

MULTIMEDIA ON NUCLEAR REACTOR PHYSICS

Version 9.0

General Information





Javier Dies

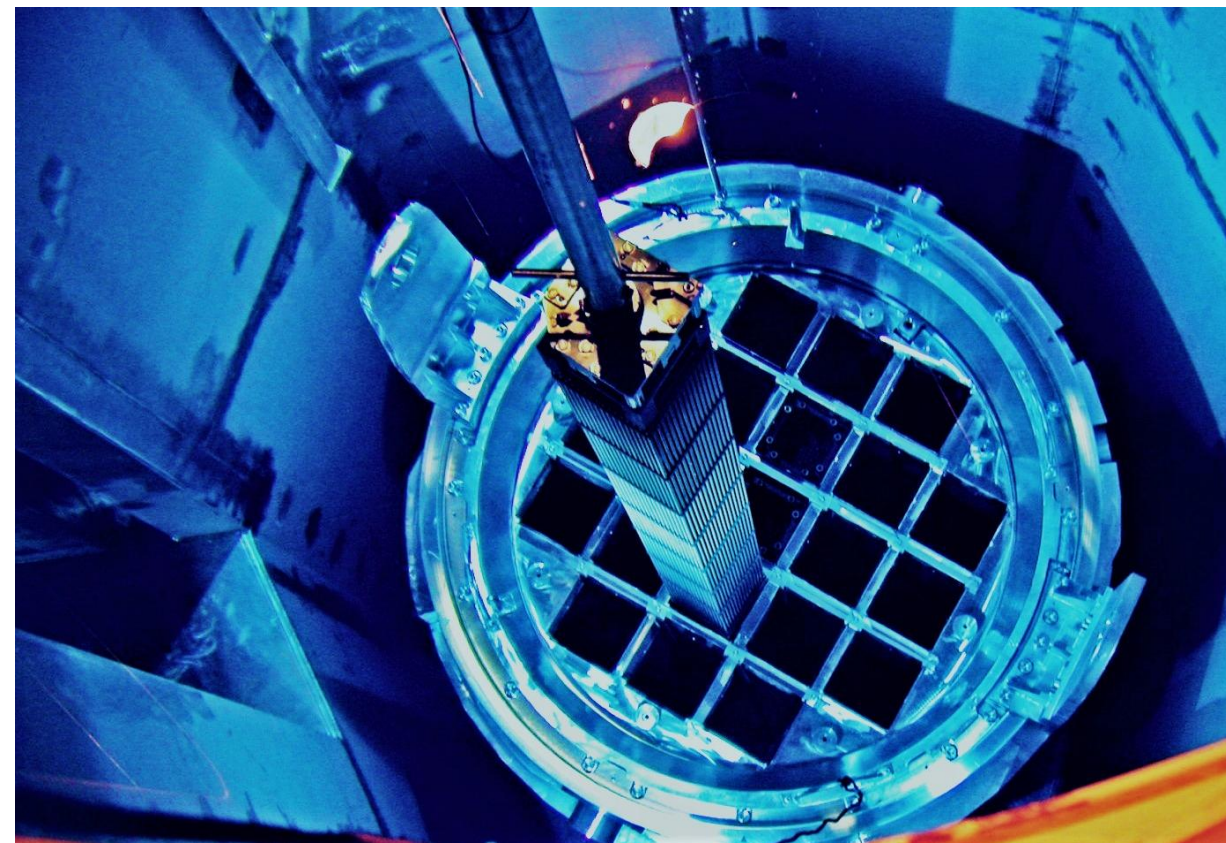
Professor Chair of Nuclear Engineering, Ph.D., UPC
(Currently on special leave)



 [Javier Dies - LinkedIn](#)



- The Multimedia on Nuclear Reactor Physics (MNRP) was developed in 2001 to enhance the quality of education and training in nuclear reactor physics.
- In some institutions, the course is referred to as Fundamentals of Nuclear Reactor Operation.
- Today, the Multimedia comprises approximately **730 slides**, with content available in six languages: **Spanish, English, French, Arabic, Chinese**, and **Russian**.
- To date, the Multimedia has been used in more than **134 countries**, reaching approximately **6,758 users**.
- Teachers use the Multimedia as a supporting tool during their lectures.
- Students use it independently at home to study and review the course material.





DISTRIBUTED TO 134 COUNTRIES

Albania, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bulgaria, Croatia, Cyprus, Czech, Denmark, Finland, France, Germany, Georgia, Greece, Hungary, Latvia, Lithuania, Luxemburg, Ireland, Italy, Macedonia, Moldova, Montenegro, Netherlands, Norway, Nord Macedonia, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, UK, Ukraine.

Argentina, Brazil, Bolivia, Canada, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Guatemala, Jamaica, Mexico, Nicaragua, Panama, Peru, Salvador, Trinidad y Tobago, Uruguay, USA, Venezuela, Virgin Islands.

Algeria, Angola, Botswana, Burkina Faso, Cameroon, Central African Republic, Congo, Egypt, Ethiopia, Ghana, Ivory Coast, Kenya, Lespitho, Liberia, Libya, Madagascar, Malawi, Morocco, Namibia, Niger, Nigeria, Rwanda, Senegal, Somalia, South Africa, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe.

Afghanistan, Bangladesh, Bhutan, Cambodia, China, Hong Kong, India, Indonesia, Iran, Iraq, Israel, Japan, Jordan, Kazakhstan, Korea, Kuwait, Laos, Lebanon, Malaysia, Mongolia, Myanmar, Nepal, Oman, Pakistan, Palestine, Philippines, Qatar, Saudi Arabia, Singapore, Sri Lanka, Syria, Uzbekistan, Taiwan, Thailand, Turkey, UAE, Vietnam, Yemen.

Australia, New Zealand

- Since the Multimedia was first developed in 2001, numerous updates have been implemented over the years, including content revisions, particularly in Chapter 1, the Introduction.
- The most recent and significant update has been the **migration from the now-obsolete Flash technology to HTML5**, providing a faster, more intuitive, and visually refreshed user experience.



Technical University of Catalonia (UPC), BarcelonaTech (Spain)
School of Engineering of Barcelona (ETSEIB)
Department of Physics and Nuclear Engineering (DFEN)
Nuclear Engineering Research Group (NERG)



MULTIMEDIA ON NUCLEAR REACTOR PHYSICS

Arabic Chinese
English Spanish
French Russian

Version 8.0

Javier Dies
Francesc Puig
Claudia Pereira




NEUTRON MULTIPLICATION IN A NUCLEAR REACTOR

Fission chain reaction

Two phenomena of great importance occur in nuclear fission. First, a release of a tremendous amount of energy and, secondly, the production of new neutrons. It is the combination of these two factors what makes the construction of a nuclear reactor possible, in which the fission chain reaction mechanism can be self maintained, providing at the same time a continuous release of energy.

