IAEA Nuclear Energy Series

No. NP-O

Basic Principles

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Nuclear Power Objectives: Achieving the Nuclear Energy Basic Principles

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Under the terms of Articles III.A and VIII.C of its Statute, the IAEA is authorized to foster the exchange of scientific and technical information on the peaceful uses of atomic energy. The publications in the **IAEA Nuclear Energy Series** provide information in the areas of nuclear power, nuclear fuel cycle, radioactive waste management and decommissioning, and on general issues that are relevant to all of the above mentioned areas. The structure of the IAEA Nuclear Energy Series comprises three levels: **1 — Basic Principles and Objectives; 2 — Guides; and 3 — Technical Reports.**

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All users of the IAEA Nuclear Energy Series publications are invited to inform the IAEA of experience in their use for the purpose of ensuring that they continue to meet user needs. Information may be provided via the IAEA Internet site, by post, at the address given above, or by email to Official.Mail@iaea.org.

NUCLEAR POWER OBJECTIVES: ACHIEVING THE NUCLEAR ENERGY BASIC PRINCIPLES

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

IAEA NUCLEAR ENERGY SERIES No. NP-O

NUCLEAR POWER OBJECTIVES: ACHIEVING THE NUCLEAR ENERGY BASIC PRINCIPLES

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FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world". To fulfil this objective, the IAEA publishes technical guides, reports on technology status and advances, and best practices for nuclear power plant operation based on inputs from international experts. These publications are included in the IAEA Nuclear Energy Series.

The Nuclear Energy Basic Principles is the apex publication in the IAEA Nuclear Energy Series. It describes the rationale and vision for the peaceful uses of nuclear energy, and presents the basic principles on which nuclear energy systems should be based to fulfil nuclear energy's potential to help meet growing global energy needs.

To establish the criteria needed to satisfy the Basic Principles, the IAEA Nuclear Energy Series includes publications presenting objectives for four areas: general nuclear issues ('Nuclear General'), 'Nuclear Power', 'Nuclear Fuel Cycle', and 'Radioactive Waste Management and Decommissioning'. This publication sets out the objectives that need to be achieved in the area of nuclear power to ensure that the Nuclear Energy Basic Principles are satisfied.

The IAEA expresses its gratitude to the many experts who contributed to the drafting of this publication. The IAEA officers responsible for this publication were J. Cleveland and P. Vincze of the Department of Nuclear Energy.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

The IAEA's Nuclear Energy Basic Principles publication [1] presents the basic principles on which nuclear energy systems should be based to fulfil nuclear energy's potential to help meet growing global energy needs. These principles are intended to provide a broad and holistic approach to the use of nuclear energy and to be equally applicable to all essential elements of the nuclear energy system, including human, technical, management and economic aspects, with due regard to protection of people and the environment, non-proliferation and security.

The following paragraphs present an overview of the Basic Principles.

Beneficial uses

— **Benefits.** The use of nuclear energy should provide benefits that outweigh the associated costs and risks.
— **Transparency.** The use of nuclear energy should be based on open and transparent communication of all its facets.

Responsible use

— **Protection of people and the environment.** The use of nuclear energy should be such that people and the environment are protected in compliance with the IAEA safety standards and other internationally recognized standards.
— **Security.** The use of nuclear energy should take due account of the risk of the malicious use of nuclear and other radioactive material.
— **Non-proliferation.** The use of nuclear energy should take due account of the risk of the proliferation of nuclear weapons.
— **Long term commitment.** The use of nuclear energy should be based on a long term commitment.

Sustainable use

— **Resource efficiency.** The use of nuclear energy should be efficient in using resources.
— **Continual improvement.** The use of nuclear energy should be such that it pursues advances in technology and engineering to continually improve

safety, security, economics, proliferation resistance, and protection of the environment.

1.2. PURPOSE AND SCOPE

This publication establishes the criteria that need to be fulfilled in order to satisfy the Nuclear Energy Basic Principles in the area of nuclear power for each of the following topics: technology development, design and construction of nuclear power plants, operation of nuclear power plants, non-electrical applications, and research reactors.

1.3. DERIVATION OF THE NUCLEAR POWER OBJECTIVES

The objectives for the topics of ***technology development*** and the ***design and construction of nuclear power plants*** are drawn from collaborative evaluations [2] by experts[1] who advise the IAEA on the development of advanced reactors and their applications, from user requirements [3, 4] for advanced reactors, from advanced reactor development programmes being conducted in several countries expecting to expand their nuclear power programmes [5], and from the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) [6].

The objectives for the ***operation of nuclear power plants*** have been established through evaluations of the IAEA's Technical Working Groups (TWGs) on Life Management of Nuclear Power Plants (TWG–LM) and the Control of Instrumentation of Nuclear Power Plants (TWG–C&I). These objectives are intended to provide global expertise and a focus on excellence in the areas of the integration of plant life management programmes and economic planning to: maintain a high level of safety; optimize the operation, maintenance and service life of systems, structures and components; maintain an acceptable performance level; maximize return on investment over the service life of the nuclear power plant; and provide operating organizations and owners with the optimum preconditions for achieving operation beyond the initial design life.

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[1] These are the Technical Working Groups (formerly called International Working Groups) on Advanced Technologies for Light Water Reactors (LWRs), Heavy Water Reactors (HWRs), Gas Cooled Reactors (GCRs) and Fast Reactors (FRs), and the International Nuclear Desalination Advisory Group.

