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Experimental Neutron Source Facility

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THE UNIVERSITY OF CHICAGO

Experimental Neutron Source Facility

Background

An Experimental Neutron Source Facility has been developed. It consists of a subcritical system driven by an electron accelerator within the cooperative activity between Argonne National Laboratory (ANL) and Kharkov Institute of Physics and Technology (KIPT) of Ukraine.

Facility Objectives

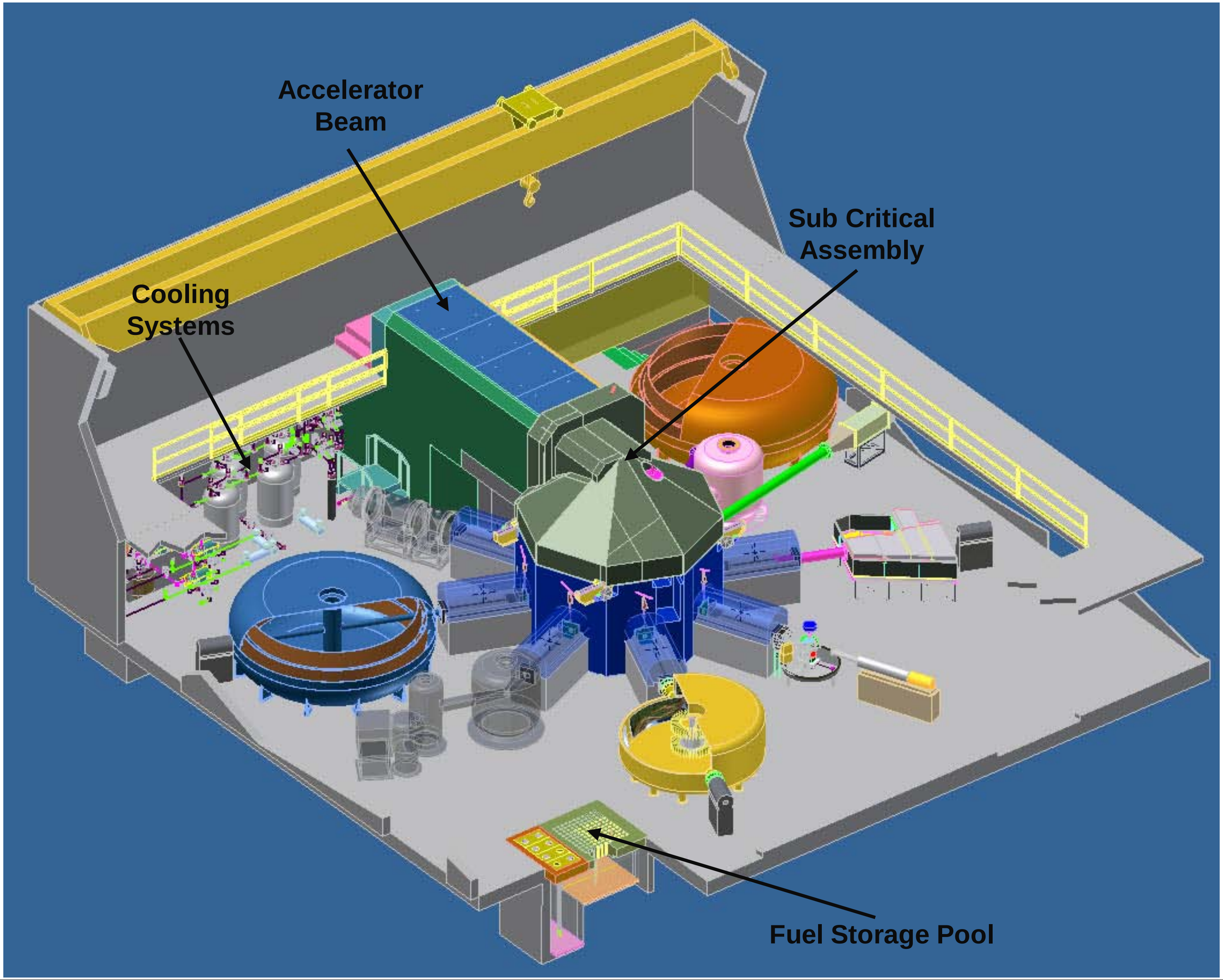
- Provides capabilities for performing basic and applied research utilizing the radial neutron beam ports of the subcritical assembly.
- Produces medical isotopes and provides neutron source for performing neutron therapy procedures.
- Provides the capabilities to perform reactor physics experiments and to train young specialists.

Experimental Neutron Source Facility

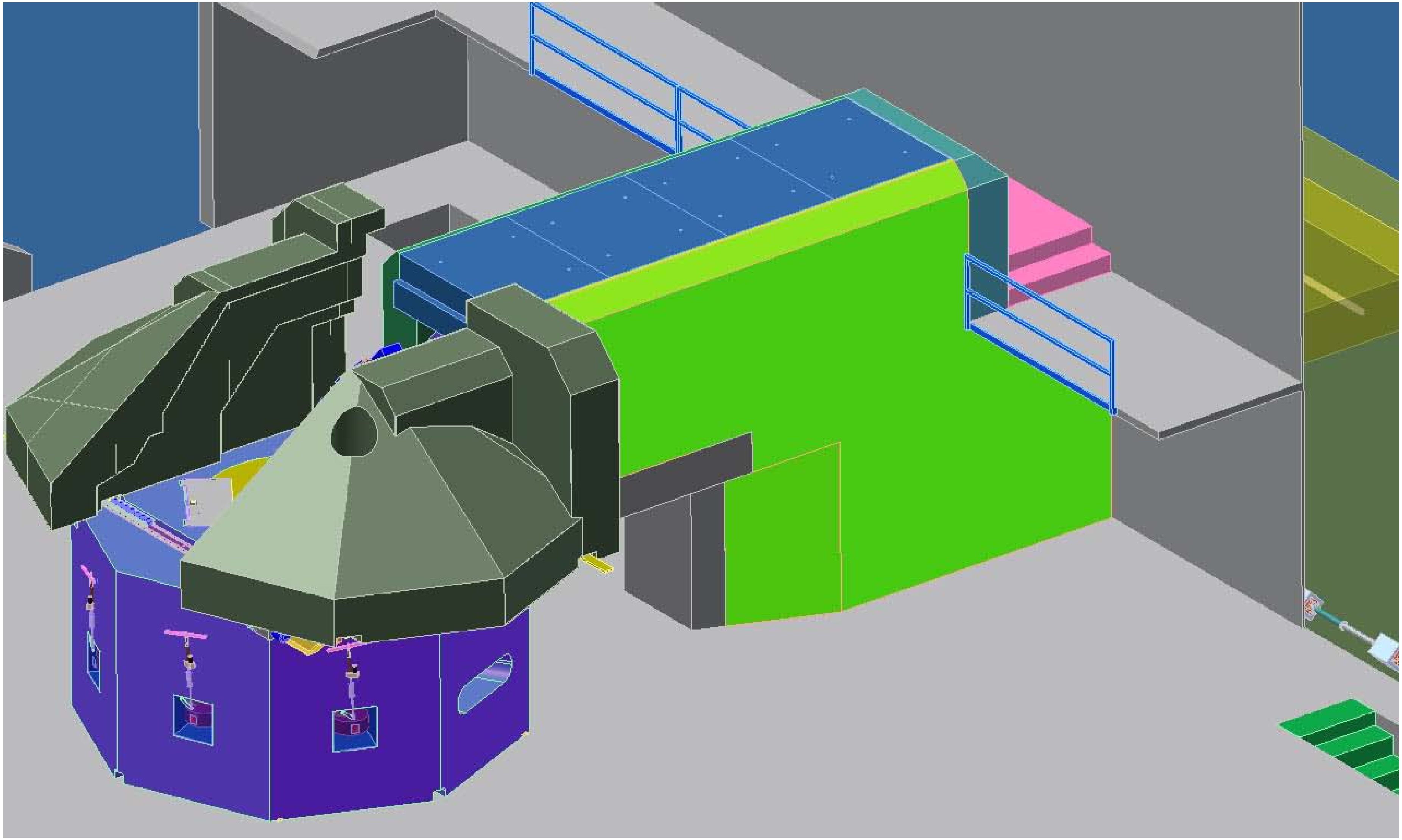
Main Components

- Electron accelerator and electron beam transport channel
- Solid target assembly for generating neutrons
- Subcritical assembly with low enrichment fuel, carbon reflector, and water coolant
- Heavy concrete biological shield
- Auxiliary equipments including the target and the subcritical assembly coolant loops
- Radial neutron channels for basic and applied research

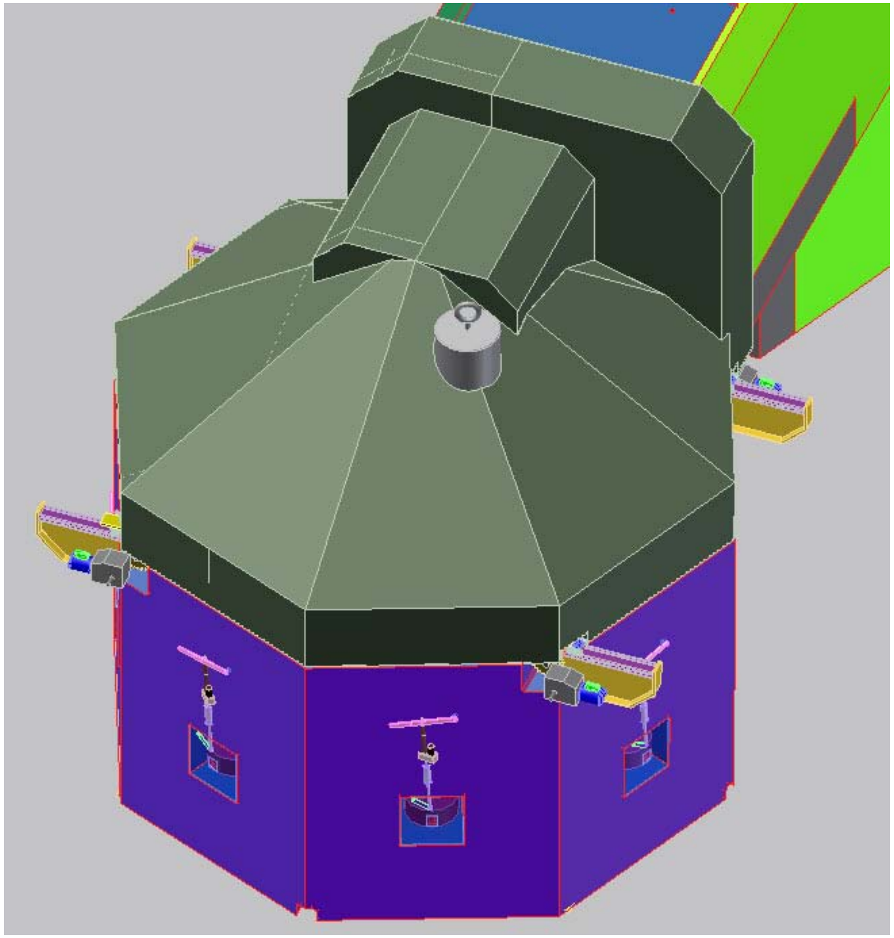
Experimental Neutron Source Facility Overview