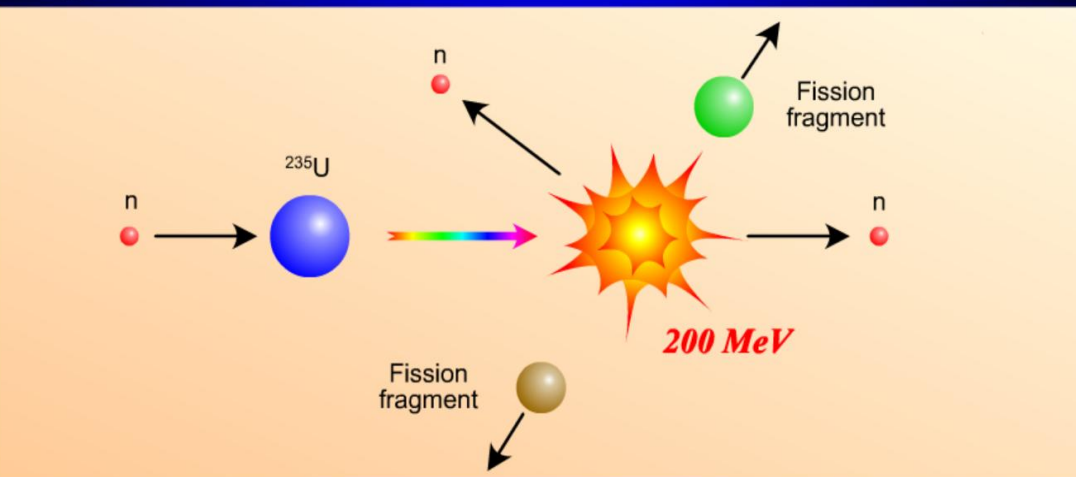


Figure 1 - Schematic illustration of ^{235}U fission reaction

Index

1 / 52

NEUTRON BALANCE

Diffusion and moderation of neutrons

- In order to design a nuclear reactor, there is need to known how neutrons are distributed in the system.
- The diffusion equation method is used for that purpose, and gives valid results for an initial rough estimate.

Neutron Flux



NEUTRON FLUX

$$F = \Sigma_t \cdot I$$

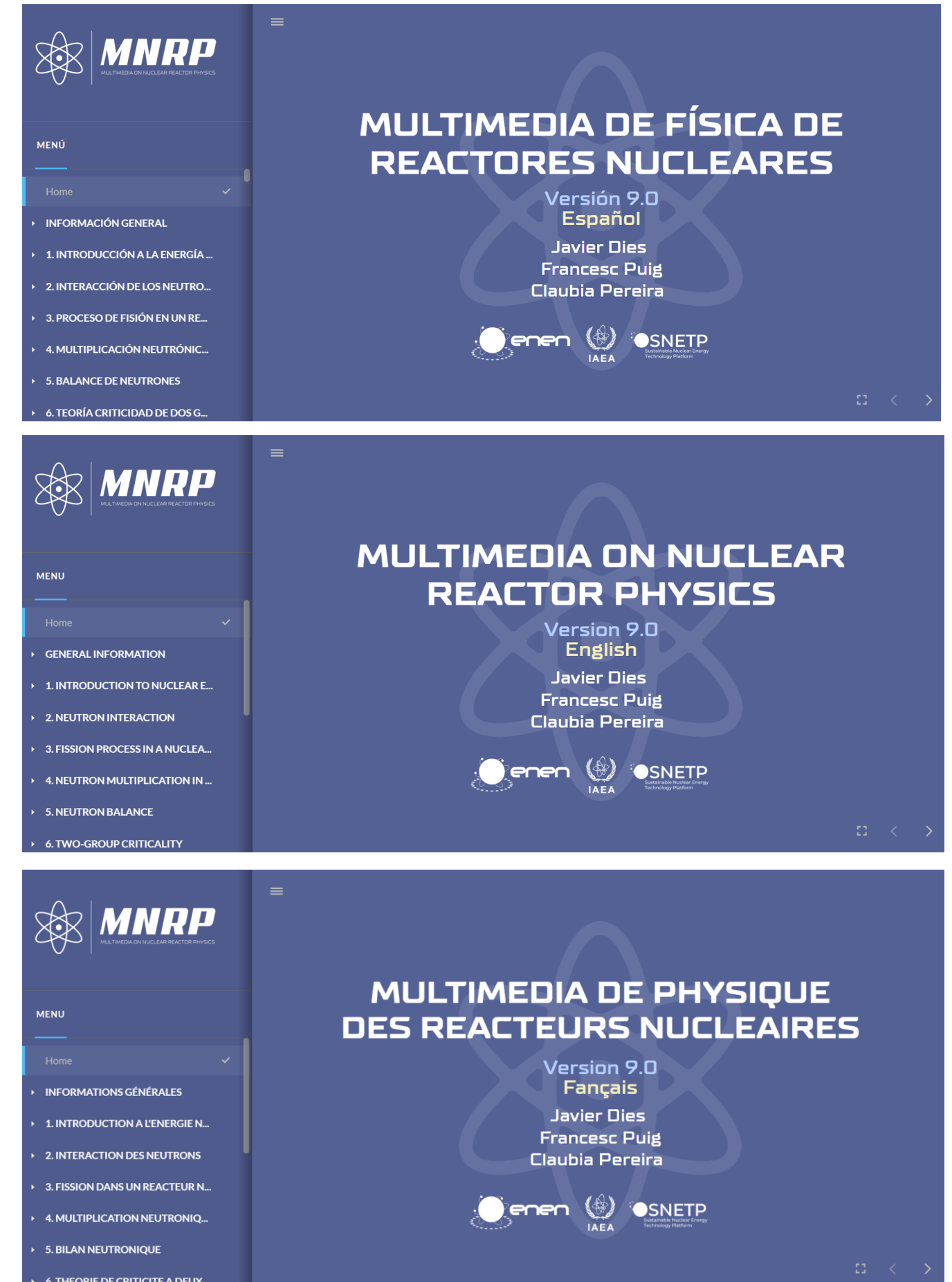
$\Sigma_t \rightarrow$ Macroscopic cross section (cm^{-1})
 $I \rightarrow$ Monoenergetic neutron beam intensity ($\text{cm}^{-2} \cdot \text{s}^{-1}$)
 $F \rightarrow$ Number of collisions ($\text{cm}^{-3} \cdot \text{s}^{-1}$)

Index

1 / 45

Sample Slides of the Multimedia 8.0 in Flash

- While Version 8.0, based on Flash, consisted of a single program containing all six languages, Multimedia 9.0 provides an **independent downloadable package for each language**.
- This approach significantly reduces the package size and allows users to download only the language version they require.



- Used since 2001 in the Nuclear Reactor Physics course at the Polytechnic University, Spain.
 - Master's Degree, Engineering Degree, and in the Nuclear Engineering specialization.
 - 60 hours – 5 ECTS credits.
 - Extended course: September to December, with final assessment in January.



- Used several times for the Fundamentals of Reactor Operation course at nuclear power plants in Spain.
- 60-hour training course, delivered in a compact format over two weeks.
- Used for:
 - New NPP employees with a university degree, including engineers, physicists, chemists, and computer scientists.
 - New nuclear power plant operators.
 - Refresher training for experienced operators.
 - Chapters 5 and 6 are omitted to adapt the course to the specific training objectives.



