Department of Nuclear Reactors: Competence for Space Power Sources

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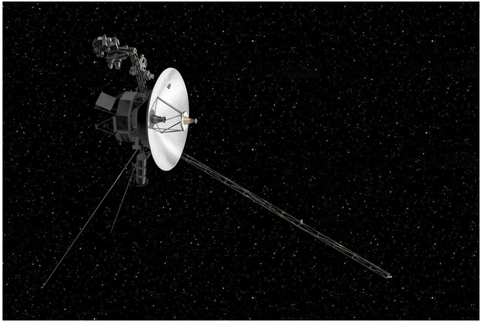
Contents

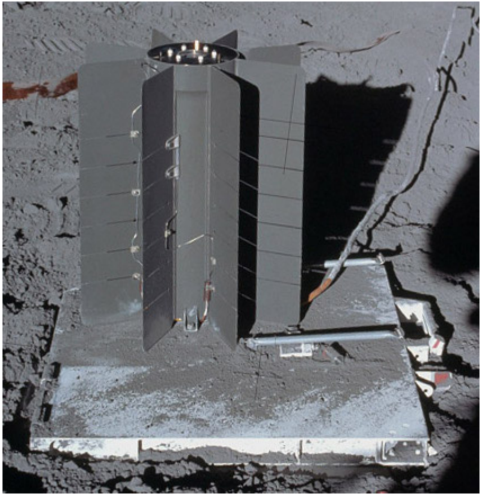
Reliable Power Sources for Space Exploration

- Many space missions, including ISS, can rely on solar power
- This option is not available for applications in deep space



- Nuclear power sources in form of radioisotopic and fission sources provide much needed versatility and reliability for current and future space applications

Radioisotope Power Sources for Space Applications



- Radioisotope source SNAP-27
- One of many radioisotope sources produced in the USA
- It was left on the Moon surface
- It contains 3.8 kg of ^{238}Pu and produces thermal power 1250 W and 75 W of electricity
- Radioisotope sources are great for less power demanding applications
- They are generating electricity via thermocouples: Radioisotope Thermoelectric Generator (RTG)

Modern MMRTG in NASA's Mars Rover Perseverance

- It is using Multi-Mission RTG to produce thermal power and electricity
- The power source still utilizes reliable system based on ^{238}Pu
- The power source charges two batteries for operations that exceed the peak power output of the RTG
- Generated heat is also used to keep the rover's tools and instruments at operational temperatures

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Production of ^{238}U for RTG

- ^{238}Pu is produced by a radiative absorption reaction at ^{237}Np target following this reaction:

$$^{237}\text{Np} + {}^{1}_{0}\text{n} \rightarrow {}^{238}\text{Np} \xrightarrow[\text{2.1 day}]{\beta^-} {}^{238}\text{Pu}$$

- Efficiency of the conversion is reduced by several losses:
  - potential fission reactions of ^{237}Np and ^{238}Np
  - contamination of ^{237}Np via (n,2n) reaction producing ^{236}Np
  - fission of produced ^{238}Pu
- Effective production schematic should consist of short high-flux irradiation periods followed by removal of plutonium
- Conversion efficiency can be optimized by a neutronic analysis
- Optimization should focus on the neptunium target and the spectrum of neutrons irradiating the target

Potential Research in the Field of Radioisotopic Sources

- There is a general shortage of radioisotopes suitable for RTGs, so optimization of their production in nuclear reactors is vital
- Options for continuous removal of the irradiated neptunium samples and shaping of the neutron spectrum to limit the probability of parasitic reactions are actively investigated
- There are alternative radioisotopes to ^{238}Pu: ^{241}Am, ^{210}Po, ^{244}Cm, ^{90}Sr etc.
- Research can be focused on elimination of complications with unfavorable characteristics of the alternatives such as high gamma or neutron emission rates
- Combination of multiple radioisotopes can be the key to longer operation of the RTGs
- It is always important to work on the overall RTG design optimization to reduce the weight and increased thermal and electrical output

Fission Reactors for Space Applications

- There were more than 30 fission reactors in space sent by Russia and only one flown by the USA – SNAP-10
- Fission reactor allows much higher thermal and electric power output compared to RTG
- Existing systems were designed with high-enriched uranium (93% enrichment)
- From the perspective of neutron energies the systems can be fast or thermal and ii is important to design an effective way to adjust the neutron reflection and absorption to control the system reactivity

Potential Research in the Field of Space Micro-Reactors

- Reactors for space applications were mostly designed with HEU fuel, so it is important to focus on the potential use of the technology and experience with commercial LEU fuels also in space
- Important feature of micro-reactors for space applications are neutron reflectors, they not only improve neutron economy, but they are also actively controling the system reactivity
- Design of reflector and control drums can be optimized to maintain their primary objectives with minimal weight
- Safety research requires development of detailed coupling of neutronics with thermal hydraulics

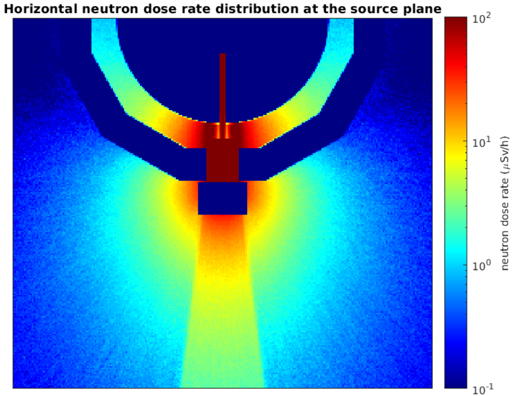
Experience of Department of Nuclear Reactors