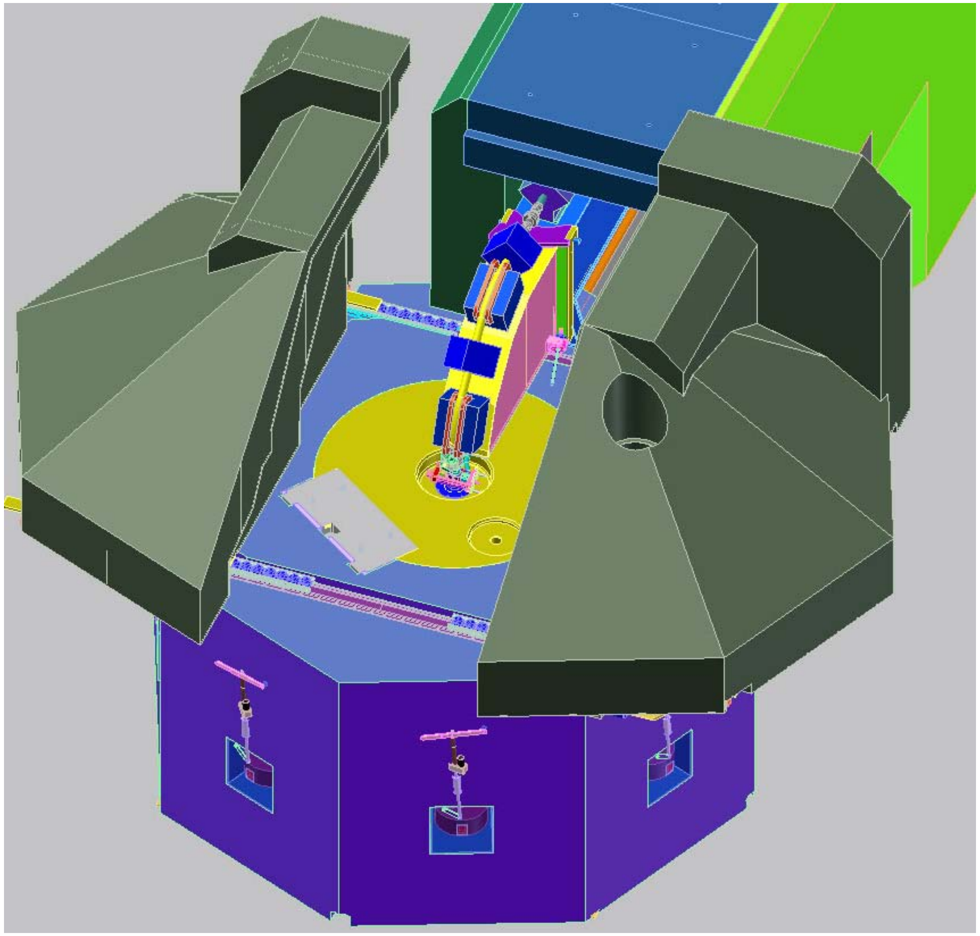
The Biological Shield of the Subcritical Assembly and the Electron Beam Cannel



The Subcritical Assembly Shield

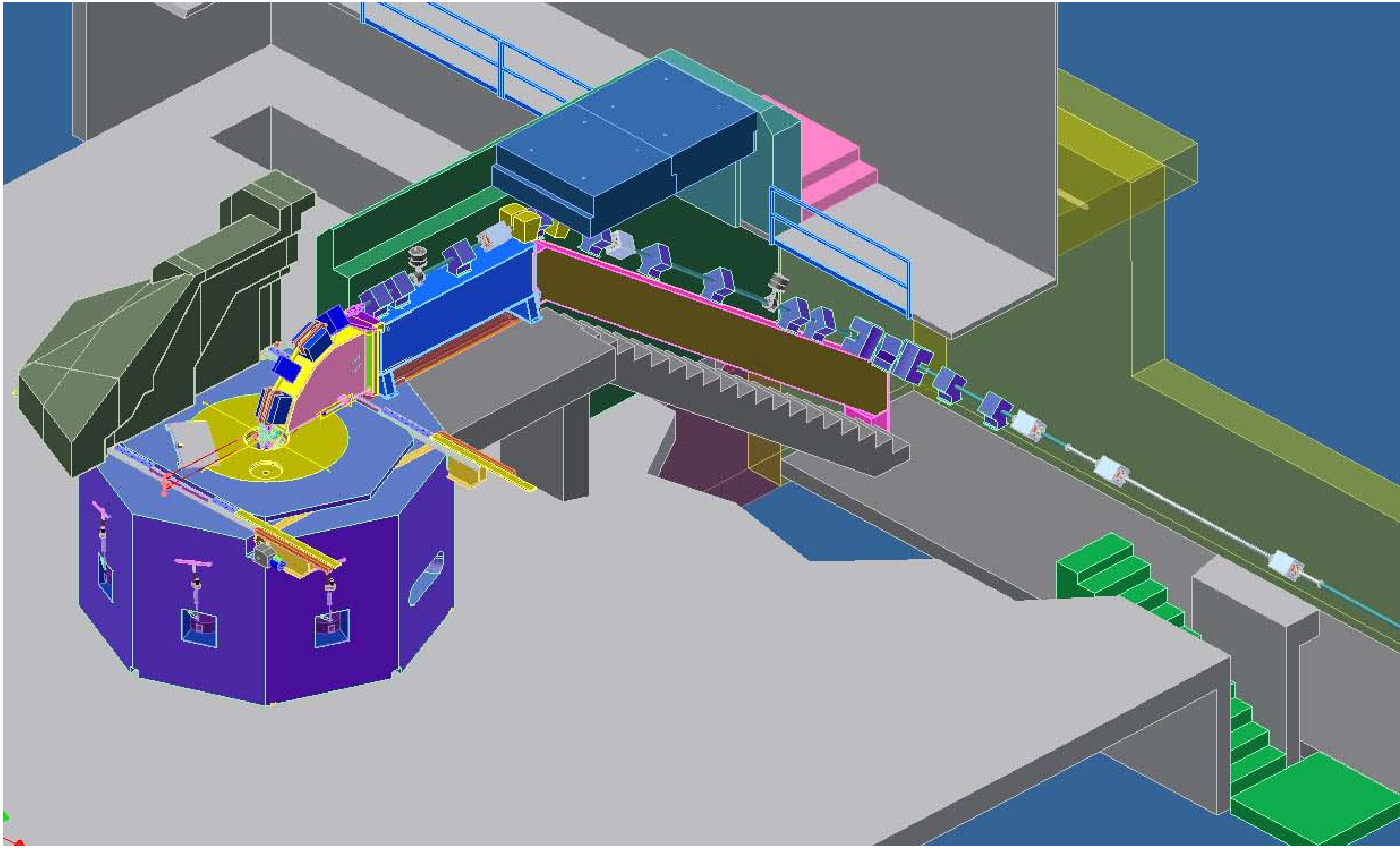


Top Shielding closed



Top Shielding opened

The Electron Beam Transport Channel

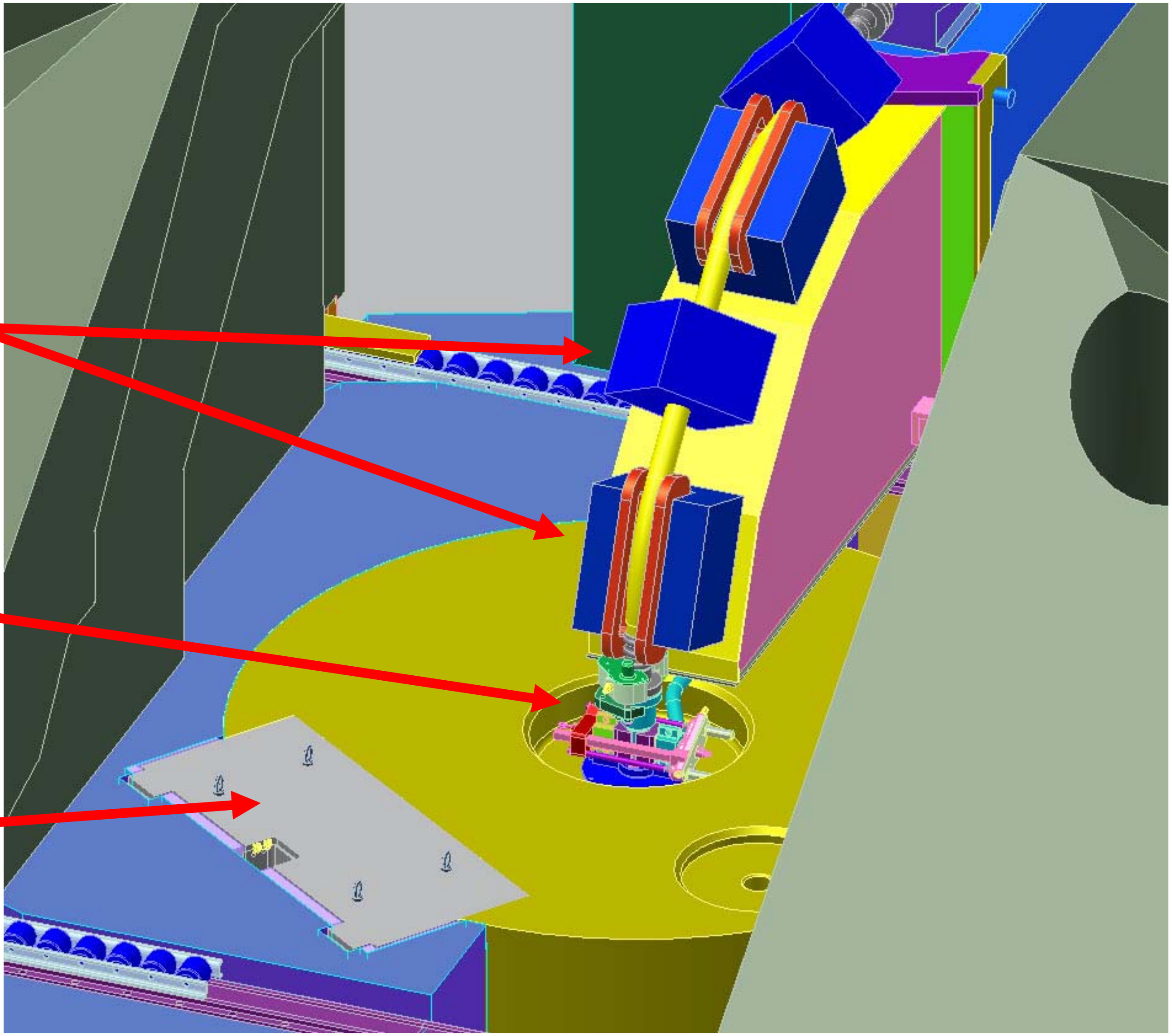


Movable Top Shielding Open for Service

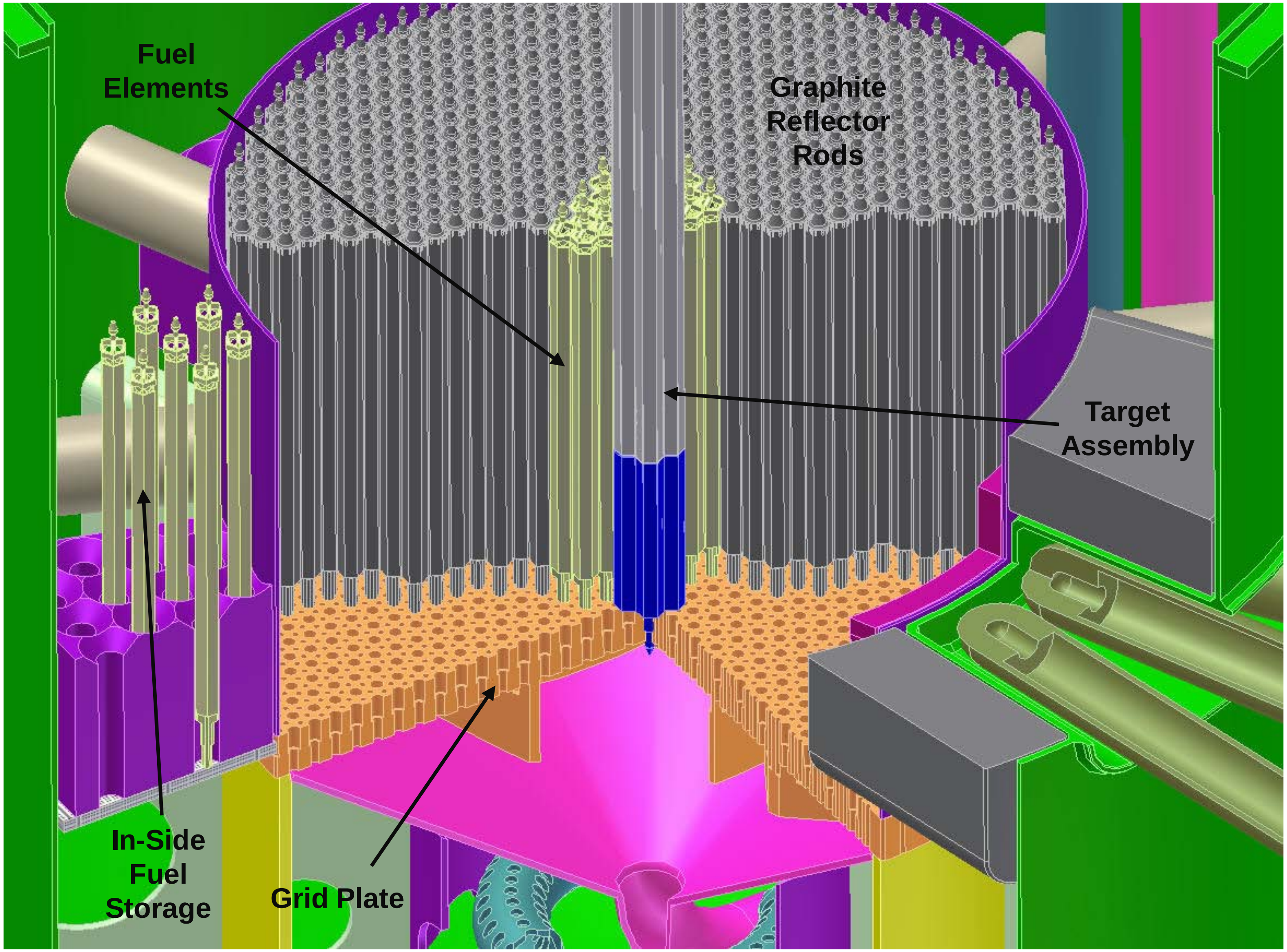
Electron Beam line
Bending / Focusing
Magnets