- The current version of the Multimedia MNRP includes an integrated self-evaluation program.
- It contains two tests:
 - **Test 1:** 14 questions covering Chapters 1–5.
 - **Test 2:** 15 questions covering Chapters 6–13.
- The tests are automatically graded, providing the user with the correct solutions and their score upon completion.



 **MNRP**

694/729

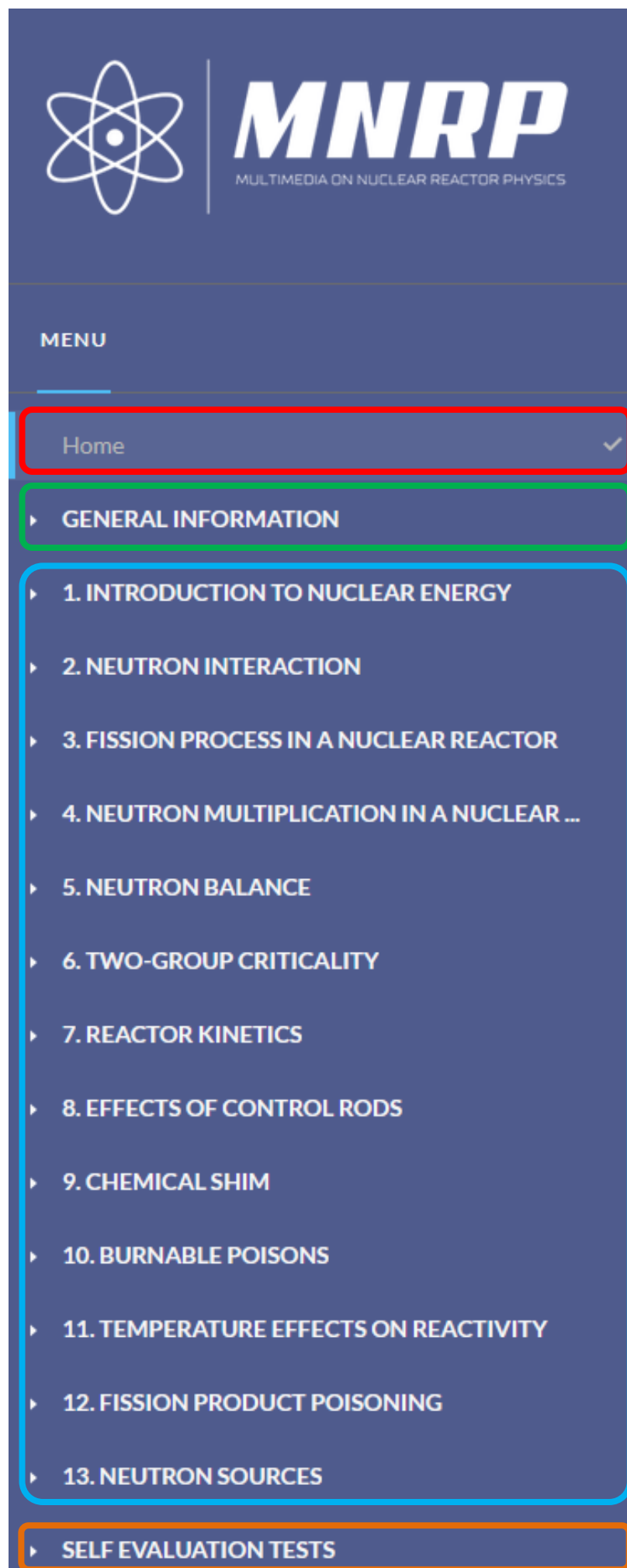
1. Which one is the correct sentence?

☐ A fast neutron is a neutron with at least 20 MeV of energy.

☐ A nuclear reaction between neutron + nuclei can produce a proton.

☐ In an elastic scattering reaction, a neutron is absorbed by the nuclei and later ejected with gamma radiation.

☐ The neutron moderation process is based in the radioactive capture reactions.



Title, version, language and authors



Information about the authors, developers, supporters and translators.



Technical content divided in 13 chapters.



2 self-evaluation tests.



MENU

Home ✓

▶ GENERAL INFORMATION

▶ 1. INTRODUCTION TO NUCLEAR ENERGY

▶ 2. NEUTRON INTERACTION

▶ 3. FISSION PROCESS IN A NUCLEAR REACTOR

▶ 4. NEUTRON MULTIPLICATION IN A NUCLEAR ...

▶ 5. NEUTRON BALANCE

▶ 6. TWO-GROUP CRITICALITY

▶ 7. REACTOR KINETICS

▶ 8. EFFECTS OF CONTROL RODS

▶ 9. CHEMICAL SHIM

▶ 10. BURNABLE POISONS

▶ 11. TEMPERATURE EFFECTS ON REACTIVITY

▶ 12. FISSION PRODUCT POISONING

▶ 13. NEUTRON SOURCES

▶ SELF EVALUATION TESTS

MULTIMEDIA ON NUCLEAR REACTOR PHYSICS

Version 9.0
English

Javier Dies
Francesc Puig
Claubia Pereira



INTRODUCTION TO NUCLEAR ENERGY

109/729

Small Modular Reactors (SMR)

Currently, there is significant interest in Small Modular Reactors (SMRs), which are advanced nuclear reactors that produce between 10 and 300 MWe per module. The following infographic outlines their main characteristics and advantages:

