National and International Accelerator Driven System Activities for Nuclear Energy

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National and International Accelerator Driven System Activities for Nuclear Energy

Outline:

- Current World Activities of Accelerator Driven Systems (ADS) for Nuclear Energy Applications
- Main US ADS Activities for Nuclear Applications

Accelerator Utilization for Nuclear Energy Applications

In the last seventy years, accelerators were considered for different nuclear applications:

- *Neutron Source - E. O. Lawrence – USA, W. N. Semenov - USSR (1940)*
- *Plutonium Production - G. Seaborg - USA (1941)*
- *Material Testing - E. O. Lawrence - USA (1950)*
- *Actinides Burner - H. Takahashi - USA (1980's)*
- *.....*
- *Tritium Breeder*
- *Fissile Isotopes Breeder*
- *Nuclear Energy Production*
- *.....*
- *Nuclear Test Facility - ANL and LANL (2000's)*
- *Material Test Station - LANL*
- *International Collaboration Activities - ANL*

Major World Developments of Accelerator Driven Systems for Nuclear Energy

European Union

- Last two EU program cycles: the 6th (2002 – 2006) and the 7th (2007 – 2013) Framework Programmes (FPs)
- EUROTRANS project of the 6th frame work program was funded with a total of EUR 45 million
- Objectives
  - Develop Preliminary designs for MYRRHA/XT-ADS (experimental ADS, 50 – 100 MW_{th})
  - Develop conceptual design - European Transmutation Demonstrator (ETD, several hundred MW_{th}, modular)
- Major projects
  - MEGAPIE target experiment at PSI
  - MYRRHA / XT-ADS project
  - GUINEVERE experimental facility
  - FASTEF facility and CDT (Central Design Team)

Lead and Lead-Bismuth European Experimental Loops

- *Liquid lead and Lead-Bismuth eutectic are used as spallation target materials and coolants for accelerator driven systems.*
- *Several laboratories and loops have been build to study the technological characteristics of these liquids.*
- *The main issues are corrosion, erosion, heat transfer and flow characteristics, and interaction with other materials under different conditions.*

KALLA Loops
FZK

STELLA Loop
CEA

CIRCE Loop
ENEA

CorrWett Loop
PSI

VICE Loop
SCK-CEN

CHEOPE Loop
ENEA

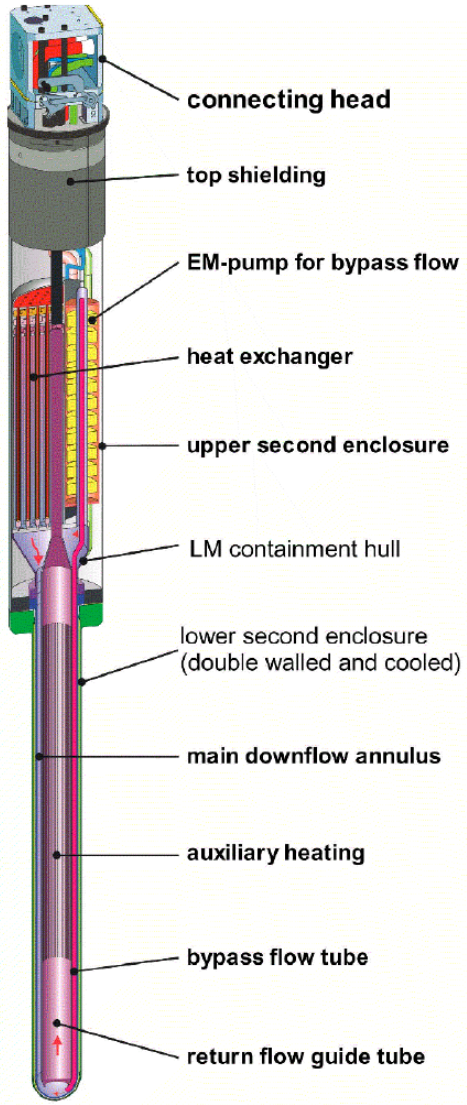
COSTA
FZK

TALL Loop
KTH

CIRCO Loop
CIEMAT

MEGAPIE MEGAwatt PIlot Experiment

- *Joint effort by 6 European Institutes (PSI, FZK, CEA, SCK•CEN, ENEA, CNRS) plus JAEA (Japan), LANL/ANL (USA) and KAERI (Rep. of Korea) to demonstrate*
  - *Design, manufacturing, safe operation, and dismantling of a liquid Pb-Bi eutectic target for high power spallation and ADS applications*
  - *Assess the target's neutronics performance*
  - *Collect material data in view of establishing a data base for liquid Pb-Bi eutectic targets*
- *MEGAPIE was the first liquid Pb-Bi eutectic target operated in the Megawatt regime (0.8 MW provided by 575 MeV protons from the PSI accelerator)*
  - *Successfully irradiated from August until December 2006 at the Swiss Spallation Neutron Source (SINQ) at PSI*
  - *MEGAPIE received a beam charge of 2.8 Ah of 575 MeV protons*
- *Dismantled for PIE studies*

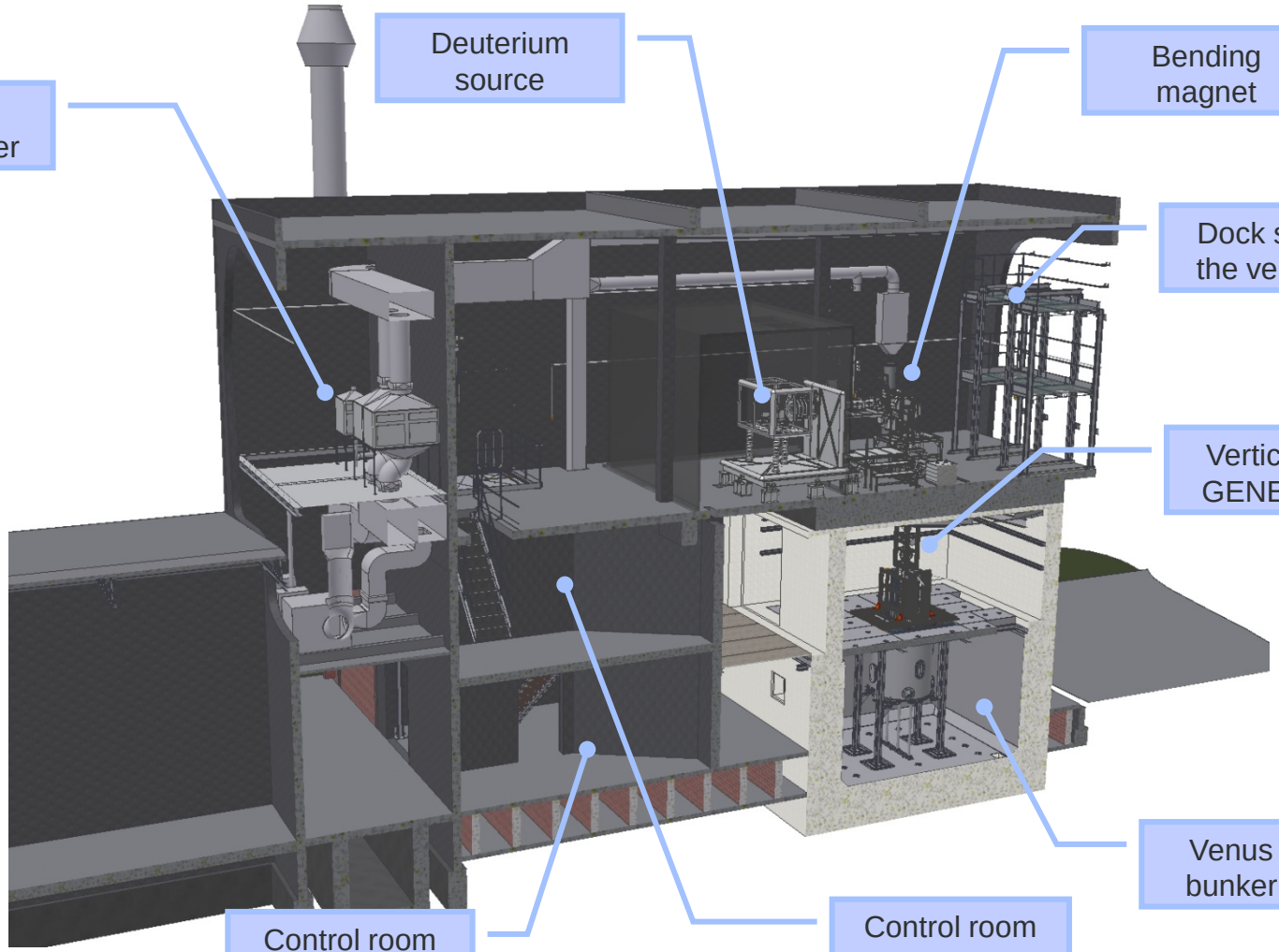


GUINEVERE Experimental Facility

Generator of Uninterrupted Intense NEutrons at the lead VEnus REactor

- Experimental facility allowing physics experiments under ADS conditions
- Deuteron GENEPI-3C accelerator operating in pulsed and continuous mode
- Ti^3H target producing 14.1 MeV neutrons
- Zero-power fast sub-critical 30% ^{235}U enriched metallic U fuelled core in Pb matrix
- GUINEVERE studies of on-line reactivity monitoring techniques at various subcriticality levels
  - Current-to-flux reactivity monitoring (GENEPI-3C in continuous mode, representative for power ADS)
  - Time dependent neutron spectra measurements after beam interruptions