Target exchange

Fuel Handling
Machine service

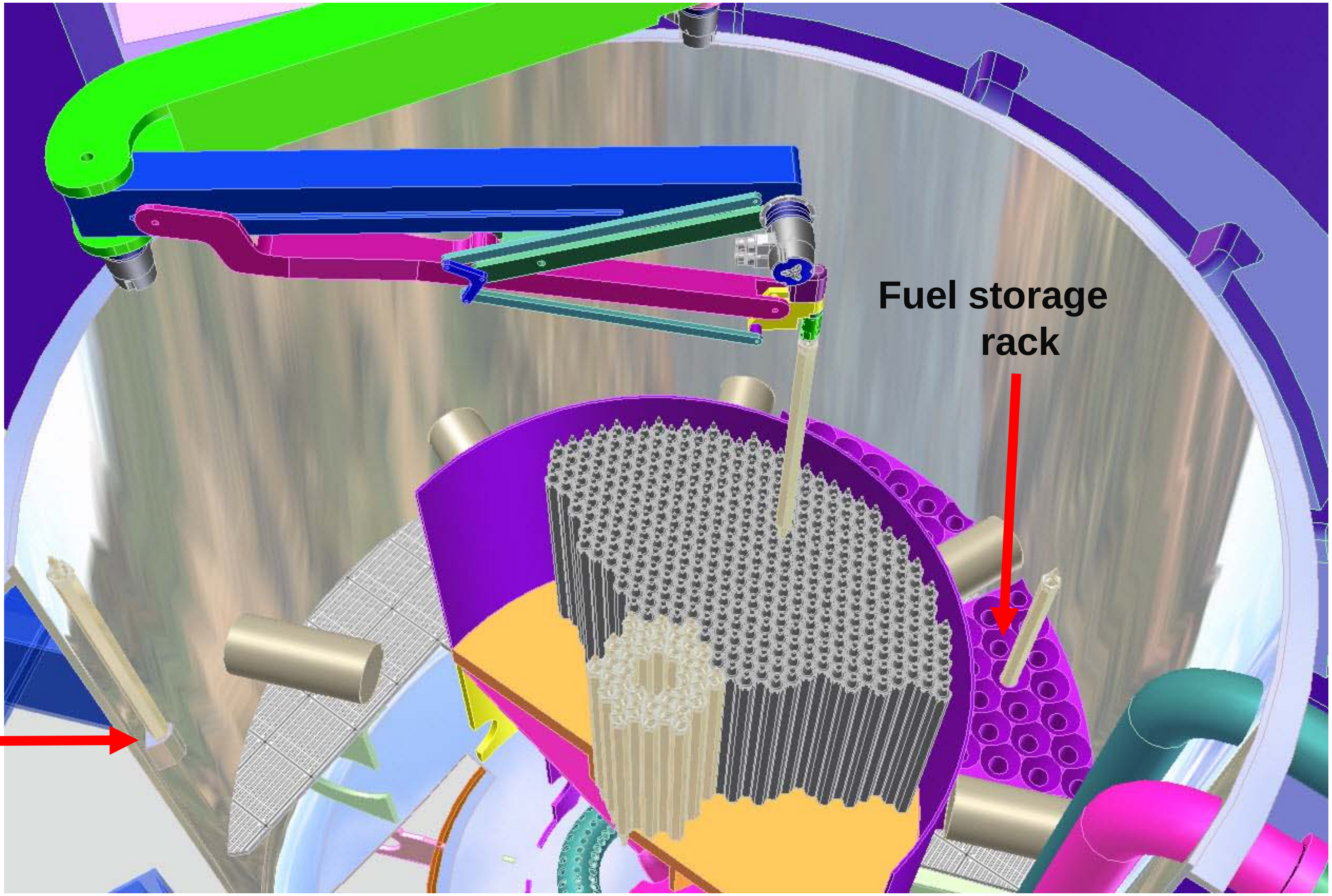


Cut-away View of the Subcritical Assembly

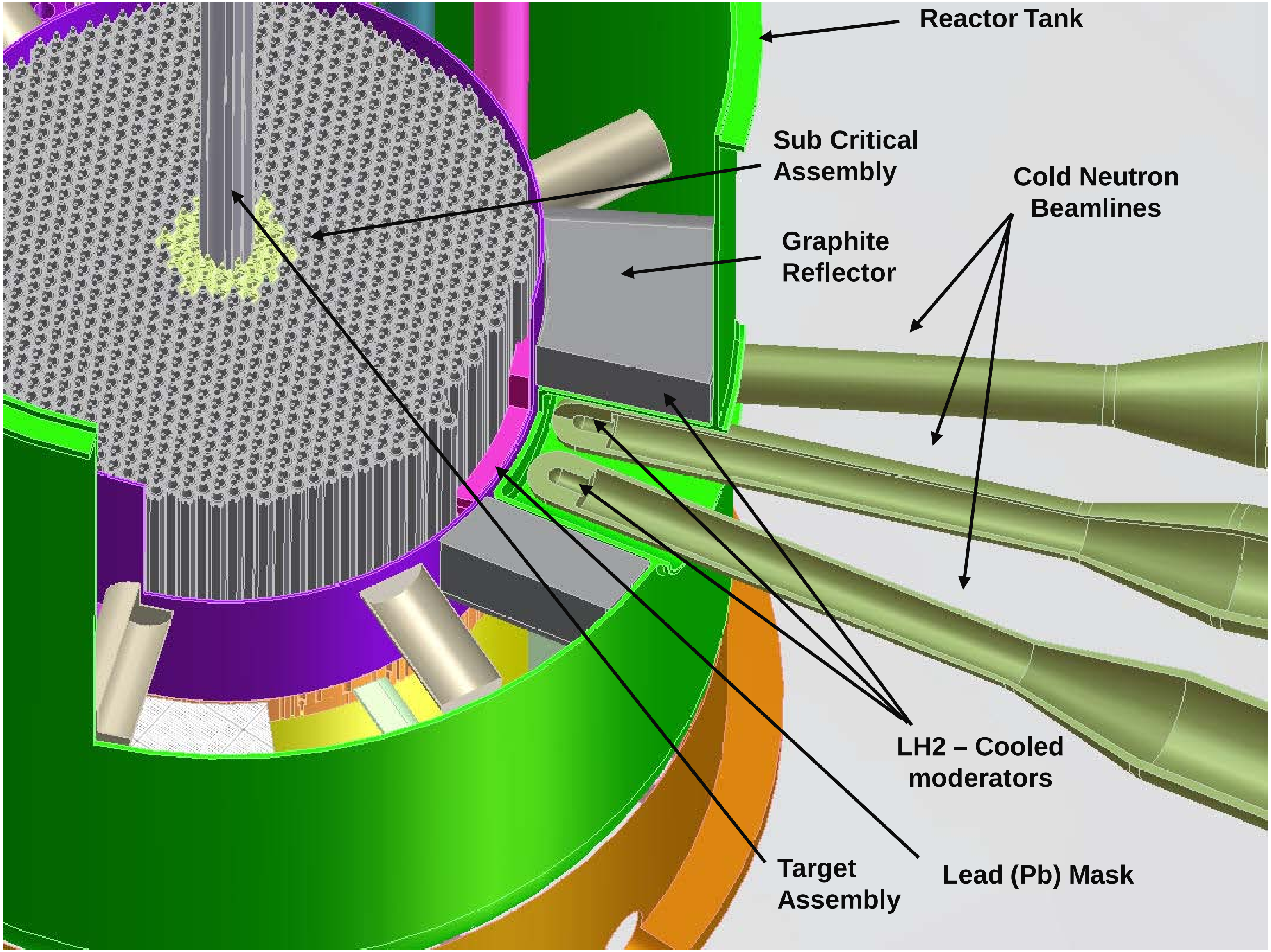


Fuel Handling Machine

Fuel Handling Machine moves Fuel Elements between core, storage rack, and transfer station



Cut-away View of Cold Neutron Sources



Target Design

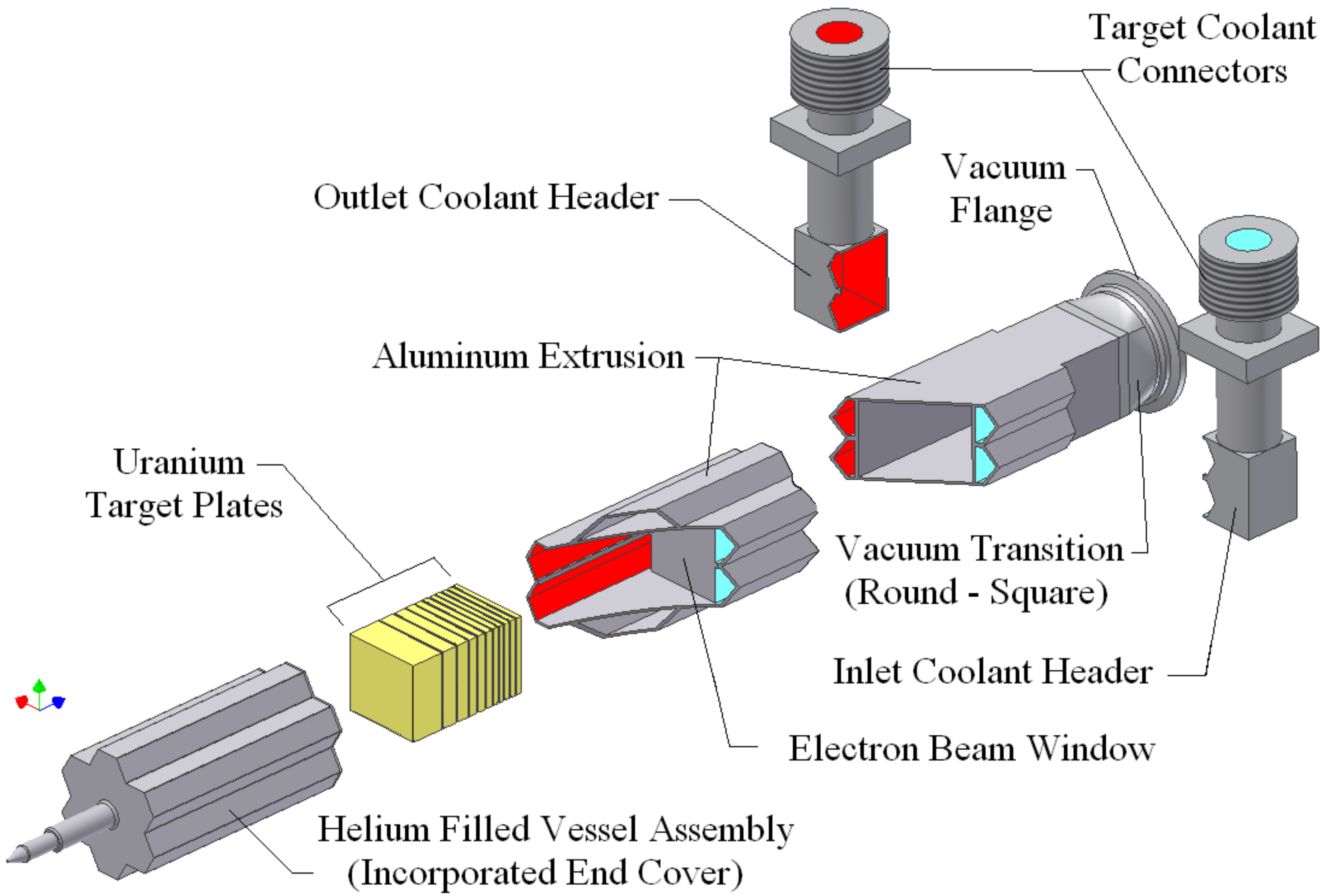
Objective:

Define an optimal target configuration that maximize the neutron production from the available electron beam power.

