Establishment of a research reactor is a major project requiring careful planning, preparation, implementation, and investment in time and human resources. The implementation of such a project requires establishment of sustainable infrastructures, including legal and regulatory, safety, technical, and economic. An analysis of the needs for a new research reactor facility should be performed including the development of a utilization plan and evaluation of site availability and suitability. All these elements should be covered by a feasibility study of the project. This paper discusses the elements of such a study with the main focus on the specific activities and steps for developing the necessary safety infrastructure. Progressive involvement of the main organizations in the project, and application of the IAEA Code of Conduct on the Safety of Research Reactors and IAEA Safety Standards in different phases of the project are presented and discussed.

1. Introduction
For more than 60 years, research reactors (RRs) have been a cornerstone in the development and application of nuclear science and technology. The multi-disciplinary research that RRs can support has led to the development of numerous capacities in a wide variety of areas including nuclear power, radioisotope production for medical and industrial applications, neutron beam research, material development, and personnel training. In addition, some countries considered RRs an important step for the development of nuclear power reactors. Recently a number of countries have started planning to build their first RR as a tool to develop the necessary national infrastructure in the view of embarking on a nuclear power programme.

The introduction of the first RR in a country requires establishment of national sustainable infrastructures which cover a wide range of areas. These include legal and regulatory framework, siting, transport of equipment and supplies to the site, facilities for fuel handling and radioactive waste management, emergency preparedness, and facilities associated with the reactor applications as well as the human and financial resources necessary to implement the project and to ensure sustainable safe, secure, and efficient operation. In order to ensure establishment of the infrastructure elements, several activities should be completed during different phases of a RR project. The main characteristics of these phases are discussed in the following sections together with the elements of the nuclear safety infrastructure, and major safety activities that should be completed in different phases of the first RR project in a country.

2. Research Reactor Project Phases
The INSAG-22 report [1] establishes five phases for the development of a national safety infrastructure for a nuclear power programme. In line with the IAEA publication NG-G-3.1 [2], the first three phases cover the period from the point of initial consideration of embarking on a nuclear power programme to the point at which a country is ready to commission and operate the first nuclear power plant. Phases 4 and 5 are concerned with the operation and decommissioning stages, respectively. The same approach is adopted for the establishment of the first RR and necessary safety infrastructure. Figure 1 presents the initial three phases...
of the first RR project and the associated milestones. Phases 4 and 5 are not discussed in the present work.

Figure 1: Phases of implementation of the first RR project

Phase 1 is related to the pre-project activities which cover all considerations before a decision to launch a RR programme is taken. These considerations are consolidated in a form of a feasibility study showing the needs (or not) for a RR. Such a study is the main deliverable of this phase and based on its results, a country should be ready to make a knowledgeable commitment to proceed (or not) with the introduction of the first RR (Milestone 1). The activities of Phase 2 cover the preparatory work for the reactor construction, including the establishment of the legal framework, regulatory body, and operating organization which should be able to select the preferred site for the reactor, develop the bid technical specifications, and be ready at the end of this phase to invite bids (Milestone 2). During Phase 3 the activities for implementing the RR project should be completed, including finalization of the design and construction stages with the relevant licensing activities. By the end of Phase 3 the RR should be ready for commissioning (Milestone 3).

Experience has shown that the duration of implementing the activities corresponding to these three phases may be up to approximately ten years, depending upon the existing infrastructure at the beginning of the project and resources available for the project. The duration also depends on the reactor type, size, intended utilization programme, and contract methodology (i.e. turn-key or contracts with different levels of national participation), and may be reduced significantly in the case of low power RRs dedicated to education and training. Similarly, a graded approach may be used in the implementation of the activities of different phases. While all the safety requirements associated with these activities should be considered, their application may be graded based on the potential hazard of the reactor.
3- Elements of nuclear safety infrastructure

The nuclear safety infrastructure is defined as the set of institutional, organizational and technical elements and conditions established to provide a sound foundation for ensuring a sustainable high level of nuclear safety [1]. The establishment of this infrastructure should start early in the process of developing the RR through effective application of the provisions of the IAEA Code of Conduct on the Safety of Research Reactors [3], and by making use of the IAEA Safety Standards. This is to ensure that relevant activities are conducted in a safe manner during different stages of the reactor lifetime, which cover siting, design, procurement and construction, commissioning, operation, utilization and decommissioning. According to the structure of the IAEA Safety Standards, the elements of the nuclear safety infrastructure can be defined as presented in Table 1, which also indicates references to the IAEA main Safety Standards which support the establishment of the infrastructure elements.

