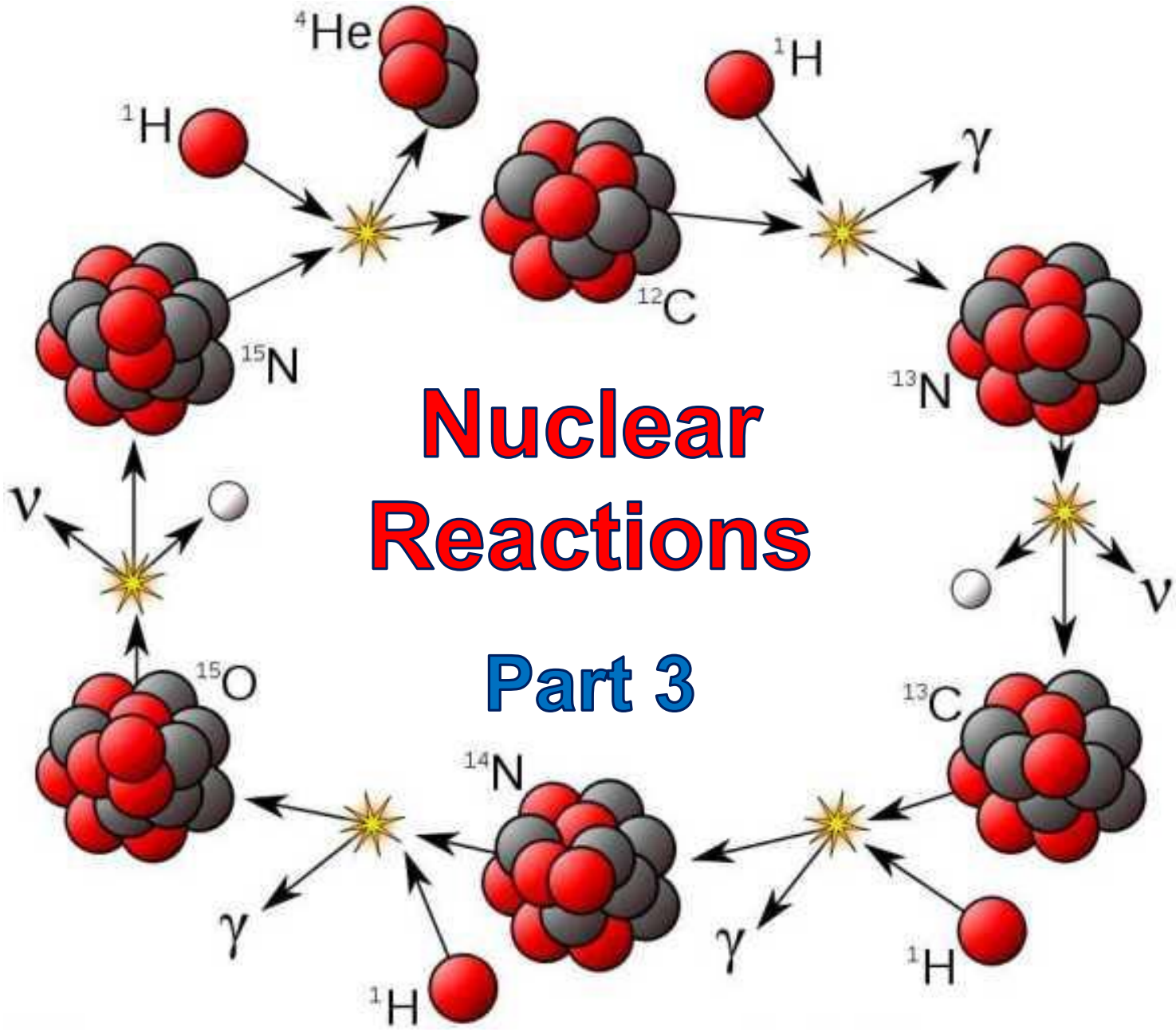


Nuclear Reactions

Part 3

Nuclear Reactions
involve change of the atomic nucleus

1. **Radioactive decay** – an unstable nucleus spontaneously emits a small particle of **ionizing radiation** to become a **different isotope** of the same element or a **different element** (the latter process is called ***transmutation***).

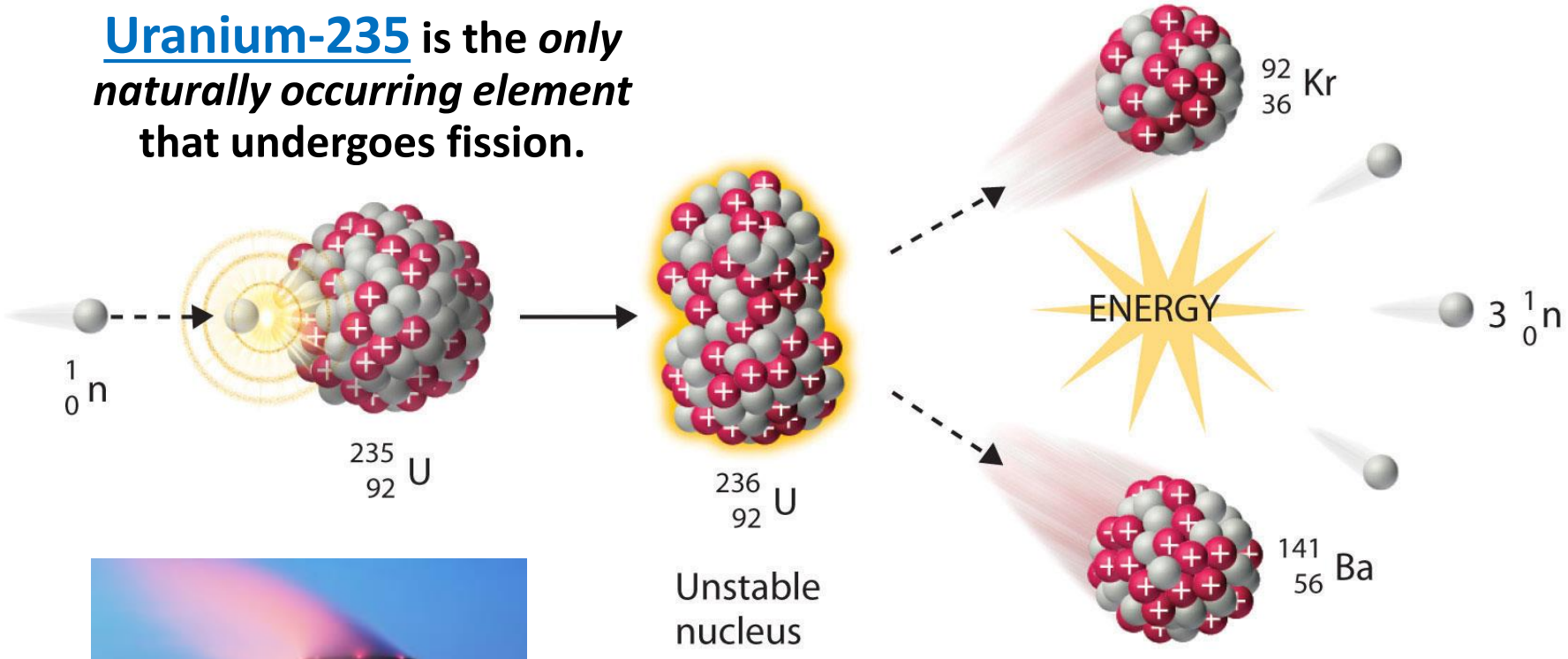
2. **Nuclear Fusion** – the **joining** of two atomic nuclei to form a larger one.

3. **Nuclear Fission** – the **splitting** of an atomic nucleus into two smaller ones.

Nuclear Fission

was discovered by Otto Hahn and Fritz Strassmann in 1938 and explained theoretically by Lise Meitner and Otto Robert Frisch in 1939.

Uranium-235 is the *only naturally occurring element* that undergoes fission.



Nuclear power plants obtain energy from fission.

Uranium Facts

Found in nature:

- U-238 99.3%
- U-235 0.7%
- U-234 trace amounts

Named for the planet **Uranus**.

Discovered by Martin Heinrich Klaproth in 1789.

Glows **GREEN** under UV light!

In the past, Uranium compounds were used to color glass and ceramics.

Uranium is found in various types of ore (rock) and is about 1,000 times more abundant than gold!