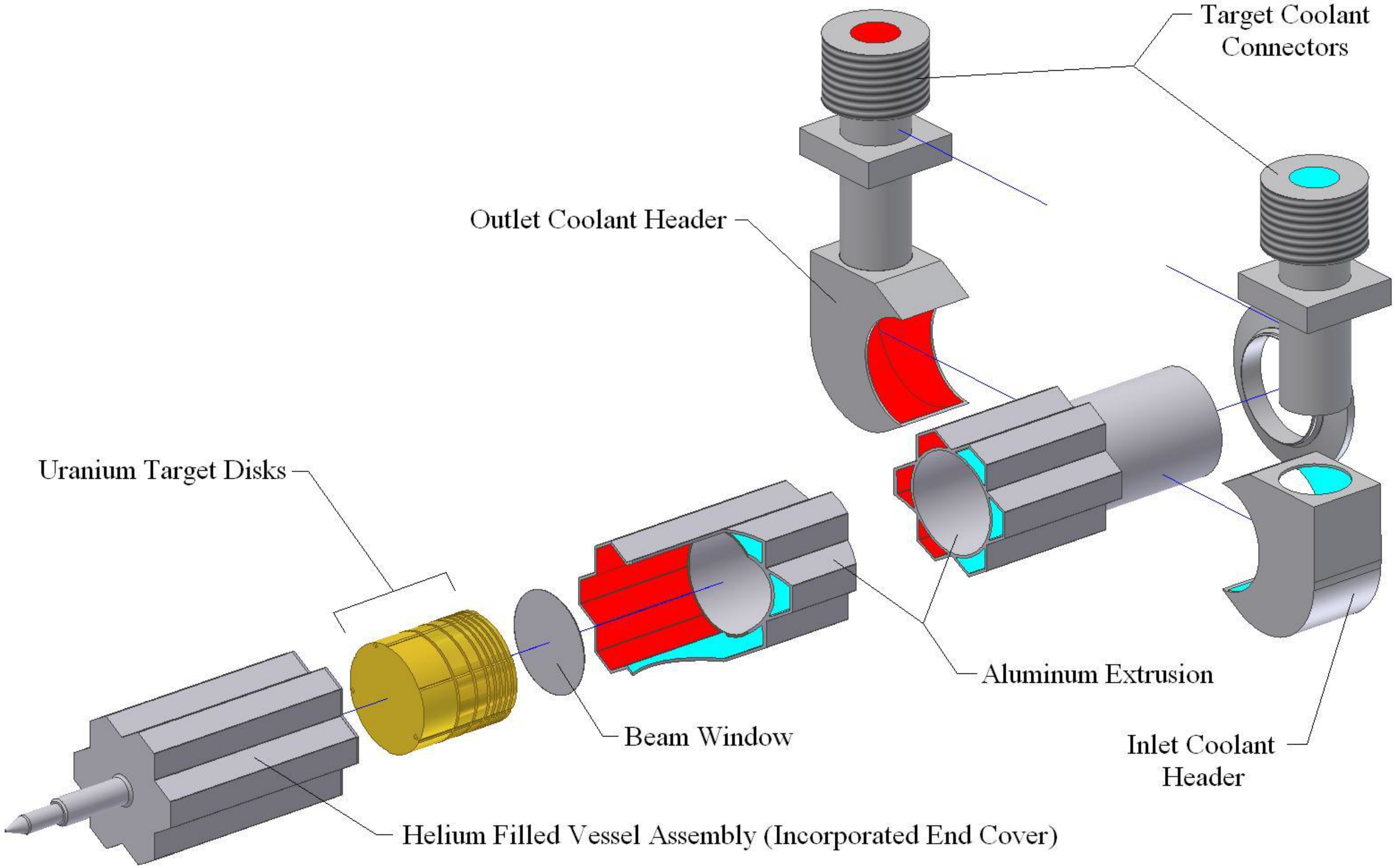
Performance and Design Parameters:

- Neutron source strength
- Neutron spatial and energy distributions
- Energy deposition in the target materials
- Beam radius relative to the target radius
- Target geometrical configuration
- Thermal hydraulics characteristics
- Thermal stress values
- Target fabrication procedure

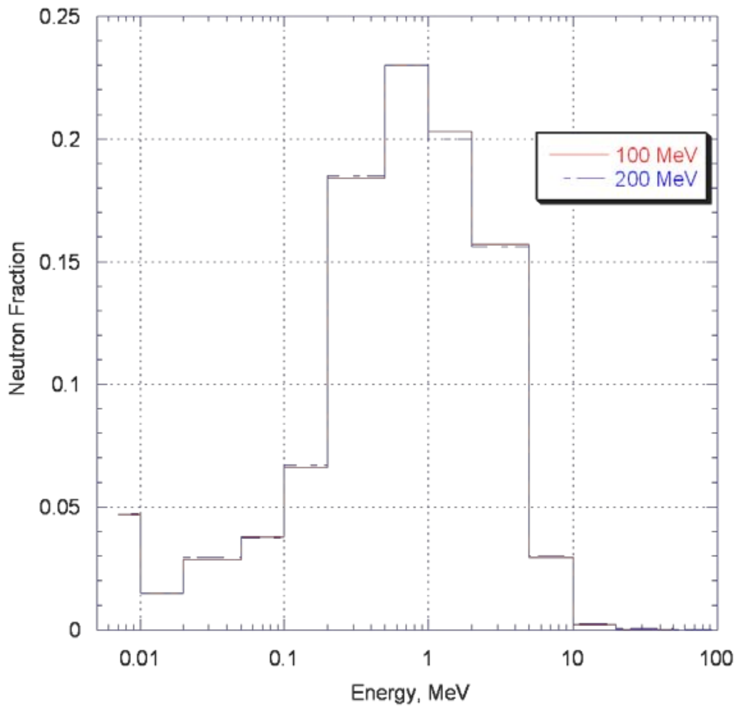
Exploded Assembly View of the Square Uranium Target Design

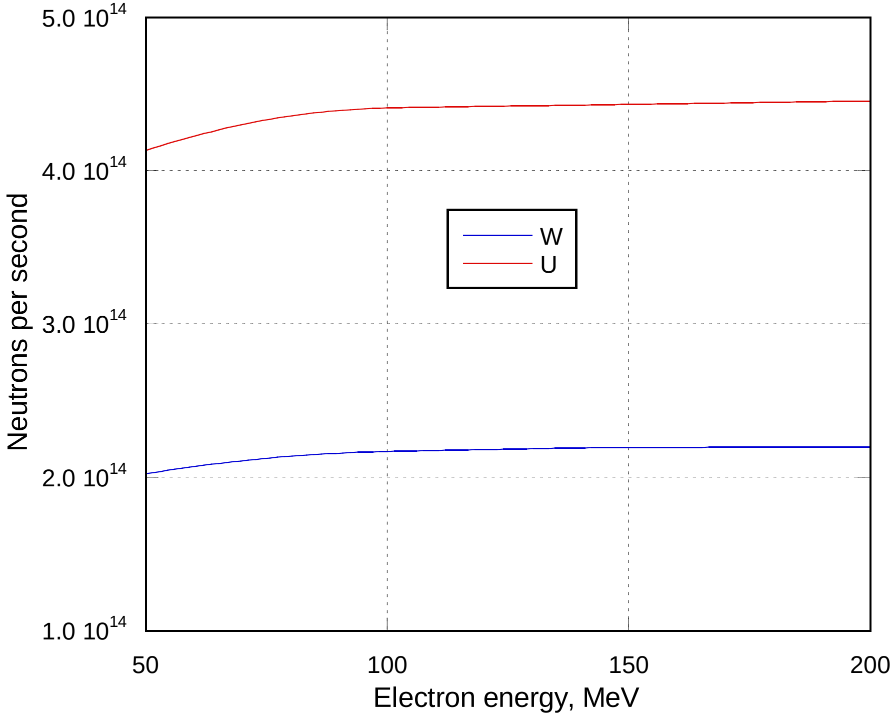


Exploded Assembly View of the Circular Uranium Target Design



Neutron Yields from Electron Interactions

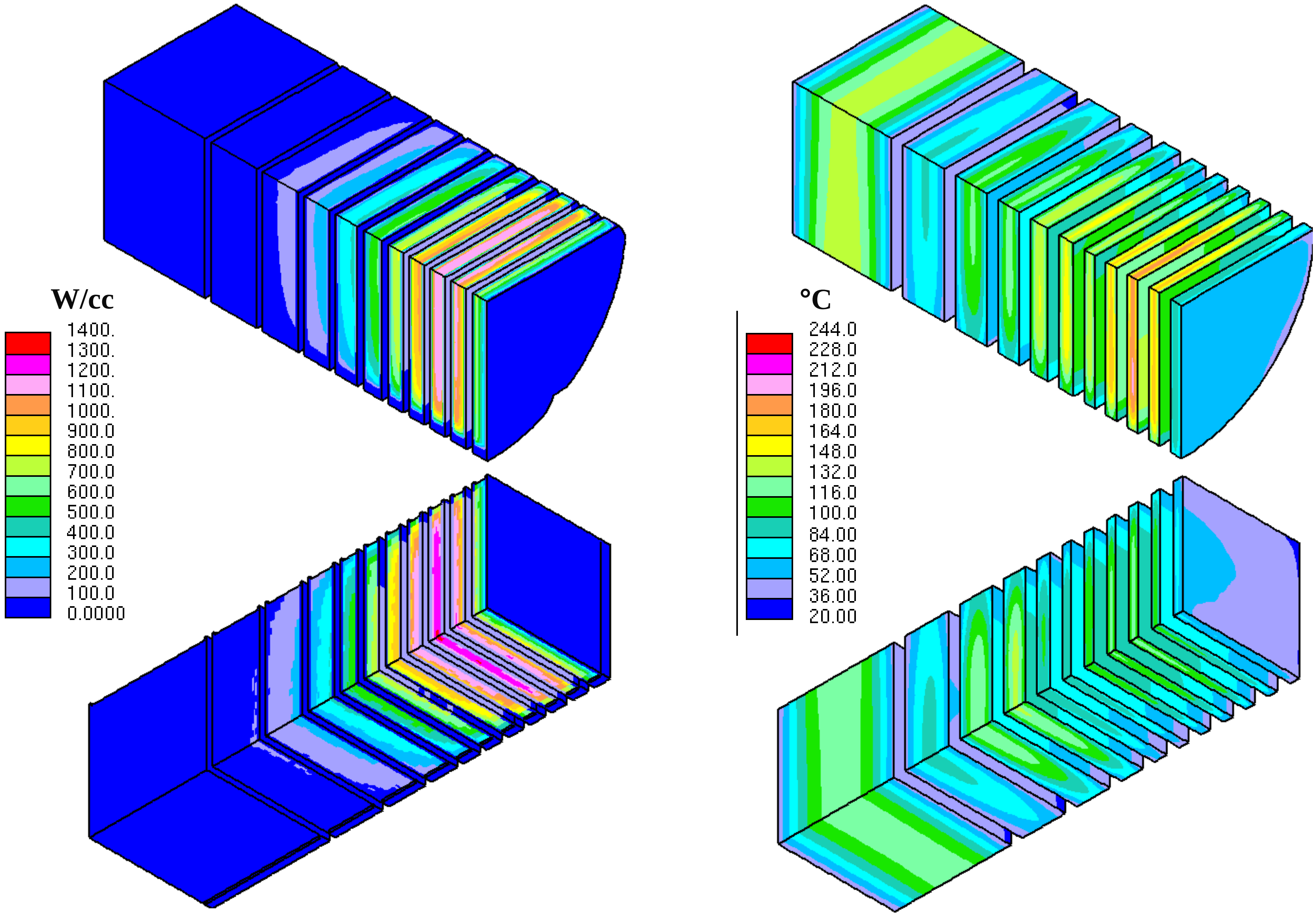




Neutron spectrum of the uranium target for different electron energies

Neutron source strength of the tungsten and uranium targets as a function of the electron energy for 100 kW beam power