GUINEVERE Experimental Facility

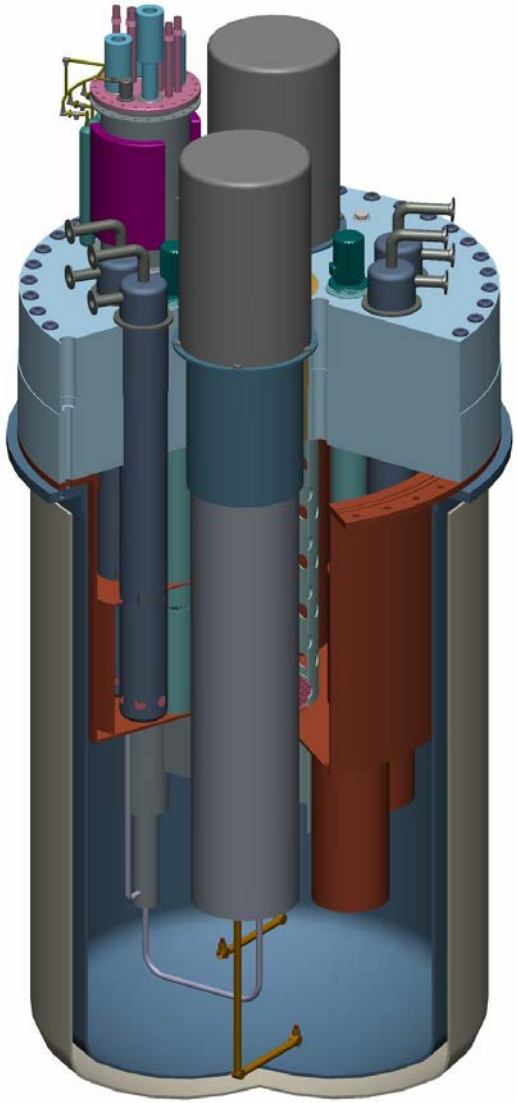


Multipurpose Hybrid Research Reactor for High-tech Applications (MYRHHA) Project

- Demonstrate an ADS concept by coupling the three components (accelerator, spallation target and sub-critical reactor) at reasonable power level scalable to an industrial demonstrator
- Contribute to the demonstration of LBE technology and to demonstrate the critical mode operation of a heavy liquid metal cooled reactor as an alternative technology to SFR
- A flexible fast spectrum irradiation facility working in subcritical and critical mode allowing for:
  - fuel developments for innovative reactor systems,
  - material developments for GEN IV systems,
  - material developments for fusion reactors,
  - commercial services
  - efficient transmutation of MA requesting high fast flux intensity ($\Phi_{>0.75MeV} = 10^{15}$ n.cm^{-2}.s^{-1});

MYRHHA Project

Parameter	unit	Value
Core power	MW_{th}	85
Active core average power density	W/cm^3	246
Fast flux above 0.75 MeV	$n/cm^2.s$	10^{15}
Inlet temperature	° C	270
Coolant ΔT	° C	130
LBE Velocity (fuel rod)	m/s	1.72
LBE Velocity (spacer-grid)	m/s	2.50
Temperature at clad surface	° C	496
Maximum linear power	W/cm	372

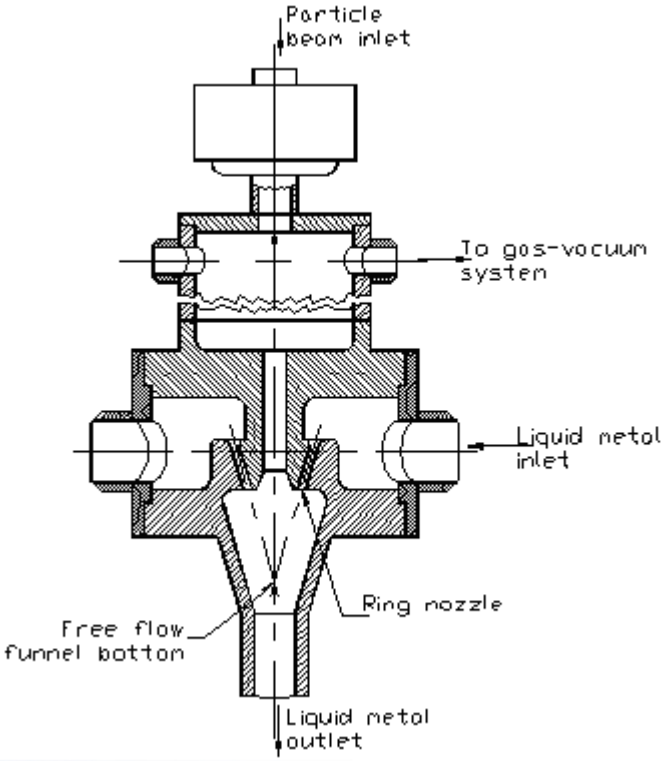


India ADS Programs

India ADS program directed to support the thorium fuel cycle by breeding ^{233}U. The Program covers the different ADS aspects.

Windowless liquid-metal spallation target

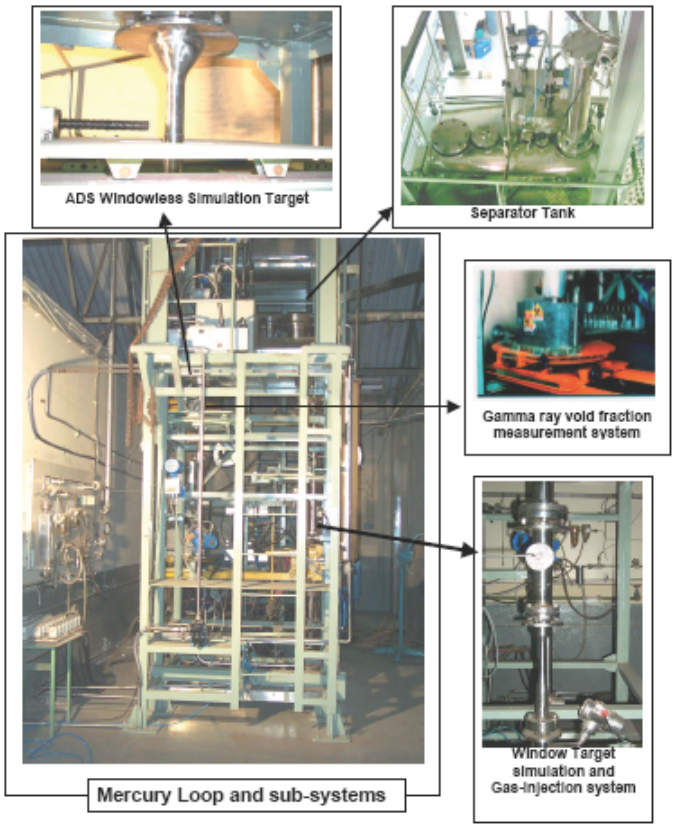
- ***The Interface between the target-coolant and the accelerator vacuum is a free surface of the liquid metal. Liquid volume below serves as spallation target.***
- ***The vapor pressure of lead and lead-bismuth at the operating temperatures of less than ~400 ^{0}C is low, ~ 10^{-4} Torr.***
- ***The need for a metallic window exposed to high radiation damage is eliminated.***