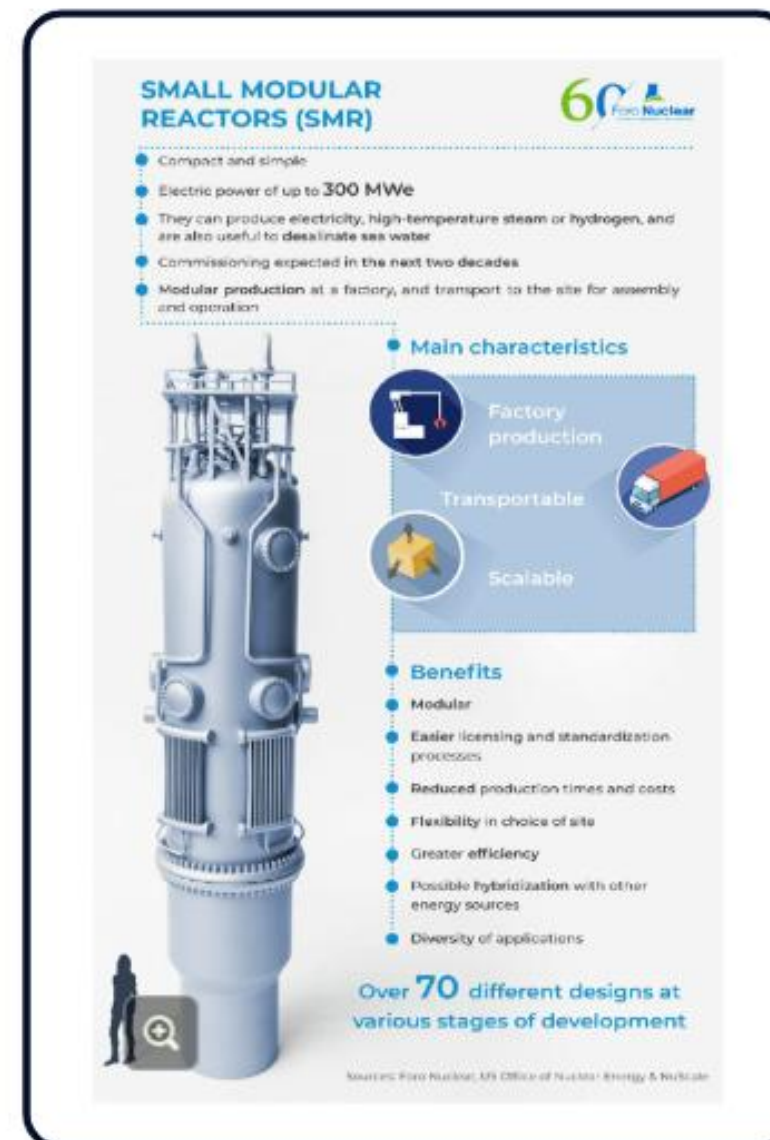
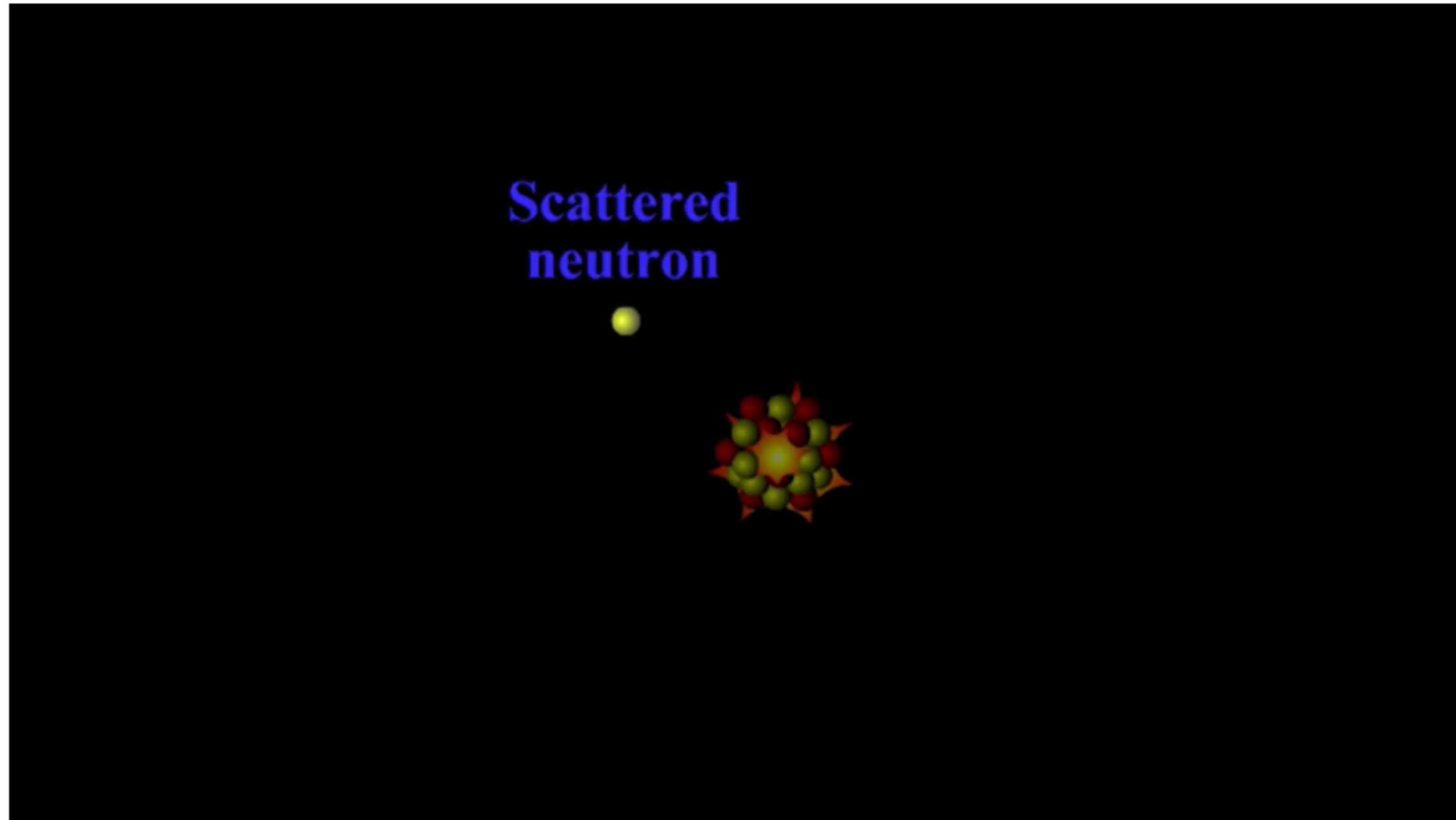


Figure 103 - Infographic about Small Modular Reactors

Elastic scattering and energy loss

In general, neutrons that are produced in nuclear reactions possess high kinetic energies, as a result of the nature and energy magnitudes involved in these type of reactions. By entering into a material medium, with an absolute temperature T , these neutrons suffer collisions with the nucleus of the medium atoms, and generally transfer part of their energy to those nuclei.



