RESEARCH REACTOR UTILISATION:
A JUSTIFICATION FOR EXISTENCE?

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ABSTRACT

The majority of Research Reactors currently under operation are constantly faced with critical issues relating to decisions justifying their sustainable existence. These issues may relate to aspects such as the age and related state of safe operation, levels of political or environmentalist support, financial independence with regard to operational costs, all of which, together with several other factors, could contribute to justifiable existence in terms of levels of utilisation and safety of these reactors.
This paper evaluates the mix of desirable characteristics regarded as essential justification to stakeholders for the extended operation and utilisation of a research reactor. The topic centres on the IAEA recommendations in terms of established Strategic Planning regarding such facilities. As an example, the model used to drive the sustained existence of the SAFARI-1 research reactor of South Africa will be evaluated.

1. Introduction

1.1. Sustainable Operation

The justification for sustainable operation of a Research Reactor (RR) is often based on the sole attribute – the reactor exists with potential to be utilised - or alternatively a selective level of utilisation exists.
The ever-increasing requirements for safe and efficient operation of the RR needs serious reconsideration in terms of acceptable (international) standards before continuous operation of the RR based on sustainability should be authorised by the relevant stakeholders.
The issues that need to be addressed in such an evaluation are:

- Technical and Financial ability to operate the plant;
- Established (licensed) Safety Aspects with regard to operating limits for the plant;
- Utilisation levels in terms of commercial and/or institutional programs
- Ability to comply with RERTR recommendations
- Security in terms of the Physical Protection of the facility
- Ability to meet Environmental requirements and public acceptance
- A Waste Control program (including final disposal facilities) for spent fuel and other High Level Waste (HLW)
- Ability to regularly Maintain/Refurbish the RR to ensure safe (extended life) operation
- An established (licensed) D&D Plan with liability allocated to a responsible authority.

The ability of the RR Management to identify any weaknesses in terms of the above and to take the necessary actions according to applicable Strategic Planning [1] is essential, if sustained operation is to be justified according to International standards as advocated by the IAEA.

1.2. A Case in Principle: SAFARI-1 Research Reactor

The SAFARI-1 (South African Fundamental Atomic Research Installation) research reactor is a 20 MW_{th} MTR based on the ORR, i.e. a tank-in-pool type reactor. It is owned and operated by the South African Nuclear Energy Corporation (Necsa) on behalf of the Department of Minerals and Energy (DME) and is located at Pelindaba ~40 km south west of Pretoria.

The major utilization of the reactor, which first went critical on 18th March 1965, is for the production of radioisotopes for medical application (national and export) as well as for the production of Neutron Transmutation Doped (NTD) silicon in the pool-side facility. There are also pneumatic and fast pneumatic systems utilized for Neutron Activation Analysis (NAA). Utilization of beam-ports for institutional (academic) purposes is encouraged and Neutron Diffraction and Neutron Radiography facilities are operational, whilst a Small Angle Neutron Scattering facility is under development.

SAFARI-1, has since initial operation, applied a management system which was primarily focused on the technical design and safe operation of the plant. Currently the plant is operated under an integrated management system, incorporating Quality, Health, Safety and Environment (QHSE). The reactor's Quality Management System (QMS) is fully certified according to ISO 9001 (2000) and it implements an incorporated Environmental Management System (EMS), fully certified according to ISO 14001 (1996). [2].

Recent evaluations [3] have indicated that an expected operational lifetime beyond 2020 would be quite realistic for the reactor. The current licence of SAFARI-1, as authorized by the National Nuclear Regulator (NNR) endorses such an approach, but requires assurance that in fact the proposed operational plan is justified, not only by the current safe operation of a well utilised RR but also by establishment of longer term sustainability plan for its operation.

2. Stakeholder: Definition and Roles

Irrespective of how high the level of utilisation of a Research Reactor (RR) and despite the fact that it might be operated well within the standards of safe operation, the final justification lies with selective decision makers or Stakeholders with regard to the sustained operation of the RR.
In this context it is convenient to define Stakeholders as:

"Person(s) and/or Institution(s) that have a direct or indirect interest or involvement in the operation of the facility".

In view of this definition, the role of potential stakeholders and the significance of their influence on a facility can be elaborated on. Although the responsibilities of these stakeholders will obviously differ for various RR facilities, a typical discussion of role significance of selective stakeholders is given for clarification below.

2.1 Government

The origin of most research reactors can probably be related to the existence of some authoritative drive that initially justified the existence of the RR. This might have been based on a need for utilisation or alternatively to obtain the national prestige of ownership of such a facility. This situation can very easily degenerate from one of supportive initiator to that of a body that regards the liability (normally financial) of keeping the RR operational as unjustified. In such a case the decision to maintain the facility is a balanced perception of the financial liability in this stakeholder's eyes versus the value that the facility might have as a contribution to national welfare or achievement.

2.2 Upper Management

The controlled operation of the RR is typically cascaded down from the upper stakeholder, e.g. government to a high level of management generally responsible for establishing operational policy and vision as well as controlling the allocation of funding for various competitive facilities. The positive sentiment of these controlling persons regarding the need for the RR is essential for its sustained ability.

2.3 Academic Institutions

The interest in utilisation of the RR as expressed by tertiary institutions such as universities or technical institutions and the ability of the RR to provide reliable service and experimental facilities for the further education of students and research and development projects for academics, is often essential for ongoing operation of a RR.