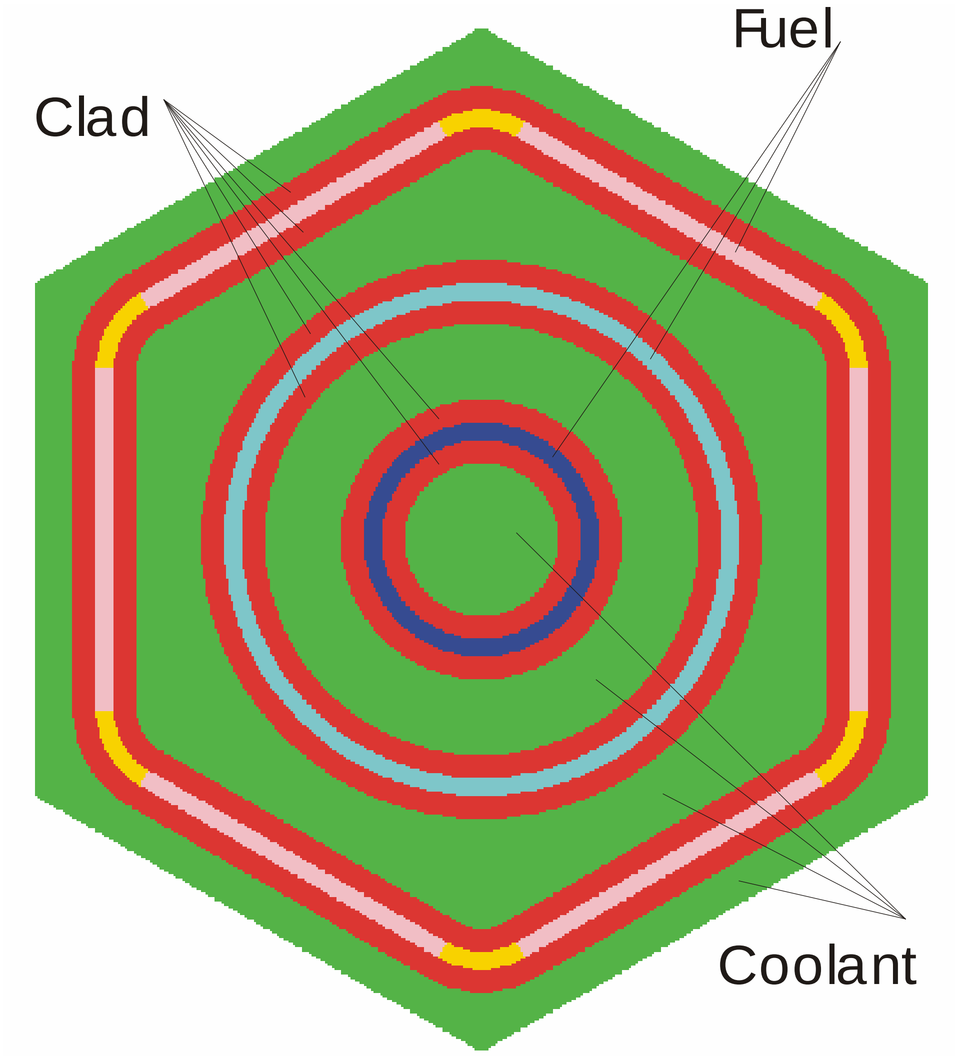
Uranium Target Energy Deposition and Temperature Distributions

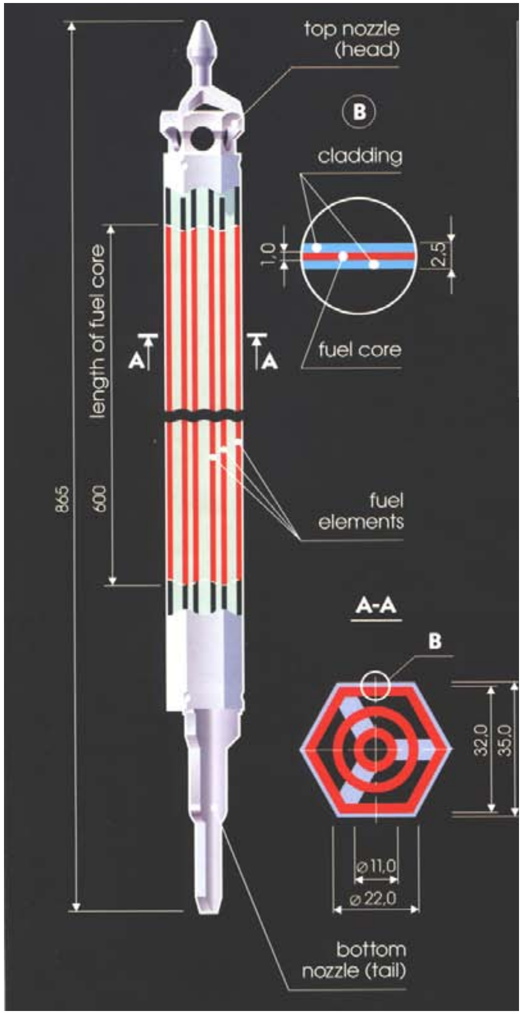


Subcritical Assembly

- The subcritical assembly performance was optimized to maximize the neutron flux field.
- Main design parameters of the subcritical assembly configuration:
  - Target material – Natural uranium
  - Fuel design and uranium enrichment – Low enriched WWR-M2 Fuel Design
  - Fuel material density – 2.7 g/cm^3
  - Reflector material - Carbon
  - Coolant material - Water
  - Structure material - Aluminum alloy
  - Beam power - 100 KW
  - Electron energy - 100 to 200 MeV

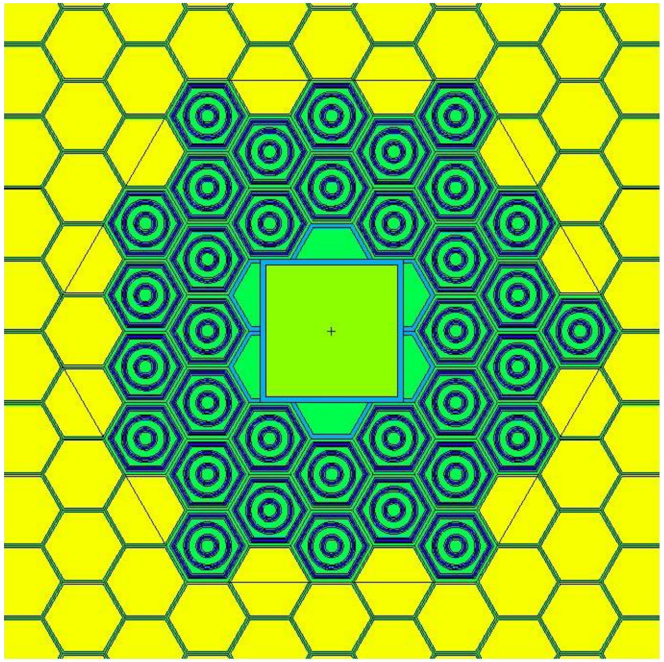
WWR-M2 Fuel Design





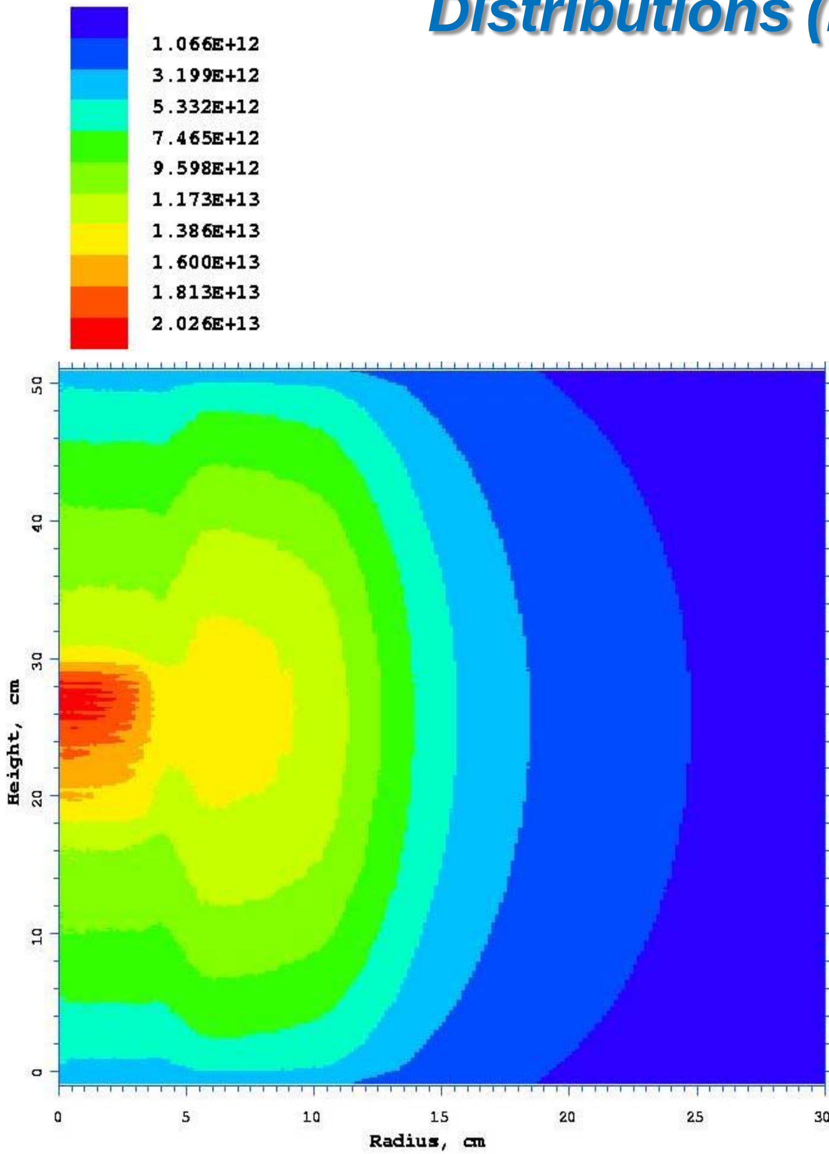
Subcritical Assembly Configuration

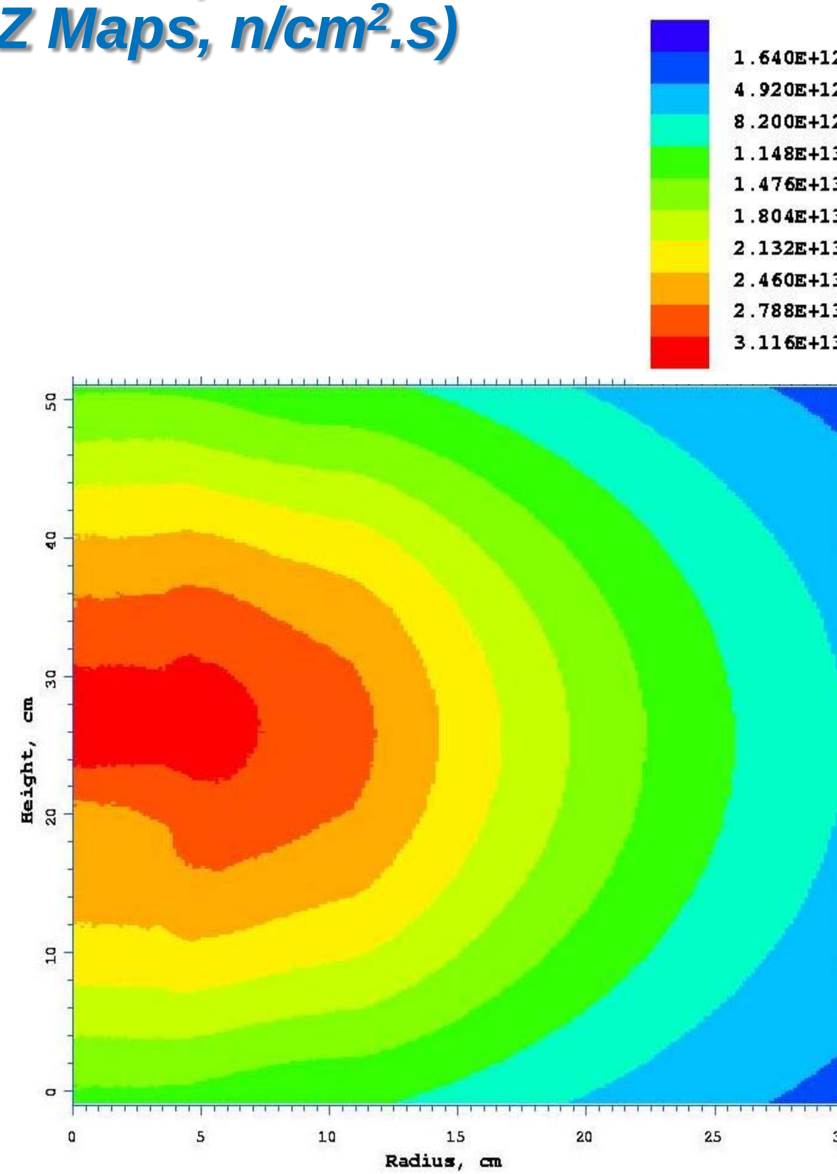
Natural uranium target, 35 fuel assemblies, Carbon Reflector, Water Coolant, k_{eff}= 0.98062



