UTILIZATION AND OPERATION OF THE DALAT NUCLEAR RESEARCH REACTOR AFTER FULL CORE CONVERSION

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- The Dalat Nuclear Research Reactor (DNRR)
- Enhancement radioisotope production
- Fuel loading patterns for refueling
- Conclusions

THE DALAT NUCLEAR RESEARCH REACTOR (1)

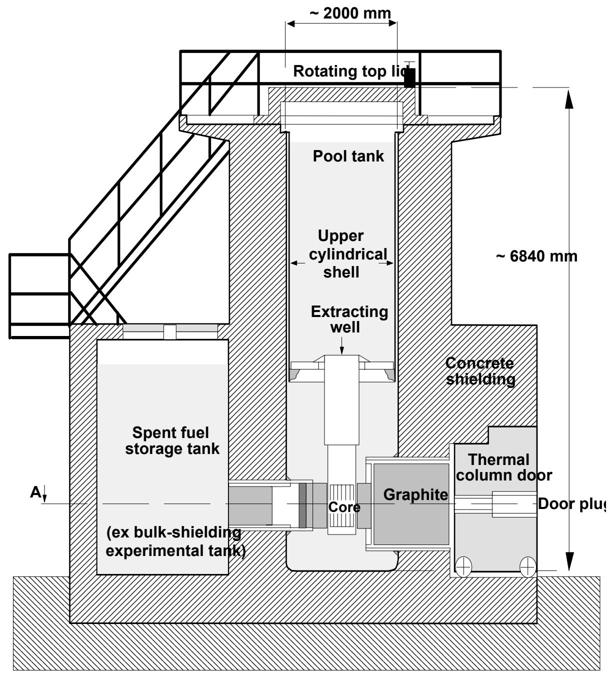
Outside view of the DNRR

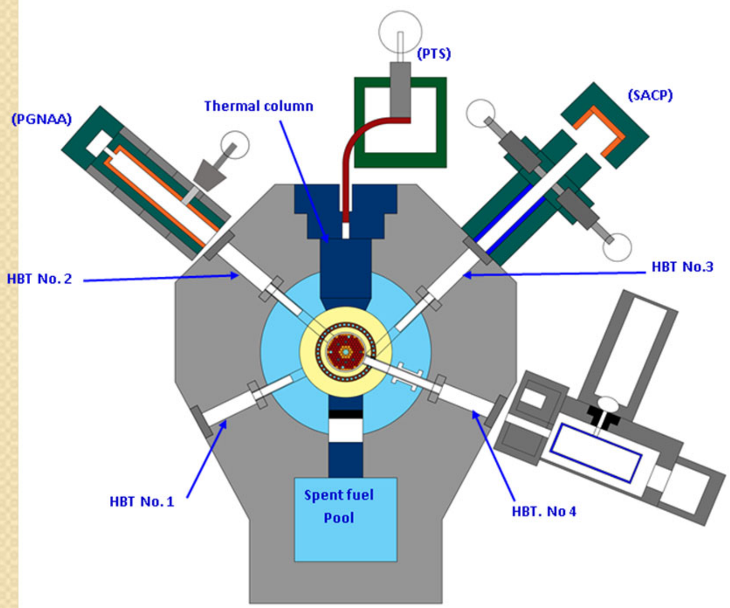
- Early 1960 - Construction of the TRIGA Mark II reactor started
- 26/2/1963 - First criticality of the TRIGA reactor
- 4/3/1963 - Official inauguration of TRIGA reactor with the nominal power of 250 kW
- 1963-1968 - Reactor operated with the 3 main purposes: Training, Research and Isotope Production
- 1968-1975 - Reactor was in extended shutdown
- 1974-1975 - Fuels were unloaded and shipped back to USA

THE DALAT NUCLEAR RESEARCH REACTOR (2)

- **<u>9/10/1979</u>: Contract No. 85/096-54100 for reconstruction and upgrading signed.**
  Reactor name was changed to "IVV-9"
- **<u>15/3/1982</u> - Start-up the reconstruction and upgrading work of the Dalat reactor.**
- **<u>01/11/1983</u> - First criticality of the IVV-9 reactor**
- **<u>20/3/1984</u> - Official inauguration of the IVV-9 reactor with the nominal power of 500 kW.**
- **<u>3/1984 -11/2011</u> - Reactor has operated using HEU fuel**
- **<u>12/2011 – present</u> - Reactor has operated using LEU fuel for**
  - *Radioisotopes production;*
  - *Neutron activation analysis;*
  - *Basic and applied research in nuclear physics;*
  - *Research on reactor physics and thermo-hydraulics;*
  - *Personnel training and education.*

REACTOR DESCRIPTION (1)