2.4 Commercial and Industrial Clients

In the situation where a level of financial dependence is essential for the RR, then the need to generate income is very dependent on the ability of the facility to provide reliable service of value to paying clients. Establishment of e.g. isotope production for medical and/or industrial irradiation applications must be of such quality and value that clients are attracted to the service options provided.

2.5 Regulatory Body

In most cases, authorisation for the facility to operate is determined by evaluation of the safety case of the RR by an individual body responsible for the licensing of the facility. If the perceived risk is unjustifiable in their opinion, simplistically it implies that the RR must be shut down, or alternatively the operational conditions are made very restrictive and often extremely difficult and subsequently too expensive to implement.

2.6 Personnel

This selection of stakeholder is a group whose contribution to the ongoing sustainability of the facility is often underestimated. If personnel are not supportive or motivated and convinced that the operation of the facility is justified in terms of their own careers, financial security, beliefs, etc. then efficient and often safe operation of the facility can be seriously jeopardised.

2.7 Public

Many countries have experienced directly the power of politics, environmentalists and associated bodies that have anti-nuclear agendas and the devastating impact that this can have on the continued operation of a facility.

2.8 IAEA

The IAEA is the internationally recognised body that identifies policies, requirements, guidelines, etc. regarding safe operation of a facility and also the controlled utilisation of nuclear fuel and related products. The contribution of the IAEA to facility evaluation and subsequent assistance with plant and/or experimental development is often a sole basis of often much needed resources, particularly for facilities in lower income countries.

3. A Ten Point Evaluation System

In order to assist RR Management to determine the long-term sustainability of the facility as perceived by the various stakeholders, an evaluation method involving ten points of approach has been proposed and could be used selectively by most RR facilities. The approach advocated is to evaluate the indicated aspects, identify the shortcomings and to incorporate corrective actions into a Strategic Plan [1] and to correct the inadequacies, where possible.

3.1. Operational Ability

This can conveniently be discussed in two categories, viz. Technical Resources and Funding.

3.1.1. Technical Resources

A facility that is technically self sufficient requires:

- **Personnel** that are technically capable in terms of training and experience and that can be entrusted with the day-to-day safe operation of the facility. Generally, capable persons with applicable engineering and/or scientific qualification as well as plant operational experience should be available.
- **Equipment** that is in good condition and that is serviceable or replaceable in case of need and has good reliability.
- **Support services** available as required by the facility according to operational needs and might typically include reliable supplies of nuclear fuel, electricity, water, compressed air, gas and liquid nitrogen. In addition, support services such as waste handling, security, IT, finances, administration and other systems are often essential for sustainable operation of the RR.

3.1.2 Financial Resources

Undoubtedly, in most cases of RR operation, the source and adequacy of funding is probably the most concerning factor relating to sustained operation of the facility. Sourcing of funds is often problematic in that stakeholders controlling the “purse strings” are often unsympathetic regarding the escalating costs relating to a nuclear facility and often give short-term indication that funds will be curtailed. It is to the advantage of the RR Management to ensure that the financial footing of the facility is sound and where possible to ensure security of funds over the term of expected operation. The following are typical aspects for selective consideration:

- **Funds for operation,** defined as the basic need to ensure required operation of the facility and incorporating amongst others, service supplies such as water, fuel, electricity, salaries, equipment maintenance, waste control, etc., are essential. Without this resource it is obvious that the safe operation of the facility is not really feasible and in fact should seriously be questioned.
- Reliability of continued **stakeholder provision** of funds (e.g. government) should be guaranteed – in consideration of funds required for basic operation and support services as defined above. Any additional needs of a facility according to a predefined budget should form part of strategic planning (typically over at least a 5 year operational period) and might require the acquisition of subsidised funding from alternative stakeholders such as university grants or industrial subsidy.
- The ideal objective is for a facility to strive towards being financially **self sustaining**. This is obviously very dependent on the size and capability of the RR to embark on a commercial or semi-commercial program and often involves dedicated marketing with a service history confirming quality and reliability of supply.

3.2. Safety (Nuclear and Conventional)

The combined safe operation of a facility in terms of its nuclear and conventional safety aspects is obviously of top priority for justifiable operation and as such, any shortcomings identified in a RR's operation should be addressed accordingly.

3.2.1. Nuclear Safety

Nuclear Safety is clearly imperative and should never be compromised:

- The setting up of well established **safety criteria** and operation limits should be established and in place for controlled implementation.
- The establishment of an **independent regulatory** control **body** that can evaluate and authorise both Operational and Radiological submissions should be able to give an unprejudiced but rational evaluation of operational proposals and accept/reject these by means of licensed authorisation.
- A **Safety Analysis Report** should be established according to international standards and incorporation of a risk assessment and hazard analysis by means of a Probabilistic Risk Assessment (PRA) is highly advocated. Unfortunately this is not always within the means of the facility and in such cases international assistance (e.g. via the IAEA) should be obtained to achieve submission and subsequent authorisation by licensing authorities.

3.2.2 Conventional Safety

The process of developing a safety culture within a facility often emphasises the nuclear aspects and frequently the importance of conventional safety is not given the necessary attention.

- Personnel training in **Occupational Safety** procedures such as overhead crane handling, personal protection equipment usage, safe manual lifting practises and many others, are highly advocated.
- Furthermore, applications in **Industrial Safety** incorporating design, manufacture and installation for mechanical, electrical and civil applications should be well established and implemented and the necessary personnel instruction applied.

3.3. Commercial

As mentioned above, with regard to financial resources, the drive for utilisation of a RR [4] is obviously very dependent on the level of funding provided by relevant stakeholders. