Version 19/10/2009

Fixed Bed Nuclear Reactor

FBNR

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International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century

27-30 October 2009, Vienna, Austria

Water Cooled FBNR Nuclear Reactor

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FBNR Nuclear Reactor

An innovative nuclear reactor for the

new era of nuclear energy and

INPRO

International Project on Innovative Nuclear Reactors and Fuel Cycles

INPRO

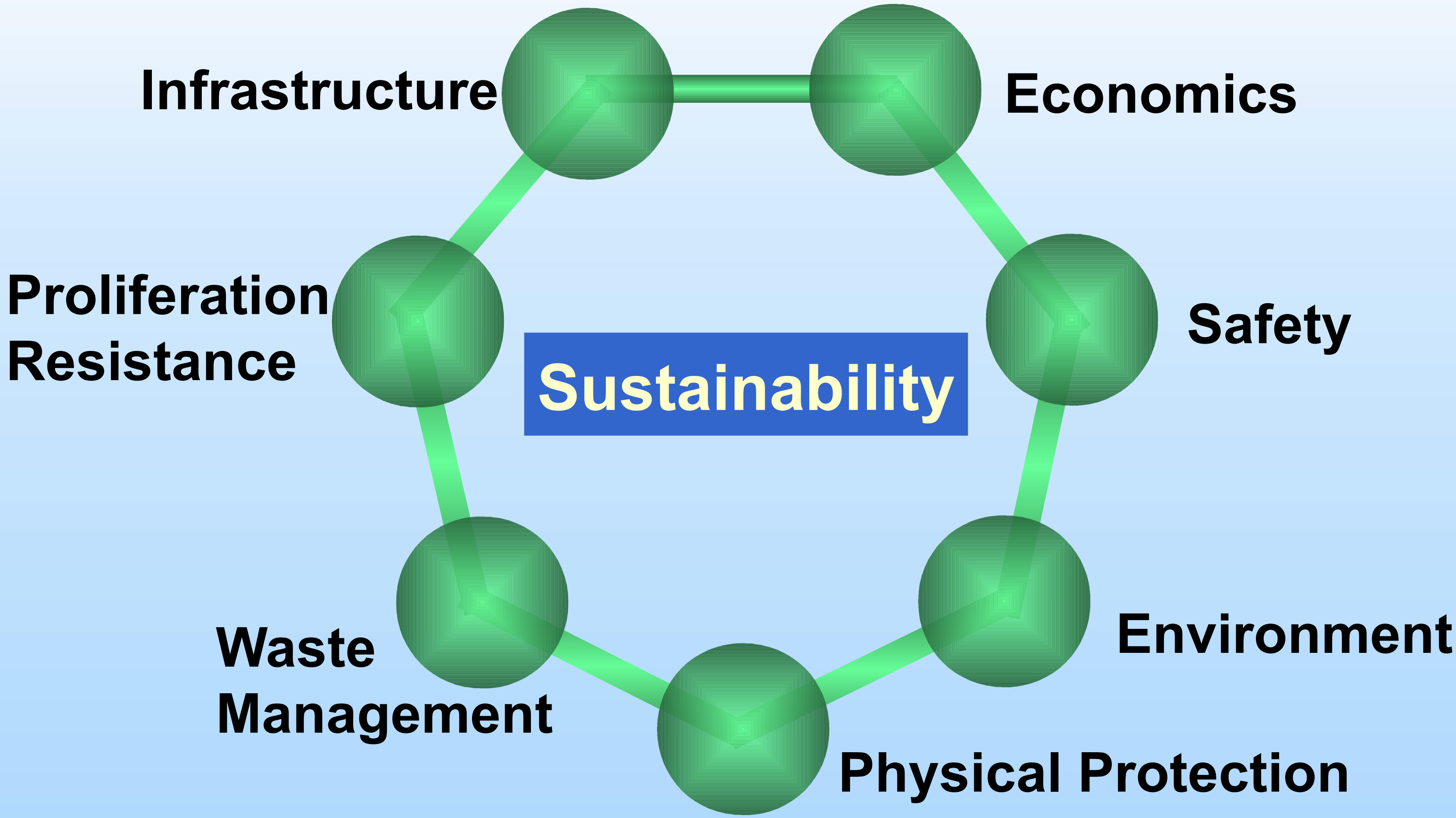
OBJECTIVES

- To help to ensure that nuclear energy is available to contribute in fulfilling energy needs in the 21st century in a sustainable manner; and
- To bring together both technology holders and technology users to consider jointly the international and national actions required to achieve desired innovations in nuclear reactors and fuel cycles.
- To create a forum of all relevant stakeholders that have an impact on, draw from and complement ongoing activities of existing institutions and ongoing initiatives.

- MISSIONS
- To provide a forum for discussion of experts and policy makers on energy planning and INS development and deployment,
- To develop a methodology to analyze INS to judge its sustainability potential ,
- To facilitate coordination and collaboration among MS to develop INS,
- To pay particular attention to the needs of developing countries.

Structure of INPRO Methodology

Holistic approach to assess INS in seven areas to assure its stainability



Here we describe the basis of a new nuclear reactor concept

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Fixed Bed Nuclear Reactor

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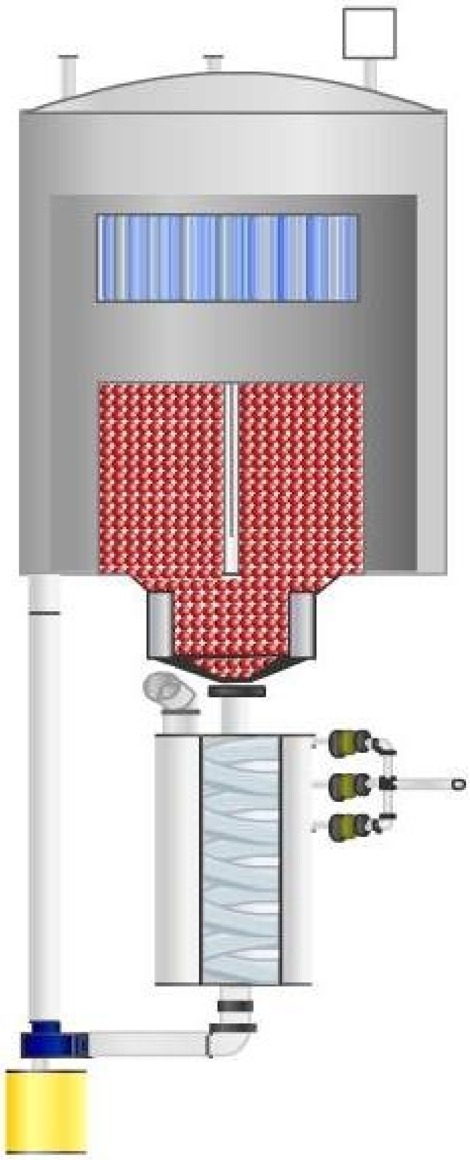
This is the

FBNR



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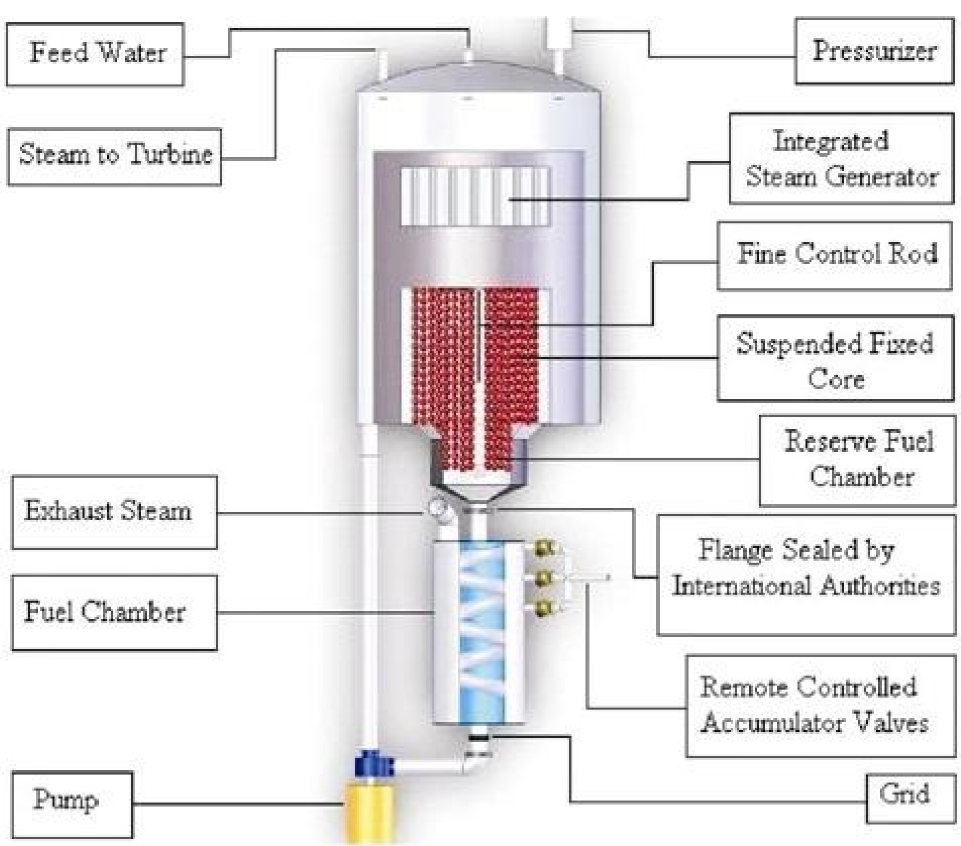
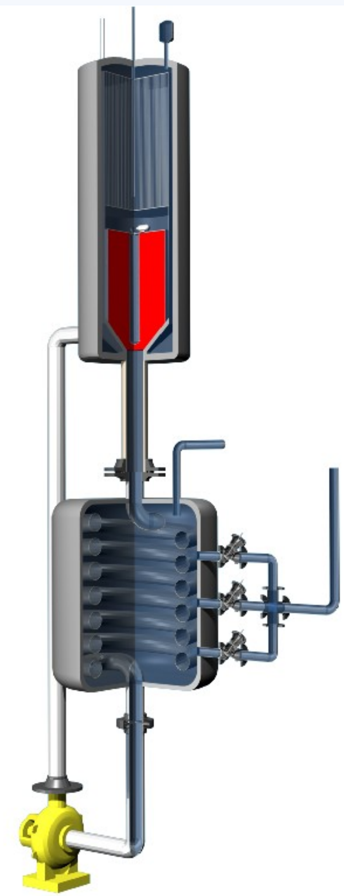
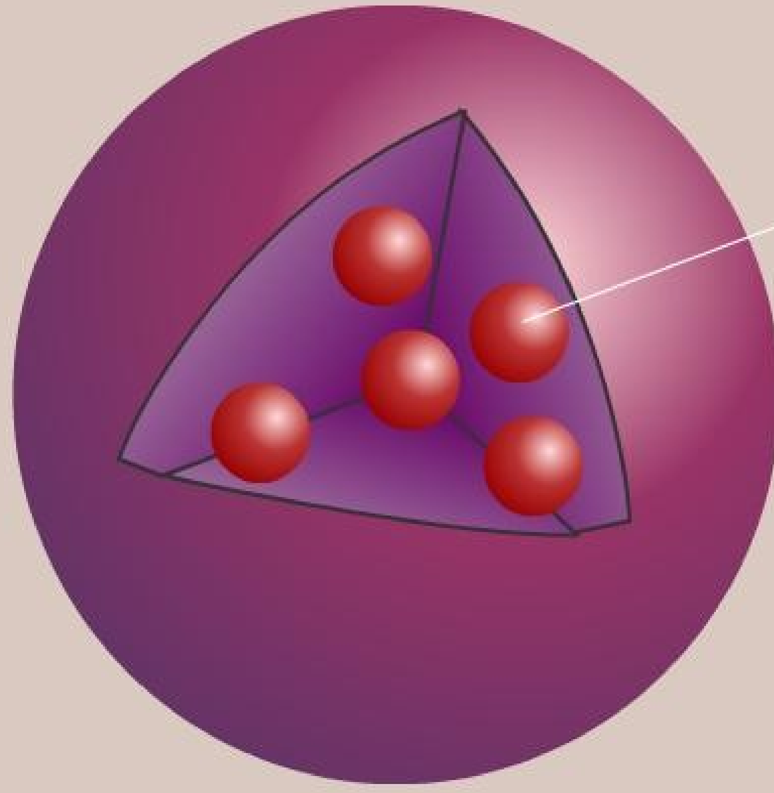


