a 1500-kVA transformer
 - ✓ Replaced and upgraded the Secondary Coolant Pump Motors from 125 to 150 HP with variable speed drives
- Replacement of the Cooling Tower
 - ✓ Replaced and upgraded an old-style 3 cell, wood-framed 10 MW cooling tower with a new 3 cell stainless steel 15 MW cooling tower



MURR in Summary

Purpose: Multi-disciplinary research and education facility also providing a broad range of analytical and irradiation services to the research community and the commercial sector.

- MURR operates 24 hours a day, seven days a week, 52 weeks a year
- 165 full-time employees



MURR®

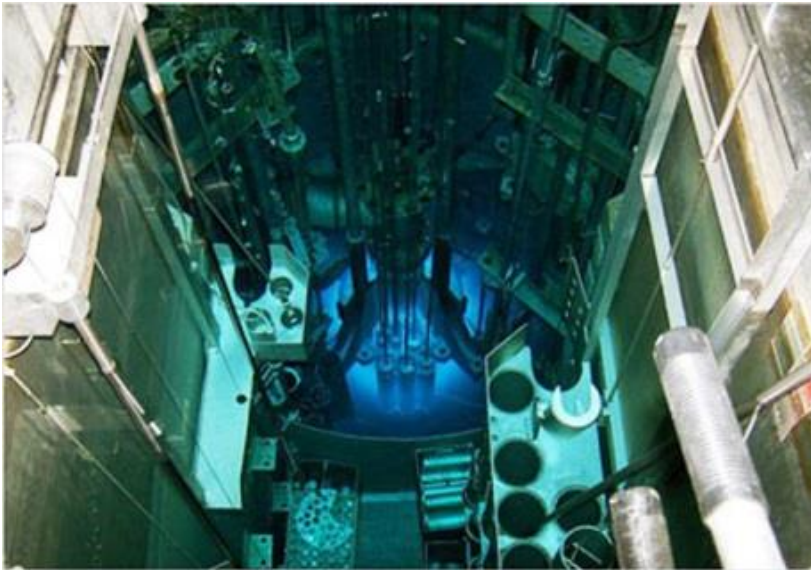
Providing quality nuclear research, education and service to a global community

University of Missouri Research Reactor, Nordion and General Atomics Collaborating to Develop a New and Reliable Supply of Mo-99 for the Future



A Canadian-US partnership has been announced to create a "new, reliable supply" of medical isotopes for use worldwide.

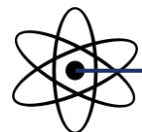
April 27, 2015



The MURR research reactor (Image: University of Missouri)