India ADS Liquid Metal Experiments

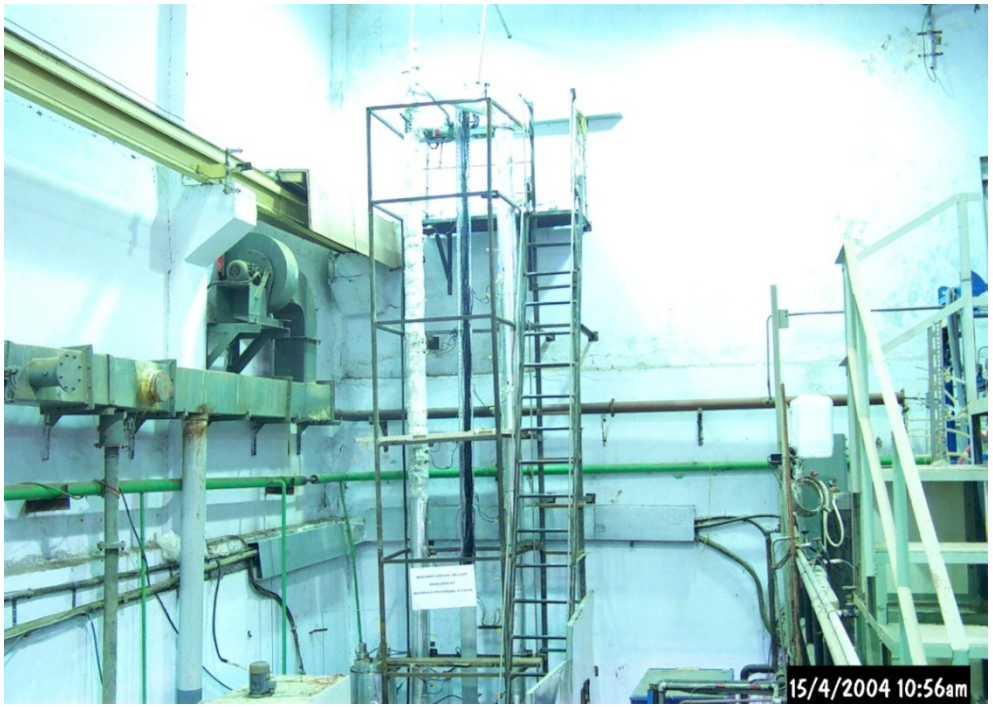
Mercury Loop

- Simulation of Window and Windowless Target
- CFD code validation



LBE Corrosion Loop

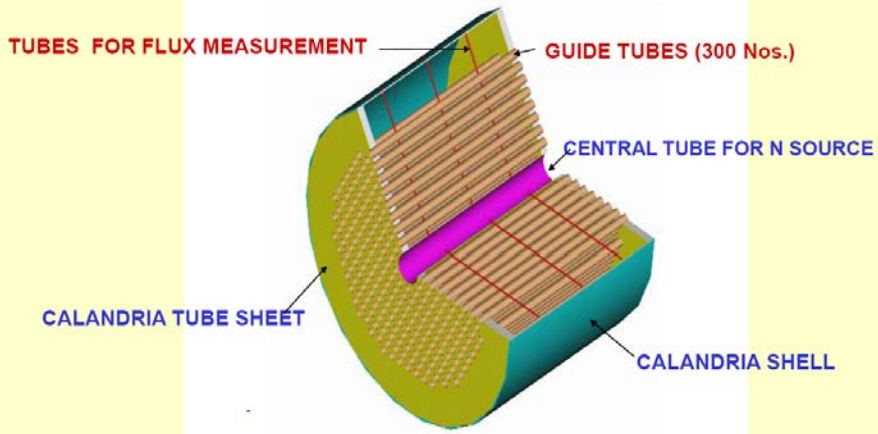
- Height ~ 7m, Flow Rate ~1.7 kg/s, Temp: 550^{0}C and 450^{0}C, Velocity in the Samples ~0.6 m/s
- Corrosion Tests: Charpy and Tensile >3000 hrs in the flow



India Physics Experiment

- *Physics validation experiments of the analytical simulations*
- *The external neutron source is 14-MeV neutrons produced by DC accelerator from D-T reaction.*
- *Simple subcritical assembly (k_{eff}=0.87) of natural uranium and light water*
- *Measurements of neutron flux distributions, neutron spectra, total fission power, source multiplication, and subcriticality will be carried out.*

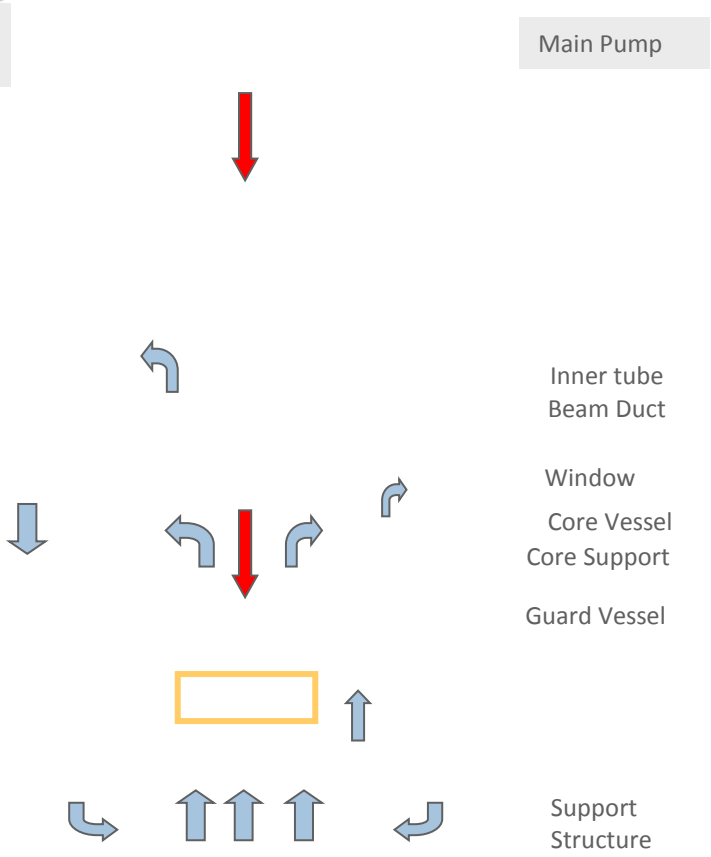
Fuel: Nat-U, Moderator: H_2O; k_{eff} = 0.873



Japan ADS Program

Japan ADS program is designed to transmute transuranics and generate Nuclear Energy

- **Proton beam : 1.5GeV ~20MW**
- **Spallation target : Pb-Bi**
- **Coolant : Pb-Bi**
- **Subcriticality : k_{eff} = 0.97**
- **Thermal output : 800MWt**
- **Core height : 1000mm**
- **MA initial inventory : 2.5t**
- **Nitride fuel, (Pu+MA)N+ZrN**
- **Transmutation rate: 10%MA / Year**



Japan Main Lead-Bismuth Target Experiments

Target Window

Proton irradiation austenitic steel data have been obtained, which included mechanical property and micro structure.

JLBL-1

Materials property under LBE flow was obtained through 18000 hrs run. Oxygen sensor property and performance of EMP were investigated.

JLBL-2

EMP drove LBE in the coaxial counter flows. EMF performance was investigated. Ultrasonic to visualize the LBE flow.

JLBL-3

Massive flow control was used (500L/min). Heat transfer coefficient of the beam model was formulized.

Japan Lead-Bismuth Experimental Facility

Japan KUCA Subcritical Assembly Experiment with 14 MeV D-T neutron source

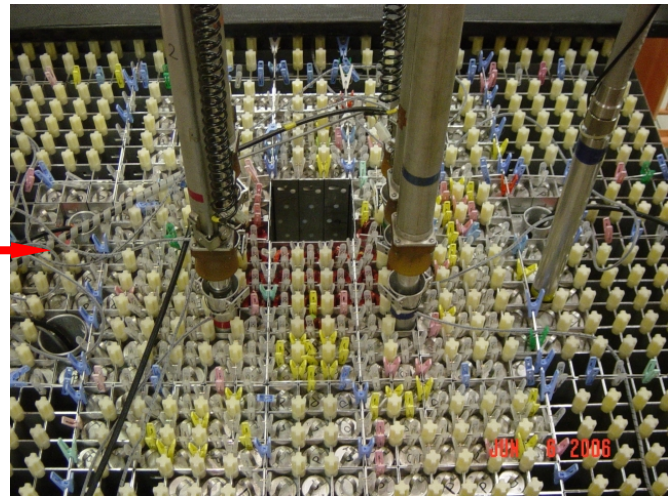
Subcritical/Critical Assembly

- ***Highly enriched uranium***
- ***Polyethylene Reflector & Moderator***
- ***Thermal neutron field***