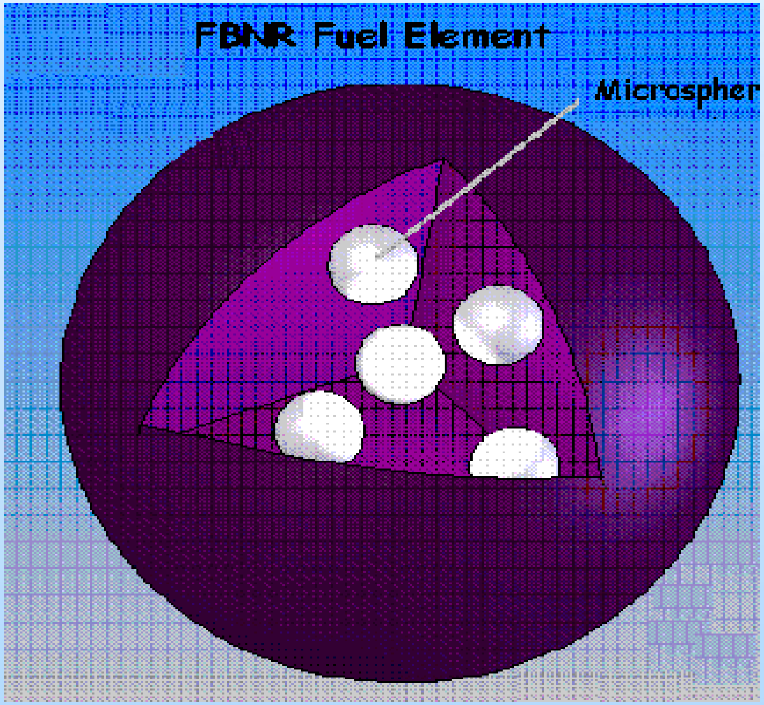
Schematic Design of FBNR





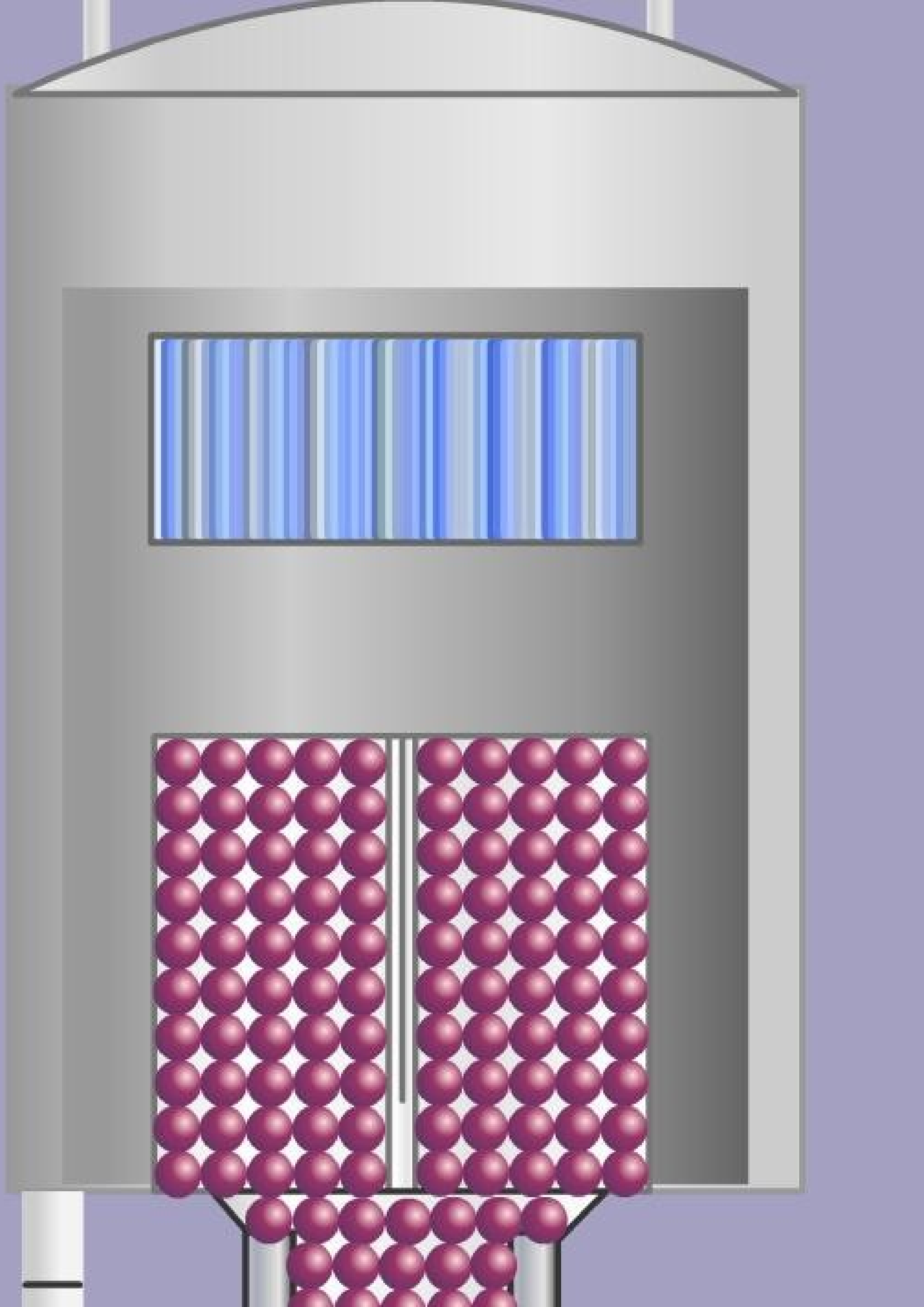
15mm Diameter Fuel Element

CERMET Fuel Element
(15 mm diameter)



The fuel elements form a fixed bed in the reactor core by the flow of water coolant at high pressure.

Here the process of fission and heat generation occurs.



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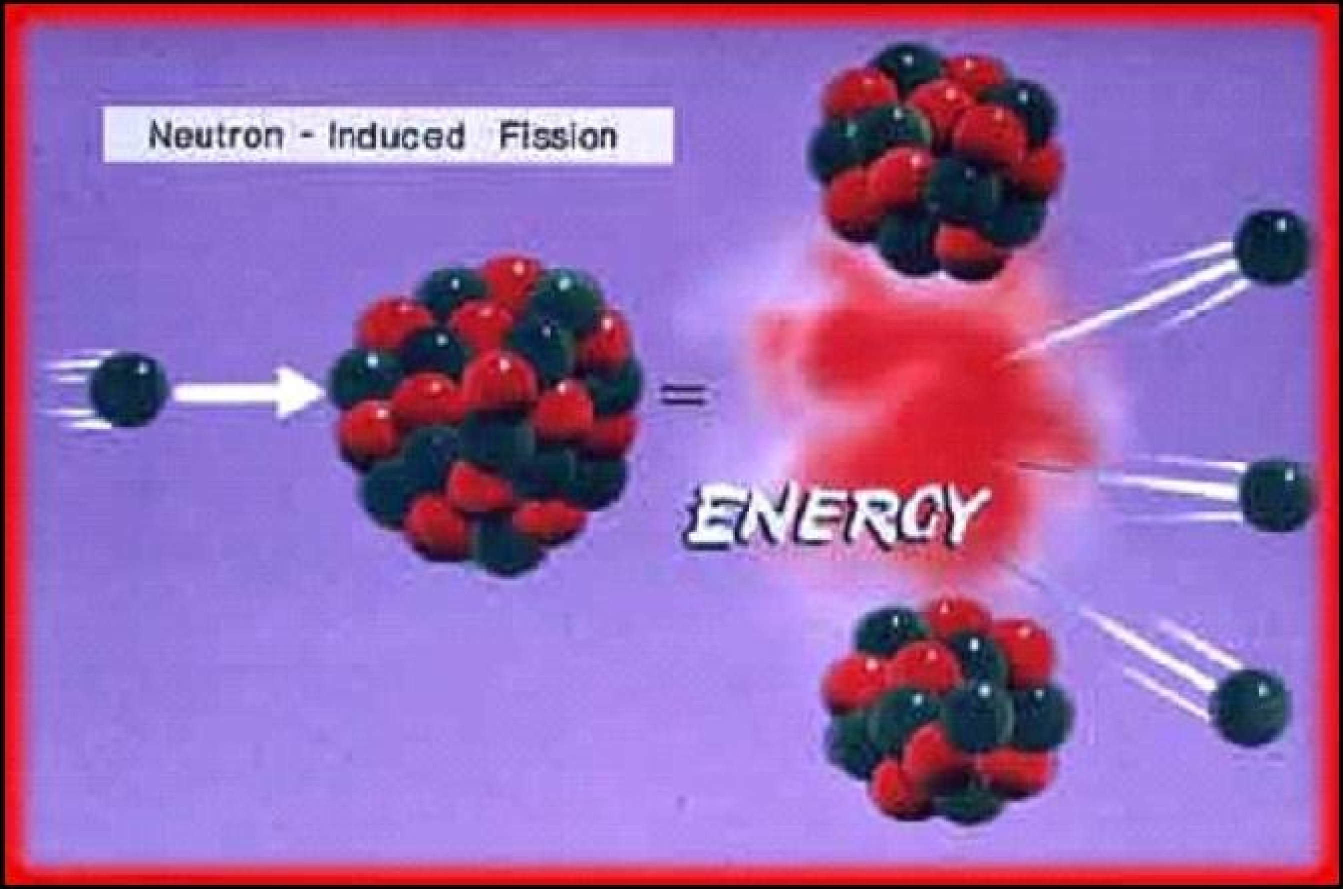
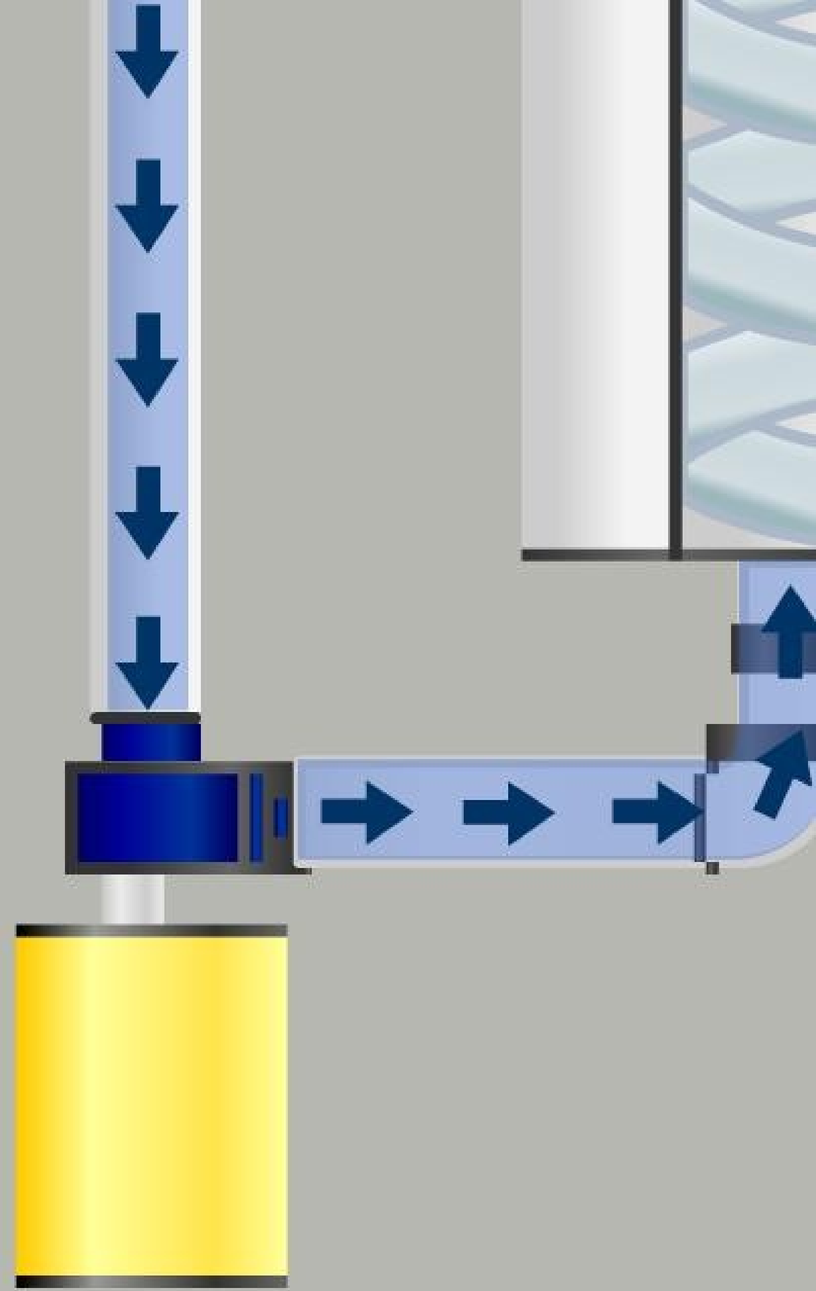
Nuclear Fission