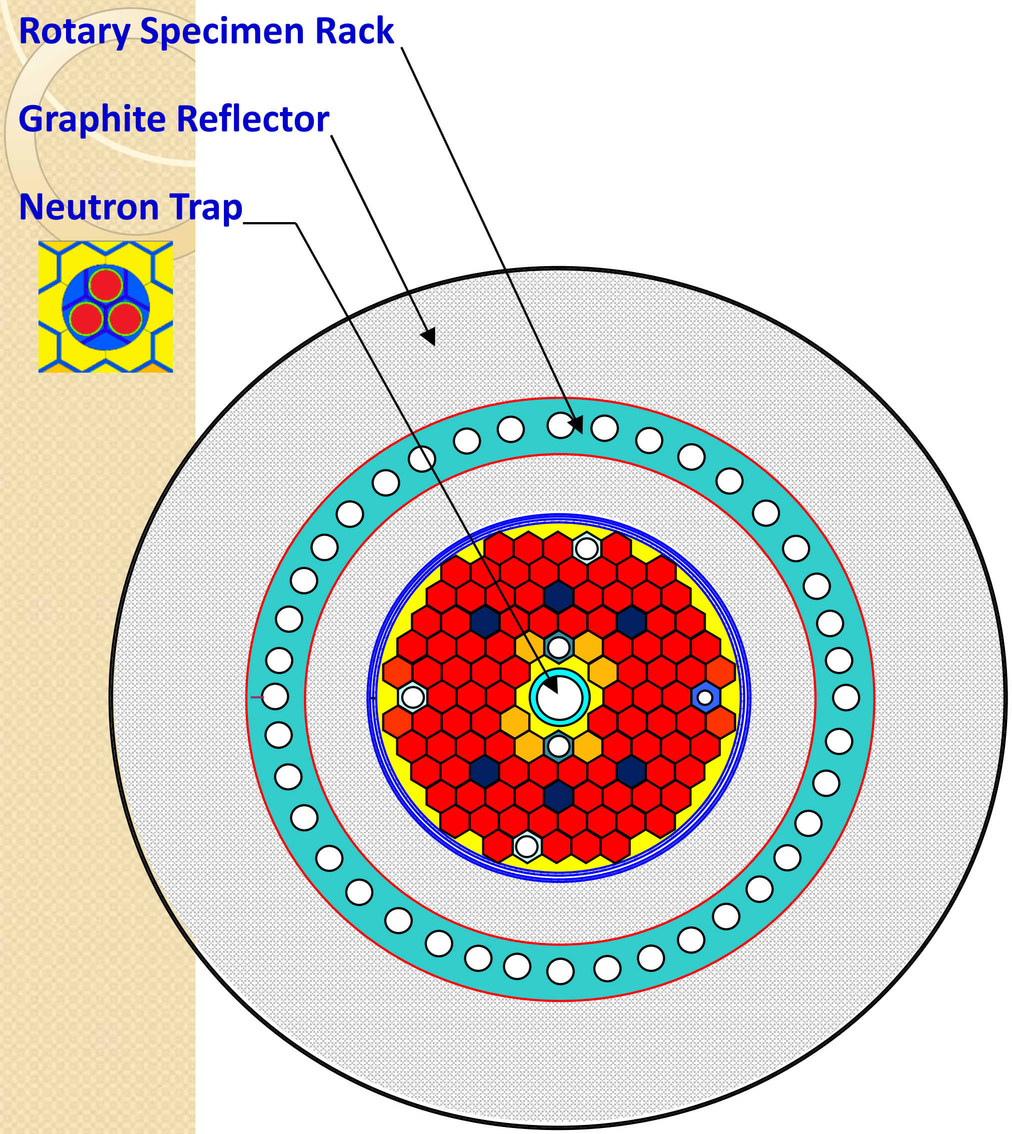




<u>MAIN CHARACTERISTICS</u>

- Thermal power: 500 kWt
- Coolant and moderator: Light water
- Core configuration: Cylindrical core of about 44.2cm diameter and 60cm height.
- Core cooling mechanism:
  Natural convection
- Number of fuel assemblies in the core:
  89 (1984-1994), 100 (1994-2002), 104 (3/2002-6/2004), 104 reshuffled (6/2004), 106 (10/2006), 98 HEU+6 LEU (9/2007), 92 HEU+12 LEU (7/2009-8/2011), **<u>92 LEU (12/2011- 4/2021), 94 LEU (5/2021-5/2022), 96 LEU (6/2022 - up to now)</u>**.
- 7 control rods: 2 safety rods (B_4C), 4 shim rods (B_4C) and one automatic regulating rod (SS)
- 3 nuclear channels: 2 ranges in each channel (Start-up range and working range)
- Neutron reflector: Beryllium and graphite.

REACTOR DESCRIPTION (2)



LEU working core configuration from 6/2022 to present with 96 LEU FAs

MAIN CHARACTERISTICS

- Vertical irradiation channels and thermal neutron flux: $n.cm^{-2}.s^{-1}$

\+ ***Wet channels:***

- Neutron trap at the core center: 2.23×10^{13}
- Irradiation hole at cell 1-4: 1.07×10^{13}
- 40 holes at rotary specimen rack: 3.85×10^{12}

\+ ***Dry channels:***

- Pneumatic transfer tube at cell 7-1: 4.21×10^{12}
- Pneumatic transfer tube at 13-2: 4.15×10^{12}