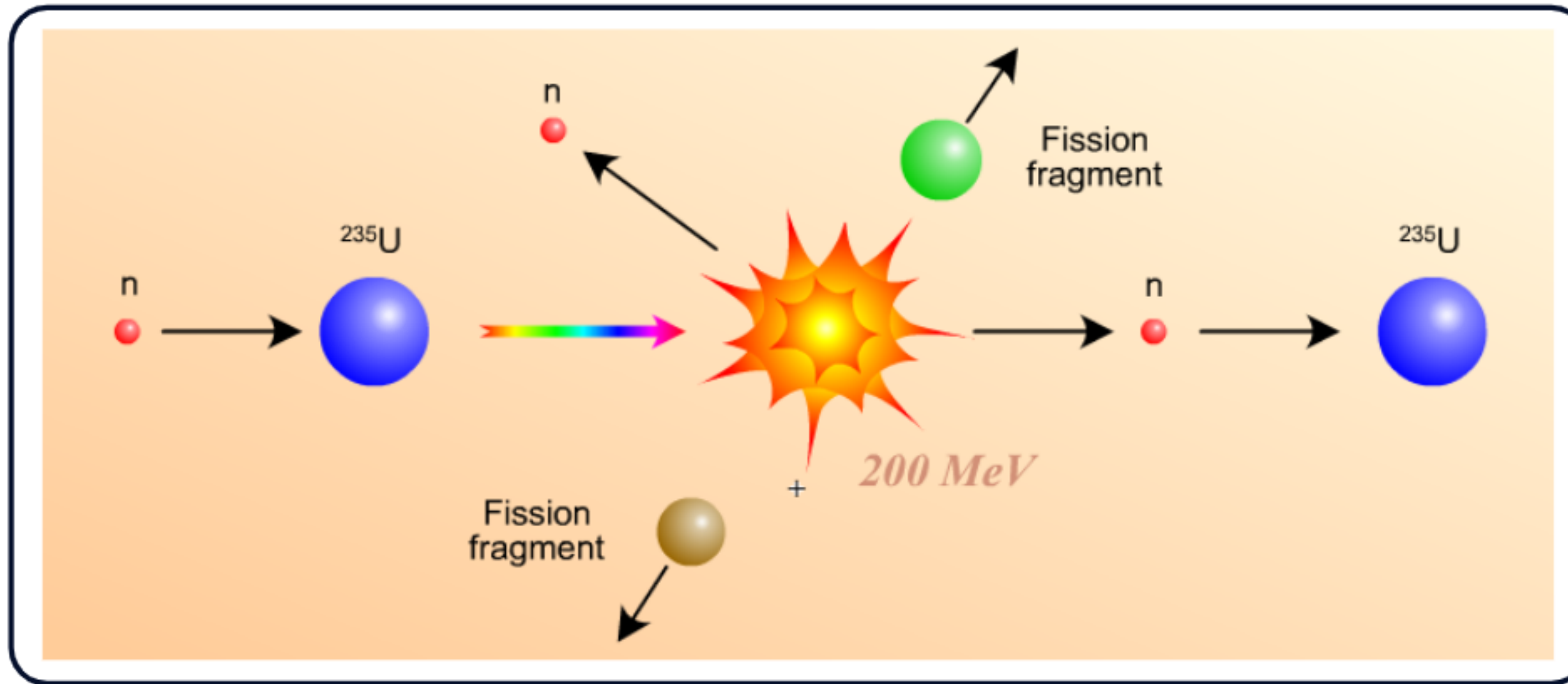


Figure 1 - Diagram of ^{235}U fission reaction

In nuclear fission the phenomenon is analogous to the one described before. The nucleus remains in its equilibrium configuration under the action of two opposing forces: the forces of instability, due to the Coulomb repulsion between its protons; and the stability forces, due to the nuclear attraction between the nucleons. When an excess of energy is received (e.g. the binding energy when a neutron is absorbed) a redistribution of this energy takes place among nucleons, and so then the nucleus starts vibrating. The amplitude of these vibrations can be such that it may cause the splitting into two or more smaller nuclei (there is a much higher prevalence of the division into two parts). The mechanism of fission is next described in greater detail.

The chain reaction is represented by the multiplication factor k , defined as the ratio between the number of fissions (or neutrons) of a given generation and the number of fissions (or neutrons) of the previous generation, or:

$$k = \frac{\text{number of fissions (or neutrons) of a given generation}}{\text{number of fissions (or neutrons) of the last generation}} \quad (1)$$

Depending on the value of k , three different situations can show up, represented in **Figure 3**:

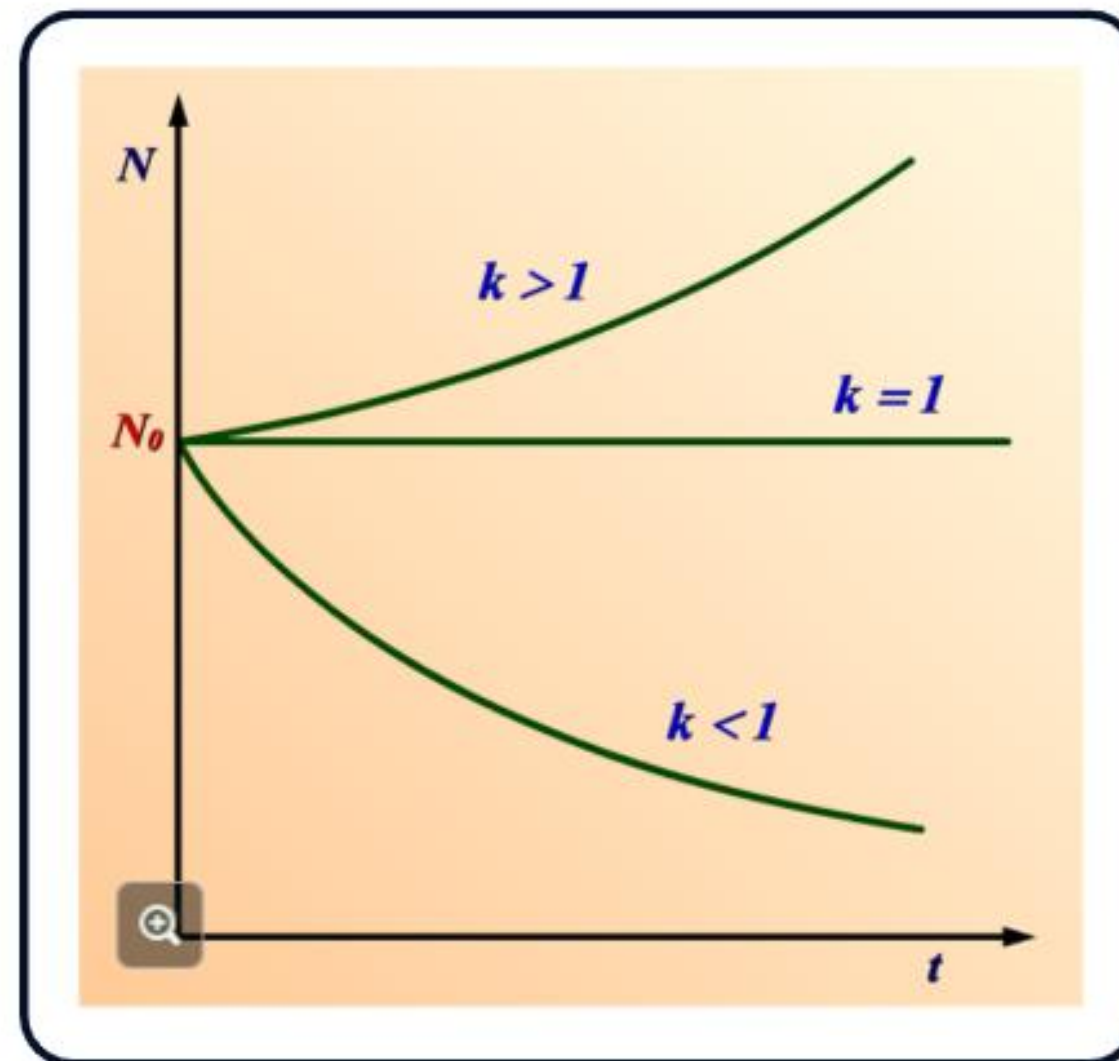


Figure 3 - Temporal evolution of neutron population in a reactor according to its effective multiplication factor k