The objectives for ***non-electrical applications*** have been developed on the basis of advice from the IAEA's International Nuclear Desalination Advisory Group (INDAG), the reactor-line TWGs and nuclear hydrogen production experts.

The objectives for ***research reactors*** have been developed from the needs of research reactors as identified in IAEA meetings; recommendations from the IAEA Conference on Research Reactor Utilization, Safety, Decommissioning, Fuel and Waste Management, and international conferences on research reactor fuel management and reduced enrichment for research and test reactors.

2. DESCRIPTION OF THE NUCLEAR POWER OBJECTIVES

The objectives for each topic within the area of nuclear power are described in accordance with the sequence in the Basic Principles publication [1].

2.1. OBJECTIVES FOR TECHNOLOGY DEVELOPMENT

Basic Principle: Benefits

Objective: Develop technologies to improve the economic competitiveness and investment attractiveness of nuclear power.

Technical approaches to improve economic competitiveness include the following general categories: (a) developing plants with capacities tailored to user needs; (b) implementing advanced construction methods to shorten the schedule and reduce construction costs; (c) developing improved materials to ensure a high level of reliability and long lifetime of systems, structures and components; (d) developing technologies leading to plant simplification, such as the use of passive safety systems when the safety function can be met more economically by them than by active systems; (e) developing highly reliable components and systems, including 'smart' components and systems which are instrumented and monitored for detecting incipient failures; (f) improving the technology base (i.e. more accurate databases of thermal hydraulic relationships and thermo-physical properties, continued verification and validation of nuclear data as well as neutronic and thermal hydraulics computer codes); and (g) development of systems with higher thermal efficiency. Economic benefits also derive from technologies that allow a high degree of involvement of local industry and labour in plant construction, operation and maintenance.

It is important to note that technologies to improve economic competitiveness and investment attractiveness of nuclear power can provide benefits for other industries and generally encourage the development of skilled human resources.

Basic Principle: Transparency

Objective: Provide accurate and clear information to all stakeholders on research and development goals and achievements.

Effective communication, including information transfer to and among all stakeholders (research institutes, plant operating organizations, the public, the regulatory authority and other governmental entities), ensures understanding of technology development status and trends. By nature, development goals generally cover both the near and the long term, and both of these aspects should be effectively communicated to stakeholders. It is important for communication to flow in both directions so that the interests of all stakeholders are considered in planning technology development programmes.

Openness and communication with the institutions responsible for the planning and implementation of educational programmes can help to ensure that nuclear science and technology are appropriately included in education.

Basic Principle: Protection of People and the Environment

Objective: Develop technologies to achieve continued advancements in safety, reduction of adverse environmental impacts and reduction of waste generation.

Development programmes should be carried out to achieve advancements in technology for nuclear power plant safety, both to improve the means of preventing accidents and to mitigate the consequences of accidents should they occur.

Adverse environmental impacts to be addressed by technology development include releases of radioactivity and hazardous non-radioactive material as well as waste heat.

Technical developments to minimize waste generation include reduction in the number of waste containing components and reduction of the necessary operations involving irradiated nuclear fuel.

Basic Principle: Security

Objective: Develop technologies and design features which strengthen security characteristics of nuclear power plants.

The IAEA has set up a framework for cooperative efforts to build and strengthen an international safety and security regime. Technologies and design features that help States to protect nuclear installations against sabotage should be pursued [7, 8]. For example, to address sabotage protection, the IAEA has published guidelines [9] for evaluating the engineering safety aspects of the protection of nuclear power plants against sabotage, including standoff attacks[2].

Basic Principle: Non-Proliferation

Objective: Develop technologies and design features which strengthen non-proliferation characteristics of nuclear systems.

Technologies should be encouraged which minimize the use of materials with the potential of abuse for non-peaceful purposes. In addition, technologies should be encouraged which inhibit the undeclared production of nuclear material or which complicate access to nuclear material.

Basic Principle: Long Term Commitment

Objective: Develop technologies to support the sustainability of nuclear power.

Sustainable energy is energy from any source — including nuclear power — that during its production or consumption has minimum negative impacts on the environment, human health and society, and that can be supplied continuously and reliably to future generations. Beyond the concerns related to

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[2] The guidance takes into account the existing robustness of structures, systems and components, and emphasizes those aspects of sabotage protection that work synergistically with protection against extreme external occurrences of accidental origin, such as earthquakes, tornadoes and human induced events.

safety, non-proliferation and economics, this definition of sustainability requires that advanced nuclear reactor designs and fuel cycle systems under development take full advantage of innovation and technological advances to ensure a ‘living’ process of continuous improvement. They must also provide for the effective use of raw materials during construction and deployment, maximum utilization of nuclear fuel, management and minimization of nuclear waste, as well as consideration of a wide range of social and institutional impacts.

Basic Principle: Resource Efficiency

Objective: Develop reactor, fuel and core designs to improve the use of fissile material.

Higher burnups, resulting in increased efficiency in the use of fissile material, can be achieved through the development of advanced fuels and core designs, and associated fuel management patterns,. Also, reactors designed to operate with a fast neutron spectrum can achieve a high breeding ratio of fertile to fissile material and utilization of higher transuranics for energy production.