Fuel assembly

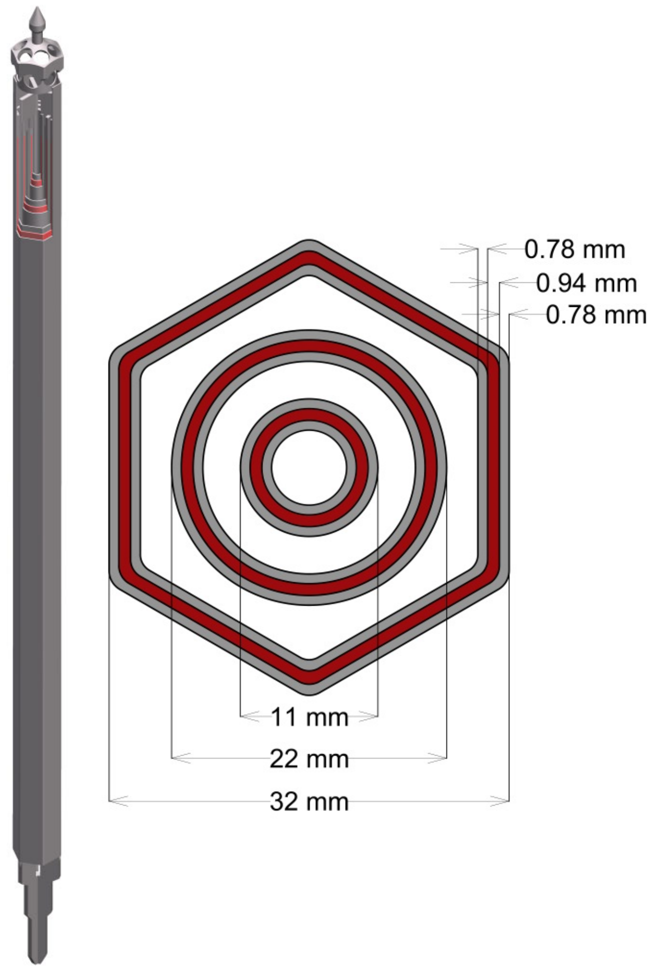
Shim and Safety rods (Boron Carbide)

Automatic regulating rod (Stainless Steel)

Beryllium rod

Sample Irradiation Channels

REACTOR DESCRIPTION (4)



HEU and LEU fuel

 Fuel assembly WWR-M2 type:

+ Total long: 865 mm

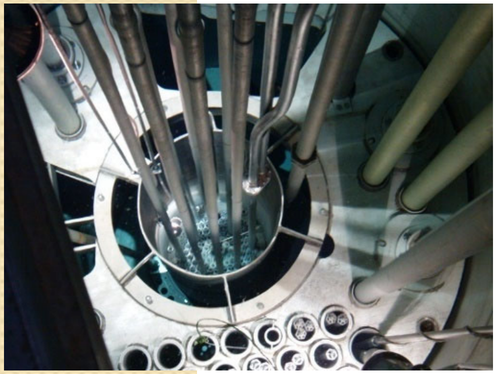
+ Fuel meat part long: 600 mm

+ 3 layers (2 round tubes inside, 1 hexagonal outside)

Parameter	HEU	LEU
Enrichment, %	**36**	**19.75**
Average mass of ^{235}U in FA, g	**40.20**	**49.70**
Fuel meat composition	**U-Al Alloy**	**UO_2+Al**
Uranium density of fuel meat, g/cm^3	**1.40**	**2.50**
Cladding material	**Al alloy (SAV-1)**	**Al alloy (SAV-1)**
Fuel element thickness (fuel meat and 2 cladding), mm	**2.50**	**2.50**
Fuel meat thickness, mm	**0.70**	**0.94**
Each cladding thickness, mm	**0.90**	**0.78**