Uranium
92
U
238.02891

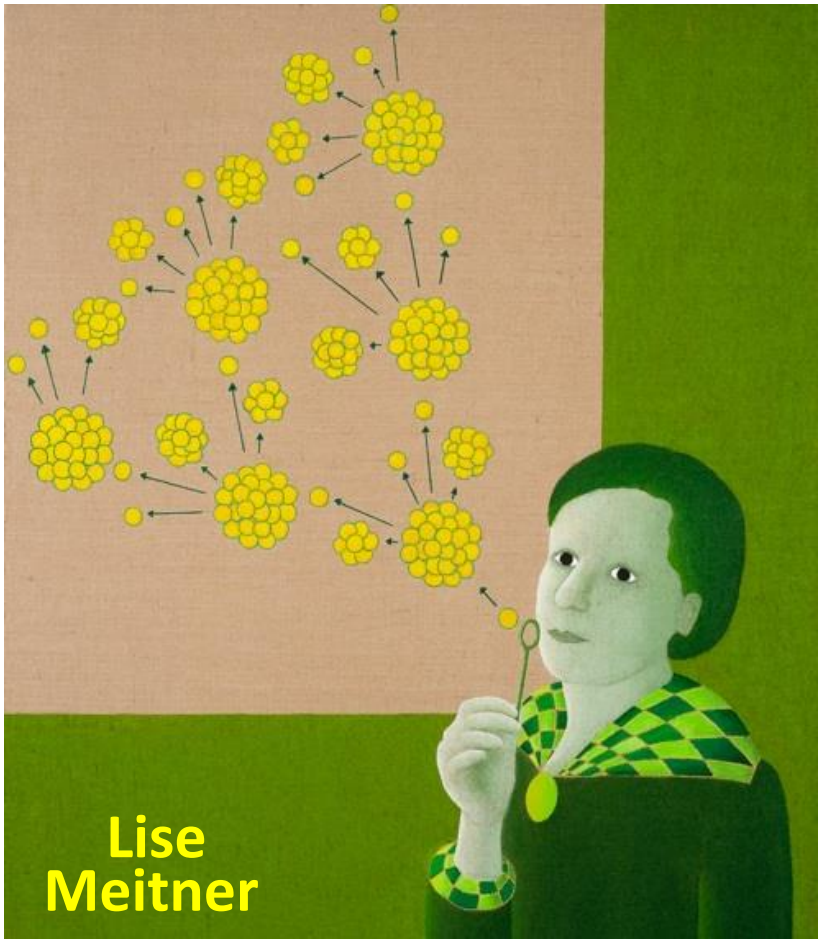
A single 7-gram pellet of *enriched* (processed to increase U-235 content to ~3-5%) Uranium produces as much energy as a ton of coal!

Fission Chain Reaction

A chain reaction is a sequence of reactions where a reactive product or by-product causes additional reactions to take place, leading to a self-supported chain of events.

- **1939, Lise Meitner: When an atom (such as U-235) undergoes nuclear fission, a few neutrons are ejected from the reaction; These free neutrons will then interact with the surrounding medium, and if more fuel is present, some may be absorbed and cause more fissions - the cycle repeats to give a reaction that is self-sustaining or self-amplifying.**

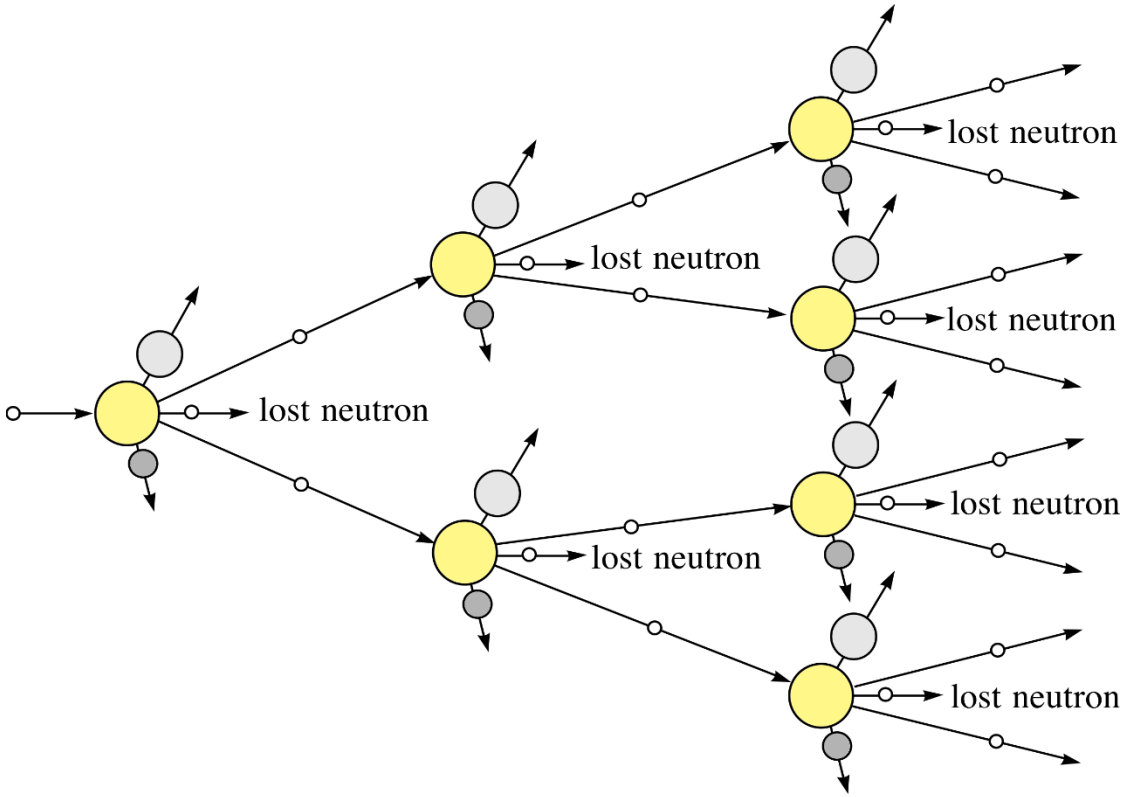
- **1939, Leó Szilárd and Enrico Fermi: searched for, and discovered, neutron multiplication in uranium**