Basic Principle: Continual Improvement

Objective: Pursue advances in nuclear power technology building on scientific and technical progress in all relevant technical and scientific areas.

For any technical endeavour, advances and progress in all relevant technical and scientific areas should be translated into improving the technology itself. To the extent possible, developing nuclear technology should thus be a continuous endeavour and an integral part of technology development in general. In addition, it should be linked to national technology development plans so that advances in technologies for other sectors of society can lead to benefits for nuclear technology, and advances in nuclear technology can lead to benefits for other sectors of society.

Objective: Establish and enhance international collaboration mechanisms to facilitate the continuous assessment of the status of nuclear science and technology and to coordinate future development efforts.

International collaboration can provide an efficient means of pooling human and financial resources to achieve technology development goals.

2.2. OBJECTIVES FOR THE DESIGN AND CONSTRUCTION OF NUCLEAR POWER PLANTS

Basic Principle: Benefits

Objective: Design to meet user interests for a range of plant capacities, and to provide an attractive investment profile.

Most advanced nuclear plant designs are for large size plants which meet the needs of industrialized countries with reasonably sized electricity distribution grids and sufficient reserve capability to withstand the shutdown of the nuclear plant. The expansion of nuclear power into developing countries may be facilitated by nuclear plants in the small to medium size range, particularly if the plants are licensable in the country of origin.

Approaches to achieve an attractive investment profile include features that facilitate incremental capacity increases matching the growth in power demand such as: system modularization, with several modules being built on a timescale that meshes with increases in demand; and multiple unit construction at a site.

Objective: Incorporate design features to achieve good economic performance.

Since nuclear plants require a large capital investment, construction techniques and procedures should be incorporated in the design phase to: achieve short construction schedules; have a long lifetime; and feature ease of operation, maintenance, inspection, repair and replacement to achieve a high availability factor. Feedback of experience from owners of existing plants can help to provide enhanced designs for the future.

To achieve a long lifetime, careful attention should be given to the choice of materials and to the operating conditions. Systems, structures and components that cannot meet the plant lifetime target should be replaceable.

To support a high level of availability, the plant should be designed to minimize the number of spurious scrams, unplanned outages and unplanned power reductions, and should have the capability for in-service inspection and maintenance and the use of automated equipment. The plant layout should provide adequate access for the removal and replacement of equipment, and include sufficient laydown space.

Good economic performance is also supported by including margins which extend beyond those provided to ensure a high level of safety. This can reduce the time and costs for equipment repair and decontamination after any unplanned event. In particular, the economic loss of the plant following an accident should be avoided.

Objective: Achieve design simplicity, standardization and ease of adaptation to different geological sites.

Simplicity should be pursued in all aspects of the plant design. Simplicity can reduce cost, reduce demands on the operating staff and facilitate the provision of simple logic and unambiguous indications of the plant condition.

Standardization can have a positive impact on reliability, constructability and economics. Establishment of a standardized design with sufficient qualification testing enables the certification of the design as the reference for replicated application. Standardization facilitates licensing, helps to ensure that construction schedules are met, and facilitates the preparation of operation, maintenance and repair procedures.

A design that is easily adaptable to different sites can be used widely without major redesign efforts.

Objective: Implement advanced construction technologies for effective project execution.

Nuclear steam suppliers and engineering procurement and construction contractors should: complete the plant design prior to starting construction; prepare a detailed construction schedule; and plan for sufficient staffing for rapid response teams at the work site for problem resolution.

State of the art construction technologies should be used for the efficient construction of nuclear power plants and to achieve shortened schedules and reduced costs without compromising quality and safety. Approaches to achieve short construction schedules include pre-ordering of long lead items; modularization and fabrication of certain structures, systems and components at factories or at the site; testing, prior to installation, of certain components and systems; and maximizing the on-site separation of nuclear and non-nuclear activities during construction.

Objective: Develop and implement an effective commissioning programme for system, structure and component function testing.

Nuclear power plant operators should be recruited and trained for health physics, operation and maintenance at their existing nuclear plants for effective commissioning of the new units.

Before a nuclear power plant is put into commercial operation, the functional adequacy of the installed components and systems, as well as the competencies of operating organization personnel, must be tested to demonstrate that the plant can be operated safely and reliably. The commissioning programme should confirm that the design functions of the components, systems and the plant as a whole are achieved. Commissioning objectives also include optimization of the plant system functions, verification of the operating procedures, getting operating personnel familiar with plant systems, and producing the plant initial startup and operating historical records.

Basic Principle: Transparency

Objective: Provide detailed, balanced and objective information on the status and prospects of advanced nuclear plant designs.

The provision of clear and concise descriptions of advanced plant designs in a balanced and objective manner promotes transparency in nuclear power programmes[3].

Basic Principle: Protection of People and the Environment

Objective: Design to meet safety requirements.

The plant design should meet the design requirements given in the IAEA's safety standards and comply with the requirements of the national regulatory organization. IAEA requirements for the design of nuclear power plants are presented in Ref. [7].

Basic Principle: Security

Objective: Incorporate design features to facilitate physical protection, and to provide a high degree of robustness against human actions of malevolent intent.