KUCA A-core

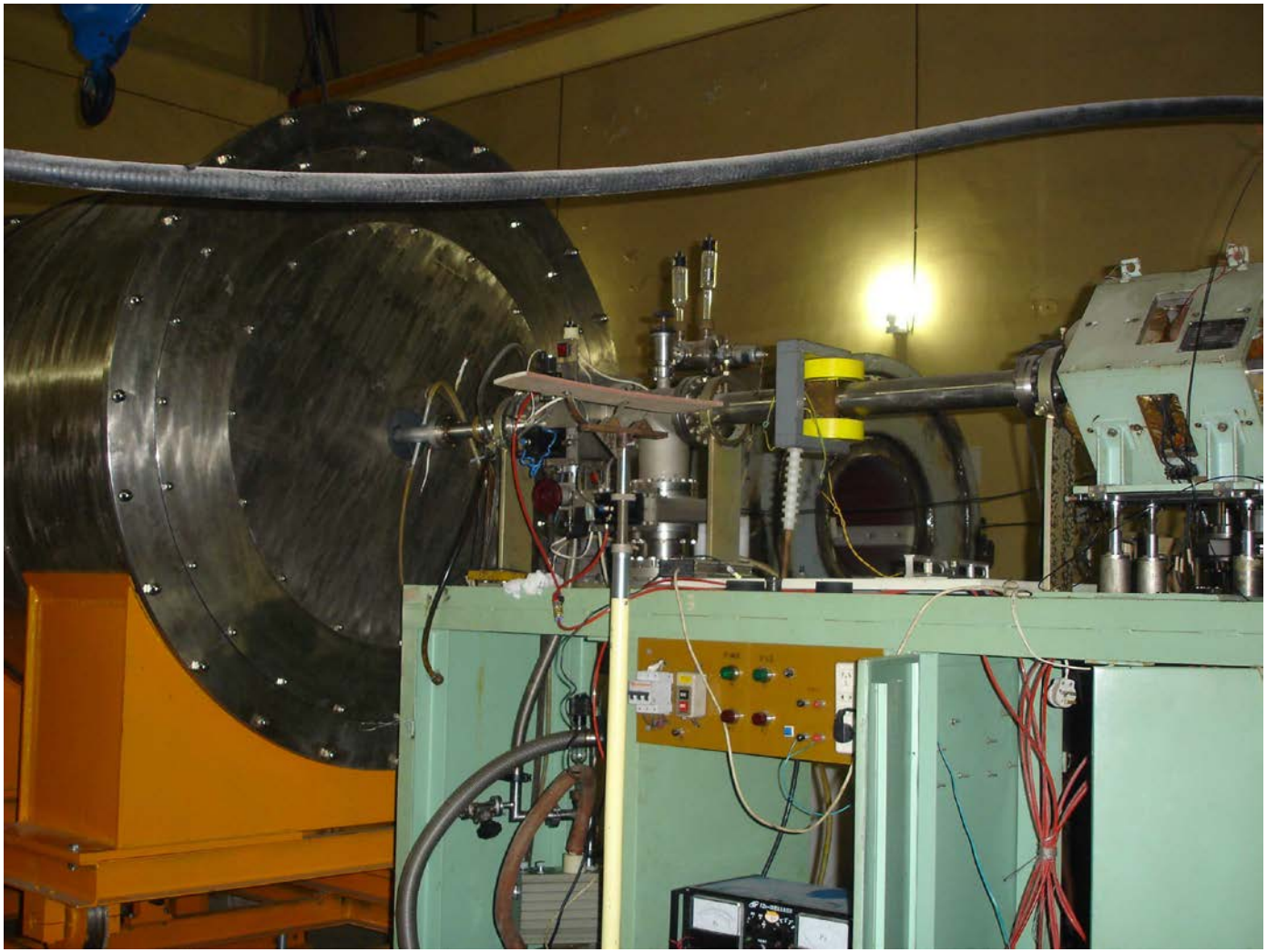
Tritium Target

14MeV Neutron Beam Injection



China ADS Program – Fissile Breeding

Venus 1 - Subcritical assembly Driven by 14 MeV Neutron Source



Other International ADS Program

- *Argentina - Physics program*
- *Brazil – Physics Program*
- *Germany – Complete ADS program*
- *Italy – Physics and technology Program*
- *Norway - Energy & Thorium Fuel Cycle*
- *Poland – Experimental physics Program*
- *Russia - Physics and technology Program*
- *South Korea – Transmutation Program*
- *Spain – Transmutation Program*
- *Sweeden - Experimental physics Program*

IAEA reported that 18 countries are performing ADS R&D

Main US ADS Activities for Nuclear Applications

Argonne National Laboratory has three main ADS activities for different missions:

I. **Develop, design, and construct an experimental neutron source facility consists of electron accelerator driven subcritical system**
II. **Analytical and experimental activities to study the physics and to develop control methods for future ADS using zero power facilities**
III. **Develop ADS concept to dispose of US spent nuclear fuel inventory with minimum extrapolation for the current technologies**

Los Alamos National Laboratory is developing materials test stand, which is presented this afternoon by Eric Pitcher

Experimental Neutron Source Facility Development, Design, and Construction

- US Government is supporting the construction of an experimental neutron source facility at Kharkov, Ukraine.
- Argonne National Laboratory developed and designed the facility in collaboration with National Science Center "Kharkov Institute of Physics & Technology" of Ukraine. The facility is under construction with a starting date of April 30, 2014.
- The facility has an electron accelerator driven subcritical system utilizing low enriched uranium oxide fuel with water coolant and beryllium-carbon reflector.
- The electron accelerator is utilized for generating the neutron source driving the subcritical assembly. The accelerator power is 100 KW beam using 100 MeV electrons.
- The target material is tungsten or natural uranium cooled with water coolant.

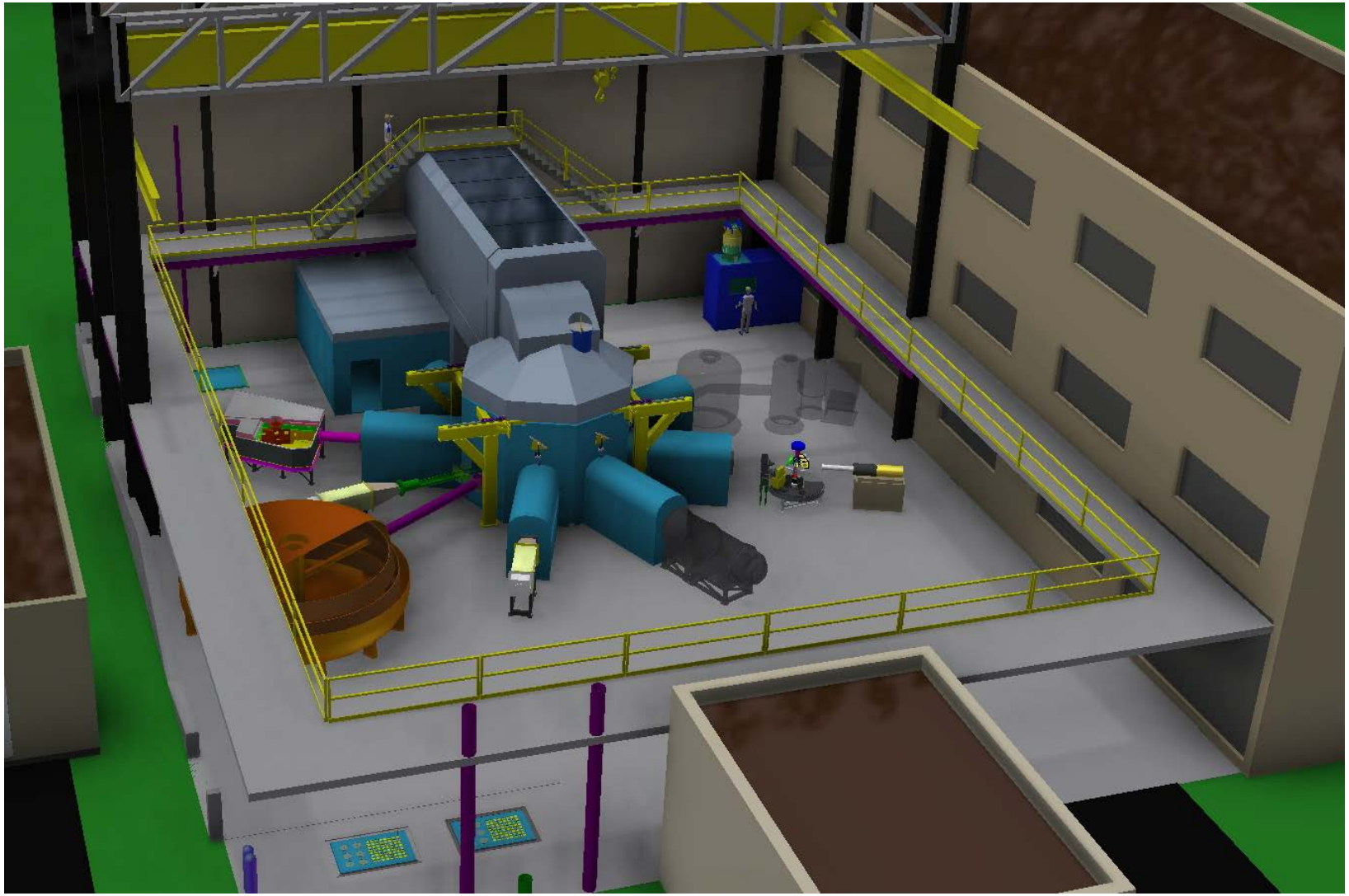
KIPT Experimental Neutron Source Facility