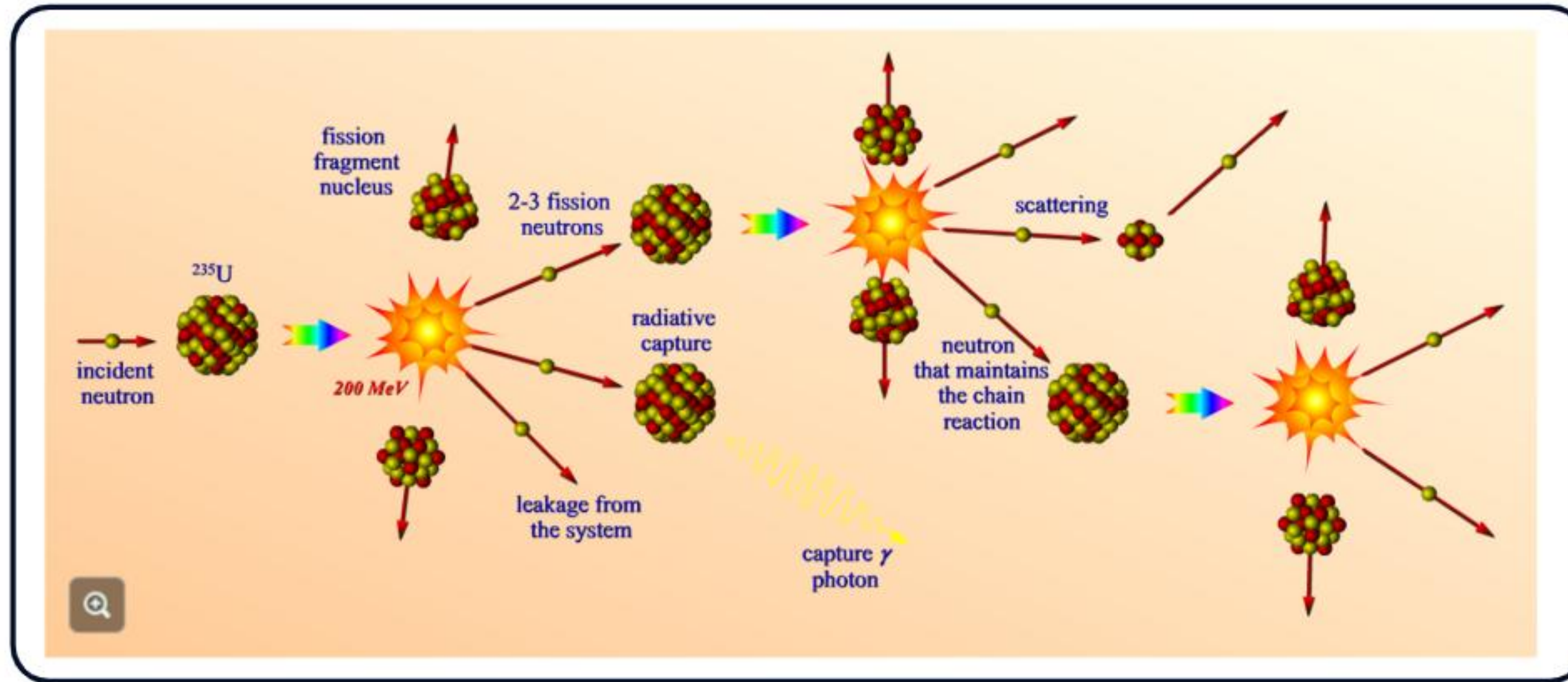


Figure 4 - Fission chain reaction

In order to adjust k to the desired value, the neutron production rate has to be adjusted with the rate of disappearance.

Neutrons from the reactor may disappear in two ways:

- (a)** escaping from the reactor through its surface and
- (b)** being absorbed by nuclear reactions and radiative capture reactions in the materials that constitute the reactor.

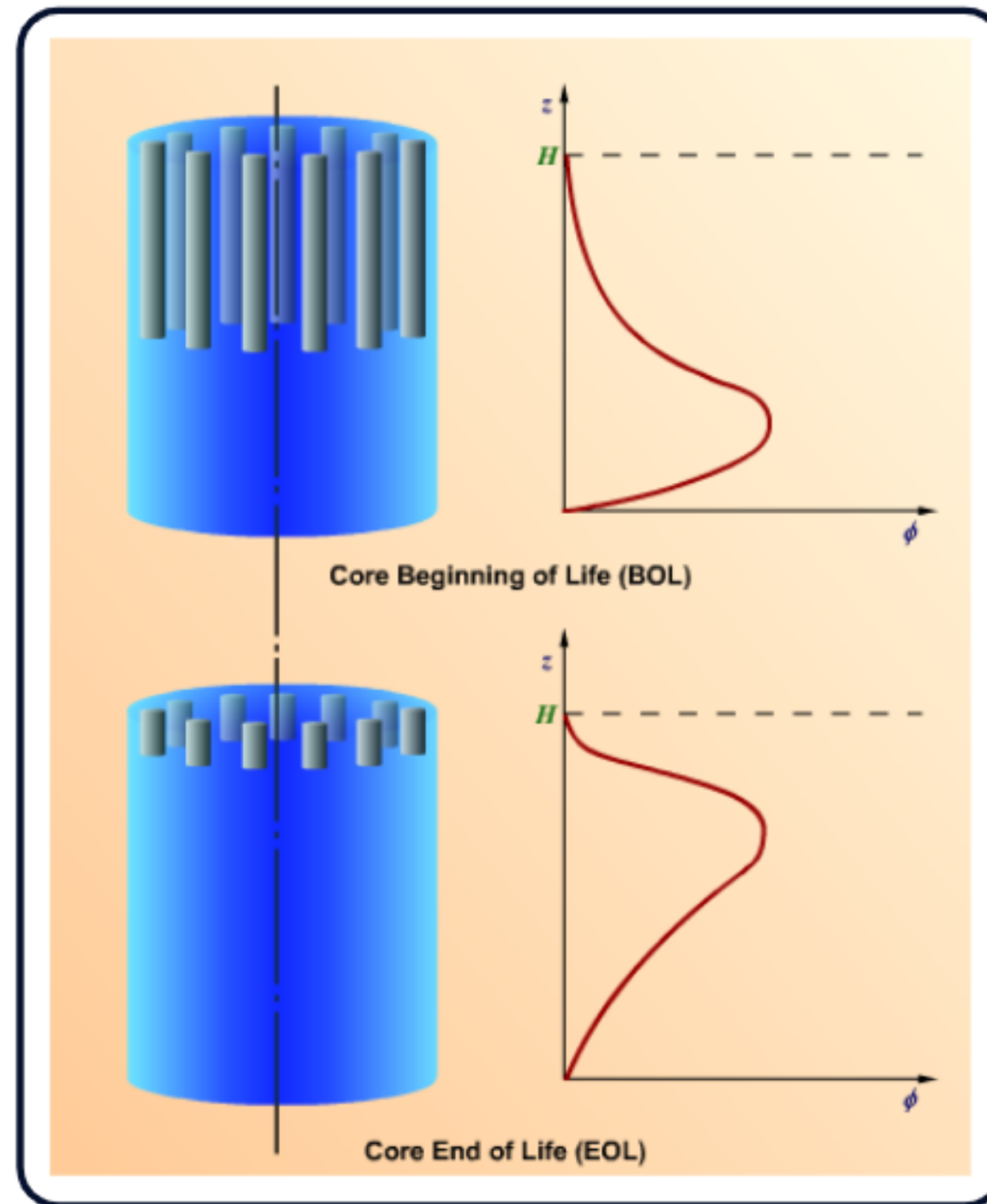


Figure 3 - Interaction between the insertion of control rods and flux profile

So, as fissions occur, consuming fuel, control rods are slowly withdrawn from the core, or the boric acid concentration is gradually reduced, to keep the reactor critical at the desired power level.

For example, if the dominant contributions on the temperature coefficient of reactivity were considered to be due to *Doppler broadening* of fuel resonances and due to changes in the neutron energy spectrum caused by variations in the moderator density, then:

$$\rho = \frac{k-1}{k} = 1 - \frac{1}{k}$$

Differentiating, and substituting in Eq. (4), leads to:

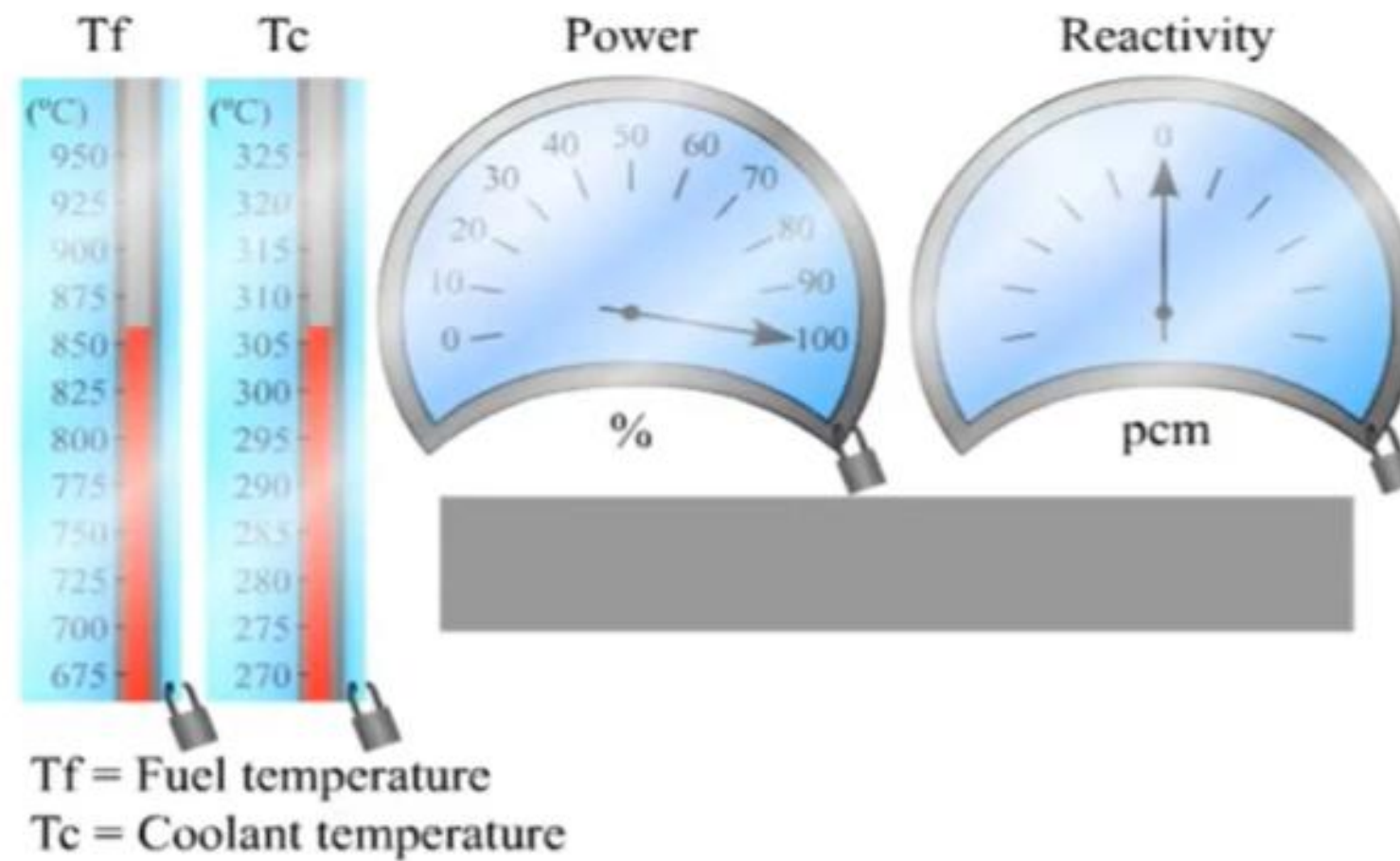
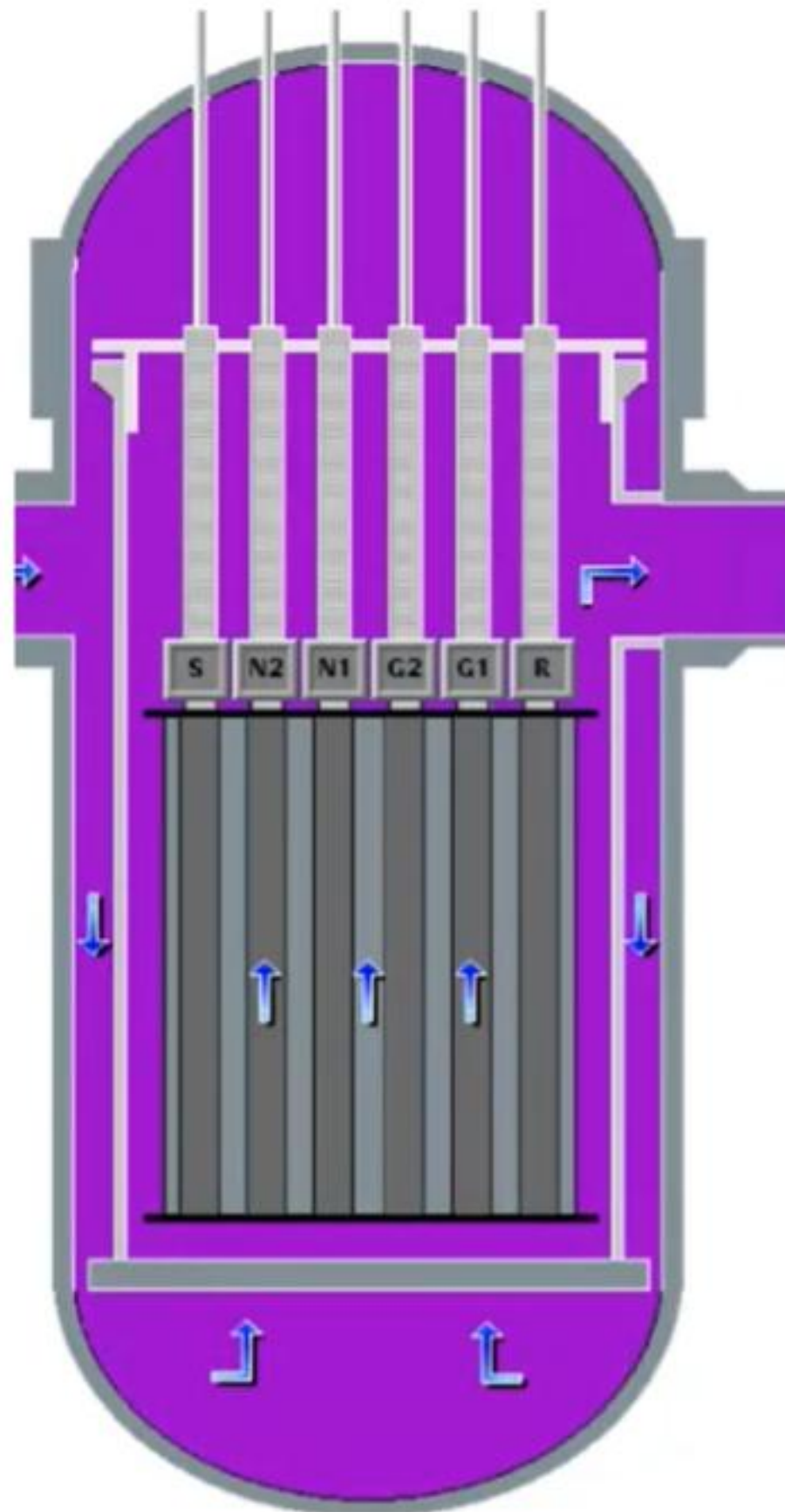
$$\alpha \equiv \frac{\delta \rho}{\delta T} \rightarrow \sum_j \frac{\delta \rho}{\delta T_j} = \sum_j \alpha_T^{(j)} \quad (4)$$