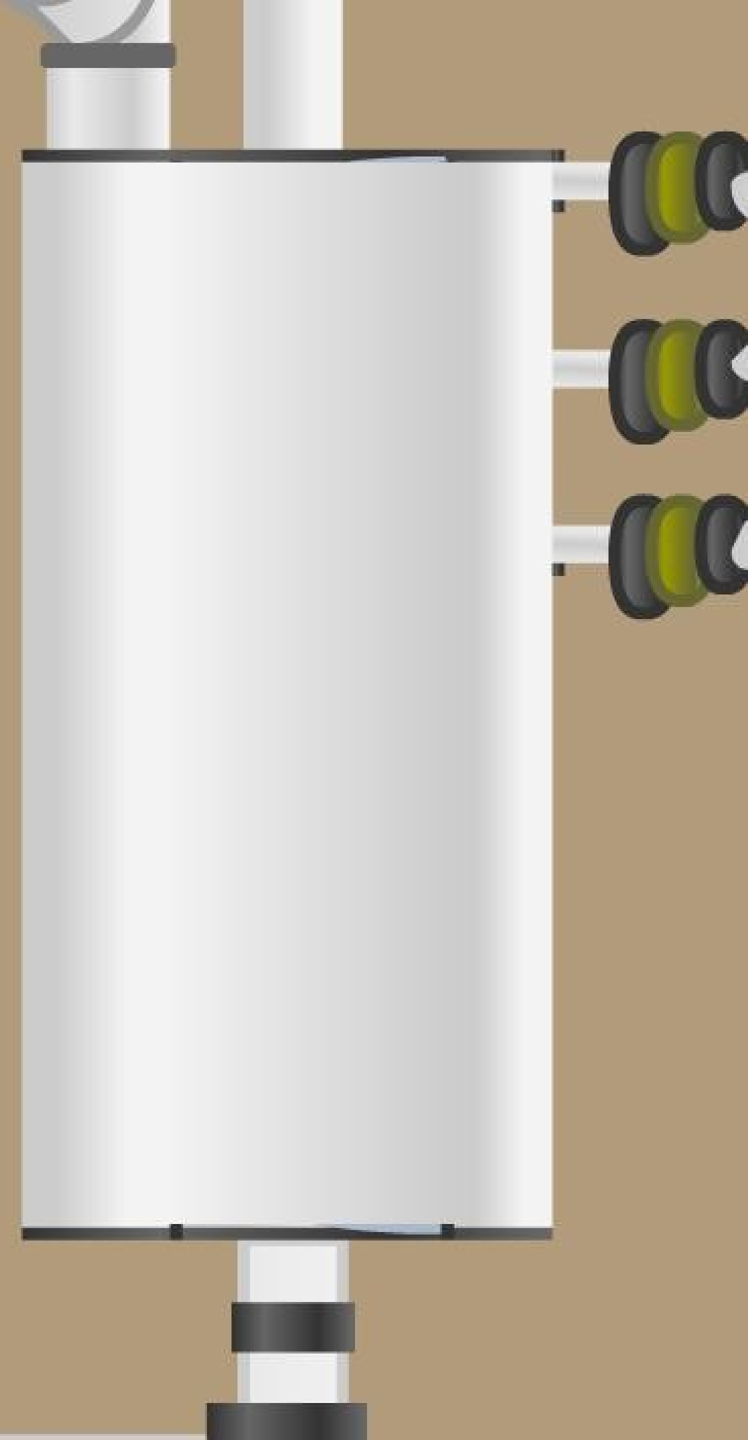
PUMP

The pump circulates the light water coolant at 160 bar pressure in the primary circuit.



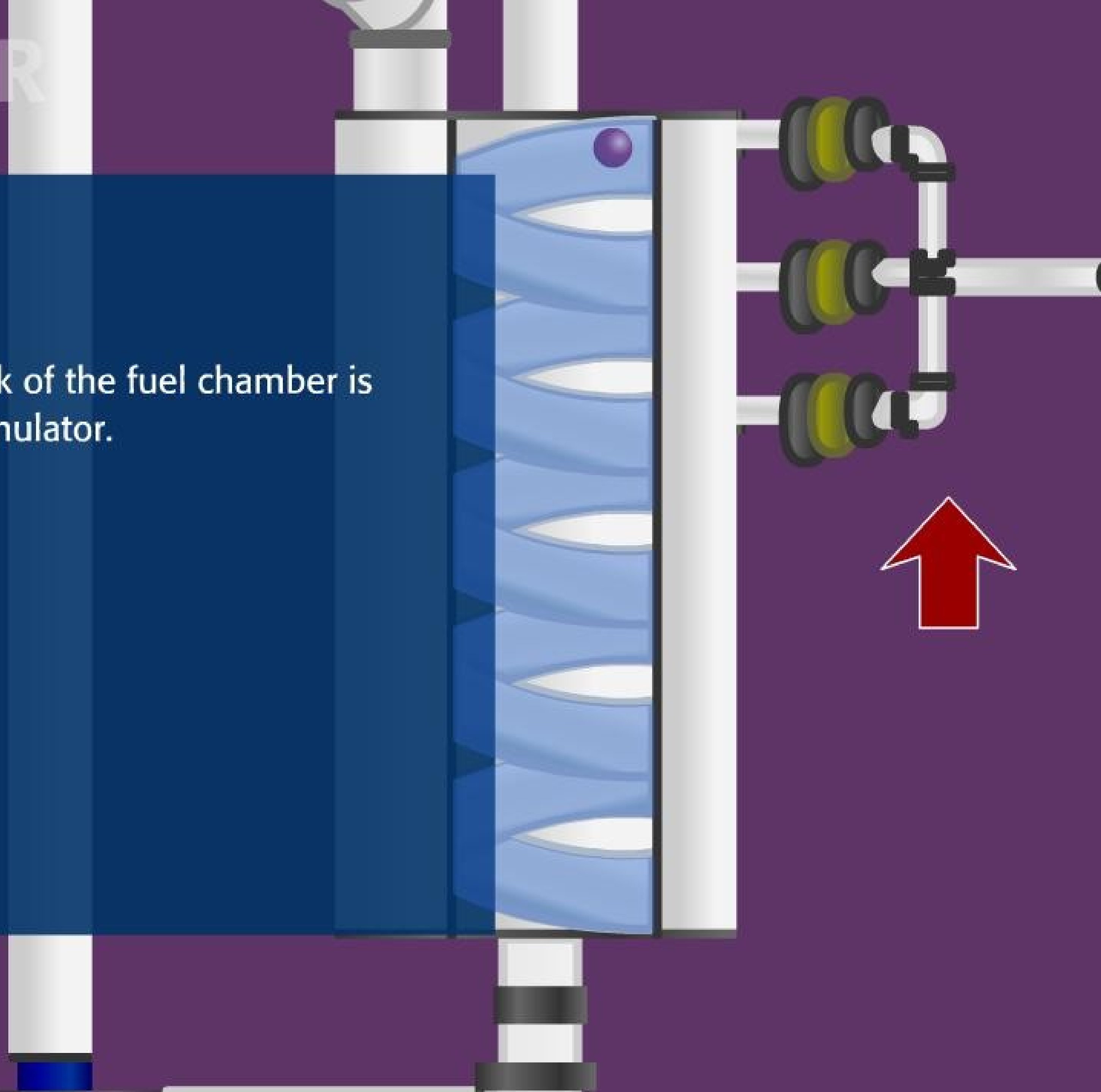
FUEL CHAMBER

The fuel chamber stores the fuel elements in a highly subcritical and passively cooled conditions.



TANK

The cooling tank of the fuel chamber is fed by an accumulator.