REACTOR OPERATION

Control Room

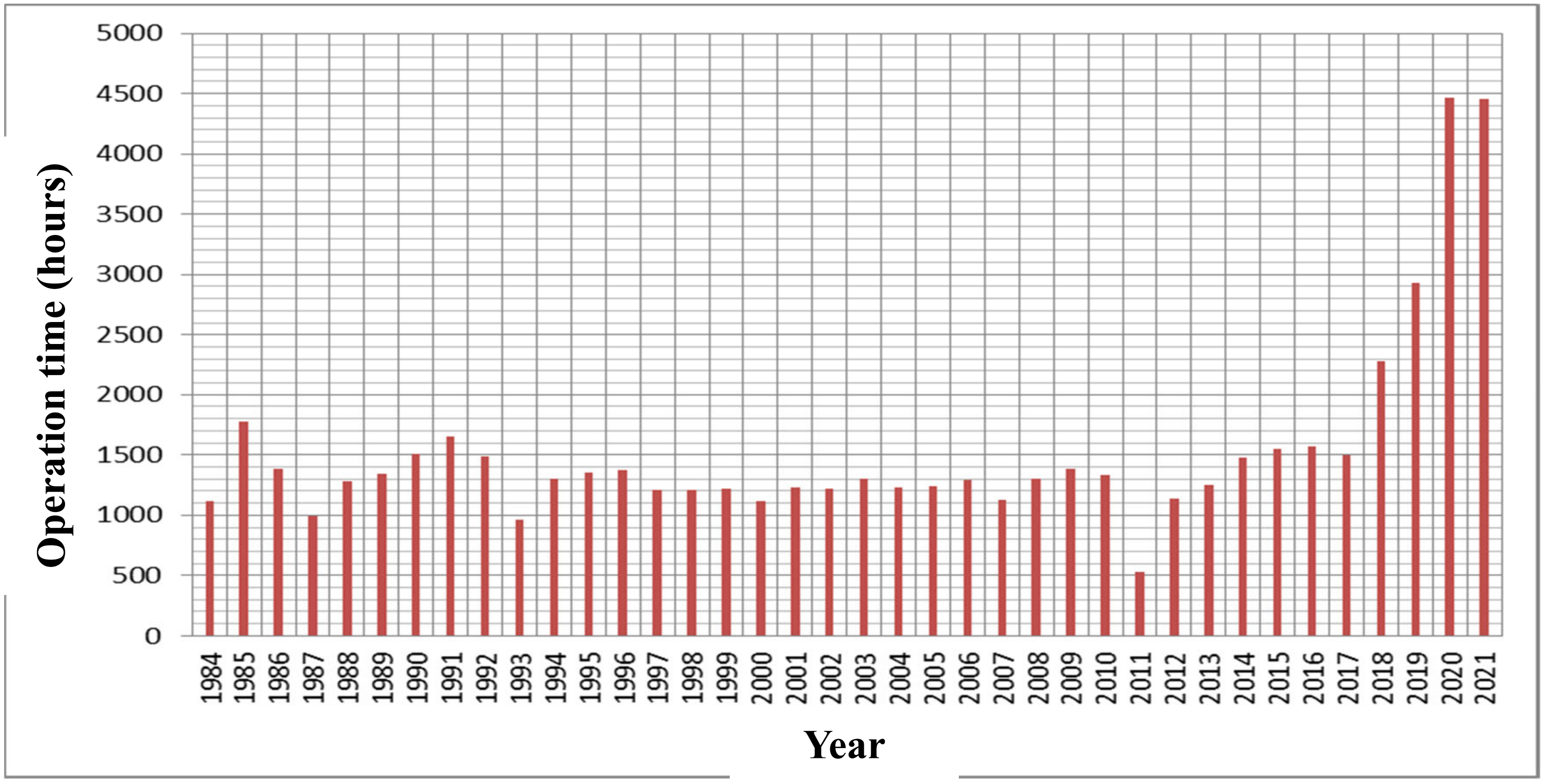


Reactor core

- **Operation regimes**:
  + Continuously at 500 kW (from 2012):

  130 – 160 hrs /cycle, 1 or 2 cycles/month,
  ➔ 1300 – 3000 hrs/year

  + 2019 to now: operation each week 85 to 100 hours



During COVID pandemic 2019, 2020 and 2022 average I-131 activity produced on the DNRR about 800 to 1000 Ci/year.

REACTOR UTILIZATION

- Production of radioisotopes and radio-pharmaceuticals for medical use, for agriculture and industry application, as well as for research and education.
- Irradiation of samples for neutron activation analysis (service for geology, oil field study, environmental research, archaeology, etc., about 2,000 samples/year).
- Neutron beam researches (PGNAA, NR, nuclear data measurement, etc.)
- Training of reactor operators and staffs.
- Practical works for students and teachers (from Universities).
- Public information for nuclear power programme.

REACTOR PHYSICS AND REACTOR TECHNOLOGIES

Study on physics characteristics and parameters of the reactor to improve technical management, operation and utilization of the Dalat Nuclear Research Reactor:

Experiments on the DNRR:

- Neutron spectra and neutron flux distribution at irradiation positions and FAs;
- Differential and integral worth of control rods;
-Temperature and power coefficients of reactivity and Xenon poisoning;
- Fuel surface temperatures at hottest FA in the core;
- Distribution of fuel burn-up;
- Behavior of fuel temperature during a reactor transient due to insertion of allowable reactivity; etc.

Calculations related to Reactor Physics and Thermal Hydraulics:

- Neutronics, Thermal hydraulics and safety analysis for reactors;

- Fuel burn-up, core and fuel management strategy;

- Reactor calculation computer codes development.

Other research topics

- Full core conversion;

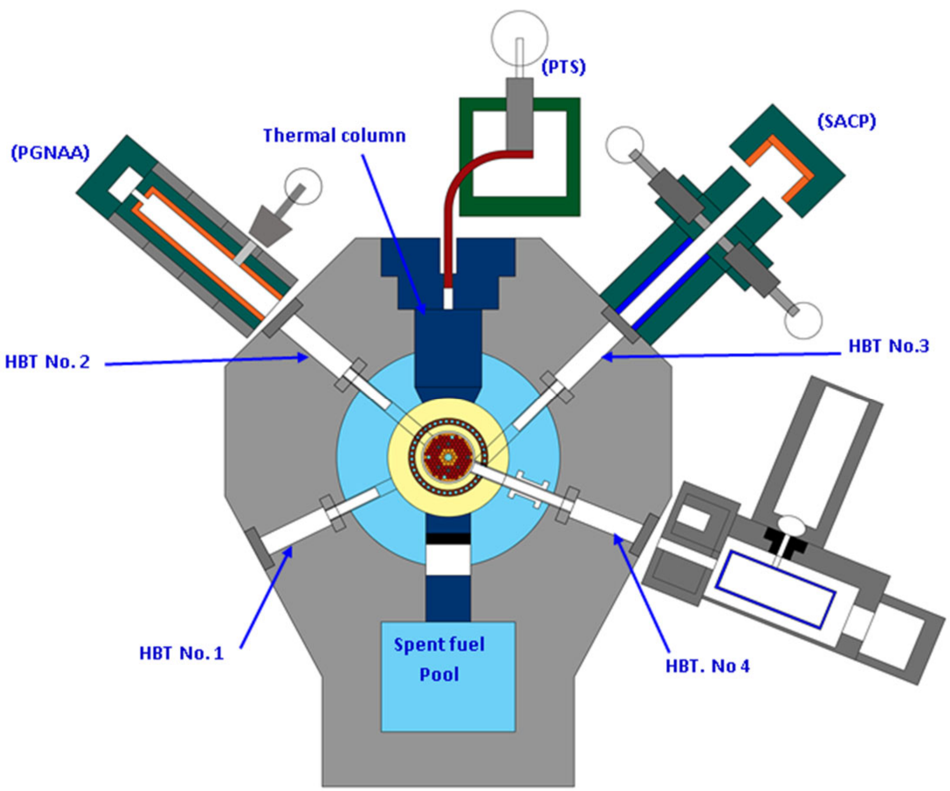
- Silicon doping testing on the DNRR;

- Enhancement radio-isotope production on the DNRR.