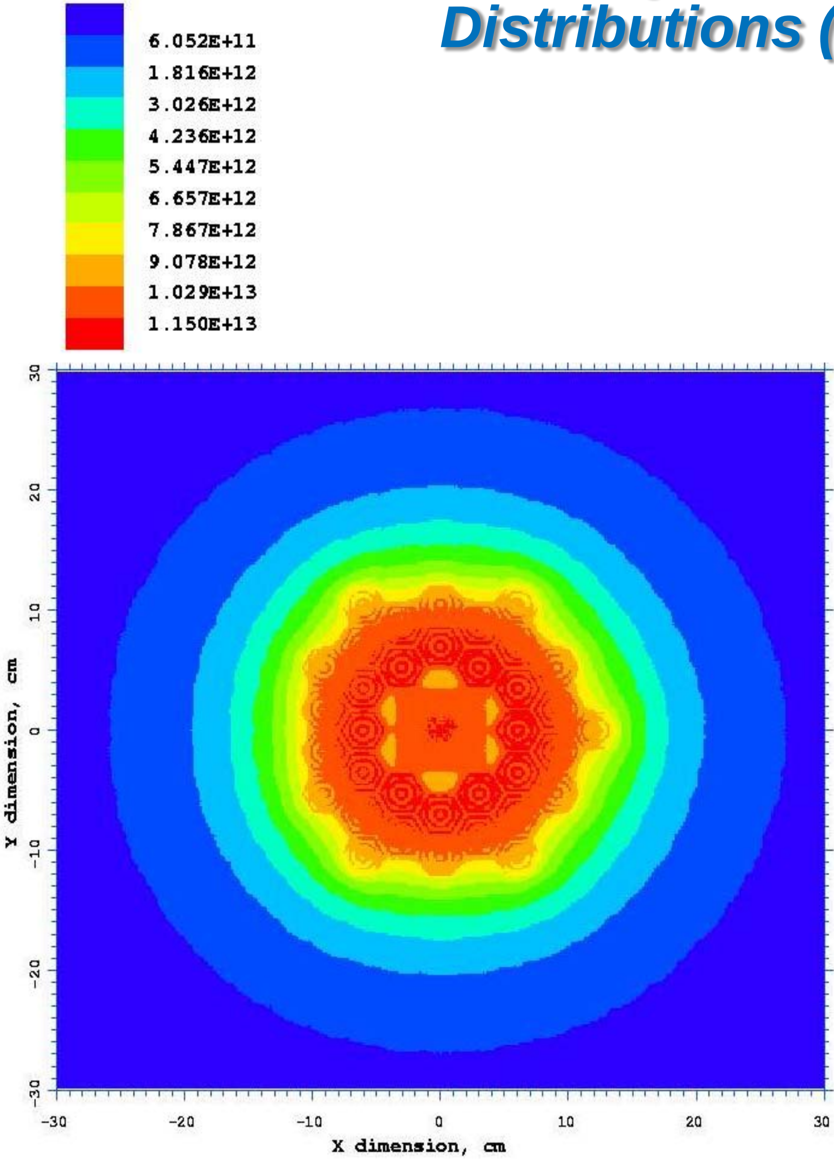
Target Material	Electron energy, MeV	Averaged Flux over target length, n/s cm^3	Averaged Flux over fuel length, n/s cm^3	Target Energy deposition, kW	Fuel Energy, deposition, kW	Reflector Energy deposition, kW	Total Energy deposition, kW
U	100	3.038E+13	2.470E+13	90.68	245.06	23.79	359.53
	200	3.134E+13	2.543E+13	91.31	259.45	23.68	374.44

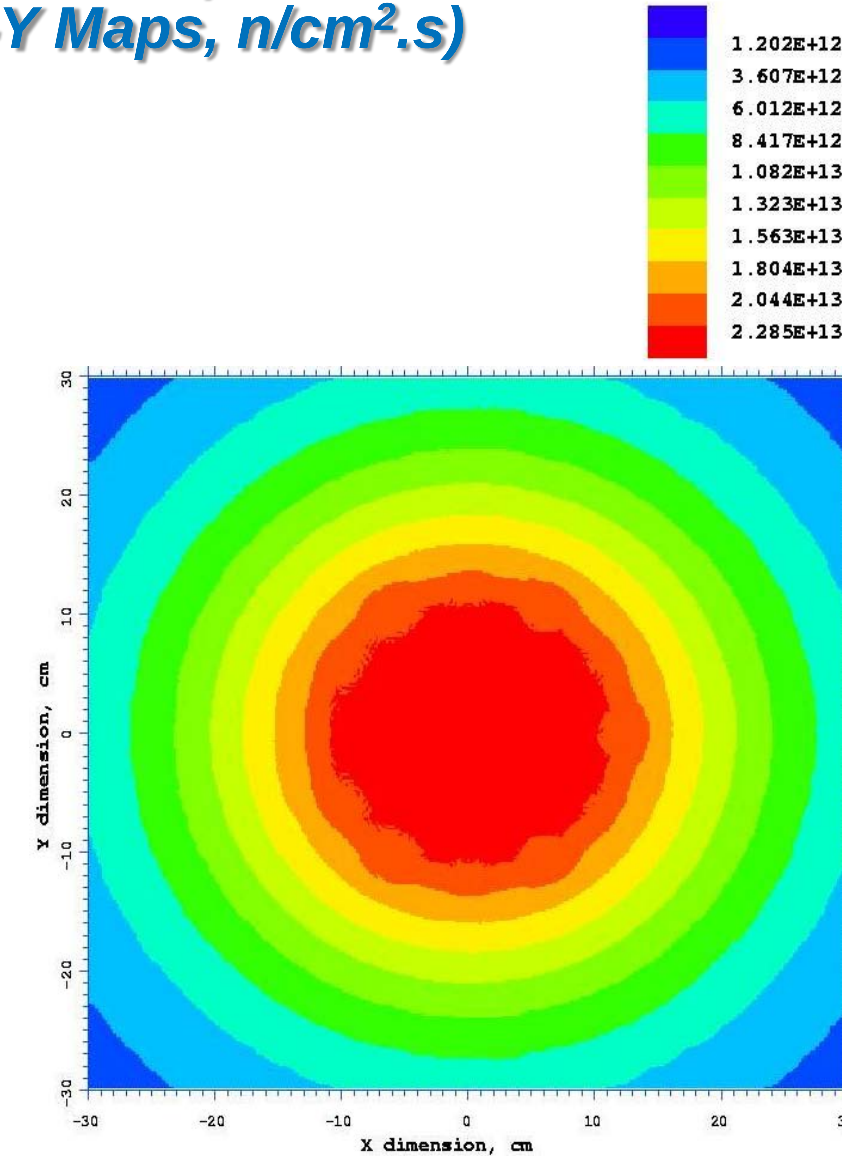
Subcritical Assembly Fast (>0.1 MeV) & Total Neutron Flux Distributions (R-Z Maps, n/cm^2.s)



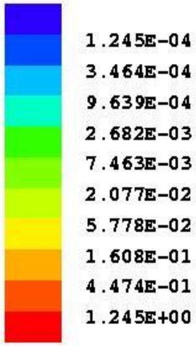


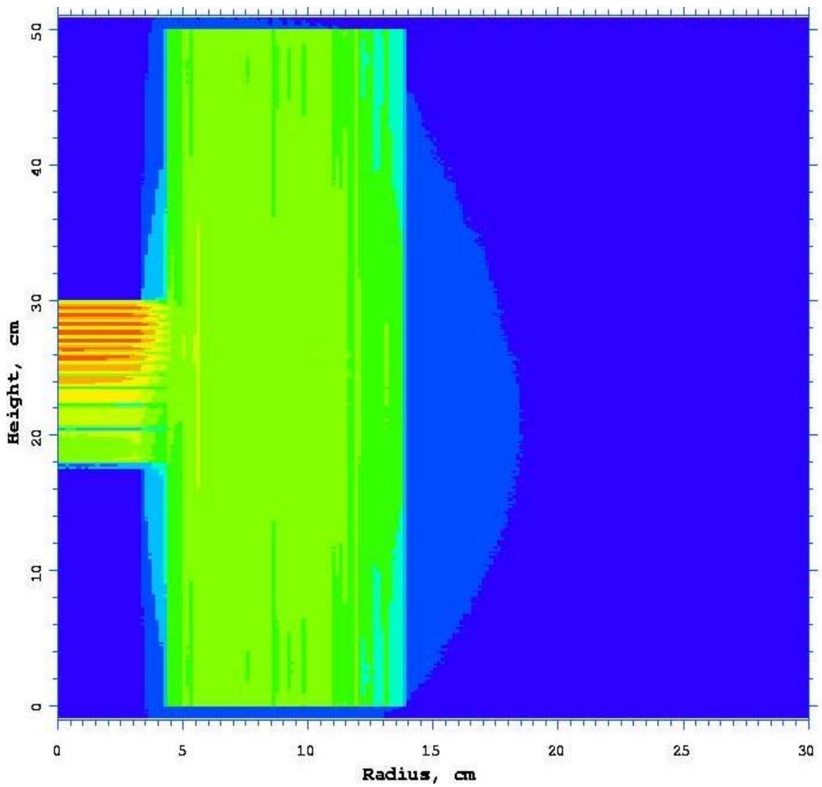
Subcritical Assembly Fast (>0.1 MeV) & Total Neutron Flux Distributions (X-Y Maps, $n/cm^2.s$)

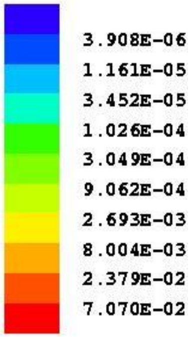


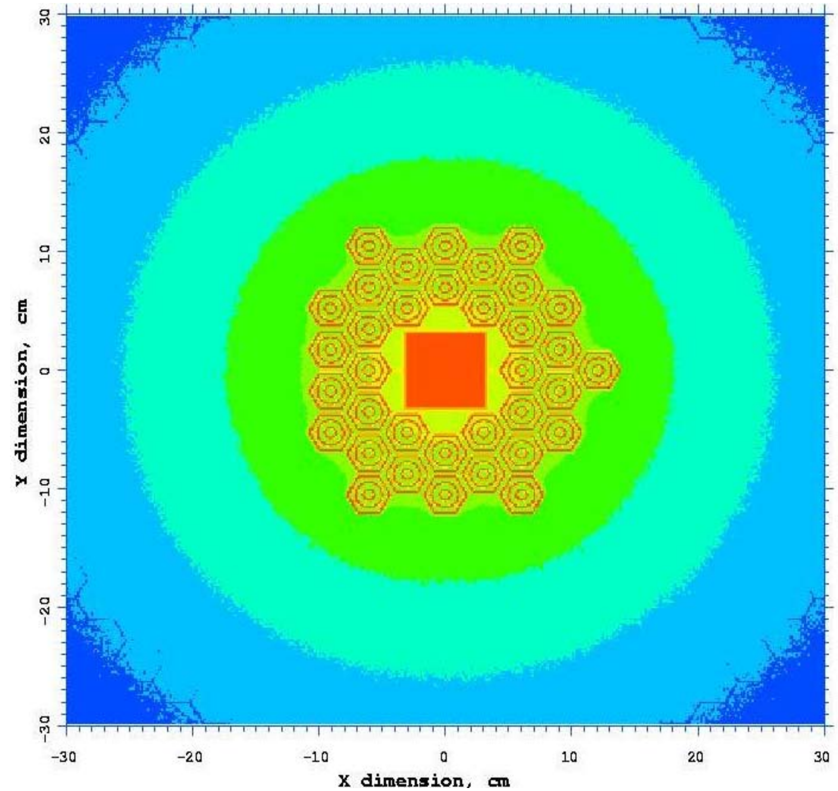


Subcritical Assembly Energy Deposition Distributions (R-Z & X-Y Maps, KW/cm^3)









Biological Shield

- Heavy concrete is used with density of 4.8 g/cm^3 .

- The international guidelines for the biological dose is $<2.5\times10^{-3}$ rem/h.

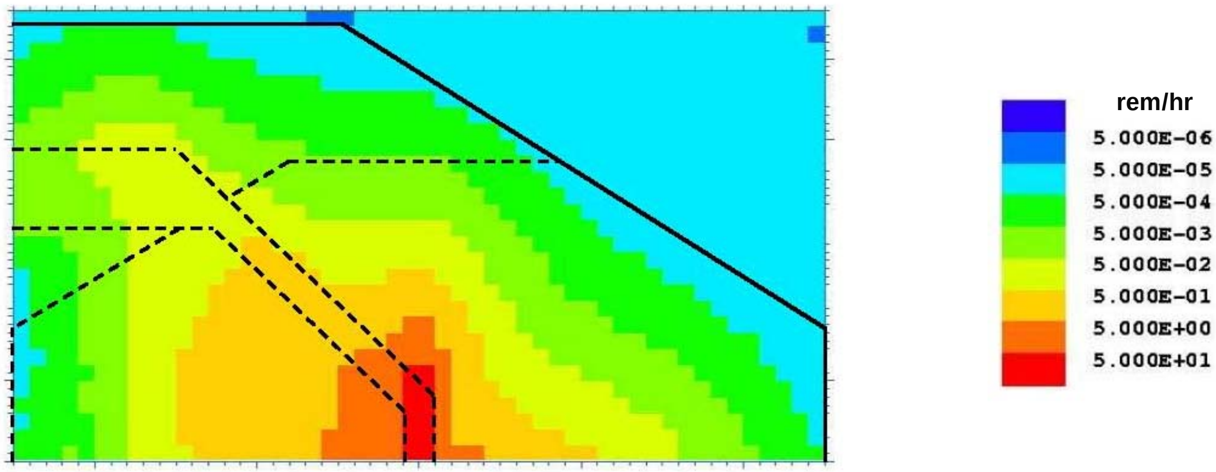
- The subcritical assembly has a radial shield thickness of 180 cm, which reduces the biological dose to 0.5×10^{-3} rem/h.