Design features should be incorporated to protect against theft, sabotage and acts of terrorism through the integration of plant arrangements and system configuration with plant security design. Features which provide robustness

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[3] The IAEA periodically publishes reports on the status of advanced plant designs, describing the various plant components and systems and the key technology advancements that are incorporated into the designs.

against human actions of malevolent intent should be considered at all stages of plant design to ensure plant safety under a variety of internal and external events and combinations thereof.

Basic Principle: Non-Proliferation

Objective: Incorporate design features to facilitate IAEA safeguards.

The IAEA offers guidelines to the designers of future reactors[4] which, if taken into account in the design of these plants, will maximize proliferation resistance and ensure efficient and effective acquisition of safeguards data to the mutual benefit of the Member State, the plant operator and the IAEA [8]. These guidelines incorporate the IAEA's experience in establishing and carrying out safeguards at currently operating nuclear power plants, the ongoing development of safeguards techniques, and feedback from plant operators and designers on the implementation of IAEA safeguards in plants. The guidelines are updated from time to time to reflect advances in safeguards technology and in safeguards implementation. Designing future nuclear plants in a way that facilitates and simplifies implementation of safeguards is also important in view of the anticipated substantial increase in the number of nuclear plants worldwide.

Basic Principle: Long Term Commitment

Objective: Design for use of future fuel options which enhance fuel utilization and reduce the burden on long term geological repositories.

Future fuel options address the sustainability of nuclear power as well as reduced fuel costs. A nuclear power plant should be able to accommodate future fuel options with minimal design changes. This objective calls for the development of designs that have the flexibility to accommodate the recycling of plutonium, utilization of higher transuranics and long term breeding capabilities, while minimizing waste production.

Objective: Provide adequate facilities for used fuel management.

Adequate storage space will accommodate spent fuel unloaded from several cycles, plus a complete core (to address special core maintenance

[4] Guidelines have been prepared for water cooled reactors, and most can be extrapolated to other reactor types.

needs), and various irradiated equipment and sufficient reloads of fresh fuel. The plant design, including the site arrangement, should take into account the possibility of expanding on-site fuel management facilities to store the fuel resulting from lifetime operation, unless there is an assurance of the availability of an off-site spent fuel storage facility.

Objective: Design to facilitate plant maintenance at all stages of life cycle and decommissioning.

Taking into consideration provisions for ease of component maintenance, removal and replacement during plant design contributes to achieving this objective. Decommissioning of nuclear plants is a significant cost factor. Consideration of preliminary decommissioning plans should be part of the design effort so as to facilitate the capability to decommission the plant.

Basic Principle: Resource Efficiency

Objective: Design to make efficient use of raw materials, human resources and accumulated knowledge on nuclear technology.

Achieving this design objective will contribute to good economic performance as well as efficient management and operation. Reducing the amount of non-renewable material required to produce the desired energy product, employing trained personnel and considering, assessing and utilizing prior accumulated knowledge on nuclear technology contributes to design and construction efficiency.

Basic Principle: Continual Improvement

Objective: Incorporate scientific and technical developments into plant designs which enhance economic performance, safety, proliferation resistance and security, and broaden the conditions of deployment and application.

New plant designs should incorporate scientific and technical developments which enhance economic performance, safety, proliferation resistance and security, and broaden the conditions of deployment and application. The advances should be thoroughly tested and proved before being incorporated into new plants.

2.3. OBJECTIVES FOR THE OPERATION OF NUCLEAR POWER PLANTS

Basic Principle: Benefits

Objective: Optimize nuclear power plant overall performance to improve availability with due regard to safety.

Optimization of the overall performance of nuclear power plants should improve the overall performance and competitiveness of these plants, with due regard to safety through the application of technological and engineering best practices, including management systems, and the utilization of relevant databases. The overall optimization should be performed principally to achieve two major business goals:

- Improve plant availability to enhance the safety margin and increase load factor.
- Optimize costs by undertaking proper maintenance of the system, structure and components at the correct interval.

Objective: Optimize operating and maintenance (O&M) costs.

The competitive environment has significant implications for plant operations, focusing the management objectives on efficient operation as the key to profitability. The best solution in a competitive framework is characterized by economic superiority and/or cost effectiveness. The plant outage strategy should be carefully established and implemented to enable the development of a comprehensive and effective outage programme. The plant outage programme should focus on optimization of the outage duration in connection with improvements in safety, quality, cost effectiveness, inventory control, high performance and availability through improvements in fuel utilization and efficient operation and maintenance.

Basic Principle: Transparency

Objective: Communicate effectively with all stakeholders to assure transparency.

Different public sectors have different expectations about openness and transparency. Effective communication means open channels between the plant operating organization, the public, the industry, the regulatory authority and other government entities.

Basic Principle: Protection of People and the Environment

Objective: Operate nuclear plants in conformance with safety requirements.

The plant should be operated in conformance with the requirements in the IAEA's safety standards, and in compliance with the requirements of the national regulatory organization. IAEA requirements for the operation of nuclear power plants are presented in Ref. [10].

Basic Principle: Security

Objective: Facilitate plant security and physical protection.

Nuclear material or systems, structures and components which could lead to unacceptable radiological consequences should only be located within protected areas. Systems, structures and components located outside the protected areas should be evaluated with respect to their potential impact on plant safety when subjected to design basis threats. The number of access points into the protected areas should be kept to a minimum. The identity of all persons entering the authorized and unescorted areas should be verified, and they should be issued with appropriately registered passes or badges. Utilities should regularly promulgate and review their comprehensive regulations for the physical protection of nuclear material and facilities to provide a high degree of robustness against human actions of malevolent intent.