- Decommissioning study: plant, technique, etc…;

NEUTRON BEAMS RESEARCHES AND APPLICATIONS

- **Set-up the neutron filters at horizontal channels to extract neutron beams from the reactor**
- **Based on these filters, thermal and quasi-monoenergetic neutrons (25keV, 55 keV, 144 keV, >1.2 MeV, etc.) can be used for nuclear data measurements, irradiation of electronic components and other purposes (n,γ; n,2γ; n,n' reactions)**



- PGNAA facility at channel No. 4
- Measurement of K_o- factors to use in PGNAA technique: Ko-factor of V, Sc, Mn, Fe, Cd, Sm, Ni, Ga were determined and used in PGNAA
- Measurement system for studying (n,2γ) reactions was installed at channel No.3
- PGNAA in BT.No. 2
- BT. No.1 wil be used for neutron radiography

RADIOISOTOPE AND RADIOPHARMACEUTICAL PRODUCTION

Hot cell and I-131 production line

RI products of DNRI

- **Main radioisotopes & radiopharmaceuticals produced for medical purposes are:**
  - **^{131}I** in **Na^{131}I** solution and capsules
  - **Tc^{99m}** generators in Sodium-(^{99m}Tc) pertechnetate
  - **^{32}P** applicator for skin disease therapeutics and **^{32}P** in injectable in orthophosphate solution
  - **^{51}Cr, ^{153}Sm,** etc. solution
  - In-vivo labeled kits for **Tc^{99m}**
  - In-vitro **T_3, T_4** kits
- **Other radioactive tracers for sedimentology study, oil field study, and industry application can also be produced:**

  ^{46}Sc, ^{192}Ir, ^{198}Au, etc.
- **Small sources:**

  ^{60}Co, ^{192}Ir, etc.

- Radiopharmaceuticals produced and supplied: $Na^{131}I$ solution, Sodium-(^{99m}Tc) pertechnetate, Sodium-(^{32}P) orthophosphate, ^{131}I-Hippuran, ^{131}I-MIBG, ^{153}Sm-EDTMP, ^{99m}Tc-MDP…

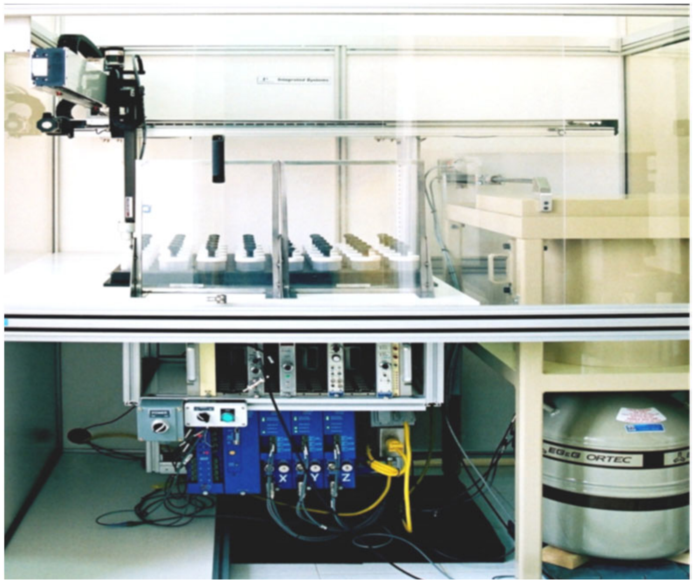
Before treatment After treatment

- ^{32}P isotope applicators produced by nuclear reactions
$^{31}P(n, \gamma)^{32}P$
- ^{32}P solution produced by nuclear reactions $^{31}P(n, p)^{32}P$

Whole Body Bone Imaging

DEVELOPMENT OF ANALYTICAL TECHNIQUES

Pneumatic transfer system



Automatic sample changer system

- **Different methods are used for element analysis:**

  . Instrumental NAA, including Ko-method

  . Radiochemical NAA

  . Prompt gamma NAA

  . Delayed NAA

  . X-Ray Fluorenscene Analyze (XFA)

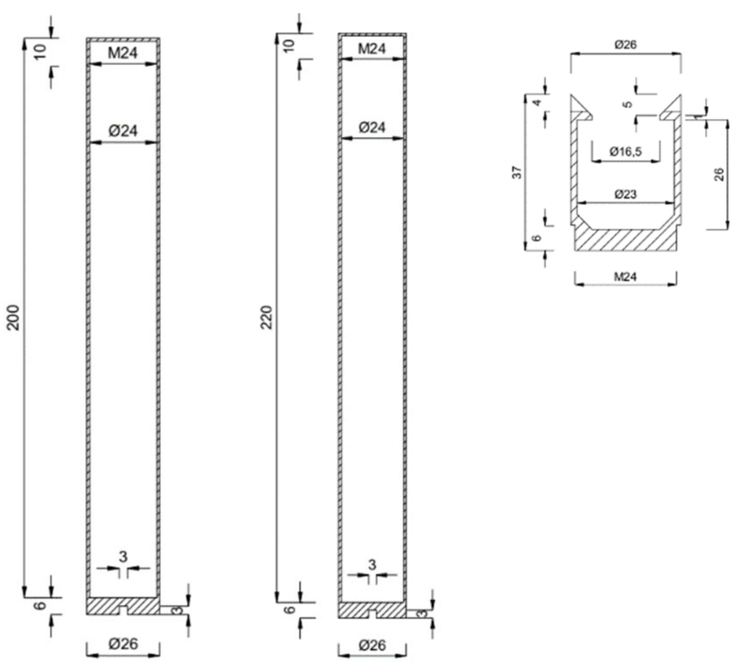
  . HPLC, LSC

  . AAS, GC, IC, UV-vis, etc.