Table 1: Elements of the safety infrastructure with the corresponding IAEA main supporting Safety Standards

<table>
<thead>
<tr>
<th>Elements of the safety infrastructure</th>
<th>IAEA main supporting Safety Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global nuclear safety regime [4,5]</td>
<td>Safety assessment [4,8]</td>
</tr>
<tr>
<td>Legal framework [4,5]</td>
<td>Safety of radioactive waste, spent fuel management and decommissioning [4,9]</td>
</tr>
<tr>
<td>Human resources development [4, 6]</td>
<td>Transport safety [12]</td>
</tr>
<tr>
<td>Research on safety for regulatory process [6]</td>
<td>Interfaces with nuclear security</td>
</tr>
</tbody>
</table>

The level of application of the IAEA Safety Standards and involvement of the government and other organizations will normally increase progressively during the different phases of developing a RR programme. While all the activities of Phase 1 are performed by the government, the operating organization and regulatory body (being established at the beginning of Phase 2) are responsible to implement the activities corresponding to this phase. The involvement of these organizations will increase gradually along Phase 2. However, the level of involvement of the regulatory body will be relatively higher due to its responsibility for establishing the safety requirements for different activities beforehand. The involvement of the operating organization, which has the prime responsibility on safety, will increase along Phase 3. The involvement of the government will be reduced significantly during Phases 2 and 3, and will include mainly support of maintenance and improvement of some infrastructure elements such as national policy and strategy, global nuclear safety regime, legal and regulatory framework, funding and financing, safety management, emergency preparedness and radioactive waste management including decommissioning.
4- Major safety activities in the different phases of building the first RR

The major safety activities in the different phases of building the first RR in a country are presented in Figure 2. The IAEA Safety Standards establish the safety requirements for the implementation of these activities and should be applied progressively during the different phases of building a RR. Figure 2 also indicates the required level of application of the IAEA Safety Standards (i.e. awareness of the requirements, requirements under implementation, and requirements fully implemented). Detailed discussions of these activities are presented in the following sections.

Figure 2: Major safety related activities in different phases of building the first RR and illustration of progressive application of the IAEA Safety Standards

4.1. Major safety activities in Phase 1

Experience has shown that a robust utilization plan was not always a part of the decision making process for determining whether a RR should be built, or should continue to operate, in a long term run. It is therefore essential at the initial stage to perform a feasibility study
justifying the need for a RR in accordance with Principle 4 (Justification of Facilities and Activities) of the Fundamental Safety Principles [13]. It is also necessary to have a clear definition of the reactor purpose, utilization, and users as well as pre-selection of the reactor type and size including experimental facilities. The feasibility study should consider the advantages and disadvantages of utilizing alternative technologies (e.g. spallation neutron source and cyclotrons), and possible use of the RRs existing in the region.

The feasibility study should also address the government commitment to adhere to the international obligations and to apply the provisions of the IAEA Code of Conduct on the Safety of Research Reactors, including the need to:

- Consider various safety principles that are applied to the development of the RR;
- Establish an effective legal and regulatory framework for safety, including an independent regulatory body, and an operating organization with prime responsibility on safety;
- Establish a sustainable financing system for all activities related to safety, both from an operational and regulatory point of view;
- Establish an effective management system and provide for a strong leadership capabilities and foster safety culture within the involved organizations;
- Provide for adequate arrangements for building the technical competence of the involved organizations;
- Develop and implement a national strategy for long-term radioactive waste and spent fuel management and decommissioning of the facility;
- Provide for adequate arrangements for emergency preparedness and response.

In addition, an initial site survey should be an essential part of the feasibility study. The initial site survey includes identification of potential and preferred candidate site(s) according to established criteria and on the basis of the existing data. Identification of the preferred candidate site(s) should be supported by a radiological impact assessment, which should also be a part of the feasibility study.