Basic Principle: Non-Proliferation

Objective: Incorporate operational features to facilitate IAEA safeguards.

Nuclear material or systems, structures and components which could lead to unacceptable radiological consequences should only be located within protected areas to establish and carry out IAEA safeguards. To incorporate operational features into IAEA safeguards, the guidelines should be updated from time to time to reflect advances in technology and in implementation.

Basic Principle: Long Term Commitment

Objective: Efficiently maintain and incorporate operating experience feedback to achieve reliable operation.

Operators should incorporate experience feedback to achieve reliable operation. Knowledge gained during operations should be managed, assessed, preserved, used and enlarged. The potential for the occurrence of events similar to both in-house and industry events can be minimized by effective multidisciplinary review and clearly defined authority and accountability for determining necessary courses of action. Plant equipment failure trending programmes, using operational experience feedback, have been effective in identifying and resolving repeated failures of important plant equipment.

Objective: Develop and maintain a plant life management and ageing management programme for long term operation.

An integrated plant life management programme should be established with a set of plant specific guidelines and generic requirements based on a periodic safety review (PSR). This includes determining what systems need to be analysed, what systems can be maintained, the priority order of the systems to be modernized, and how the systems should be modernized.

The ageing management programmes should be prepared according to the current state of science and technology and thus benefit from results of experience, lessons learned and advances in understanding of materials and human behaviour.

Objective: Incorporate advanced technologies for system, structure and component condition monitoring.

The adoption of advanced technologies for component and system monitoring such as on-line monitoring, diagnostic and eventually prognostic technologies should be incorporated to ensure reliable and accurate functioning of the systems, structures and components.

Basic Principle: Resource Efficiency

Objective: Maximize workforce to enhance the capability of personnel performance.

Staffing plans should be prepared to provide a standardized methodology for overall human resource development, including the preservation, transfer between generations and effective use of accumulated knowledge, driven by safety requirements, strategic and business goals. These plans will identify upcoming retirements and vacant positions, as well as the required staffing levels needed to support business strategies to utilize accumulated proven practices, developed for improving personnel performance and maintaining high standards. Plans also must include appropriate actions for transferring tacit and explicit knowledge, in addition to attrition data, development strategies, succession arrangements, safety requirements and current work force requirements.

Basic Principle: Continual Improvement

Objective: Conduct plant modification and environmental impact assessment in conformance with the approved basis for granting or renewing the operating licence.

Plant modifications should be monitored to ensure that the configuration of the plant is ready at all times to meet safety and environmental requirements. The modified configuration should conform to the approved basis for granting a nuclear power plant operating licence. An environmental impact assessment considers the ensuing natural environmental impacts to decide whether to proceed with granting or renewing the operating licence.

2.4. OBJECTIVES FOR NON-ELECTRICAL APPLICATIONS

Basic Principle: Benefits

Objective: Expand the range of products

Nuclear energy is capable of providing heat for various applications. Applications of nuclear energy include seawater desalination, district heating, heat for industrial processes, and electricity and heat for hydrogen production. In addition, in the transportation sector, since nuclear electricity is generally produced in a baseload mode at stable prices, there is considerable near term potential for nuclear power to contribute further as a carbon free source of electricity for transportation systems (e.g. trains and subway systems) powered by electricity, and for charging electric and plug-in hybrid vehicles. Through such applications, nuclear energy can be used in energy sectors served by fossil fuels that are characterized by price volatility, finite supply and environmental concerns.

Basic Principle: Transparency

Objective: Communicate effectively with all stakeholders to assure transparency.

Each of the different sectors of the public has different expectations about openness and transparency. Effective communication means open channels between the plant operating organization, the public, the industry, the regulatory authority and other governmental entities. It is important that this communication occur in both directions so that the interests of all stakeholders are considered in planning the development and implementation of non-electrical applications.

2.4.1. Basic Principle: Protection of People and the Environment

Objective: Design and operate the integrated nuclear systems for non-electrical applications in conformance with safety requirements.

The integrated nuclear system should be designed and operated in conformance with requirements in the IAEA safety standards, and in compliance with the requirements of the national regulatory organization. The product should also comply with national and international standards, regulations, and radiological limits (for example, the World Health Organization for desalinated water).

Basic Principle: Continual Improvement

Objective: Keep abreast of market trends and new needs and identify, design and implement new potential non-electrical applications.

While currently operating and evolutionary water cooled reactors clearly do, and will, contribute significantly to world electricity generation, much of global energy consumption is for heat and transportation. By penetrating these energy sectors, the contribution of nuclear power to meeting the world's energy needs can be greatly increased.

2.5. OBJECTIVES FOR RESEARCH REACTORS

The research reactor objectives in this publication have been developed with the understanding that many objectives listed in the columns for nuclear power plants in Annex I are also applicable to research reactors to varying degrees. Specific distinctions between nuclear power plants and research reactors will be highlighted and developed in greater detail in forthcoming IAEA Nuclear Energy Series guides and reports.

Basic Principle: Benefits

Objective: Develop facility designs that are optimized to research and production needs.