**While maintaining
MURR Core Missions
of Research and Education**

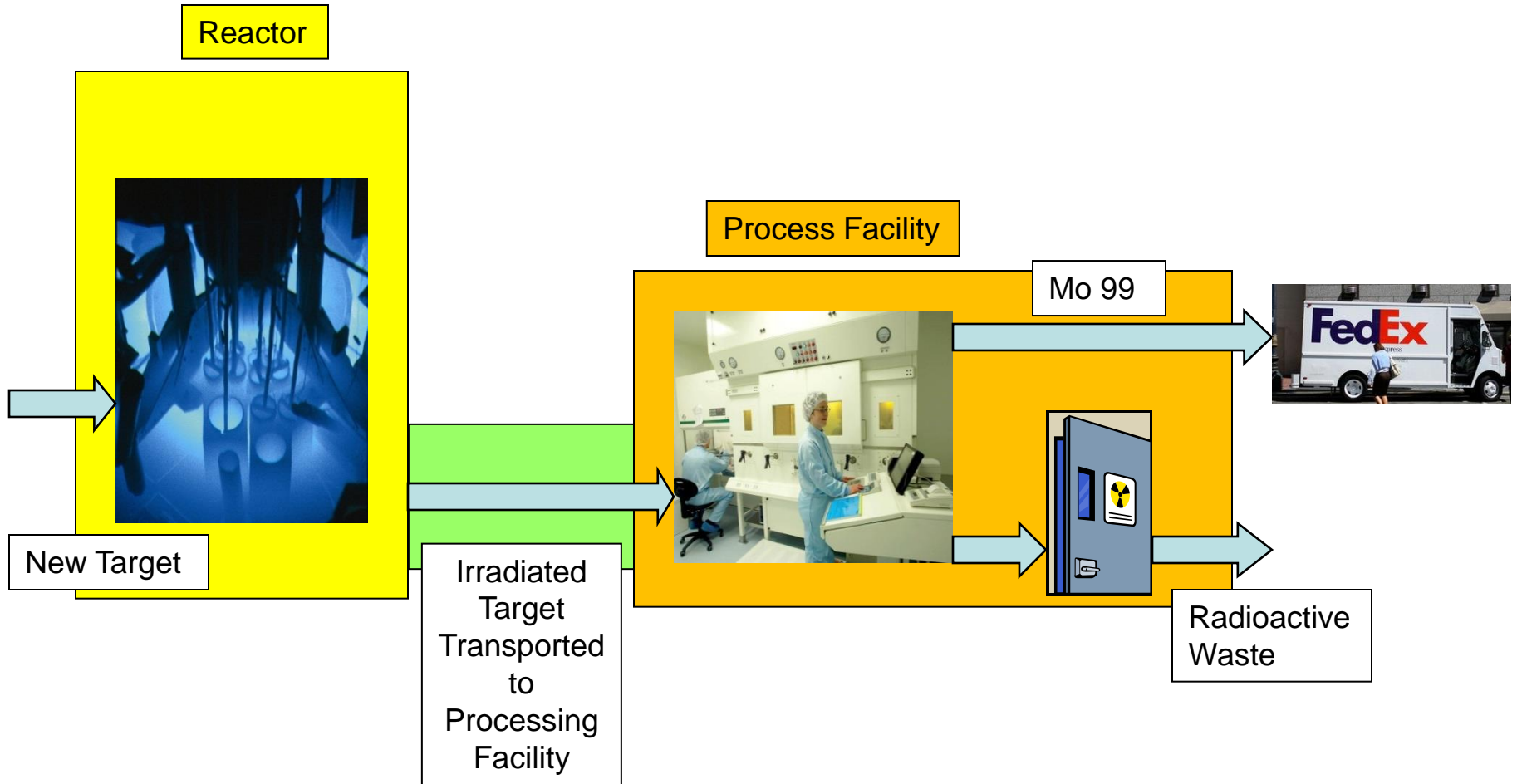
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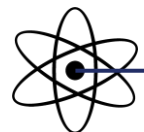
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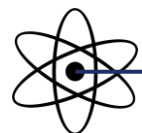
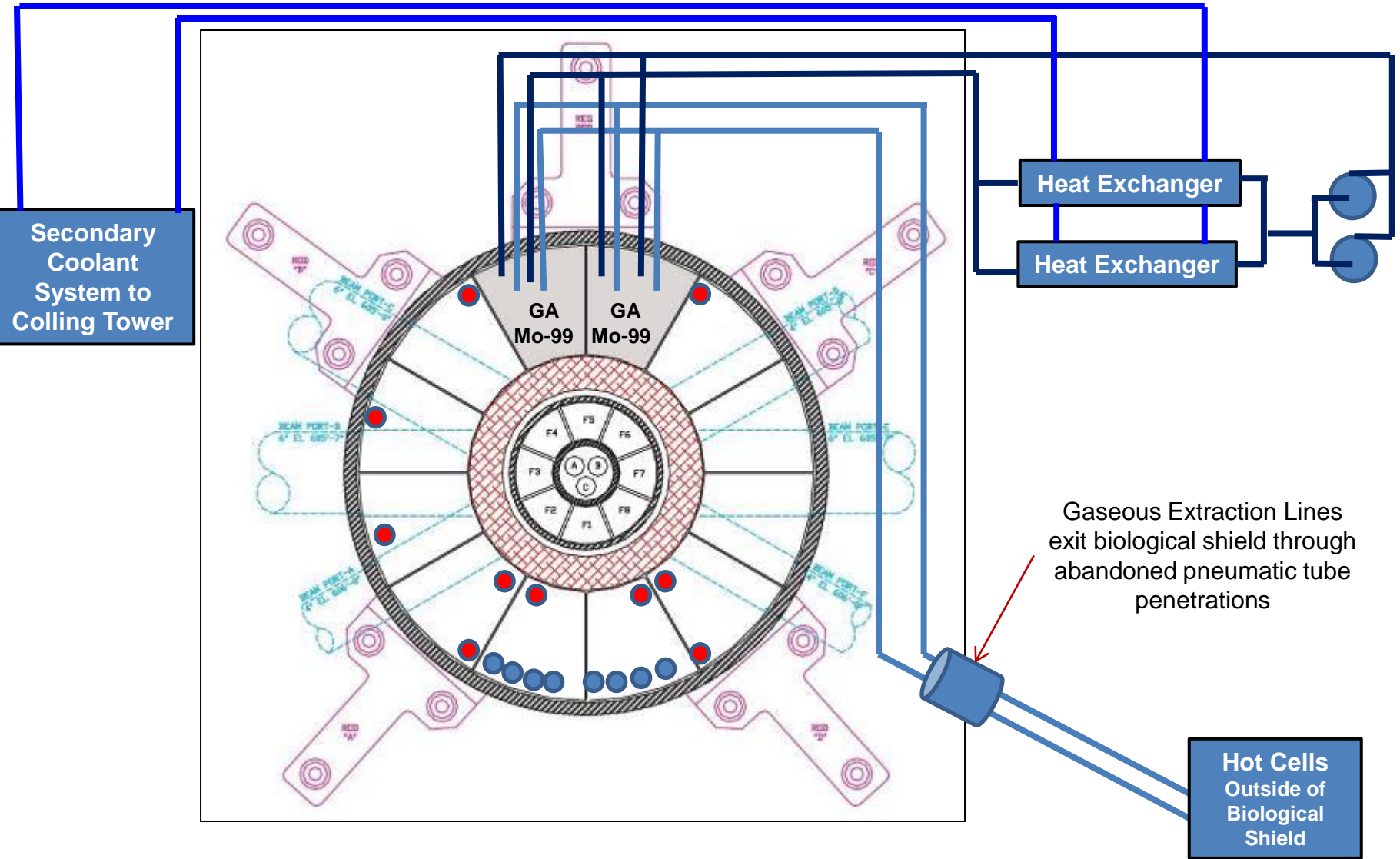
Typical Molybdenum-99 Project