Facility Objectives

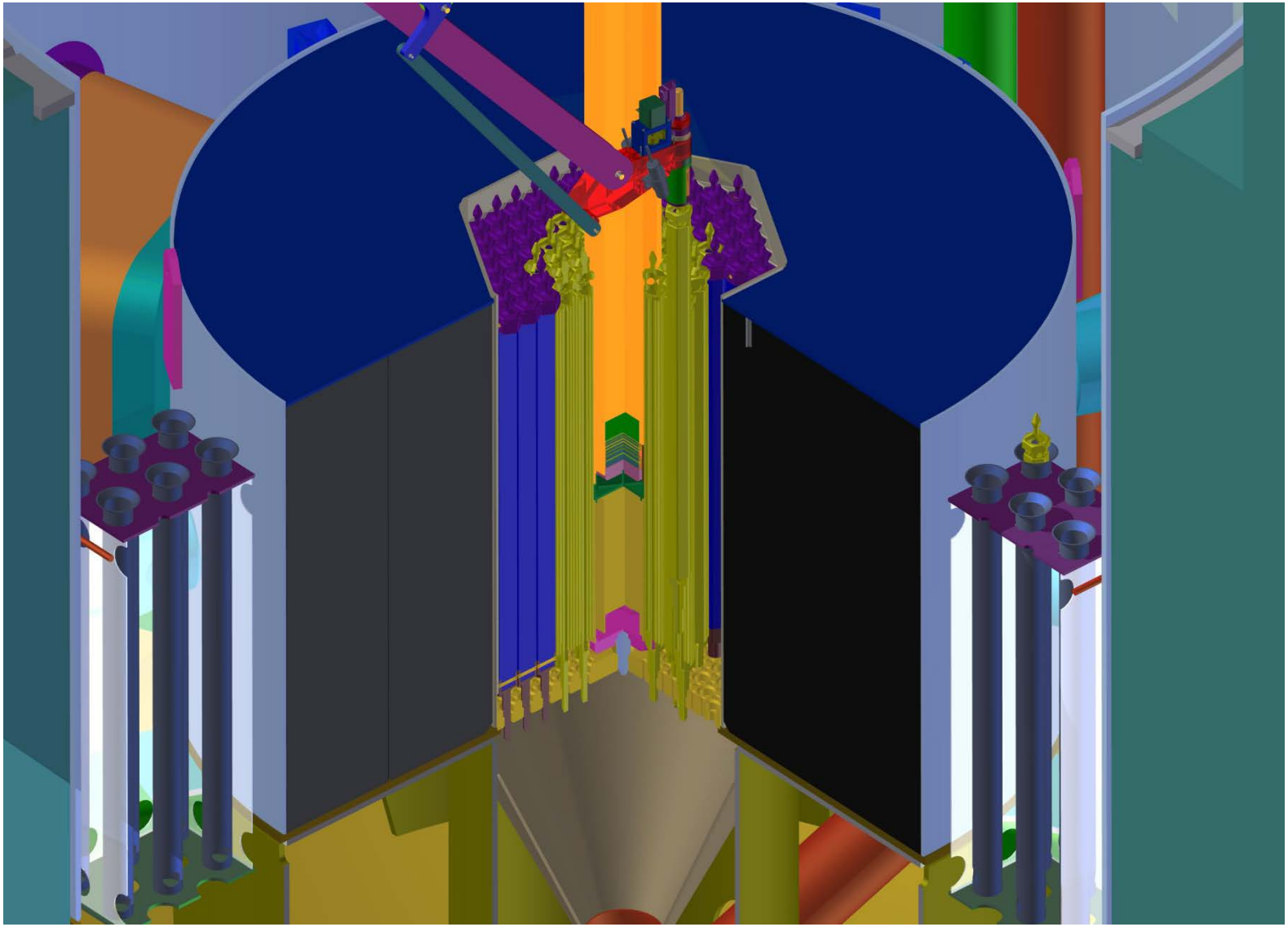
- Provide capabilities for performing basic and applied research using neutrons
- Perform physics and material experiments inside the subcritical assembly and neutron experiments using the radial neutron beam ports of the subcritical assembly
- Produce medical isotopes and provide neutron source for performing neutron therapy procedures
- Support the Ukraine nuclear power industry by providing the capabilities to train young specialists

KIPT Experimental Neutron Source Facility

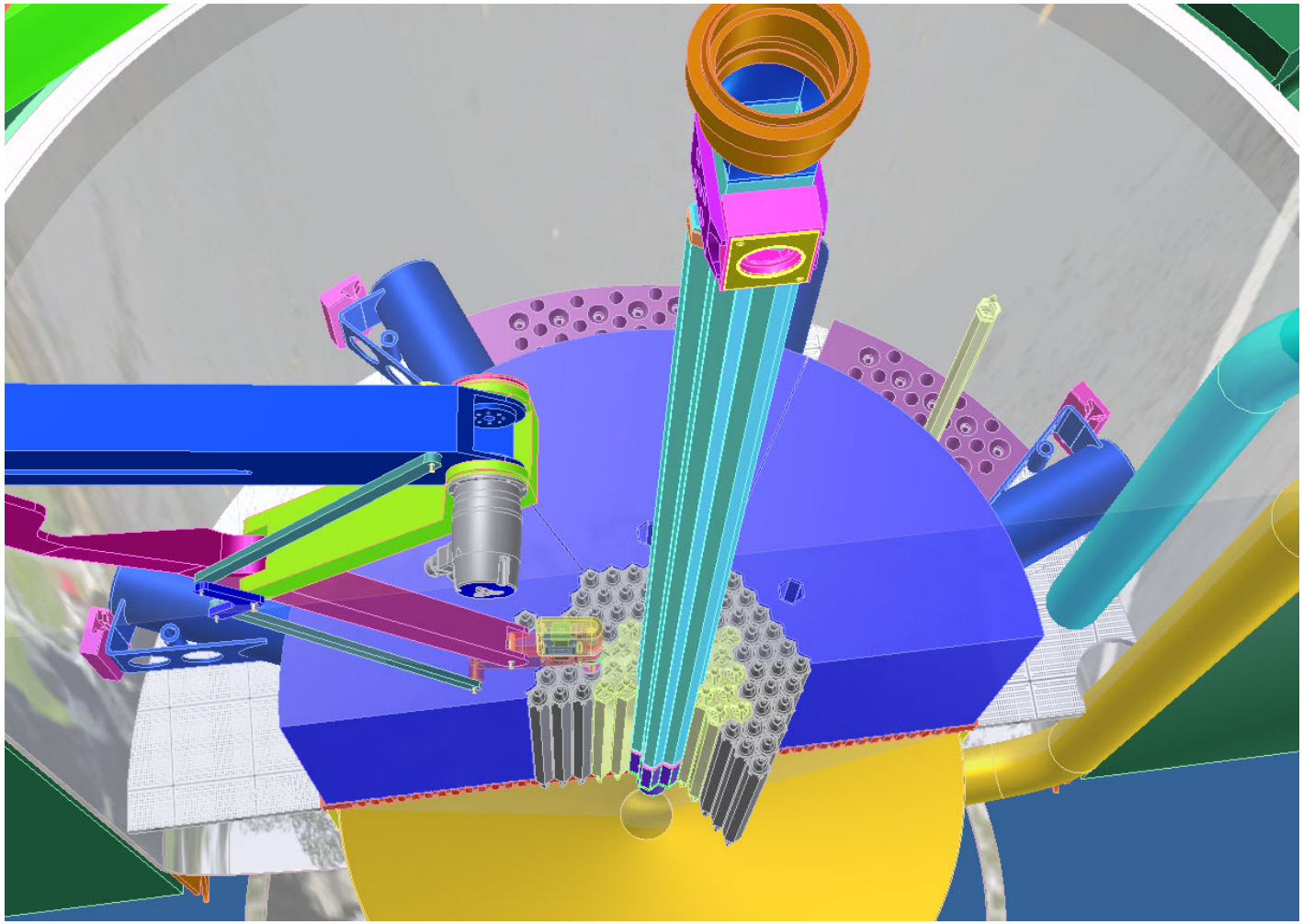
KIPT Experimental Neutron Source Facility Overview