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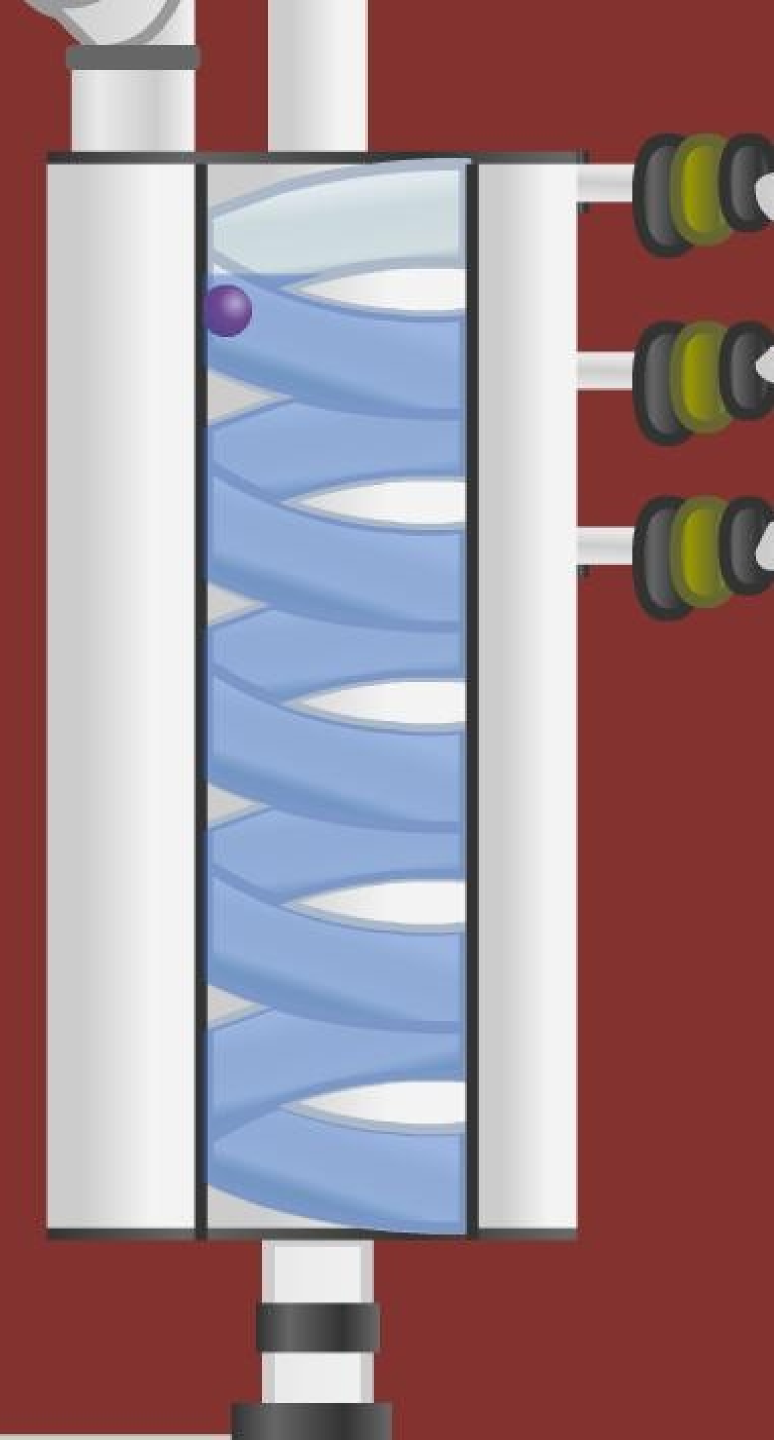
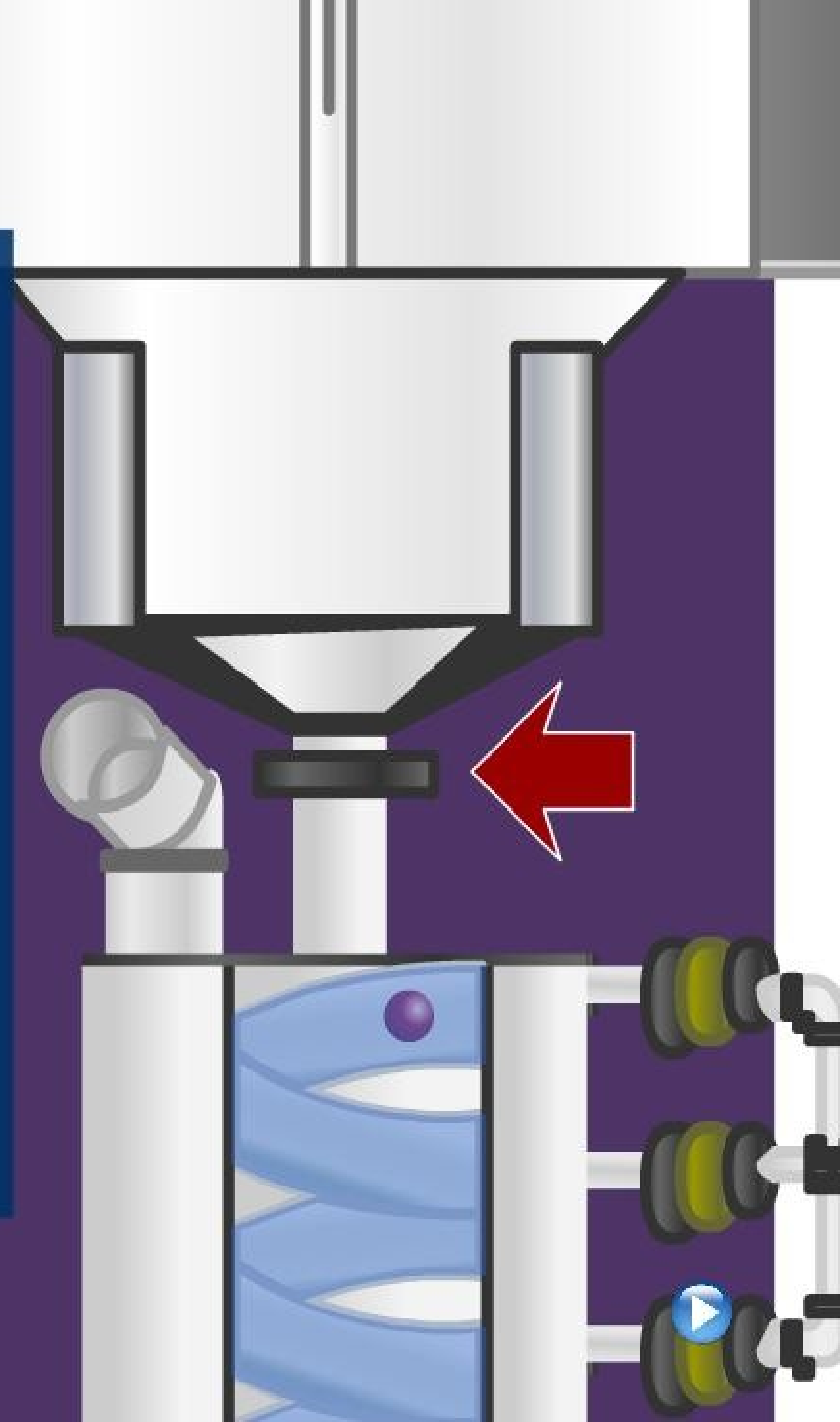
FUEL CHAMBER

The coolant flow, at a velocity higher than the terminal velocity, carries the fuel elements into the reactor core.



SEALED FLANGE

The fuel chamber is sealed by the safeguard authorities in order to avoid theft and nuclear proliferation.



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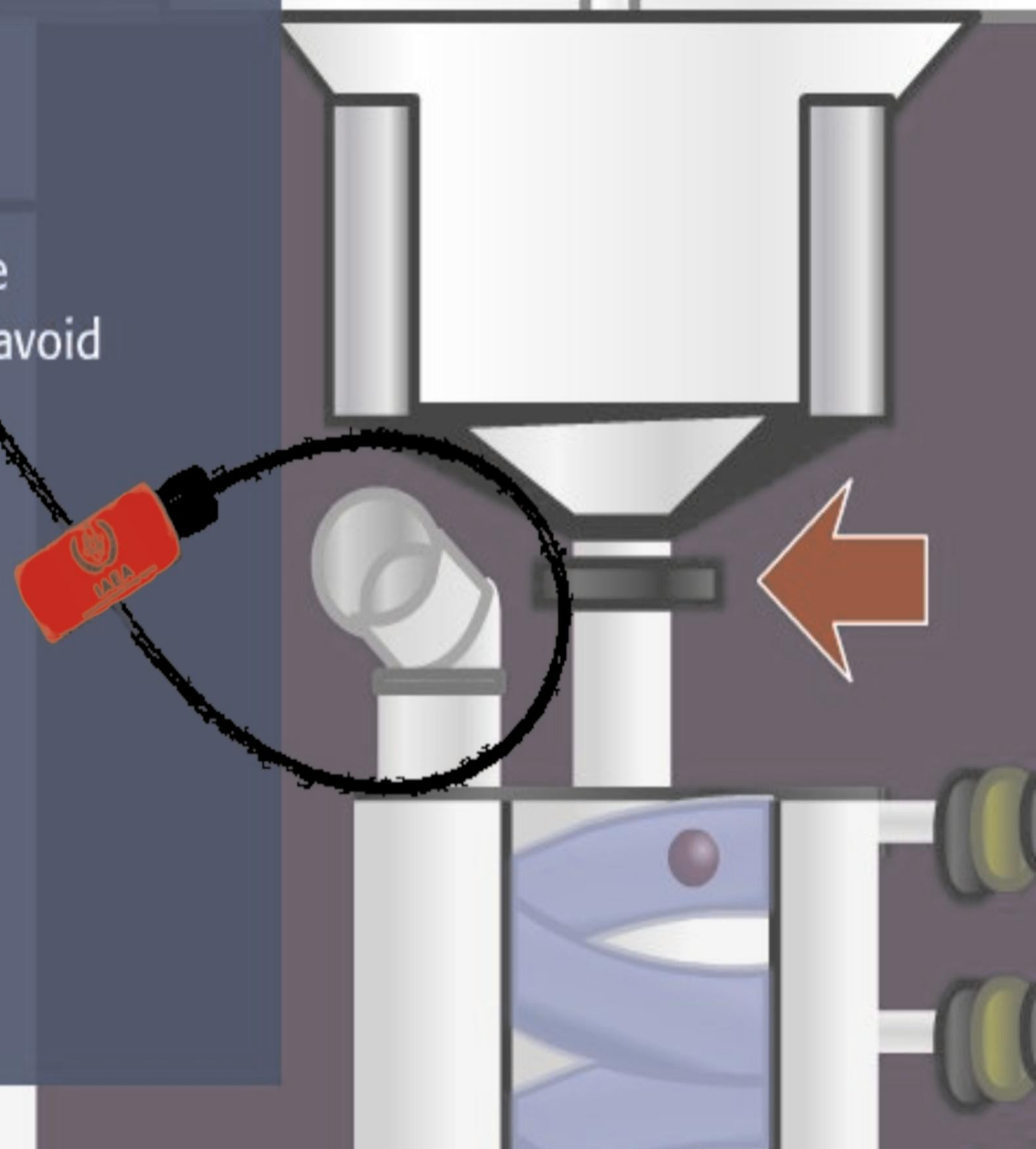