Two principal applications of research reactors are to conduct basic and applied research as well as produce unique goods and services for a variety of customers and stakeholders. Over time, demands will evolve which will require innovative design development and deployment for both existing and newly conceptualized research reactor facilities. The optimization of these designs includes not only their suitability for current needs, but also incorporating flexibility for future modifications. Older research reactor facilities must achieve this objective in the context of ageing related challenges.

Objective: Develop innovative technologies and research reactor applications.

Research reactor organizations continuously strive to develop innovative applications of their existing facilities and systems. Many organizations need to develop new, quasi-commercial, business technologies to supplement shrinking external financial support. Some research reactors focus principally on applied research and development, the outputs of which are then passed on to larger production facilities as part of a strategic network or coalition.

Objective: Support nuclear science and industry human resource skill development.

Many research reactors, particularly low power facilities affiliated with educational institutions, are utilized for education and training. Increasing demand for skilled nuclear human resources will require heavier utilization of these facilities as well as the adoption of greater training and education roles for facilities not currently involved in such work.

Objective: Enhance research reactor utilization.

Areas of potential enhancements which would result in direct and tangible benefits include, but are not limited to, the following:

— Education and training;
— Isotope production;
— Neutron radiography;
— Neutron beam research;
— Material characterization and testing;
— Support for evolutionary and innovative nuclear power reactors and fuel cycles;
— Other commercial applications of research reactors.

Basic Principle: Transparency

Objective: Communicate effectively with all stakeholders to ensure transparency.

Effective communications embody more than the conveyance of clear and factual information. Research reactor organizations nurture positive and effective relationships with all stakeholders through trust and consistency. Open, objective and timely communication contributes significantly to the development of these relationships, and ultimately to mutually agreed transparency.

Basic Principle: Protection of People and the Environment

Objective: Design, operate and maintain research reactors in conformance with safety and environmental requirements.

As nuclear facilities, research reactors are bound by regulations to satisfy minimum safety and environmental criteria at all times. Many research reactor organizations are working to optimize design, operating and maintenance techniques, technologies and programmes which will permit effective and optimum operation while maintaining adequate margins for safety at all times and in all operating modes. Older research reactors must often complete large modification projects to comply with modern safety standards.

Basic Principle: Security

Objective: Incorporate design and operational features to facilitate physical protection.

Many research reactors are located in easily accessible urban areas, including numerous university campuses. In addition, many rely on sensitive material, including high enriched uranium (HEU), for their operation or research activities. Research reactors should incorporate features to facilitate physical protection within the specific context of their individual constraints.

Basic Principle: Non-Proliferation

Objective: Incorporate design and operational features to facilitate IAEA safeguards.

Research reactors are involved in a diverse array of activities. Some have lifetime cores and will operate during their entire design lifetime with no fuel or sensitive nuclear material handling other than initial core loading and decommissioning. Other research reactors are located on larger nuclear research campuses, are involved in the routine transfer of sensitive material such as HEU, the fabrication and transfer of reactor fuel that has been custom manufactured on-site and/or the testing of advanced fuel and sensitive material such as advanced power reactor fuel. Research reactors should incorporate features to facilitate IAEA safeguards as necessary given the specific nature of their operations.

Objective: Minimize the use of high enriched uranium at research reactors.

HEU used in reactor fuel and in the production of radioisotopes is a significant, internationally recognized proliferation concern. HEU related proliferation risks can be reduced through conversion to low enriched uranium (LEU) fuel and isotope production targets, use of LEU in new and innovative research reactor designs, and the return of fresh and spent HEU fuel and possibly target material to the country of origin for final disposition.

Some high performance research reactors would be unable to achieve their technical missions, if converted, using existing LEU fuel technology. The development and qualification of advanced, high density LEU research reactor fuel will enable the conversion of high performance facilities and further reduce proliferation risks by the removal of HEU from civilian commerce.

Basic Principle: Long Term Commitment

Objective: Develop the criteria and techniques to evaluate proposals for new research reactors.

Increasing interest in the peaceful application of nuclear technologies will result in proposals for new research reactors in different Member States. For some, a research reactor will be the first reactor of any kind, possibly a step towards a fully developed nuclear power programme. Other countries with existing facilities may not have constructed a nuclear facility for decades. In either case, Member States interested in new research reactors require current techniques and criteria with which to objectively evaluate their available resources against the costs and potential benefits of a new research reactor.

Objective: Develop and maintain a plant life management programme for long term operation.

Most research reactors and their support facilities are several decades old and are challenged by ageing related issues. However, the demand for research reactor goods and services is increasing. Support of advanced material testing, nuclear fuel development, as well as a rapidly growing radiopharmaceutical industry, are just a few examples. To satisfy these demands, facility availability and reliability are ensured by proper management of ageing systems, through proper maintenance planning and larger periodic engineering projects.

Objective: Develop plans for the management of spent research reactor fuel, waste management and decommissioning.

Research reactor organizations must effectively plan for the safe and secure disposition of waste, including spent fuel, as well as decommissioning. For research reactor organizations in Member States with significant, existing nuclear infrastructure, this planning is often integrated into larger plans encompassing many facilities including nuclear power reactors. Member States with little or no nuclear infrastructure may seek opportunities for regional solutions with similar organizations in other countries (spreading costs and risks and reducing both to manageable levels), partnerships with Member States with larger nuclear programmes and fully developed waste management plans, or work to develop their own national strategy.