Subcritical Assembly Overview



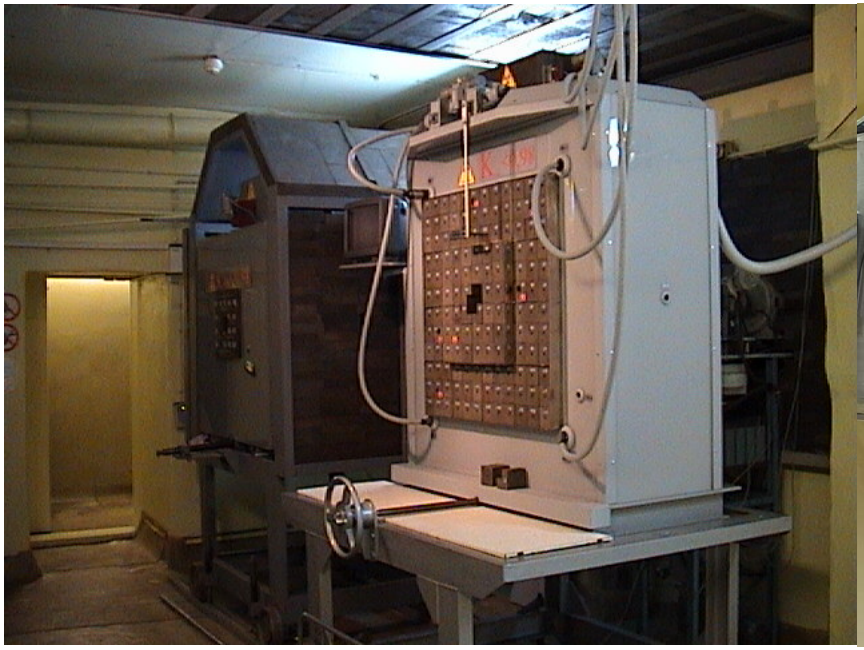
Top View of the Subcritical assembly

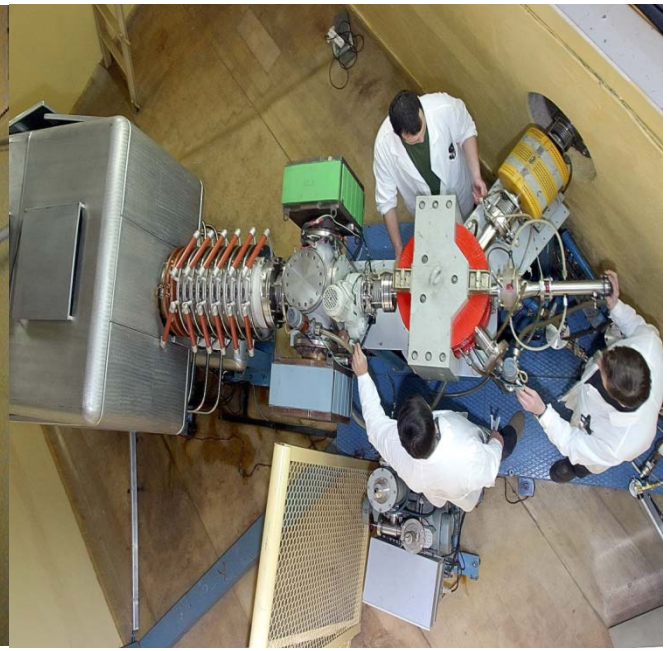


US-Belarus ADS Program

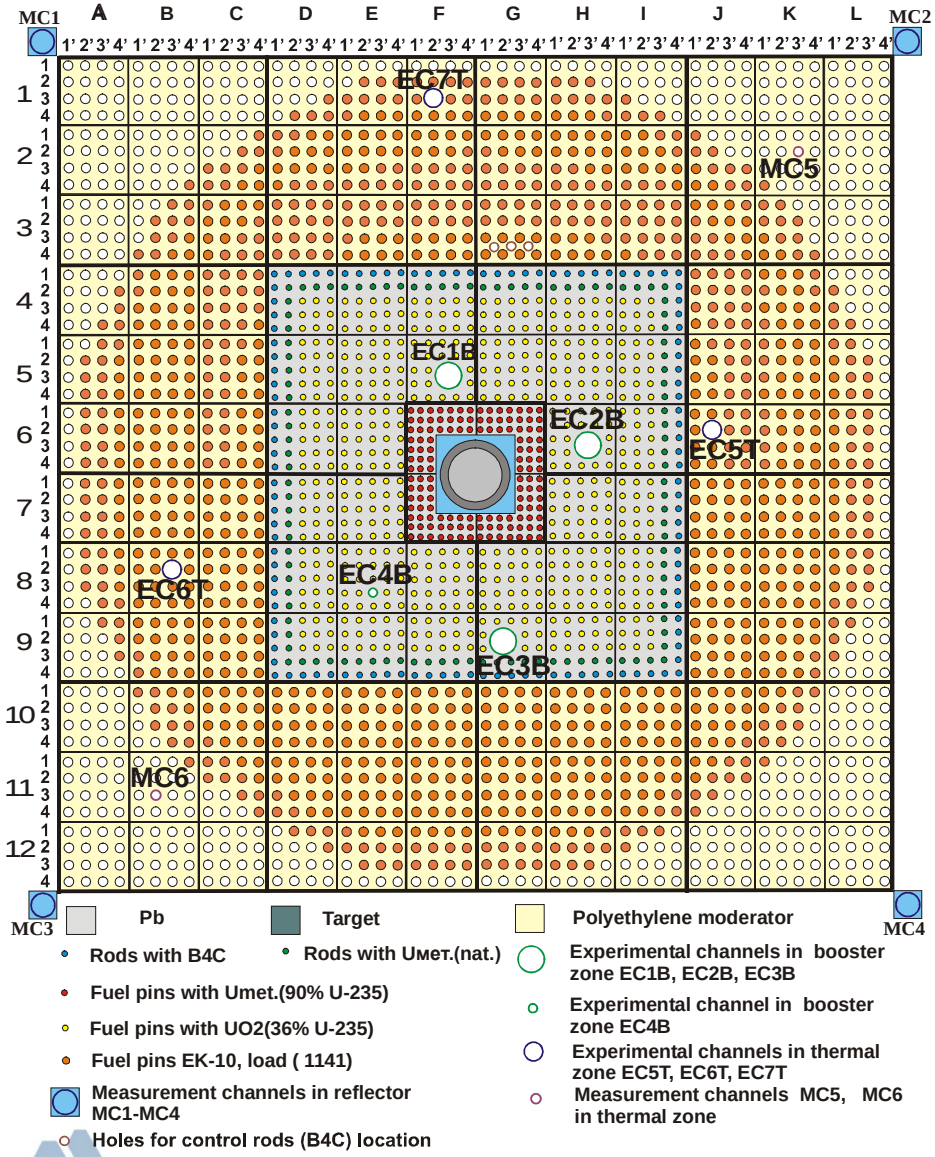
Argonne is cooperating with Joint Institute for Power and Nuclear Research – SOSNY (JIPNR-SOSNY) using the YALINA Facilities (YALINA-BOOSTER and YALINA-Thermal) to:

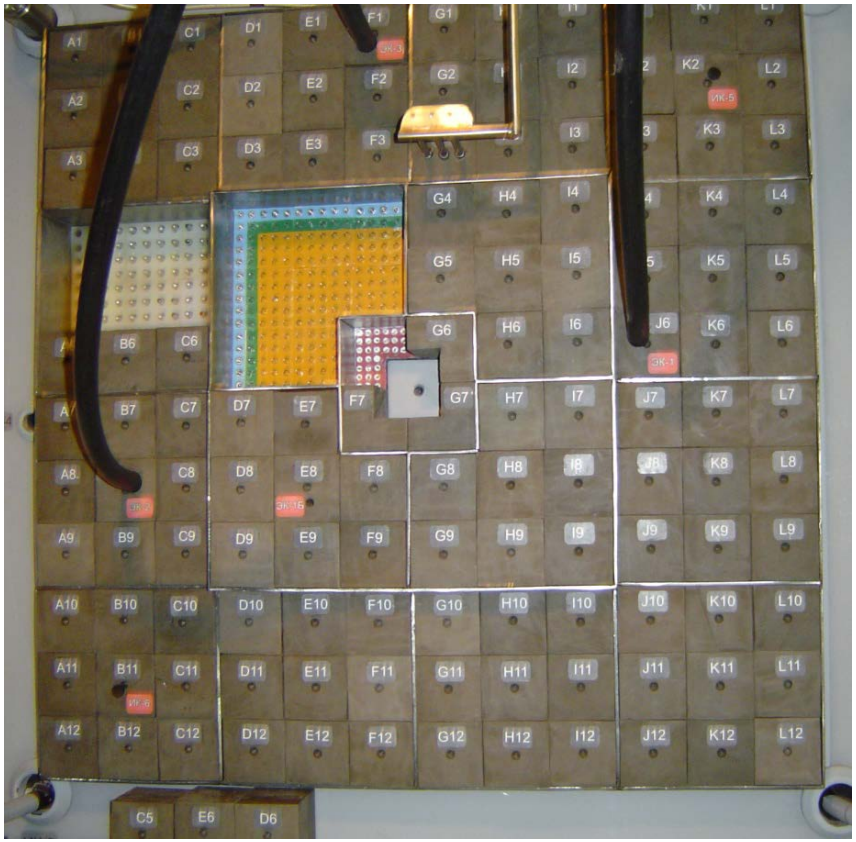
- ***Develop and test reactivity monitoring techniques***
- ***Investigate spatial kinetics of subcritical systems***
- ***Measure transmutation reaction rates***
- ***Obtain operational experience running accelerator driven systems***