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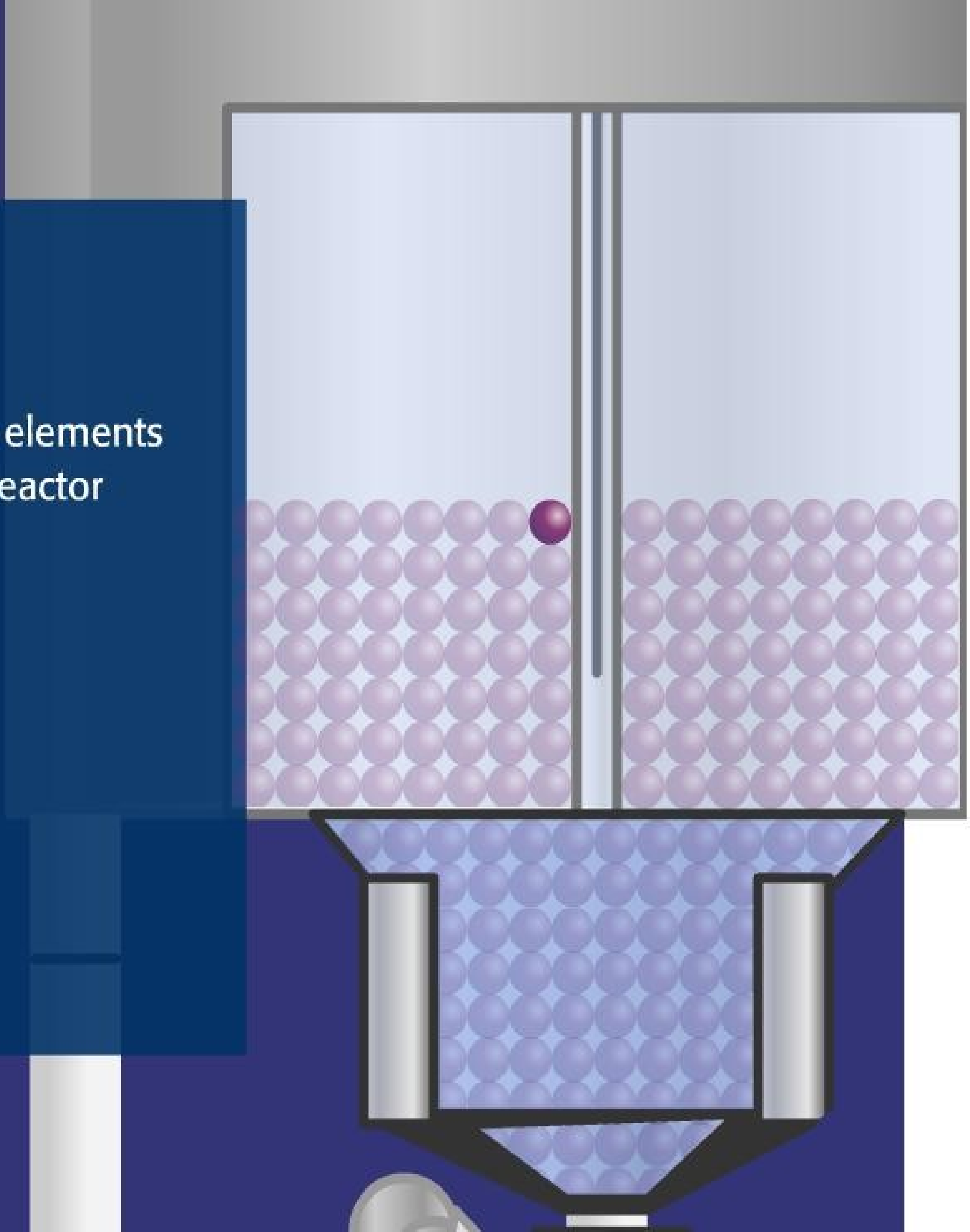
REACTOR CORE

The coolant flow carries the fuel elements from the fuel chamber into the reactor forming a fixed suspended core.



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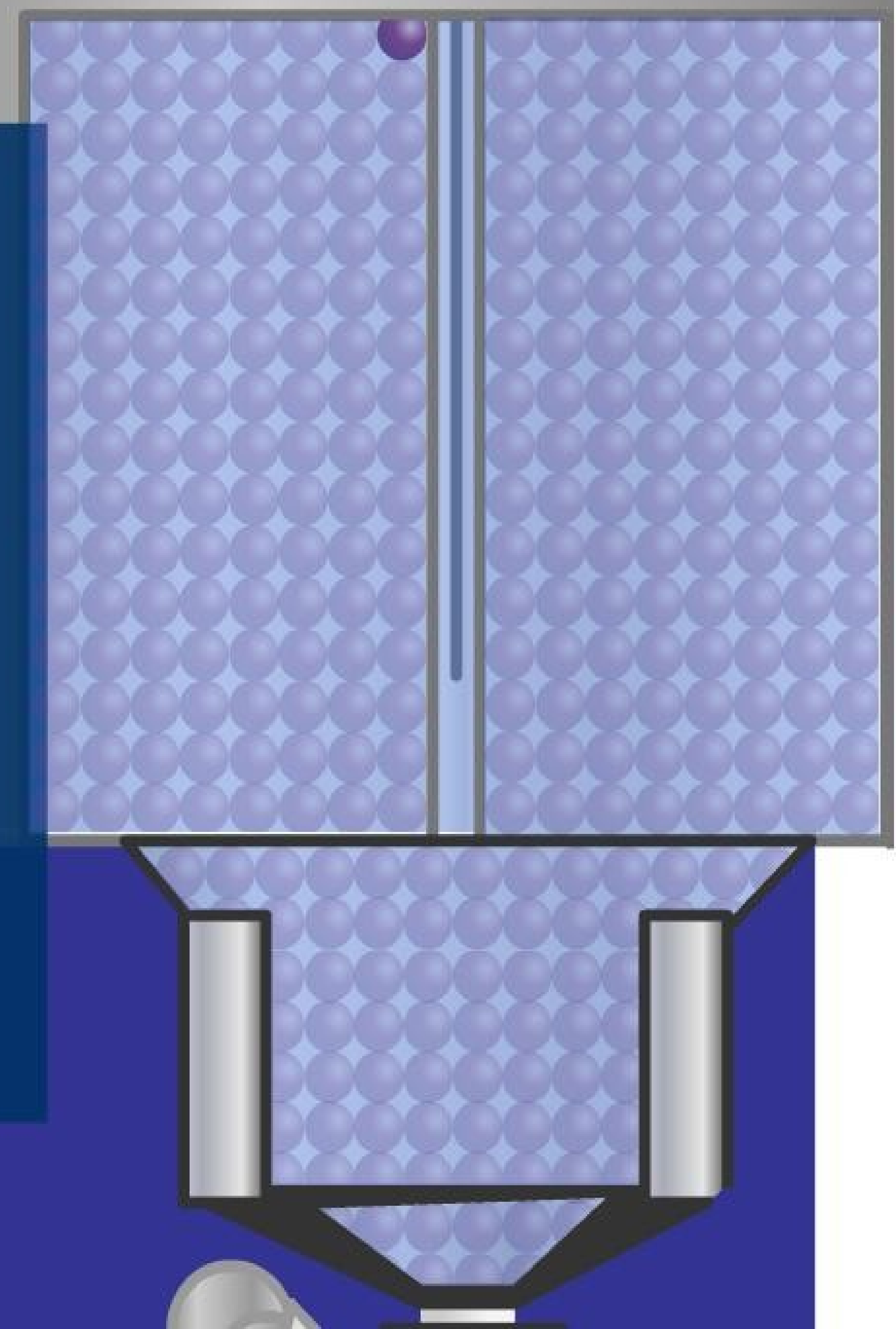

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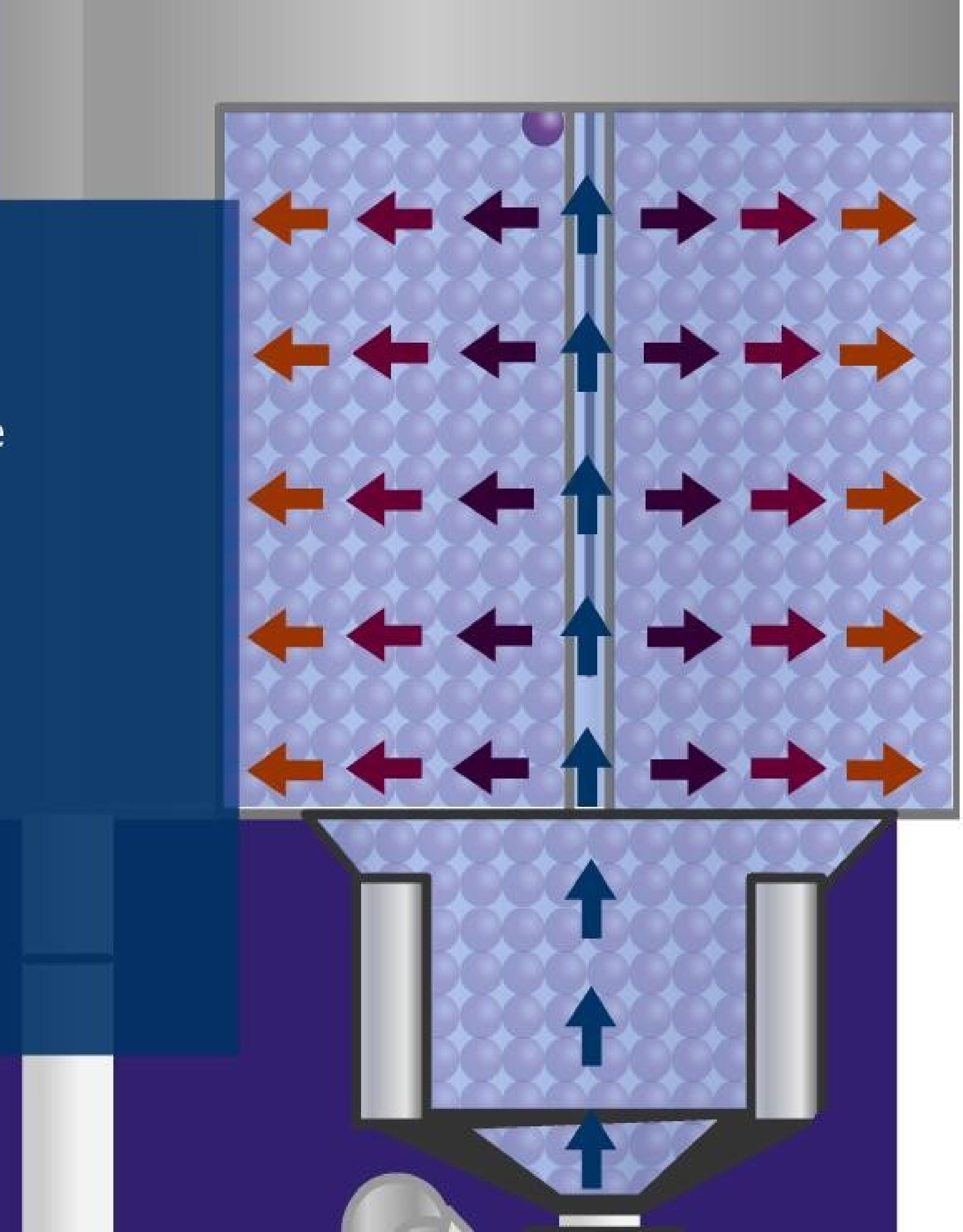
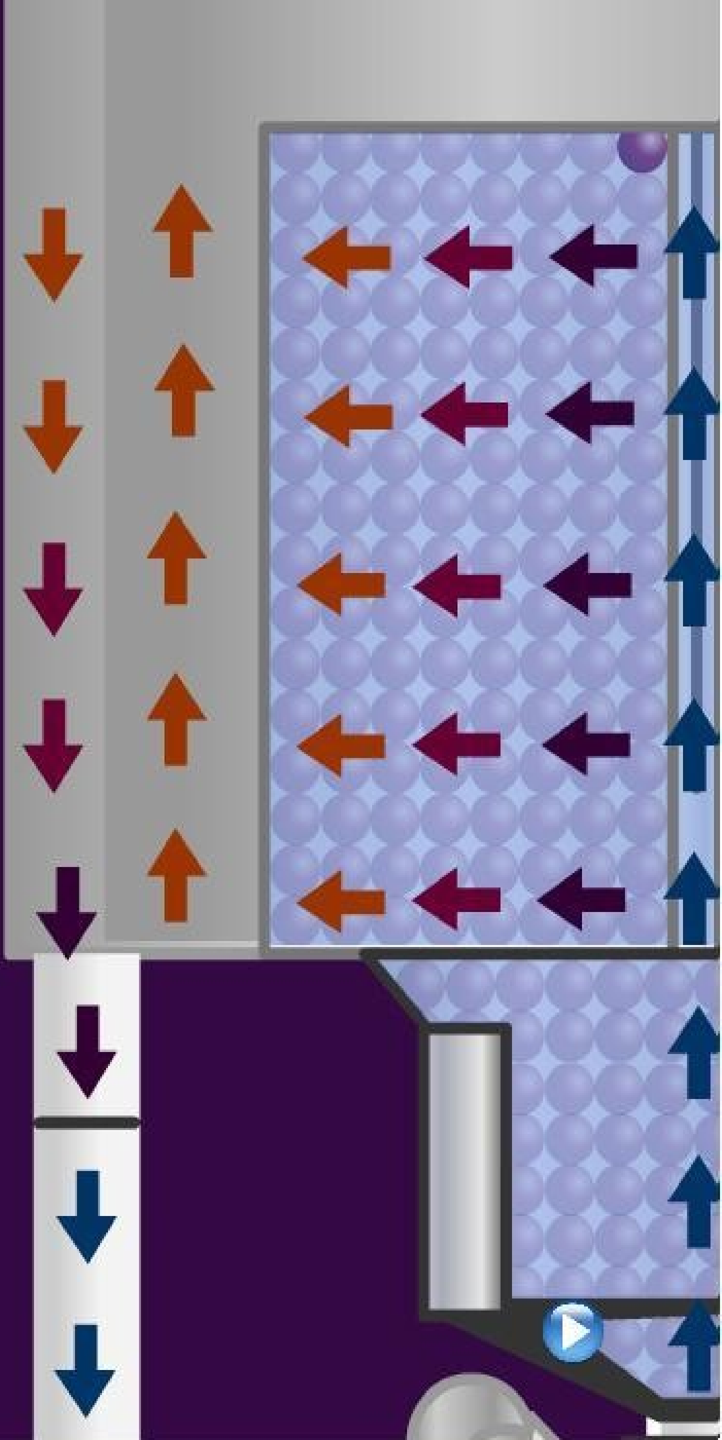
HEAT GENERATION