- **K-zero method for INAA has been developed to analyse airborne particulate samples for investigation of air pollution; crude oil samples and base rock samples for oil field study.**

ENHANCEMENT RADIOISOTOPE PRODUCTION I-131

- Increasing demand of I-131 for hospitals in the country.
- Increasing activity of I-131 isotope and decreasing operation time.
- Do not make the changing of neutron field inside the reactor core and confirm the established operation conditions.

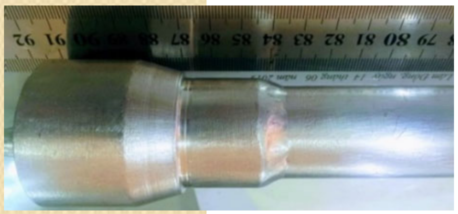


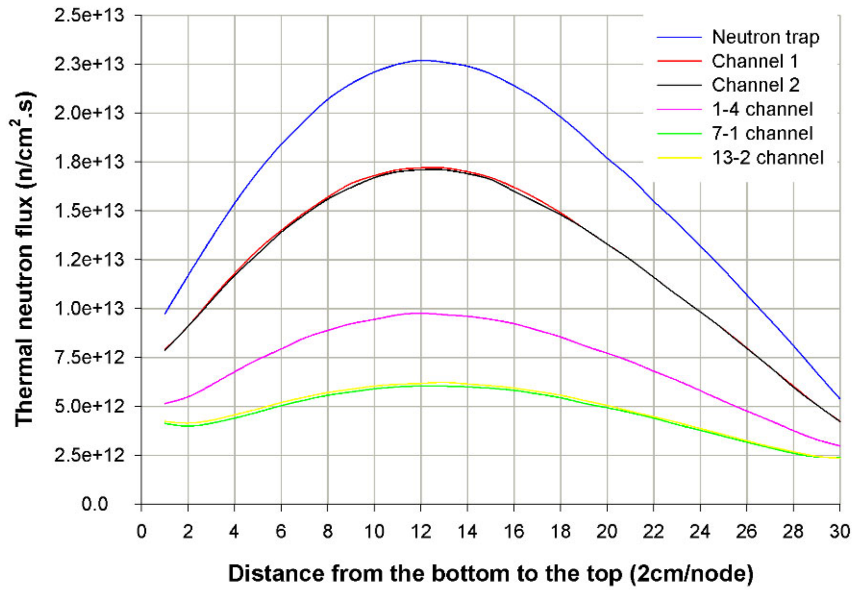
Aluminum container used for I-131 isotope production

ENHANCEMENT RADIOISOTOPE PRODUCTION I-131

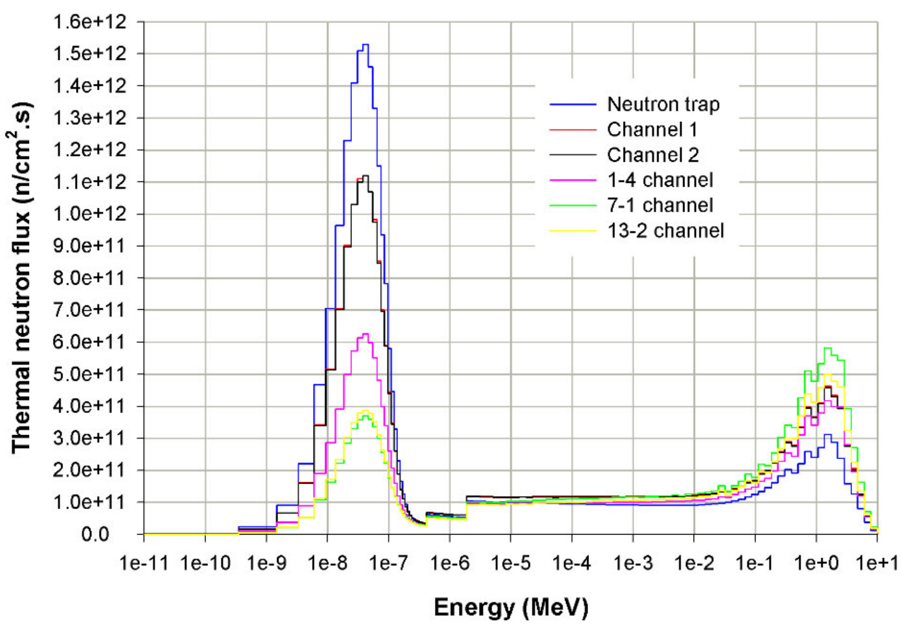
- Adding irradiation channels at cells 5-6 and 9-6: high thermal neutron flux, symmetry, having beryllium for moderation neutron, positions far from Shim rods, safety rods hang on during reactor operation (*September 2019*).
- Loading additional irradiation target TeO_2 containers: from 9 (only at neutron trap) to 15 (neutron trap + 02 new channels)
- Accumulation neutron irradiation for containers: from rotary specimen (1 or 2 weeks) to new irradiation channels (1 week) and neutron trap (1 week) then take out.
- The average activity of each container is about 4.5 to 5 Ci. Each month total I-131 activity is more than 100 Ci.