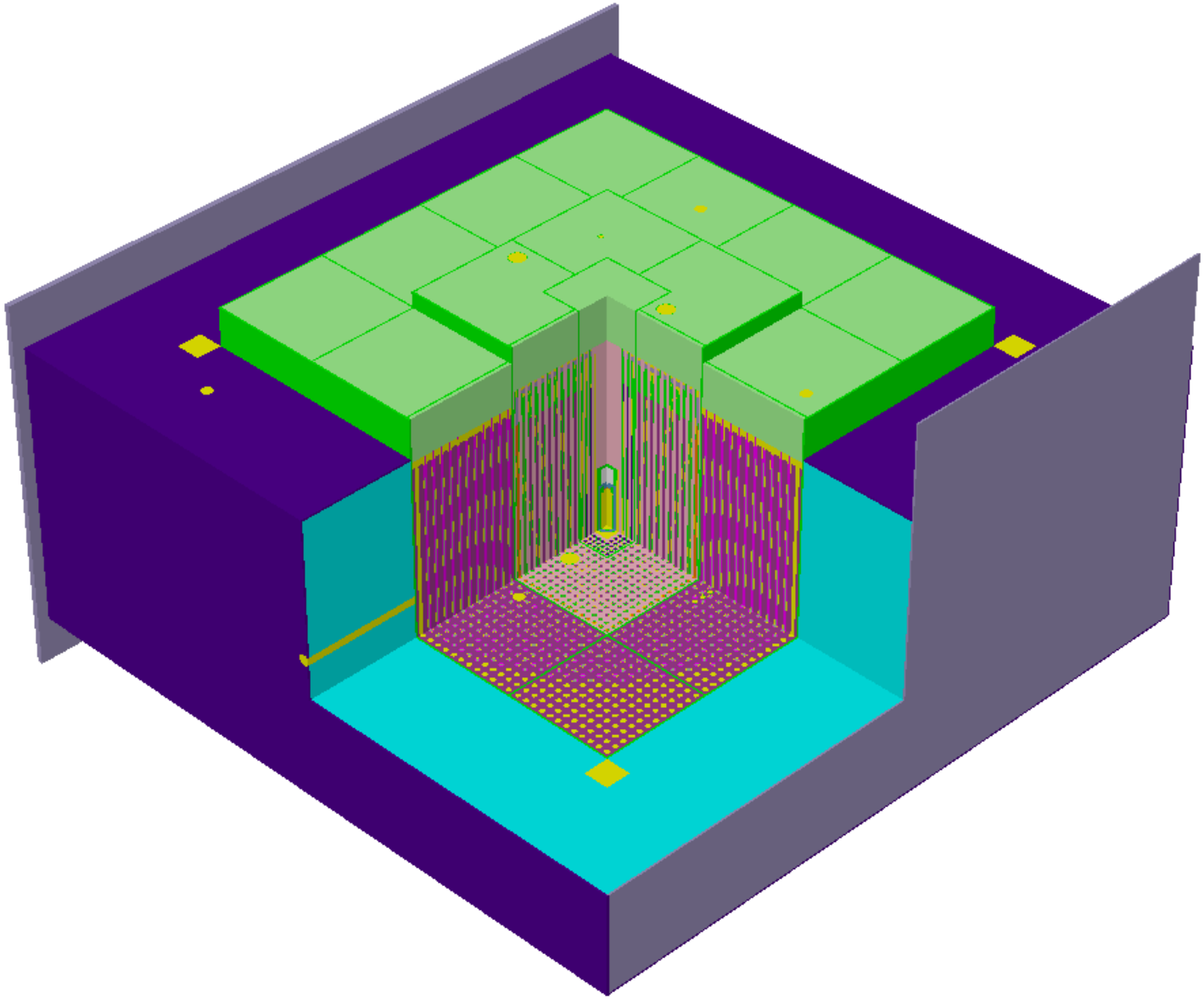
YALINA-Booster Subcritical Assembly



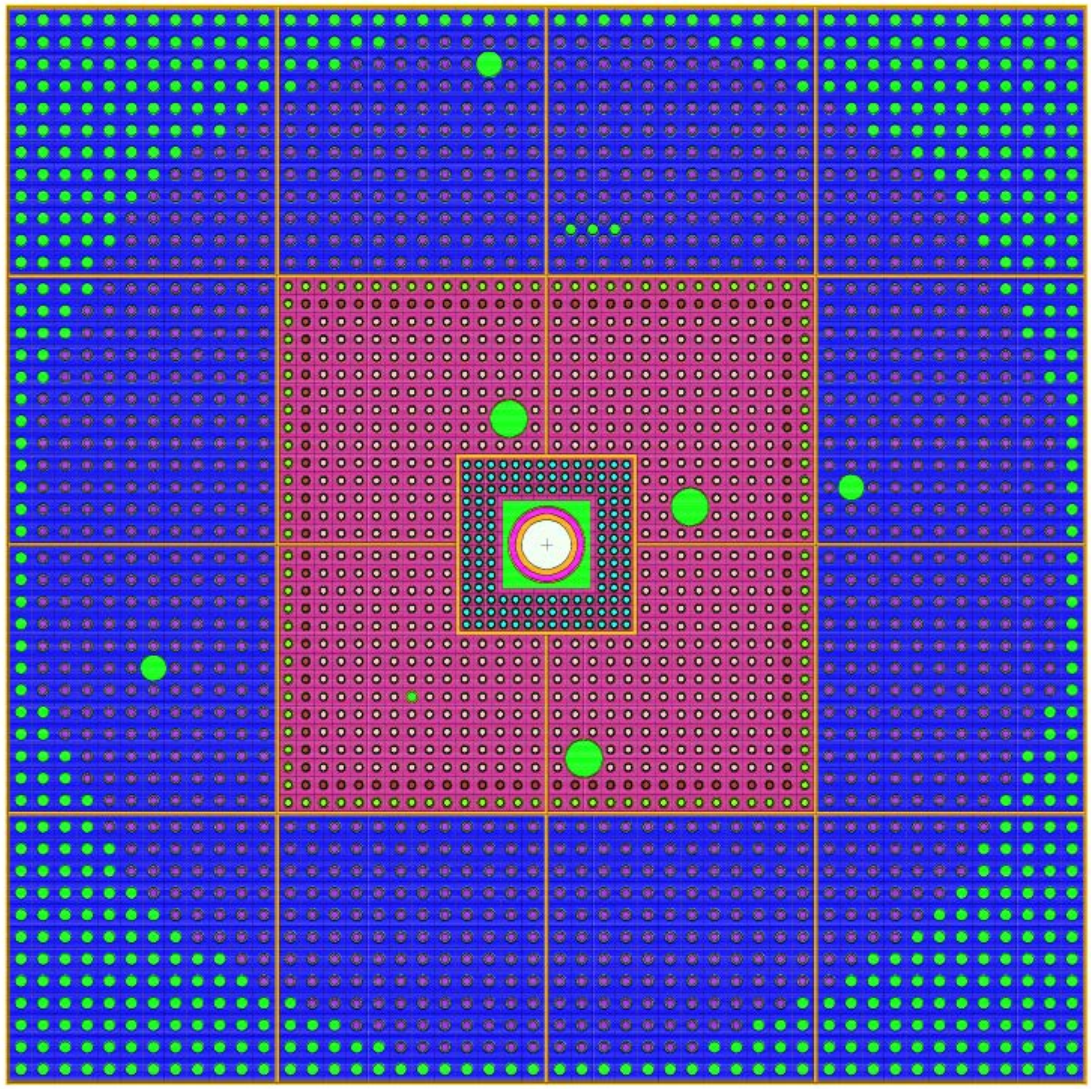


YALINA-Booster assembly front view

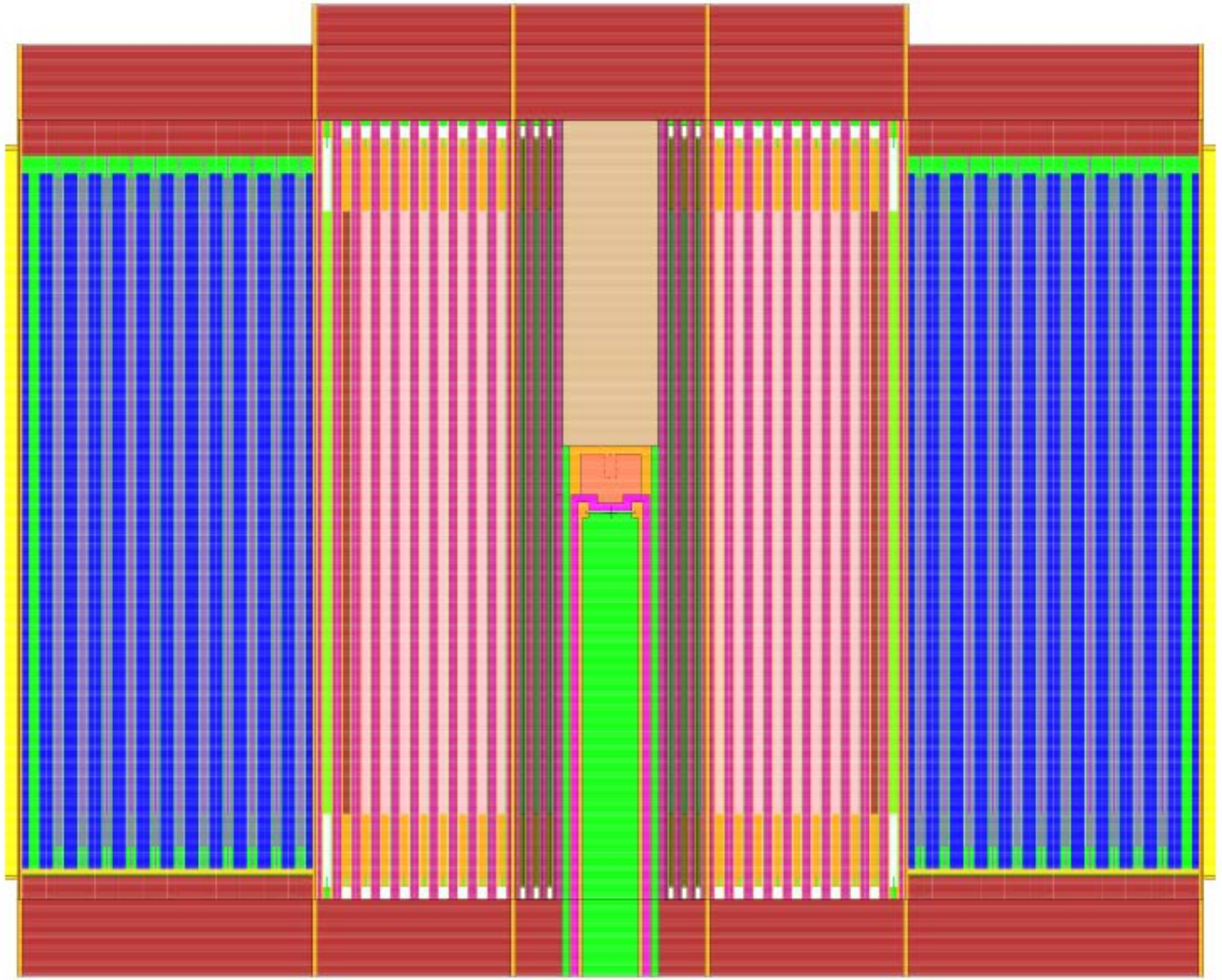
YALINA Booster Isometric View of the Monte Carlo Model