The water flows through the core and absorbs the heat.



STEAM GENERATION

The coolant after becomes heated, flows into the steam generator and returns to the pump.



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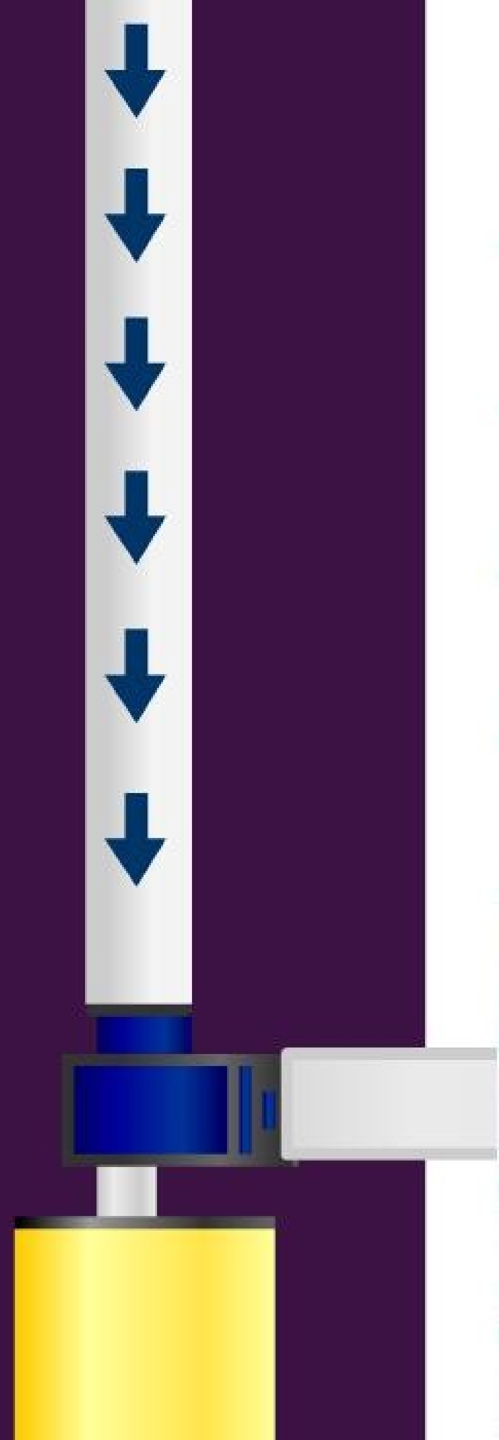
ELECTRICITY GENERATION

The steam produced in the steam generator runs the turbine that turns the generator producing electricity.

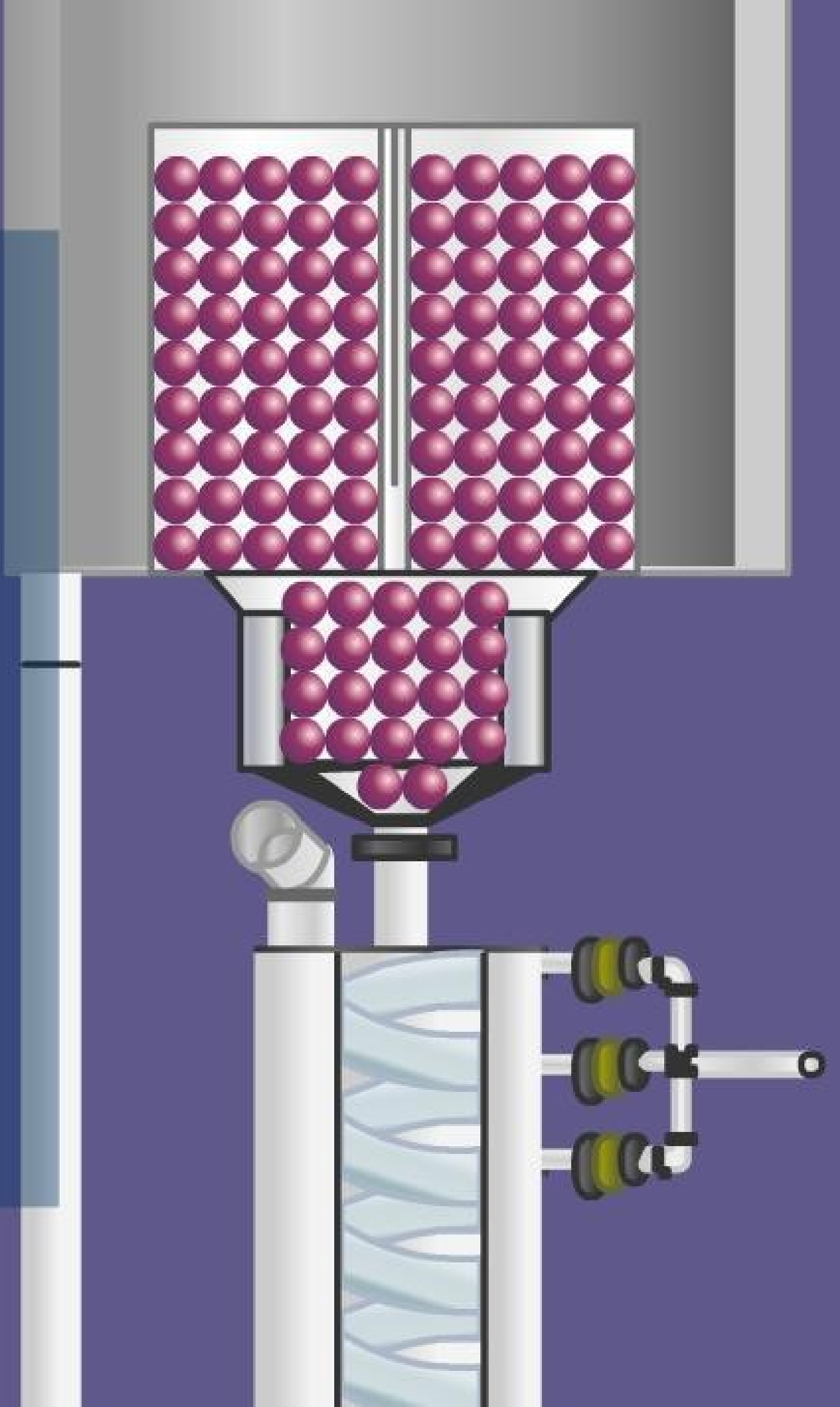


FBNR

SAFETY

Under any adverse operating condition, the pump is turned off, and the fuel elements fall back into the fuel chamber by the force of gravity.

Click here to see the reactor off >



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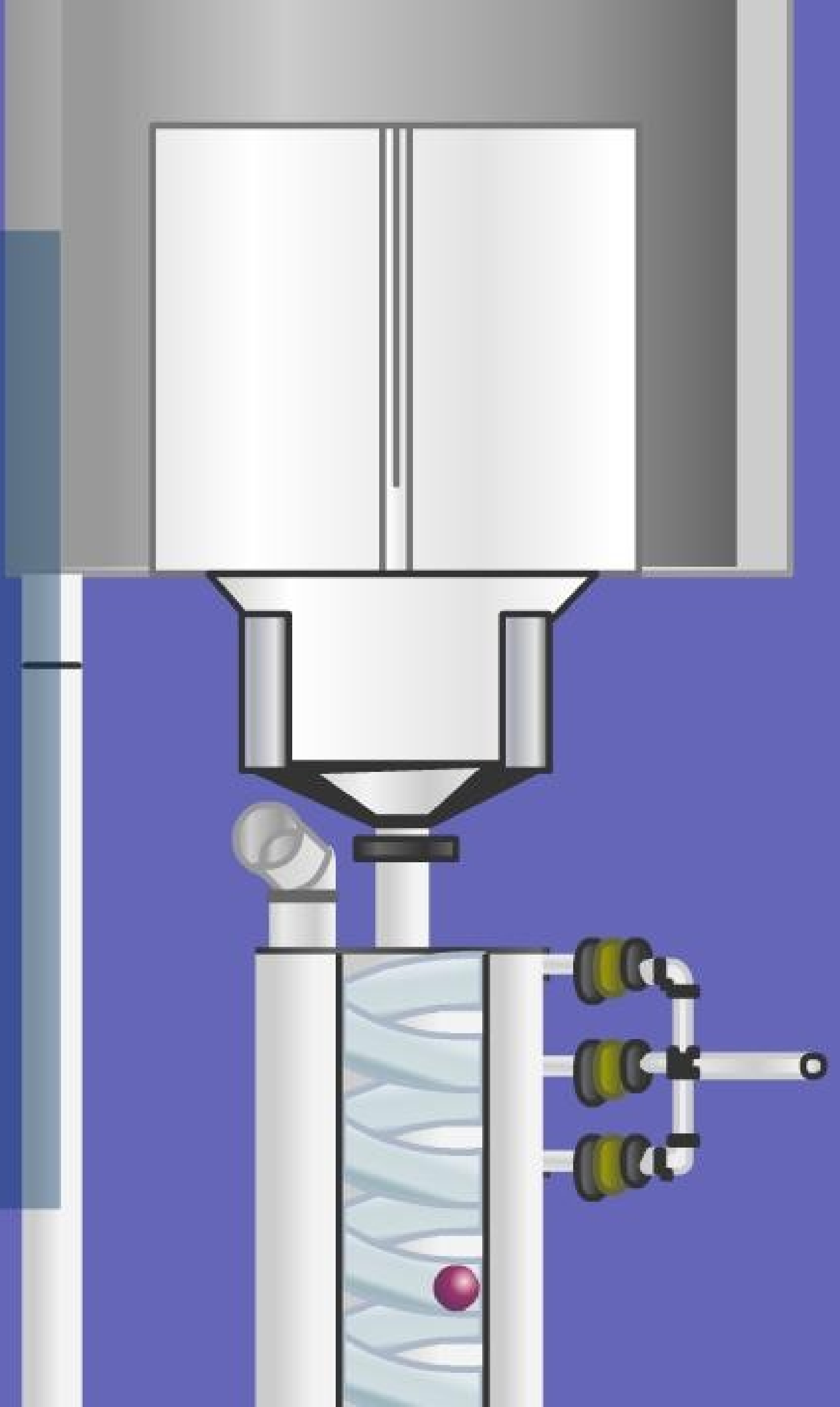


Diversity of applications

- The FBNR is a land-based nuclear power plant for urban or remote localities
- The FBNR is designed to produce electricity alone or to operate as a cogeneration plant producing simultaneously:
  - electricity
  - desalinated water
  - steam for industrial purposes
  - heat for district heating.