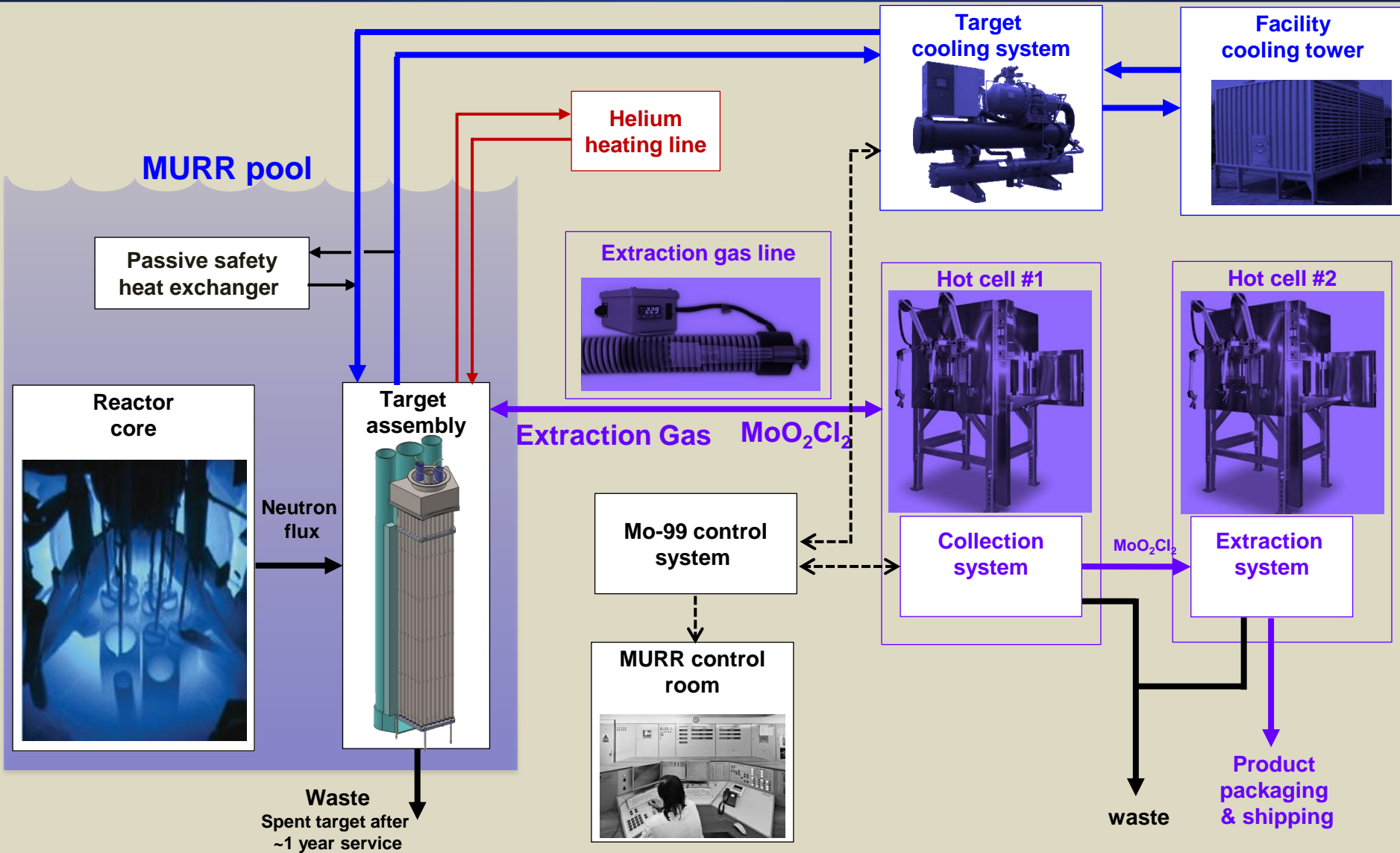
*In the GA/Nordion Project target remains in the reflector region for >one year



Simplified Reactor Plan View



Selective Gas Extraction Process Overview



BREAK

Proprietary Session