Fission Chain Reaction Rate

self-amplifying

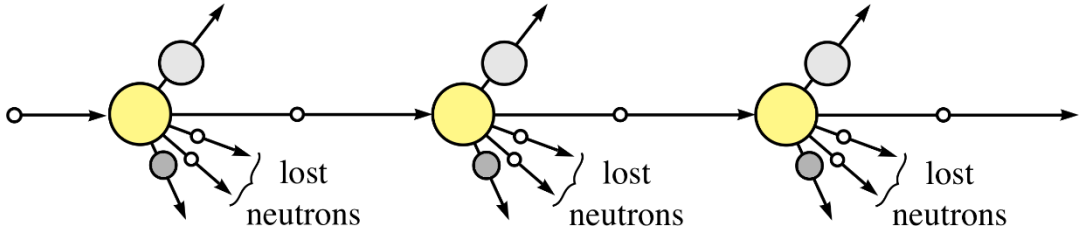
Two to three new neutrons produce fission at each step; the reaction is self-perpetuating with uncontrolled (explosive) release of energy.



VS

self-sustaining

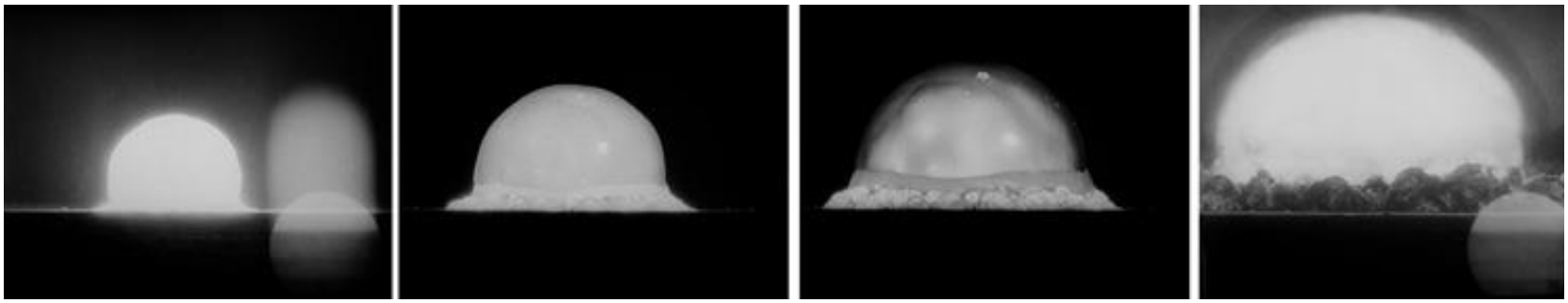
On average, just one new neutron will produce fission at each step; this will lead to a steady release of energy.



Manhattan Project


Robert Oppenheimer

- **Manhattan Project (1939-1946): a research and development project that produced the first atomic bombs during World War II.**
- **December 2, 1942: the *first artificial self-sustaining* nuclear chain reaction, Chicago Pile-1 (CP-1), was created.**
- **July 16, 1945, Trinity test: the first detonation of a nuclear weapon ("Gadget") was conducted by the United States Army in New Mexico.**



"…we all… hope… that man will soon grow sufficiently adult to make good use of the powers that he acquires over nature." Enrico Fermi

Explosive vs Controlled

Nuclear weapons

are specifically engineered to produce a reaction that is so fast and intense it cannot be controlled after it has started and leads to an explosive energy release.