Some characteristics of FBNR

- FBNR is a small, simple in design, inherently safe and passively cooled nuclear reactor with reduced adverse environmental impact
- The FBNR is shop fabricated, thus it guarantees the high quality fabrication and economic mass production process.
- FBNR uses a proven technology namely that of the conventional pressurized water reactors (PWR).
- FBNR is small in nature. The optimum size is about 70 MWe. The larger size can be achieved at the cost of a lower thermodynamic efficiency.
- The obvious simplicity of the design and the lack of necessity for complicated control system, make the reactor highly economic.
- The steam generator is housed within the pressure vessel having an integrated primary circuit.
- Easy dismantling and transportability.
- The reactor can be operated with a reduced number of operators or even be remotely operated without any operator on site.

Fuelling of FBNR

- The FBNR has a very long lifetime according to the user’s need and will not be refueled on the site.
- The FBNR modules are fabricated, fueled, and sealed in the factory under the supervision of the IAEA safeguard program.
- They are taken to the site and installed in the reactor and the spent fuel chamber will return to its final destination as sealed.
- The spent fuel chamber is stored in a passively cooled intermediate storage at the reactor site before going to the final disposal site or to the reprocessing plant or any other future destination.
- No unauthorized access to the fresh or spent fuel is possible because the fuel elements are either
  - In the core or,
  - In the fuel chamber under sealed condition
- Therefore, no clandestine diversion of nuclear fuel material is possible.

FBNR Safety

- The spherical fuel elements are fixed in the suspended core by the flow of water coolant.
- Any malfunction in the reactor system will cut off the power to the coolant pump causing a stop in the flow.
- This results in making the fuel elements fall out of the reactor core by the force of gravity and become stored in the passively cooled fuel chamber under sub critical condition.
- Reactivity excursion accident cannot be provoked, because the reactor core is filled with fuel only when all operational conditions are met.
- A heat transfer analysis of the fuel elements has shown that, due to a high convective heat transfer coefficient and a large heat transfer surface-to-volume ratio, the maximum fuel temperature and power extracted from the reactor core is restricted by the mass flow of the coolant corresponding to a selected pumping power ratio, rather than by design limits of the materials.

High level of safety

- Strong reliance on
  - Inherent safety (rely on the law of gravity)
  - Passive cooling (rely on natural convection)
  - Passive control system: The normal state of control system is “switch off”. The pump is “on” only when all operating conditions are simultaneously met.

Underground containment and environment

- The inherent safety and passive cooling characteristics of the reactor eliminate the need for containment. However,
- an underground containment is envisaged for the reactor to mitigate any imagined adverse event, but
- mainly to help with the visual effects by hiding the industrial equipments underground and
- presenting the **nuclear plant as a beautiful garden** compatible with the environment acceptable to the public.

Utilization of spent fuel, nuclear waste and environment

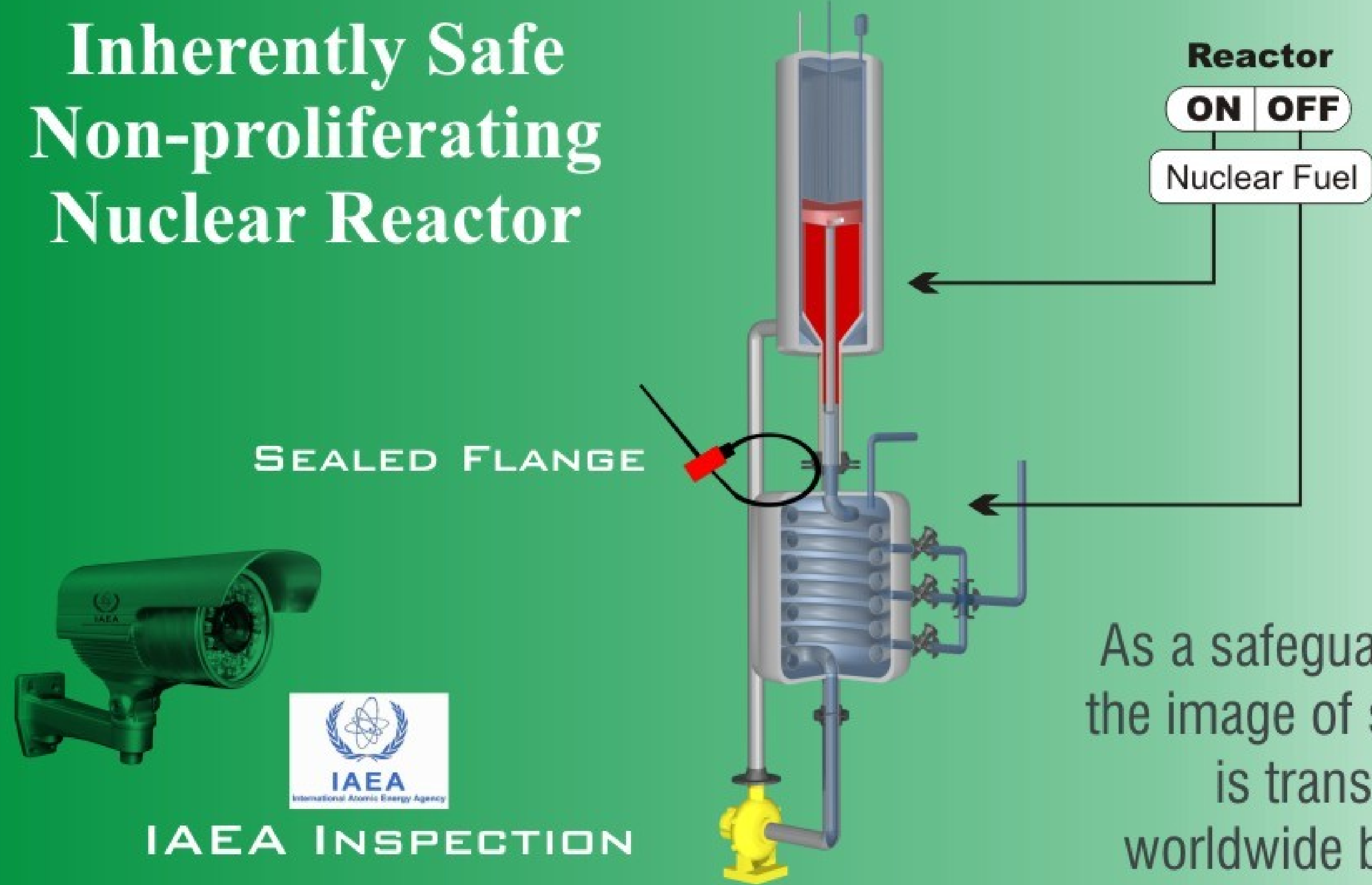
- The spent fuel from FBNR is in a form and size (15 mm dia. spheres) that can directly be used as a source of radiation for irradiation purposes in agriculture, industry, and medicine. Therefore,
- The spent fuel from FBNR may not be considered as waste as it can perform useful functions.
- Should reprocessing not be allowed, the spent fuel elements can easily be vitrified in the fuel chamber and the whole chamber be deposited directly in a waste repository.
- These factors result in reduced adverse environmental impact.

Fool proof nuclear non-proliferation characteristic

- The non-proliferation characteristics of the FBNR is based on both the extrinsic concept of sealing and the intrinsic concept of isotope denaturing.
- Its small spherical fuel elements are confined in a fuel chamber that can be sealed by the authorities for inspection at any time.
- Only the fuel chamber is needed to be transported from the fuel factory to the site and back.
- There is no possibility of neutron irradiation to any external fertile material.
- Isotopic denaturing of the fuel cycle either in the U-233/Th or Pu-239/U cycle increases the proliferation resistance substantially.
- Both concepts of “sealing” and “isotope denaturing” contribute to the fool proof non-proliferation characteristics of FBNR.

FBNR
is a fool proof non-proliferating
nuclear reactor

Inherently Safe Non-proliferating Nuclear Reactor



As a safeguard measure the image of sealed flange is transmitted worldwide by internet.

Proliferation Resistance – Definition

Proliferation resistance is that characteristic of a nuclear system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by States in order to acquire nuclear weapons or other nuclear explosive devices.

Como II, IAEA STR-332, December 2002

Proliferation Resistance – *Intrinsic/ Extrinsic*

Intrinsic proliferation resistance features are those features that result from the technical design of nuclear energy systems, including those that facilitate the implementation of extrinsic measures.

Extrinsic proliferation resistance measures are those that result from States' undertakings related to nuclear energy systems.

Proliferation Resistance – Safeguards

Safeguards is an extrinsic measure comprising legal agreements between the party having authority over the nuclear energy system and a verification control authority (e.g. IAEA or a Regional Safeguards System)

Proliferation Resistance Fundamentals

- Proliferation Resistance will be enhanced when taken into account as early as possible in the design and development of a nuclear energy system.
- Proliferation Resistance will be most effective when an optimal combination of intrinsic features and extrinsic measures, compatible with other design considerations, can be included in a nuclear energy system.

IAEA STR-332, December 2002

Concept of Proliferation Resistance

- The proliferation resistance is that characteristic of the reactor that impedes the diversion or undeclared production of nuclear materials by a country with the intention of acquiring nuclear weapons. The degree of proliferation resistance results from intrinsic features and extrinsic measures. Intrinsic proliferation resistance features result from the technical design of the reactor. Extrinsic proliferation resistance measures are those measures that result from country's decision and undertakings. Safeguard is an extrinsic measure comprising legal agreements between the countries and the IAEA.
- According to INPRO definitions, intrinsic ***proliferation resistance features*** are those features that result from the technical design of nuclear energy systems, including those that facilitate the implementation of extrinsic measures. ***Extrinsic proliferation resistance measures*** are those measures that result from States' decisions and undertakings related to nuclear energy systems. ***Safeguards*** is an extrinsic measure comprising legal agreements between the party having authority over the nuclear energy system and a verification or control authority, binding obligations on both parties and verification using, inter alia, on site inspections. This term has different meanings depending on context. Here "**safeguards**" refers to IAEA safeguards implemented under Safeguards Agreements between a State and the IAEA. The term "**Regional safeguards**" are used to refer to a regime of independent international verification of commitments made by States within Regional Agreements.