4.2. Major safety activities in Phase 2

Once the decision to build the RR has been made, based on the results of the feasibility study, the activities to establish the necessary safety infrastructure should proceed during Phases 2 and 3. The highest priority is given to enacting the essential elements of the legal framework including establishment of an effective and independent regulatory body and the operating organization. During this phase the regulatory body should establish a licensing process for the RR, specifying the documentation and procedures in the various steps. Establishment of a suitable working relationship between the regulatory body and operating organization, and early involvement of the regulatory body in the process, including specification of the safety requirements needed for the bidding process, are essential for successful implementation of the project.

During this phase, the decisions that need to be made by the operating organization typically include the type, size, and safety features of the RR to be built as well as the associated experimental facilities. The operating organization should also proceed with the reactor site evaluation and selection. The site parameters which are needed for the reactor design and operation should be identified and included in the technical specifications of the bid. Attention should be given to the availability of expertise in site selection, bidding, and evaluation of the technical offers from different vendors.

Development of human resources and competences is a high priority task in this phase. The regulatory body should start developing the necessary competences in establishing regulations and performing regulatory review, licensing and inspection. It is also essential
that the operating organization start developing the knowledge and skills through specialized training (and even fundamental education to some extent). The needed competences include performance of safety assessment, reactor commissioning, operation, maintenance, and utilization in compliance with the safety requirements. In addition to these topics, specialized training is also needed in reactor physics, thermal-hydraulics, radiation protection, core management and fuel handling, quality assurance, and safety culture. Such training requirements could be obtained from the reactor vendor in accordance with the technical specifications of the bid.

4.3- Major safety activities in Phase 3

This phase consists of intensive activities to build the RR. One of the first activities in this phase is the technical evaluation of the bids. In this regard, the operating organization should ensure adequate safety review of the design proposed by the vendors in the submitted bids. Adherence of the design to the IAEA Safety Standards should be one of the criteria established for the selection of the winning bid. The project execution schedule should include hold points for regulatory review and verification that the activities of safety significance are properly implemented.

This phase requires significant development and training for all levels of staff. Recruitment of the operation and maintenance personnel should begin early in this phase. The participation of reactor staff in different activities of this phase including design review, construction activities, and development of operating documents will have a positive impact on safety and effective utilization of the reactor. It will also help development of a safety culture and acceptance of the responsibilities for the transferred systems at the end of Phase 3. It is beneficial to include in the project organization chart a group (or individual) responsible for human resources development, whose duties will include establishing links with the vendor to ensure knowledge transfer to the operating organization and adequate training of the reactor staff.

Preparation of the Safety Analysis Report (SAR) should start as early as possible in the design stage. The operating organization should ensure proper interaction with the reactor designer in the preparation of the safety documents. The SAR, including a comprehensive safety assessment, Operational Limits and Conditions (OLCs) and specification of the codes and standards which provide acceptable reference for design and construction, is the main safety document for the licensing process. The regulatory body, prior to issuing the construction license, should assess the SAR and verify that the relevant safety requirements can be met.

During the construction stage, the operating organization should ensure adequate involvement in the construction process to ensure that the safety systems and components are constructed according to the approved design. A process should be in place, in accordance with the management system, to address changes in the design during the construction, and maintain the knowledge on the design and construction during the lifetime of the reactor. These items should also be verified by the regulatory body.

In addition to the commissioning programme, all the management programmes for operation should be developed during this phase. These include the operating procedures, maintenance, periodic testing, and inspection programmes. The operational radiation
protection programme and the emergency plan should be fully implemented at the time fuel is received at the reactor building. The corresponding chapters of the SAR should be prepared by the operating organization and assessed by the regulatory body during preparation for commissioning.

5. Conclusion
The decision to build a RR should be based on a study showing the feasibility of the reactor. The study should evaluate the real needs, utilization programme, and availability of a suitable site. It should also show the commitment to establish the necessary safety and technical infrastructures. Establishment of such infrastructures should start early in the process and should be achieved progressively during the different phases of the project through effective application of the IAEA Code of Conduct on the Safety of Research Reactors and by making use of the IAEA Safety Standards.

Through the lifetime of the RR, periodic safety reviews aiming at ensuring high level of safety should be performed to deal with cumulative effects of reactor ageing, modifications, changes in utilization programme or installation of new experimental devices, operating experience feedback, and changes in safety requirements, as well as site-related aspects.

6. References