Nuclear weapons employ high purity, highly enriched fuel:

>85% U-235

or

>95% Pu-239

Nuclear power plants

operate by precisely controlling the rate at which nuclear reactions occur.

The fuel for a nuclear fission reactor usually consists of a low-enriched oxide material:

3-5% Uranium-235

Natural Fission Reactor

Natural nuclear fission reactor is a rich uranium deposit where self-sustaining nuclear chain fission reactions have naturally occurred in the past:

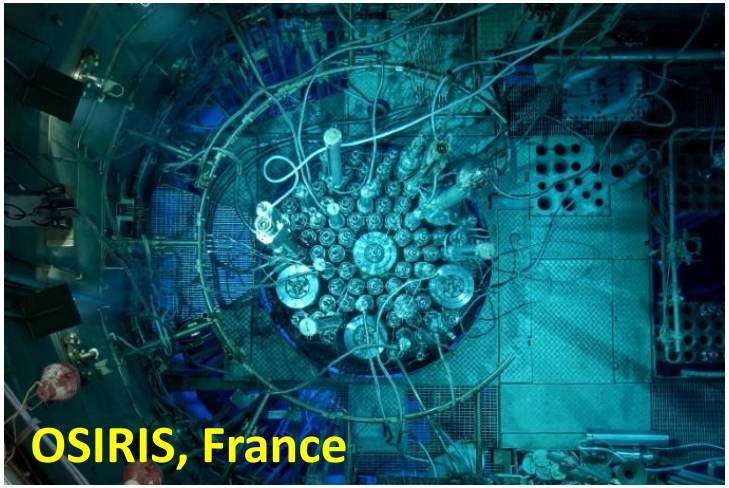
- **existence predicted in 1956 by Paul Kazuo Kuroda**
- **discovered in 1972 by French physicist Francis Perrin**

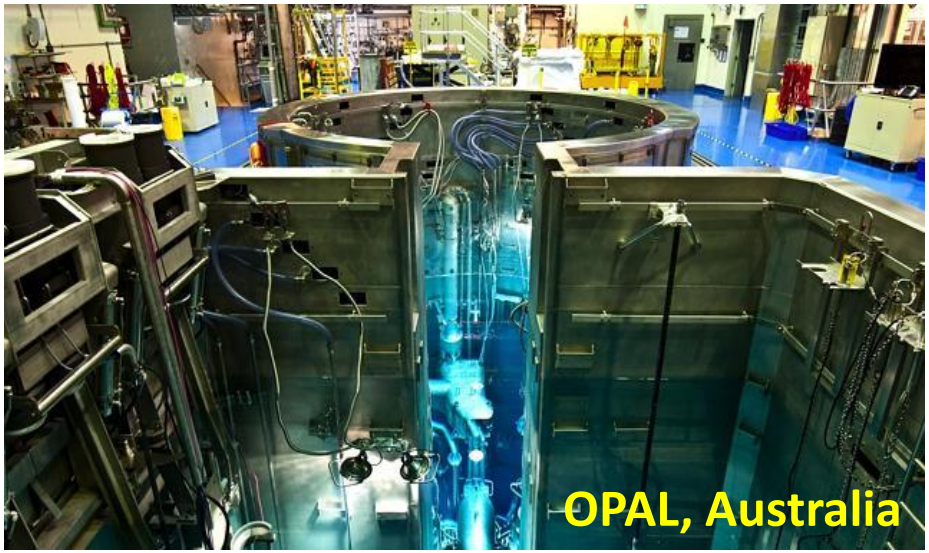
- **Location – Oklo, Gabon, Africa (consists of 17 sites), the only one in the world found so far.**
- **Evidence – anomalous uranium isotope content, showing loss of Uranium-235.**
- **Timing - reactions took place approximately 1.7 billion years ago and ran for a few hundred thousand years.**
- **Power - averaging 100 kW of thermal power during that time.**

Research Nuclear Reactor

Research (non-power) reactors are nuclear reactors that serve primarily as a neutron source:

- used for research and training, materials testing, or the production of radioisotopes for medicine and industry
- tend to be low power, low maintenance
- there are about 240 such reactors operating in 56 countries.


OSIRIS, France


OPAL, Australia

- Most common design of research reactors, called the pool type, has a core (fuel elements and control rods) immersed in an open pool of water; the layer of water directly above the reactor core shields the radiation so completely that operators may work close to the reactor safely.

This design is also known as Swimming Pool…