Intrinsic features of FBNR

- The first type of intrinsic proliferation resistance feature consists of the technical features of a nuclear energy system that reduce the attractiveness for nuclear weapons programs of nuclear material during production, use, transport, storage and disposal.
  - For FBNR, this is accomplished by denaturing of the fuel.
- The second type of intrinsic proliferation resistance feature comprises the technical features of a nuclear energy system that prevent or inhibit the diversion of nuclear material.
  - For FBNR, this is accomplished by sealing the fuel chamber.
- The third type of intrinsic proliferation resistance feature consists of the technical features of a nuclear energy system that prevent or inhibit the undeclared production of direct-use material.
  - For FBNR, this is accomplished by coating the vessel by a neutron absorber material.
- The fourth type of intrinsic proliferation resistance feature consists of the technical features of a nuclear energy system that facilitate verification, including continuity of knowledge.
  - For FBNR, this is accomplished by the use of a TV camera to do the surveillance of the fuel chamber.

  - All four types of intrinsic features of FBNR make a great reduction of costs and efforts of international safeguards implementation.

Extrinsic measures

There are five types of extrinsic proliferation resistance measures.

1. The first is the country's commitment to non-proliferation.
2. The second category is the agreement between the exporting and importing countries about the use of the reactor.
3. The third category consists of commercial, legal or institutional agreements on access to materials.
4. The fourth category is application of IAEA verification measures.
5. The fifth consists of legal arrangements against violations of non-proliferation.

The countries utilising FBNR are obliged to agree on all the IAEA safeguard requirements.

The International Atomic Energy Agency (IAEA) through its International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) recommends that

- “proliferation resistant features and measures should be provided in innovative nuclear energy systems to minimize the possibilities of misuse of nuclear materials for nuclear weapons.
- Both intrinsic features and extrinsic measures are essential, and neither should be considered sufficient by itself.
- Extrinsic proliferation resistance measures, such as control and verification measures will remain essential, whatever the level of effectiveness of intrinsic features.
- From a proliferation resistance point of view, the development and implementation of intrinsic features should be encouraged.
- Communication between stakeholders will be facilitated by clear, documented and transparent methodologies for comparison or evaluation/assessment of proliferation resistance” (IAEA-TECDOC-1362).

INPRO defines B*asic Principle for* Proliferation Resistance

Proliferation resistance intrinsic features and extrinsic measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons program. Both intrinsic features and extrinsic measures are essential, and neither can be considered sufficient by itself.

FBNR meets the requirements

- The FBNR reactor meets the IAEA requirements for non-proliferation. The concept is based on both sealing of the fuel chamber and denaturing of the fuel itself.
- The sealing of the fuel in the fuel chamber accompanied by surveillance, permits the continuous inspection from “cradle to grave” allowing the continuity of knowledge (COK) about the fuel which guarantees an effective control.
- The isotopic denaturing of the fissile fuel, both in the U-233/Thorium cycle as well as for the classical Pu-239/Uranium cycle, would further increase the proliferation resistance as it will require isotope separation technology to produce weapon grade materials.

Impossibility of fissile material production in FBNR

The neutron leakage from the reactor is negligible. However, the reactor pressure vessel is cladded by neutron absorbing materials in order to eliminate the possibility of neutron irradiation to any external nuclear material.

Intrinsic features

- Adopting a thorium cycle as an intrinsic measure will hinder the possibility of misuse of nuclear materials for nuclear weapons. The mixing of thorium with low enriched uranium or plutonium results in the production of U-233 that is diluted along with U-235 in U-238. The access to uranium-233 will only be possible through isotope separation techniques. Additionally the production of gamma emitting Tl-208 in the thorium cycle is hindrance to nuclear proliferation.

- If the U- Pu cycle is applied, one can increase the Pu-238 concentration by adding Np to the fresh fuel. From a certain concentration of Pu-238 on (~ 8%) , the alpha decay heat is so strong that the metallic Pu-sphere, as well as the surrounding chemical explosives, in a nuclear device become plastic or even melts so that the fuel of the reactor at any time is not useful for weapons. Thus, the combination of sealing the reactor, as described above, and the isotopic denaturing of the irradiated fuel will additionally increase the proliferation resistance.

Fixed Bed Nuclear Reactor

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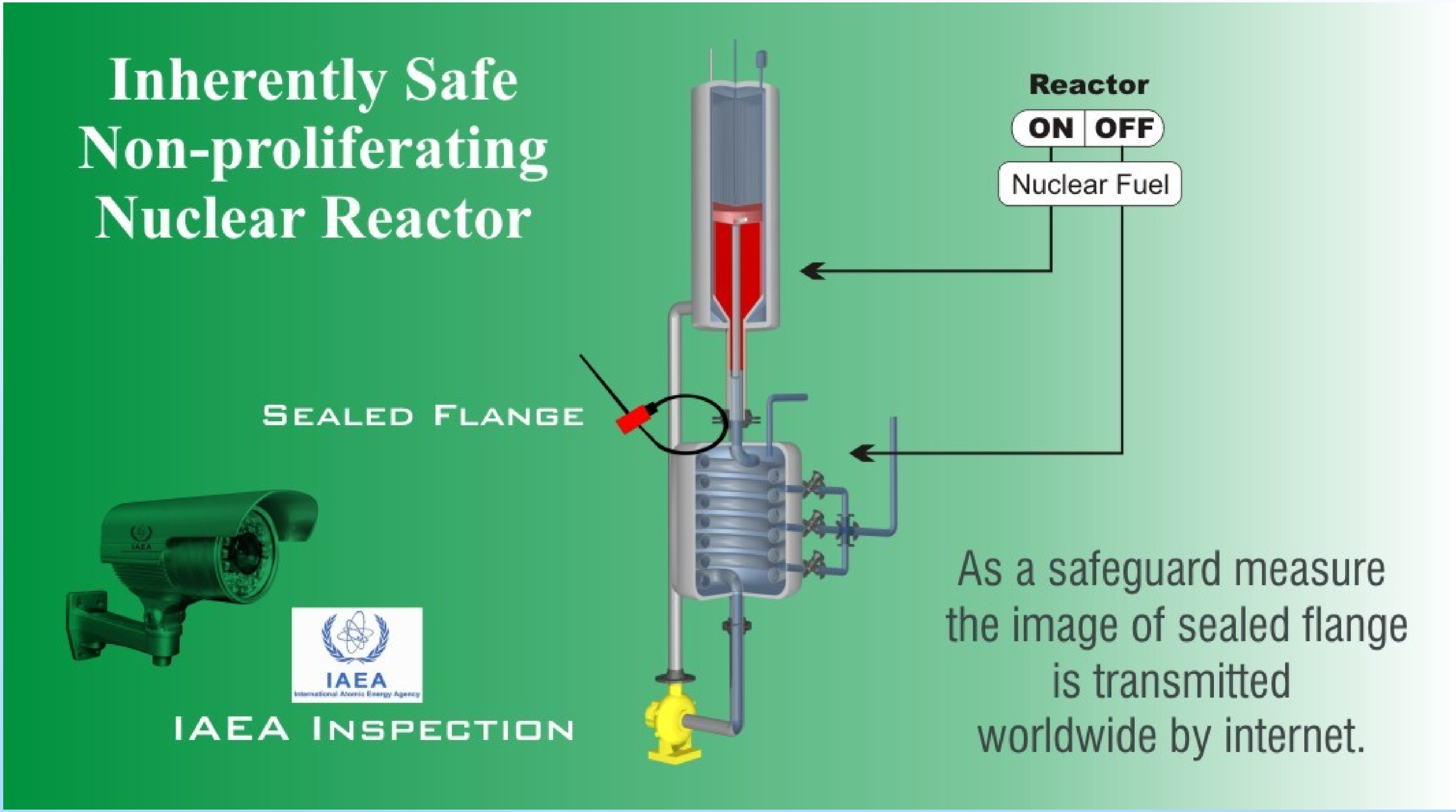
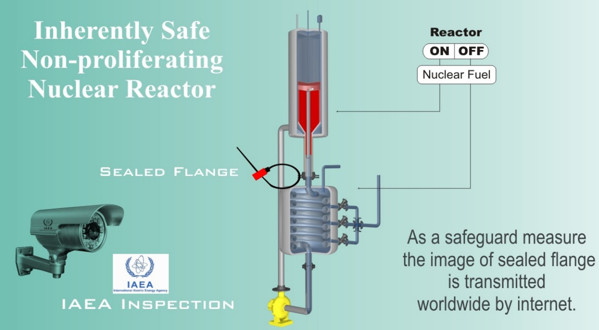


FBNR is a fool proof non-proliferating nuclear reactor

It uses both the extrinsic measure of sealing the fuel chamber and intrinsic feature of denaturing the fuel.



Some Characteristics of FBNR

- an innovative concept
- small power production - 70 MWe
- simple in design
- inherently safe
- passively cooled
- non-proliferating
- affordable
- environmental friendly
- using PWR technology
- producing electricity alone or
  as a cogeneration plant producing simultaneously electricity, desalinated water, steam for industrial purposes, and heat for district heating.
- simple control system
- remotely controlled or with reduced number of operators.
- for urban or remote localities
- easy dismantling and transportability
- no need for on-site refueling
- fuel chamber is fuelled in the factory.
- resists against terrorist action, explosion, earthquake, flooding, fire, tornado, and bombing.
- its underground containment building hides its industrial image.

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Fixed Bed Nuclear Reactor

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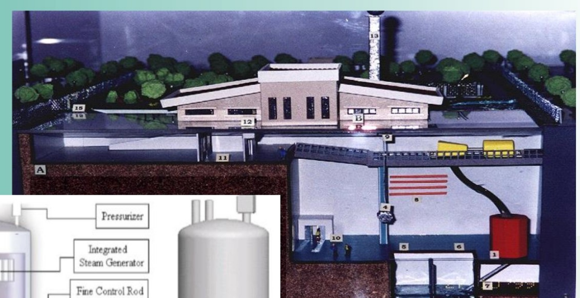
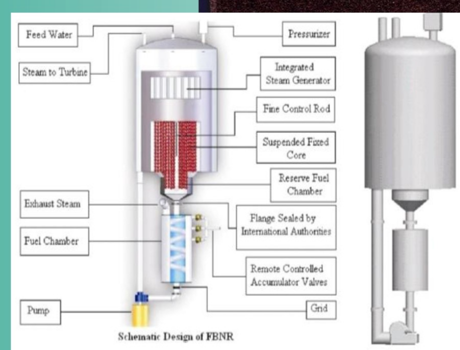
FBNR Nuclear Reactor is a small, innovative, inherently safe, and non-proliferating nuclear reactor to produce electricity and desalinated water.

Countries involved with the FBNR project will be stakeholders in nuclear technology and not merely the users.

FBNR is a joint project of industrialized and developing countries.





Schematic Design of FBNR

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- Countries involved with FBNR project will be stakeholder in nuclear technology and not merely users.
- FBNR is a joint project of industrialized and developing countries.
- A country with no nuclear technology and modest capital investment can get engaged with the development of the FBNR in order to help advancement of science and technology as well as economic gains for that country.

FBNR is being developed under the auspices of the IAEA at the service of humanity

ALL ARE INVITED TO PARTICIPATE IN THE PROJECT