- Department of Nuclear Reactors is focused on the reactor core neutronics, thermal hydraulics, and thermal mechanics
- We are using the current versions of stochastic codes MCNP 6.2 and Serpent 2.2 with the latest nuclear data
- Fuel depletion, activation, and shielding can be analysed with advanced methods available in SCALE 6.2.4 package
- Core thermal hydraulics can be studied by subchannel and CFD codes
- We are also equipped with fuel performance codes FRAPCON/FRAPTRAN and TRANSURANUS
- All these calculation tools can be combined for sensitivity and uncertainty analyses

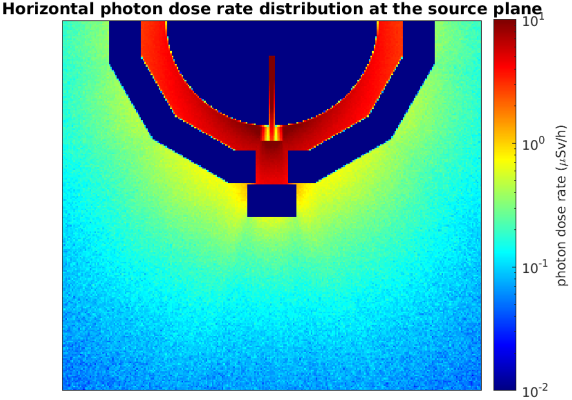
Experience of Department of Nuclear Reactors (2)

- Department of Nuclear Reactors operates Training reactor VR-1, which serves as a neutron source for experiments
- There are also other neutron sources including DD and DT generators, ^{252}Cf and AmBe neutron sources
- We are building a new subcritical reactor with the flexibility to assembly various fuel combinations (natural and 10% enrichment)
- We have a traditional collaboration with UJP developing fuel mixtures and fuel claddings tolerant to accident conditions
- There is experience with testing of electronics in the radiation field

Shielding Design for VR-2 Subcritical Reactor

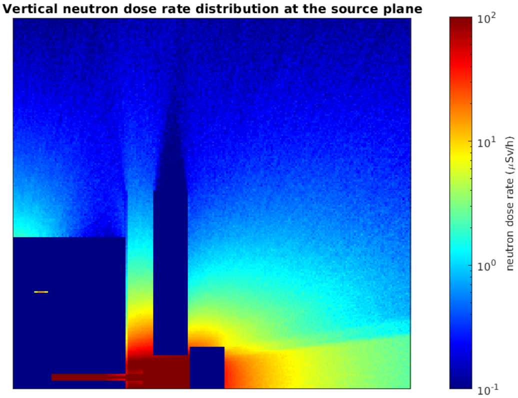


neutron dose rate in horizontal direction

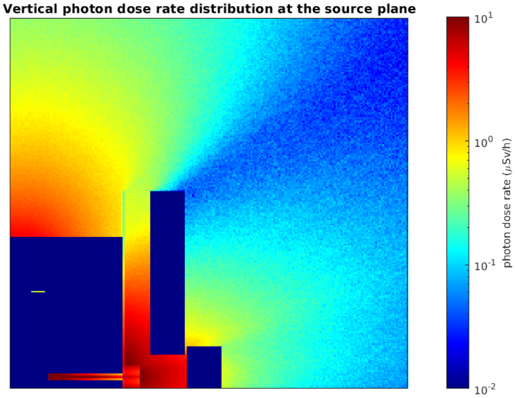


photon dose rate in horizontal direction

Shielding Design for VR-2 Subcritical Reactor (2)

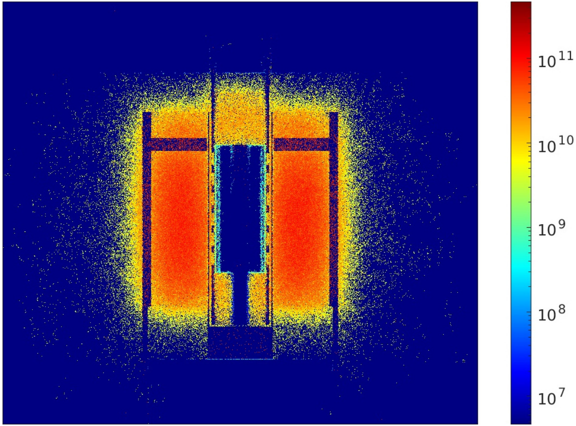


neutron dose rate in vertical direction

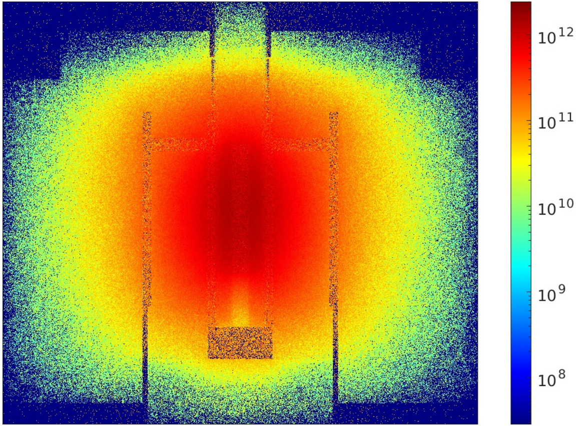


photon dose rate in vertical direction

Neutron Flux in Serpent 2 Model of KRUSTY Reactor



thermal neutron flux



fast neutron flux

Thank you for your attention