YALINA Booster X-Y Cross Section of the Monte Carlo Model

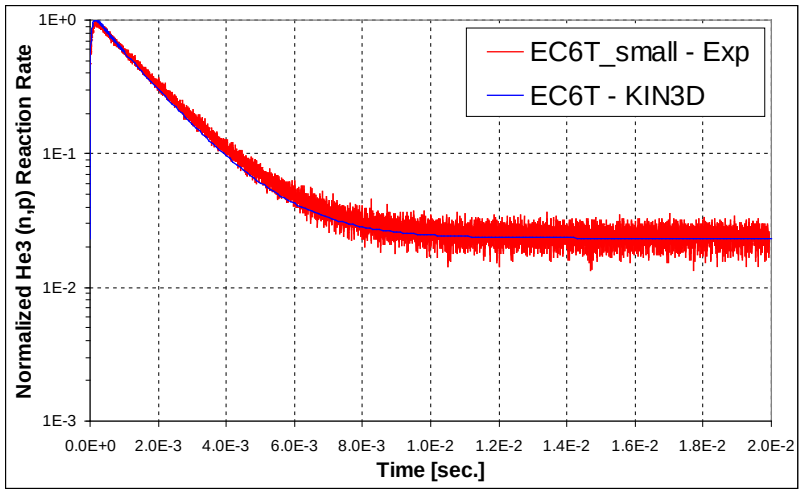


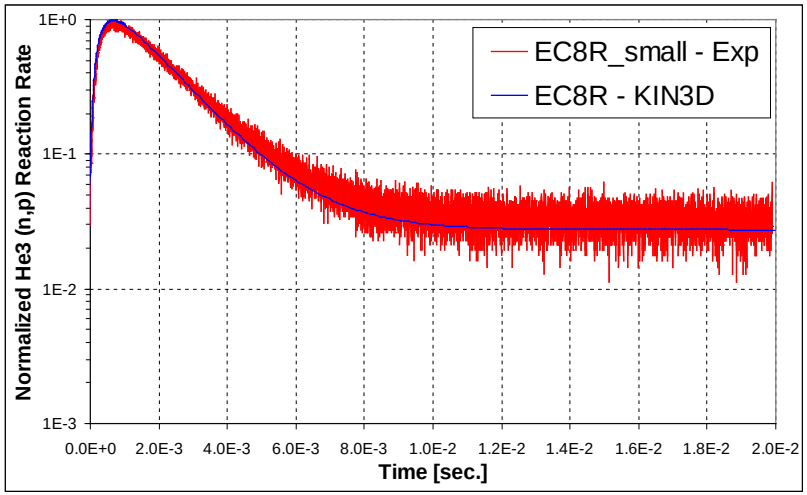
YALINA Booster Y-Z Cross Section of the Monte Carlo Model at X = 0.87



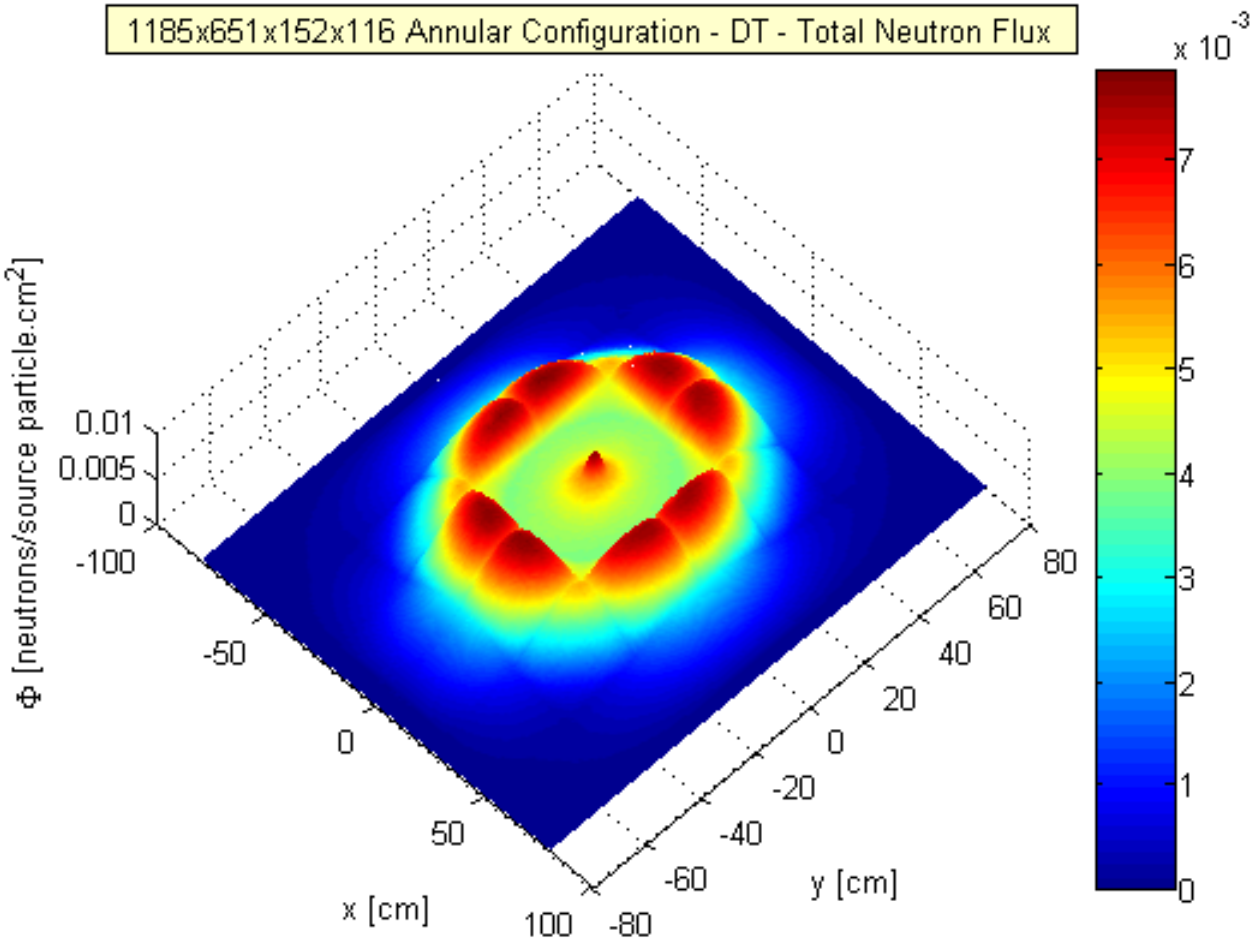
YALINA Booster

Comparison of the analytical and the experimental results of the configuration with the 90% and the 36% enriched uranium fuels in the fast zone and 1141 EK-10 fuel pins in the thermal zone using ERANOS with JEF3.1 nuclear data files simulating a D-D pulsed neutron source measured with He-3 detector





Total Neutron Flux Map of the YALINA-Booster Configuration with 21% Enriched Uranium Oxide Fuel in the Booster Zone and 14.1 MeV External Neutron Source



Acknowledgements

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