Basic Principle: Resource Efficiency

Objective: Ensure efficient use of all resources.

Human resource challenges differ greatly between research reactors. Some research reactors compete directly with power reactors for resources. Others enter into collaborative agreements to feed resources directly into the industry (training reactors). Facilities at either end of this spectrum can optimize their human resources through improved training, succession planning and staff development initiatives — particularly those that emphasize the unique attributes of a facility such as specific areas of technology or research. A knowledge management programme should be established to accumulate, assess, preserve and transfer knowledge between generations of staff.

Natural resources are managed through effective facility design (optimized modifications), operations and maintenance. High quality operations management results in reduced unplanned outages or outage extensions. Thorough maintenance planning and implementation ensure the achievement of strategic goals through sustained high performance of critical systems and components. Fuel cycle optimization through maximized utilization and high fuel burnup also aids in the efficient use of natural resources.

Basic Principle: Continual Improvement

Objective: Continuously improve research reactor economic performance and sustainability.

Continuous improvement programmes, based on sound strategic planning and aimed at the optimization of research reactor fuel cycle economics, operational performance (high availability and reliability), human resources management, etc., will improve facility sustainability through higher utilization and achievement of customer needs within stakeholder constraints. The unique and diverse mission of research reactors typically challenges available resources. Sustainability of these reactors is defined through their utilization and customer base, and can often be justified through proper neutron accountancy.

Objective: Develop and benchmark innovative methods in research reactor utilization and analysis.

Research reactor core designs and experiments involve unique and diverse complexities. The ability to model fuel load designs, experiments or proposed changes often challenges facility operators as well as regulators. The development of innovative methods in research reactor analysis will help mitigate these challenges. Continuous improvement can be facilitated by an open exchange of information and benchmarking of these methods. The combination of experiments in a few high performance facilities and improved simulation codes can satisfy the needs of some research reactor customers and stakeholders in different Member States, thereby relieving some demand for research reactor capabilities.

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Annex I

SUMMARY TABLE OF OBJECTIVES FOR EACH NUCLEAR ENERGY BASIC PRINCIPLE (BP)

BP	Technology development	Design and construction of nuclear power plants	Operation of nuclear power plants	Non-electrical applications	Research reactors
1. BENEFITS	• Develop technologies to improve the economic competitiveness and investment attractiveness of nuclear power.	• Design to meet user interests for a range of plant capacities, and to provide an attractive investment profile. • Incorporate design features to achieve good economic performance. • Achieve design simplicity, standardization and ease of adaptation to different geological sites. • Implement advanced construction technologies for effective project execution. • Develop and implement an effective commissioning programme for system, structure and component function testing.	• Optimize nuclear power plant overall performance to improve availability with due regard to safety. • Optimize operating and maintenance (O&M) costs.	• Expand the range of products.	• Develop facility designs that are optimized to research and production needs • Develop innovative technologies and research reactor applications • Support nuclear science and industry human resource skill development • Enhance research reactor utilization
2. TRANSPARENCY	• Provide accurate and clear information to all stakeholders on research and development goals and achievements.	• Provide detailed, balanced and objective information on the status and prospects of advanced nuclear plant designs.	• Communicate effectively with all stakeholders to ensure transparency.	• Communicate effectively with all stakeholders to ensure transparency.	• Communicate effectively with all stakeholders to ensure transparency.

BP	Technology development	Design and construction of nuclear power plants	Operation of nuclear power plants	Non-electrical applications	Research reactors
3. PROTECTION OF PEOPLE AND THE ENVIRONMENT	• Develop technologies to achieve continued advancements in safety, reduction of adverse environmental impacts and waste generation.	• Design to meet safety requirements.	• Operate nuclear plants in conformance with safety requirements.	• Design and operate integrated nuclear systems for non-electrical applications in conformance with safety requirements.	• Design, operate and maintain research reactors in conformance with safety and environmental requirements.
4. SECURITY	• Develop technologies and design features which strengthen security characteristics of nuclear power plants.	• Incorporate design features to facilitate physical protection, and to provide a high degree of robustness against human actions of malevolent intent.	• Facilitate plant security and physical protection.		• Incorporate design and operational features to facilitate physical protection.
5. NON-PROLIFERATION	• Develop technologies and design features which strengthen the non-proliferation characteristics of nuclear systems.	• Incorporate design features to facilitate IAEA safeguards.	• Incorporate operational features to facilitate IAEA safeguards.		• Incorporate design and operational features to facilitate IAEA safeguards. • Minimize the use of HEU in research reactors.

BP	Technology development	Design and construction of nuclear power plants	Operation of nuclear power plants	Non-electrical applications	Research reactors
6. LONG TERM COMMITMENT	• Develop technologies to support the sustainability of nuclear power.	• Design for the use of future fuel options which enhance fuel utilization and reduce the burden on long term geological repositories. • Provide adequate facilities for spent fuel management. • Design to facilitate plant maintenance at all stages of life cycle and decommissioning.	• Efficiently maintain and incorporate operating experience feedback to achieve reliable operation. • Develop and maintain a plant life management and ageing management programme for long term operation. • Incorporate advanced technologies for structure, system and component condition monitoring.		• Develop the criteria and techniques to evaluate proposals for new research reactors. • Develop and maintain a plant life management programme for long term operation. • Develop plans for the management of spent research reactor fuel, waste management and decommissioning.
7. RESOURCE EFFICIENCY	• Develop reactor, fuel and core designs to improve the use of fissile material.	• Design to make efficient use of raw materials, human resources and accumulated knowledge on nuclear technology.	• Maximize workforce to enhance personnel performance.		• Ensure efficient use of all resources.