ENHANCEMENT RADIOISOTOPE PRODUCTION I-131

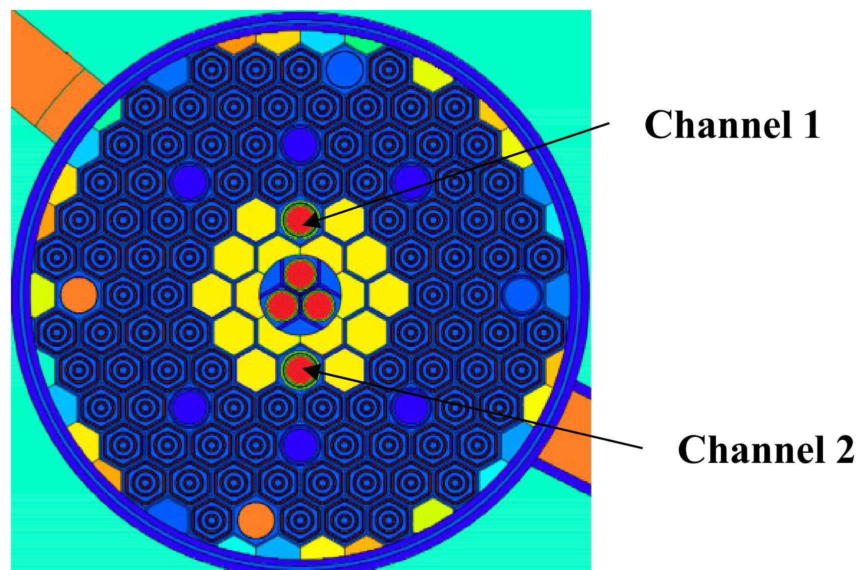




Thermal neutron flux distribution of irradiation channels in axial



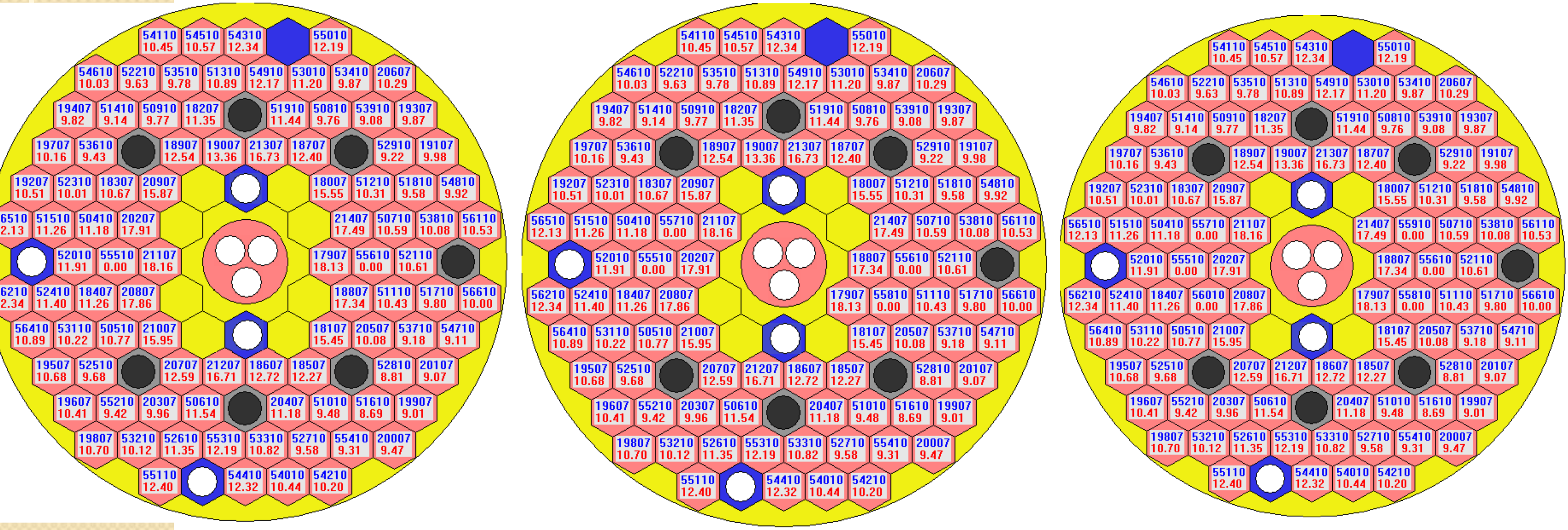
Neutron spectra of irradiation channels



FUEL LOADING PATTERNS FOR REFUELING

- Assuring safety: shutdown margin ($<-1\%\Delta k/k$), enough excess reactivity for operation 1 to 3 years, assure of safe operation as well as operation conditions.
- Using fuel as high as burn-up possible, extending operation time while keeping all irradiation positions in the reactor core (neutron trap, wet channels: 1-4, 5-6 and 9-6, dry channels: 7-1 and 13-2).
- Forward 98 FAs core configurations for using effective two new irradiation channels by keeping beryllium rods around.
- Establishing 3 steps for refueling: each step will be loaded 2 FAs.

FUEL LOADING PATTERNS FOR REFUELING



Adding reactivity ~ operation hours

Step 1: 1.25 $ ~ 5000 hs.

Step 2: 1.275 $ ~ 5100 hs.

Step 3: 1.125 $ ~ 4500 hs.