$$\alpha_T = \frac{1}{k^2} \cdot \frac{\delta k}{\delta T}$$

Based on the reactivity definition. As the multiplication factor is always very close to 1, then $k^2 \cong k$ and

$$\alpha_T \cong \frac{1}{k} \cdot \frac{dk}{dT} \quad (6)$$

Physically, Eq. (6) means that the temperature coefficient is the product of the multiplication factor variation fraction (dk/k) and the degree of temperature variation ($1/dT$), having therefore as unit the inverse of temperature (1/temperature degree).



Introduction

Certain water moderated reactors are partly controlled by varying the concentration of boric acid (H_3BO_3) dissolved into the moderator.

As this procedure adds a chemical product in the water with the purpose of controlling the reactor reactivity, this type of control is called chemical control.

When choosing both emitter isotopes and target nuclei, it is important to bear in mind that the alpha particle (with its two protons) must be able to reach the target nucleus, so it must overcome the potential energy barrier (*Coulomb barrier*) of the latter.

As shown in **Figure 1**, the repulsion between **2** protons of the alpha particle with **4** protons of the beryllium nucleus gives rise to a potential barrier of **4 MeV**. Therefore, disregarding the possible tunnel effect, the energy that is required for the incident α particle to succeed in colliding with the beryllium nucleus exceeds **4 MeV**.

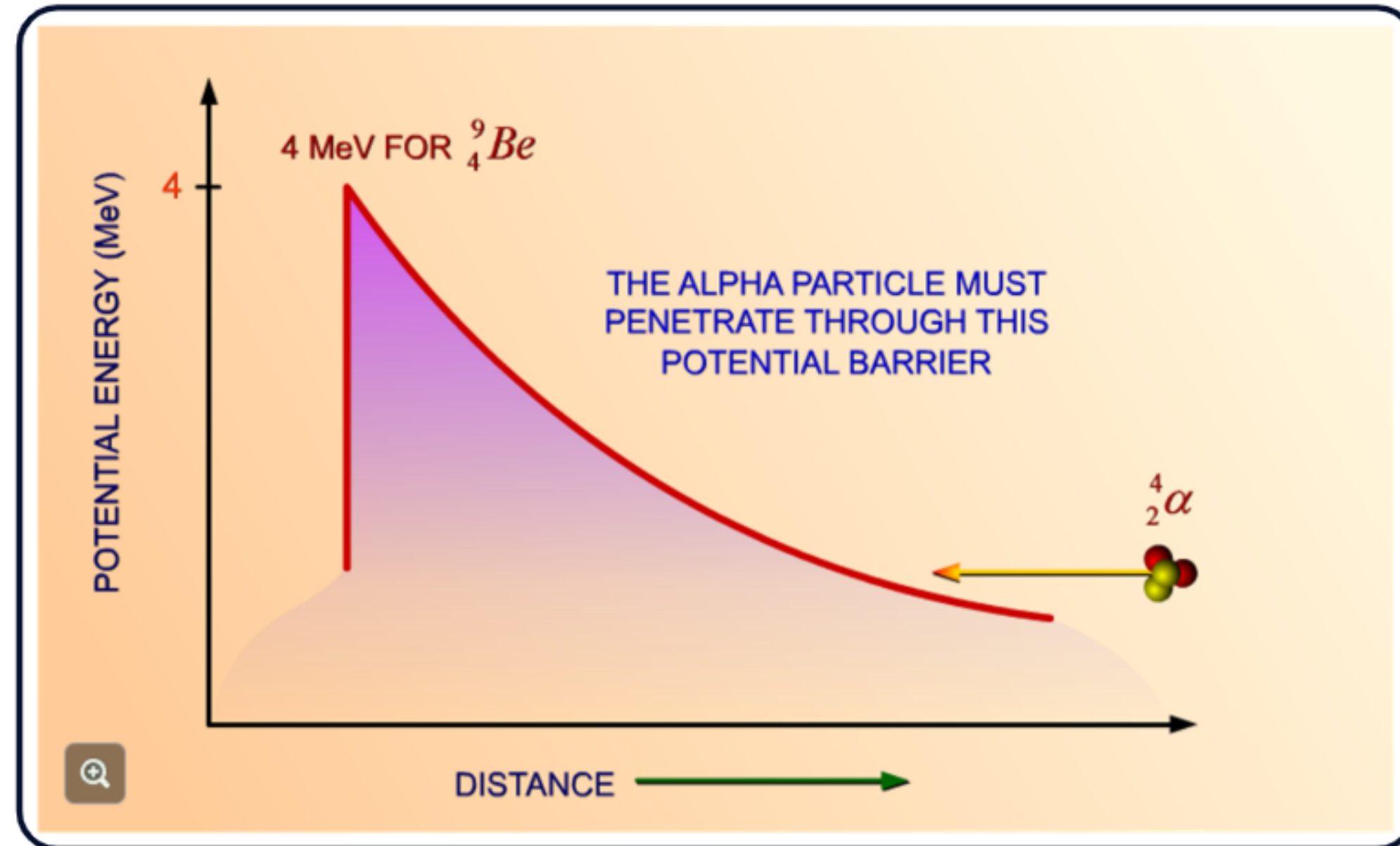


Figure 1 - Potential barrier of a beryllium nucleus against an alpha particle



MNRP

MULTIMEDIA ON NUCLEAR REACTOR PHYSICS