Chapter 1
Introduction

Since nuclear fission[1] was first discovered in 1938, scientists have taken a great interest in this property of matter which, when properly managed, can produce large amounts of energy that can be converted into electricity. To develop the use of this form of energy, it has been necessary over time to conduct numerous studies and experiments, mostly using research reactors, which are essential for acquiring knowledge and developing the techniques necessary to design and operate nuclear power plants under sufficiently safe conditions. But, in parallel, many other uses of research reactors have also developed.

For the purposes of this publication, the widely used English term "research reactor" is used, even though in France many of these facilities are known as "réacteurs d'experimentation" (experimental reactors). Research reactors are not to be confused with experimental or prototype nuclear power reactors, such as the EL[2]4 heavy water reactor in France (Brennilis nuclear power plant) or the Lucens nuclear power reactor in Switzerland. However, some nuclear power reactors will be discussed if experiments were or are being conducted there (e.g. PHENIX, a sodium-cooled fast neutron reactor used for electricity production) even though they are not strictly categorized as research reactors.

Research reactors are nuclear facilities used to supply intense neutron fluxes[3]. These reactors, which operate at low temperatures and pressures, are simpler than nuclear

1. Phenomenon whereby the nucleus of a heavy atom splits into two smaller nuclei due to the impact of a neutron.
2. *Eau lourde* in French.
3. Refers to the number of neutrons passing through a closed unit of area during a unit of time.

power reactors. They require little fuel and their fission product inventory[4] remains much lower. However, they require the use of a fuel that is much more highly enriched with uranium-235 than the fuel used in power reactors. The enrichment level of research reactor fuel can be as high as 20% uranium-235, or even 93% in some cases.

Since the divergence[5] of the first nuclear reactor (Chicago Pile-1) on 2 December 1942 by a team led by Enrico Fermi at the University of Chicago (the first divergence of a research reactor in France, the ZOÉ atomic pile[6], took place in December 1948), more than 800 research reactors have been or are being built throughout the world. Around 220 research reactors are in operation in nearly 55 countries. Their thermal power varies from 0 to 250 MW (compared to the thermal power of around 3,000 MW of a PWR producing 900 MWe of electricity), but, in the case of around 90% of them, it is below 10 MW. Their designs, modes of operation and uses are very diverse.

The many uses of research reactors include fundamental research and applied research (i.e. research with defined practical objectives), education and training of engineers and nuclear power industry personnel, and the production of radioisotopes for medical use. In the applied research field, research reactors have played a key role in the development of nuclear power reactor technologies, including the technologies of devices and systems that perform a safety role. Research reactors have made it possible to conduct studies of the neutron physics of power reactor cores and to test the behaviour of the fuels and materials in these reactors under the effect of irradiation. They have also enabled studies of accident situations to be conducted, up to and including fuel melt and the resulting transfer of fission products into the environment.

As regards safety, like all nuclear reactors, research reactors host a chain reaction that needs to be controlled, and they are therefore subject to all the risks associated with any other type of nuclear reactor (damage to the fuel, dispersion of radioactive substances, irradiation of personnel, etc.). But the nature and scale of those risks varies according to the research reactor and its uses. Consequently, safety analyses need to be conducted on a case-by-case basis, and the conditions in which different experiments are run must be checked to ensure that they are compatible with safety requirements.

However, there are some generic safety issues for research reactors. For many existing reactors (in operation), the service life for which they were designed has already been exceeded; 60% of them are more than 40 years old. Consequently, there are some particularly pressing issues to be attended to as regards the ageing[7] and obsolescence of certain components and the need for upgrading work, particularly to take account of more advanced knowledge of certain risks and changes in safety criteria.

Depending on type and use, research reactors can pose some specific problems regarding human and organizational factors. For example, conducting experiments in research reactors can involve many reactor core handling operations, including while the reactor is in operation.

4. Expression commonly used to refer to the quantities and types (isotopes) of fission products.
5. Nuclear divergence is the start of the nuclear chain reaction process in a nuclear reactor.
6. ZOÉ (ZerO Energy) an alternative name for the EL1 reactor.
7. Known as "ageing management". This concept will be discussed in more detail in paragraph 2.2.2.

This publication is in two parts:

- the first part gives a general overview of research reactors internationally and looks at some generic aspects of the safety of these reactors. The actions and work of the IAEA are presented, along with serious incidents and accidents and the reassessments carried out internationally following the accident at the Fukushima Daiichi nuclear power plant in 2011;
- the second part, which goes into more detail, looks specifically at French research reactors and at different aspects of their safety: the agencies involved in and the structural organization of safety monitoring in France, general safety objectives, principles and procedures, accidents taken into account for their design, experience feedback (including from the accidents at the Chernobyl and Fukushima Daiichi nuclear power plants), key improvements made during safety reviews, etc.