Shutdown margin reactivity

Step 1: -5.4 %Δk/k

Step 2: -5.0 %Δk/k

Step 3: -4.4 % Δk/k

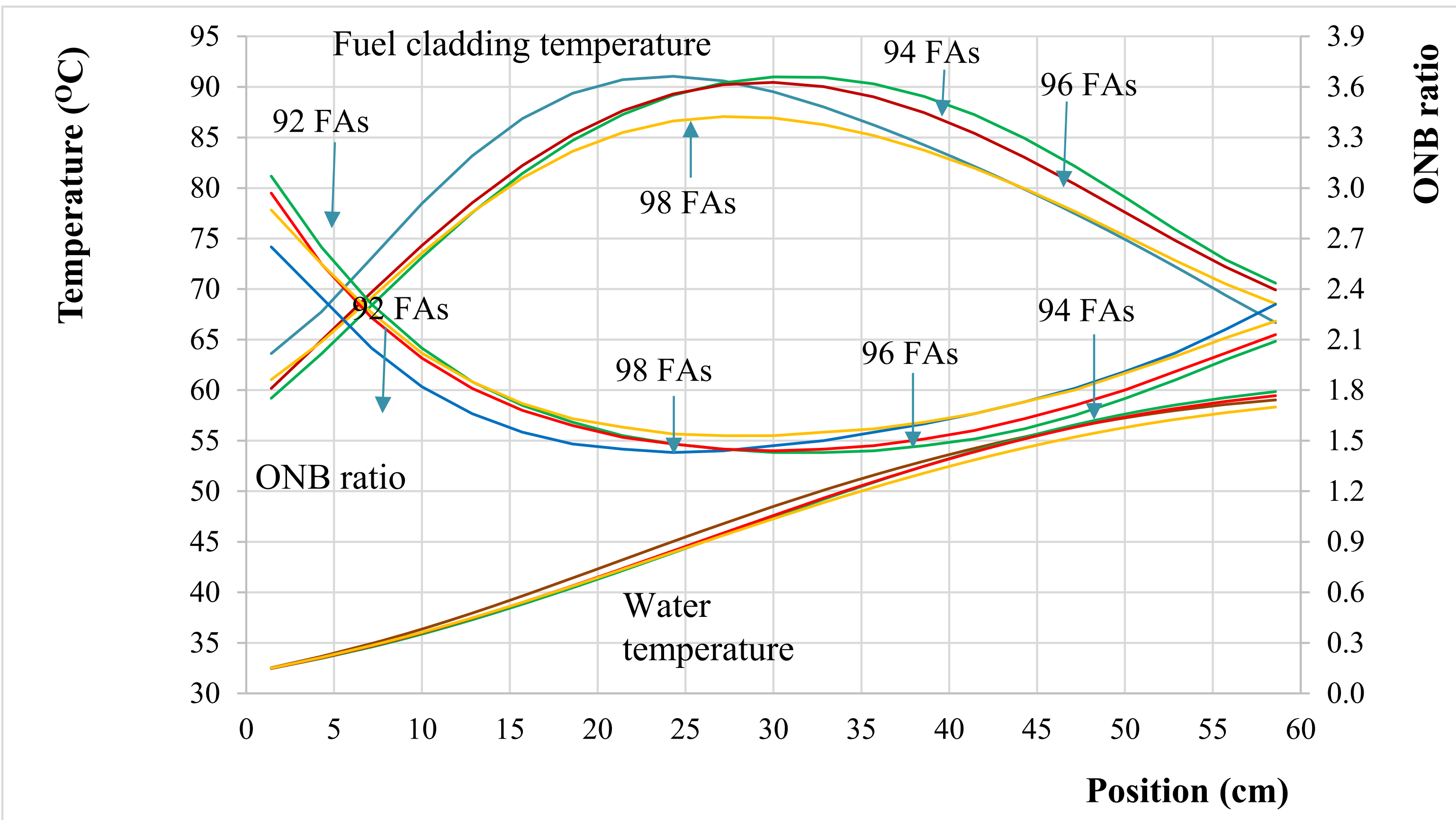
FUEL LOADING PATTERNS FOR REFUELING

- Reducing the thermal neutron flux by 4.7%, 11.7%, and 18.2% at the neutron trap for core configurations of 94, 96, and 98 FAs, respectively.
- Reducing by 1.4%, 5.7%, and 9.9% at two new irradiation channels with core configurations of 94, 96, and 98 FAs, respectively.

Position	Thermal neutron flux n/cm^2.s			
	92 Fas	94 FAs	96 FAs	98 FAs
Neutron trap	8.26×10^{12}	7.87×10^{12}	7.29×10^{12}	6.76×10^{12}
2 new channels	7.28×10^{12}	7.17×10^{12}	6.86×10^{12}	6.56×10^{12}
1-4 channel	4.17×10^{12}	4.16×10^{12}	4.10×10^{12}	4.03×10^{12}

FUEL LOADING PATTERNS FOR REFUELING

- Maximum fuel cladding: 91.1^{o}C, 91.0^{o}C, 90.4^{o}C and 87.1^{o}C and ONB ratio: 1.43, 1.43, 1.44 and 1.53 for core configurations of 92, 94, 96, and 98 FAs, respectively (inlet temperature ~ 32^{0}C).



CONCLUSIONS

- The Dalat NRR has been safely operated and effectively utilized for 38 years;

- The main utilization of the Dalat NRR is for radioisotope production, neutron activation analysis, basic and applied research, nuclear education and training;

- Adding two new irradiation channels combination with accumulation neutron irradiation of containers, the activity of I-131 can reach more than 100 Ci per month;

- Establishing fuel loading patterns for refueling in order to get the core configuration with 98 FAs to sastisfy for safe operation and effectibe utilization.

Thank You for Your Kind Attention!