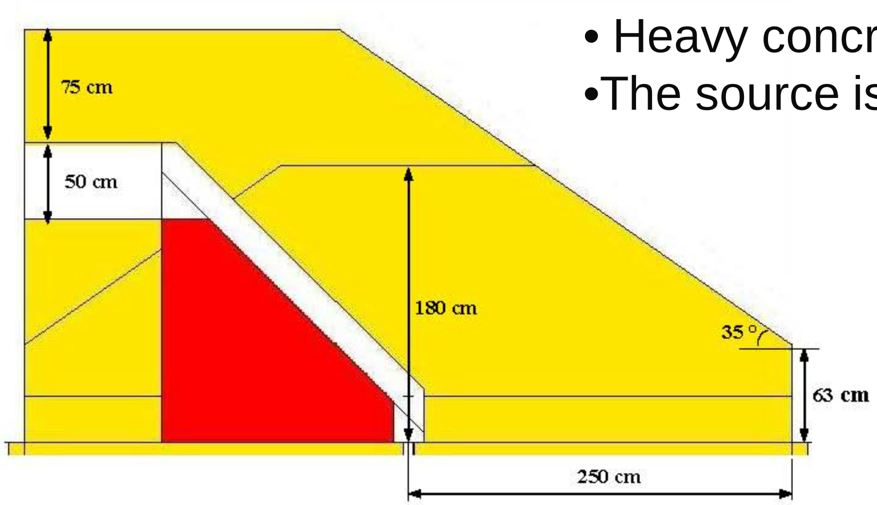
Radial Concrete Shield

- Heavy concrete is used with density of 4.8 g/cm^3.
- The international guidelines for the biological dose is <2.5 mrem/h.
- For radial shield thickness of 180 cm, the biological dose is 0.5 mrem/h.

Shield Thickness (cm)	Shield Radius cm	Neutron Dose (mrem/hr)	σ, %	Photon Dose (mrem/hr)	σ, %
152.0	252.0	2.43	12.6	4.59E-04	12.2
162.0	262.0	1.39	12.6	2.50E-04	12.0
172.0	272.0	0.72	11.8	1.58E-04	17.3
182.0	282.0	0.48	11.1	8.32E-05	10.7

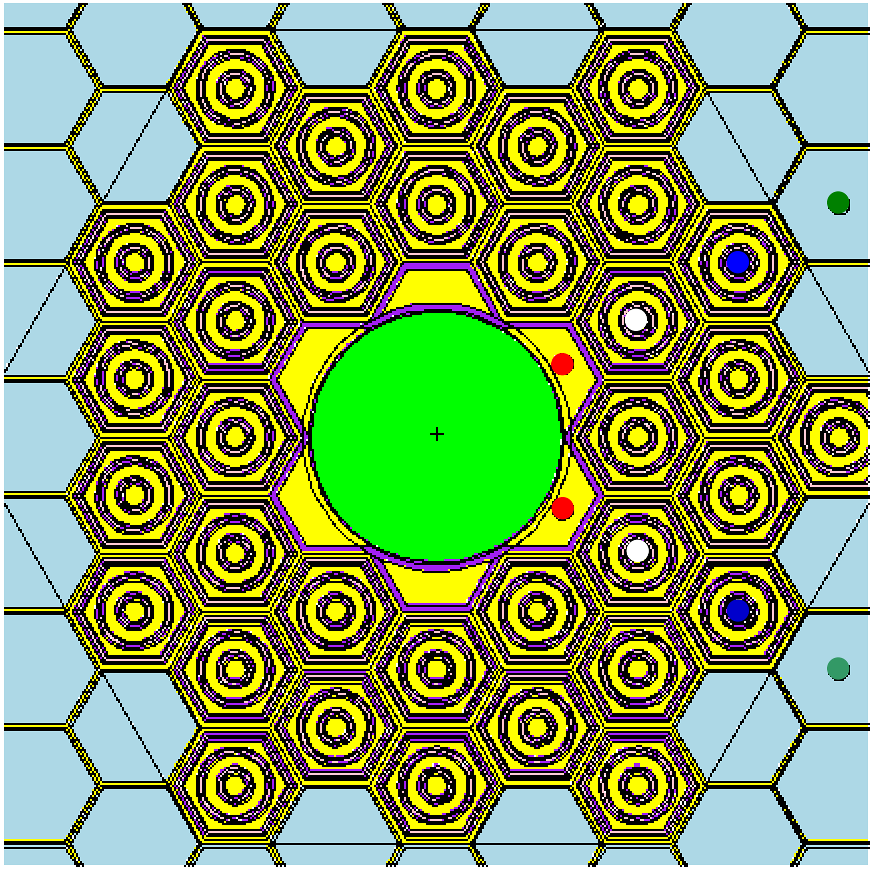
Shield Requirements for the Top Section





- Heavy concrete shield
- The source is the subcritical assembly

Neutron Irradiation Locations

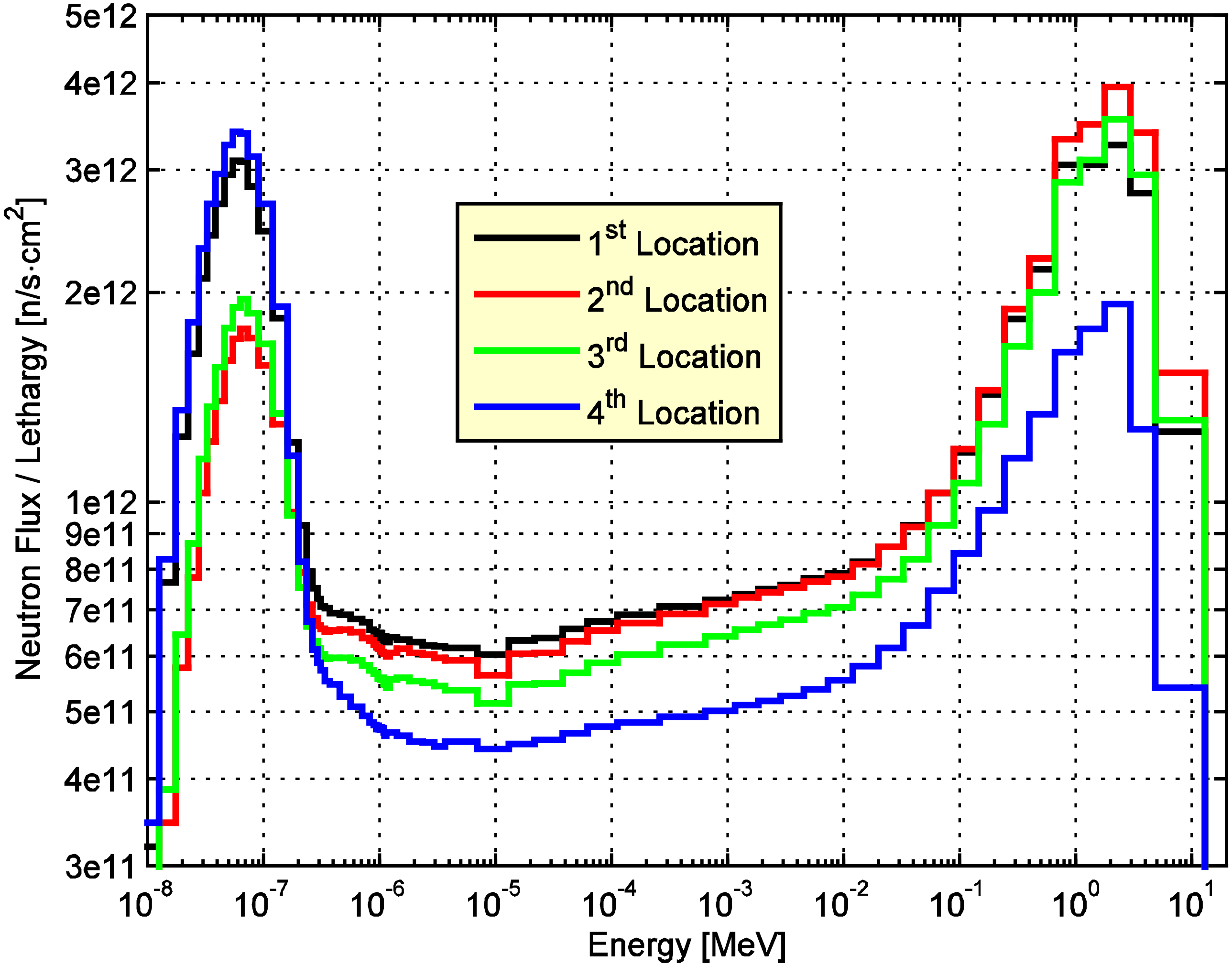


Irradiation Locations

1 2 3 4

Water	Graphite	Nat U	Aluminum	LEU Uranium
Coolant	Reflector	Target	Structure	Fuel

Neutron Spectrum of the Irradiation Locations



Medical isotopes decay modes and their applications

Isotope	Decay mode	Medical Applications
^{111}Ag	β	Cancer therapy
^{74}As	ε(66%)β(34%)	Positron emitter
^{77}As	β	Cancer therapy
^{199}Au	β	Rheumatoid arthritis and cancer therapy
^{213}Bi	β(97.91%)α(2.09)	Targeted alpha therapy
^{77}Br	ε	Radioimmunotherapy
^{82}Br	β	Metabolism
^{14}C	β	Metabolism
^{47}Ca	β	Bone formation and cell function
^{109}Cd	ε	Metal alloys analysis and scrap sorting
^{139}Ce	ε	Gamma-ray calibration
^{141}Ce	β	Lung density and myocardial blood flow
^{252}Cf	α	Cervical cancer and gliomas
^{57}Co	ε	Calibration of imaging instruments; gastrointestinal absorption
^{58}Co	ε	Anemia diagnosis; gastrointestinal absorption
^{60}Co	β	External cancer therapy and surgical instruments sterilization
^{51}Cr	ε	Red blood cells labeling and gastro-intestinal protein loss
^{137}Cs	β	Cancer therapy
^{61}Cu	ε	Positron emitter
^{64}Cu	ε(61%) β(39%)	Genetic diseases from copper metabolism (Wilson's and Menkel's diseases) and positron emitter
^{67}Cu	β	Cancer therapy
^{165}Dy	β	Rheumatoid arthritis
^{169}Er	β	Alleviation of arthritis pain in synovial joints
^{253}Es	α	Labeling of antibodies for cancer therapy
^{55}Fe	ε	x-ray fluorescence
^{59}Fe	β	Metabolism in the spleen
^{255}Fm	α	Labeling of antibodies for cancer therapy
^{159}Gd	β	Cancer therapy
^{3}H	β	Tritiated water
^{166}Ho	β	Rheumatoid arthritis and cancer therapy
^{123}I	ε	Organs imaging (brain)
^{125}I	ε	Liver and brain cancers, veinthrombosis in leg and detection of tiny quantities of hormones
^{129}I	β	In vitro diagnosis
^{131}I	β	Thyroid cancer and renal blood flow