BP	Technology development	Design and construction of nuclear power plants	Operation of nuclear power plants	Non-electrical applications	Research reactors
8. CONTINUAL IMPROVEMENT	• Pursue advances in nuclear power technology, building on scientific and technical progress in all relevant technical and scientific areas. • Establish and enhance international collaboration mechanisms to facilitate the continuous assessment of the status of nuclear science and technology and to coordinate future development efforts.	• Incorporate scientific and technical developments into plant designs which enhance economic performance, safety, proliferation resistance and security, and broaden the conditions of deployment and application.	• Conduct plant modification and environmental impact assessment in conformance with the approved basis for granting or renewing the operating licence.	• Keep abreast of market trends and new needs and identify, design and implement new potential non-electrical applications.	• Continuously improve research reactor economic performance and sustainability. • Develop and benchmark innovative methods in research reactor utilization and analysis.

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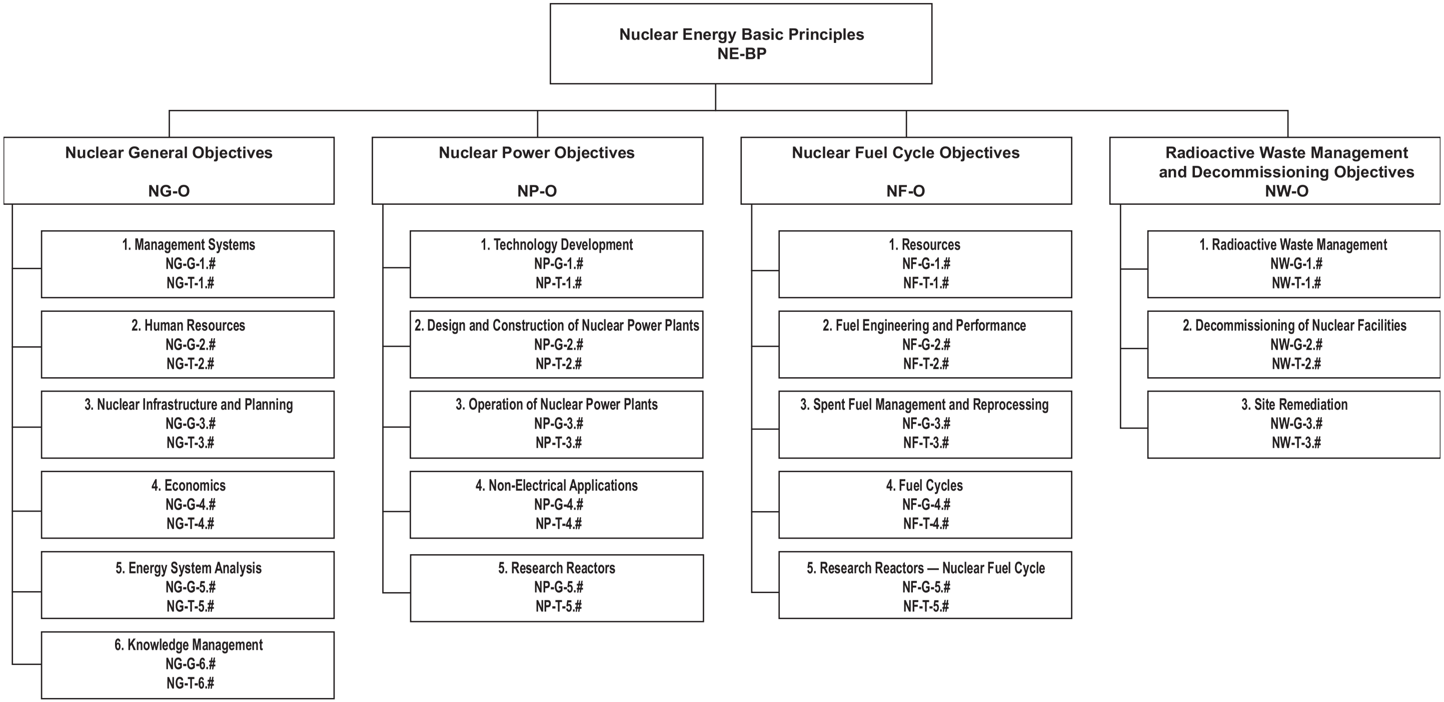

Key

BP: Basic Principles
O: Objectives
G: Guides
T: Technical Reports
Nos. 1-6: Topic designations
#: Guide or Report number (1, 2, 3, 4, etc.)

Examples

NG-G-3.1: Nuclear General (**NG**), **G**uide, Nuclear Infrastructure and Planning (topic **3**), **#1**
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The Nuclear Energy Basic Principles is the apex publication in the IAEA Nuclear Energy Series. It describes the rationale and vision for the peaceful uses of nuclear energy, and presents the basic principles on which nuclear energy systems should be based to fulfil nuclear energy's potential to help meet growing global energy needs. This publication sets out the objectives that need to be achieved in the area of nuclear power to ensure that the Nuclear Energy Basic Principles are satisfied.

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