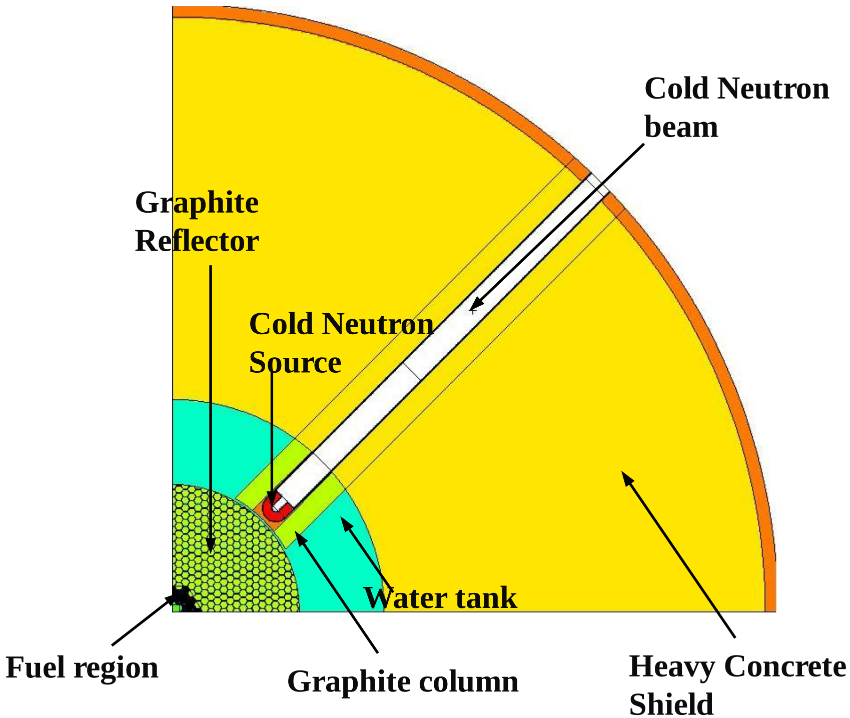
Medical isotopes decay modes and their applications (Continued)

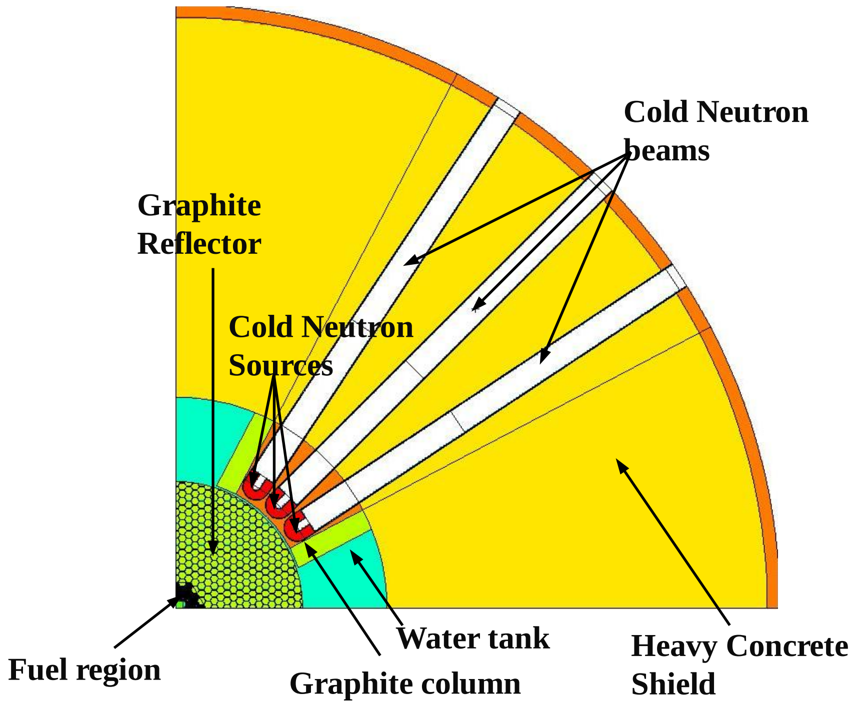
^{111}In	ε	Radioimmunotherapy
^{191m}Ir	ι	Cardiovascular angiography
^{192}Ir	ε(4.76%) β(95.24%)	Intravascular brachytherapy
^{194}Ir	β	Cancer therapy
^{42}K	β	Coronary blood flow
^{177}Lu	β	Organs Imaging
^{177m}Lu	ι(78.3%) β(21.7%)	Endocrine Cancers and labeling of antibodies for cancer therapy
^{24}Na	β	Electrolytes within the body
^{32}P	β	Genetics and polycythemia vera (excess of red blood cells)
^{33}P	β	Cancer therapy and genetics
^{103}Pd	ε	Prostate cancer
^{195m}Pt	ι	Pharmacokinetics of antitumor agents
^{186}Re	ε(6.9) β(93.1)	Bone cancer, rheumatoid arthritis and labeling of antibodies for cancer therapy
^{188}Re	β	Thyroid carcinoma, alleviation of pain in bone cancer and angioplasty balloon
^{97}Ru	ε	Hepatobiliary function and tumor localization
^{35}S	β	Genetics (nucleic acid labeling)
^{47}Sc	β	Cancer therapy
^{75}Se	ε	Protein studies (digestive enzymes)
^{145}Sm	ε	Ocular cancer
^{153}Sm	β	Alleviation of pain in bone cancer and labeling of antibodies for cancer therapy
^{85}Sr	ε	Bone formation
^{89}Sr	β	Alleviation of pain in bone and prostate cancers
^{179}Ta	ε	X-ray fluorescence
^{99m}Tc	ι (99.9963%) β (0.0037%)	Organs imaging
^{123m}Te	ι	Lung densities and cardiology
^{117m}Sn	ι	Alleviation of pain in bone cancer
^{133}Xe	β	Lung ventilation; cerebral blood flow
^{88}Y	ε	Radioimmunotherapy
^{90}Y	β	Labeling of antibodies for cancer therapy, cancer therapy and non-Hodgkin's lymphoma
^{169}Yb	ε	Cerebrospinal fluid in the brain
^{89}Zr	ε	Radioimmunotheraphy and positron emitter
^{166}Dy	β	Parent of ^{166}Ho
^{99}Mo	β	Parent of ^{99m}Tc
^{191}Os	β	Parent of ^{191m}Ir
^{194}Os	β	Parent of ^{194}Ir
^{90}Sr	β	Parent of ^{90}Y
^{188}W	β	Parent of ^{188}Re

Medical Isotopes Production Main Conclusions

- The study results show that the facility has excellent capability for producing medical isotopes.
- Generally, the optimal irradiation location lies in the reflector next to a fuel assembly, where the neutron flux has a thermal spectrum.
- The axial neutron distribution exhibits a cosine distribution and the radial one has an exponential distribution.
- The optimal sample size can have a length up to 30 cm and a radius of 0.1 to 0.3 cm

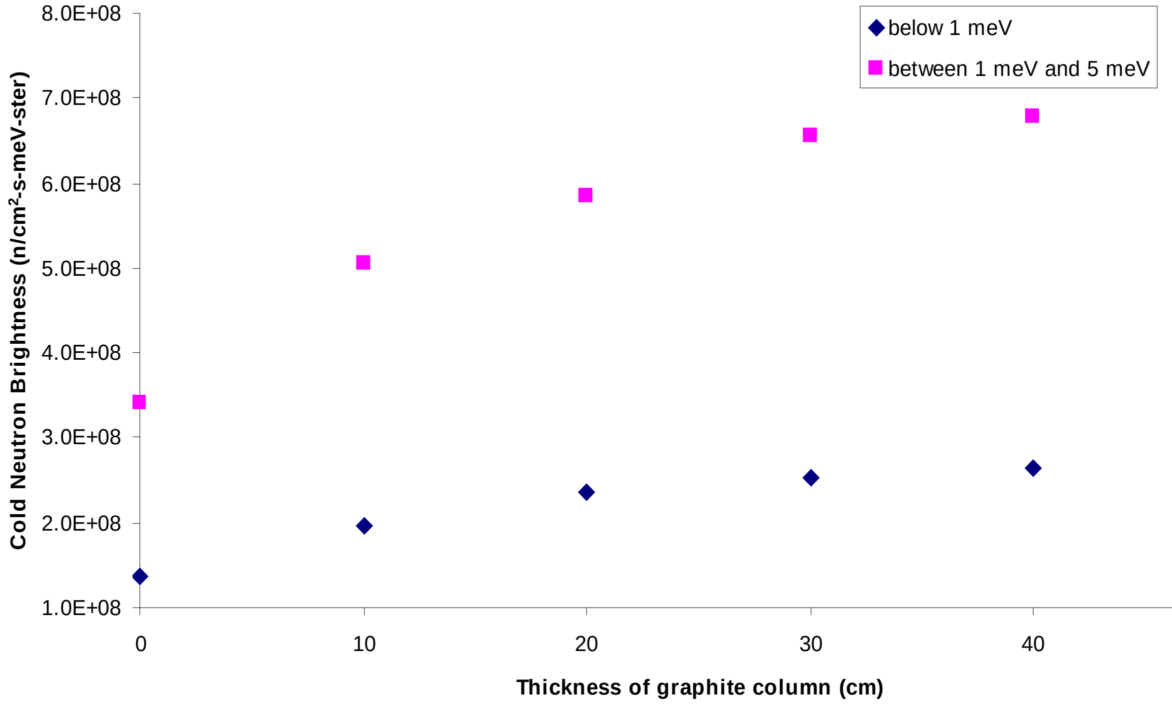
Cold Neutron Source Configurations



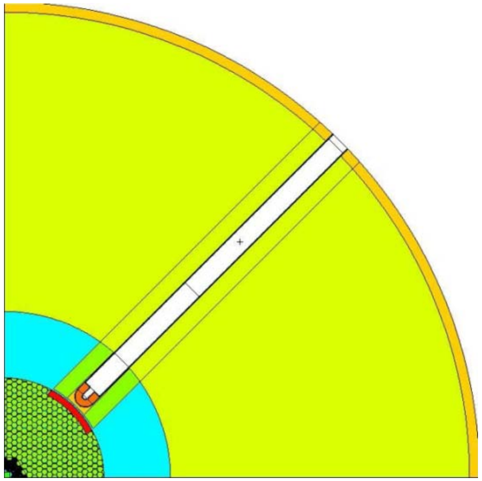


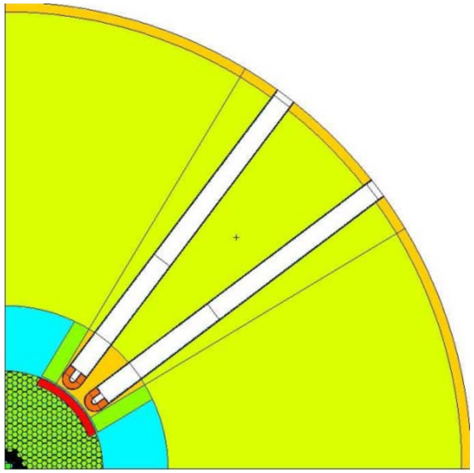
- Liquid hydrogen, deuterium, or solid methane is the moderator material.
- Graphite is used around the cold neutron source to enhance its performance
- Lead is used to attenuate the gamma rays.
- Parametric studies defined the design parameters.

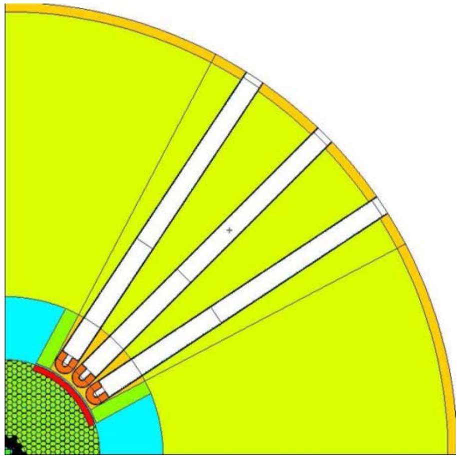
Cold Neutron Source Performance as a Function of the Graphite Thickness for Para-Liquid Hydrogen Moderator



Performance Comparison of Different Cold Neutron Source Configurations







Upper energy limit	Brightness of cold neutron (n/cm^2-s-meV-ster)					
	Single CNS and single channel	Two CNS and two channels		Three CNS and three channels		
		Channel 1	Channel 2	Channel 1	Channel 2	Channel 3
1 meV	2.08e+08 (±3.06 %)	2.02e+08 (±3.16 %)	1.86e+08 (±3.31 %)	1.95e+08 (±4.79 %)	1.84e+08 (±3.23 %)	1.89e+08 (±3.23 %)
5 meV	5.20e+08 (±2.57 %)	4.95e+08 (±2.21 %)	5.03e+08 (±2.65 %)	4.46e+08 (±2.96 %)	4.71e+08 (±2.62 %)	4.76e+08 (±2.57 %)
10 meV	5.75e+08 (±3.34 %)	4.75e+08 (±2.77 %)	4.95e+08 (±3.05 %)	4.54e+08 (±3.35 %)	5.14e+08 (±3.87 %)	5.11e+08 (±3.48 %)
100 meV	3.70e+07 (±2.84 %)	3.86e+07 (±3.23 %)	3.68e+07 (±3.01 %)	3.25e+07 (±3.45 %)	3.57e+07 (±3.38 %)	3.38e+07 (±3.11 %)

Main Conclusions

- A neutron source facility has been successfully developed using electron accelerator driven subcritical assembly facility concept with low enriched uranium fuel.
- The developed concept satisfies the facility objectives and it has flexibility for future upgrades and new functions.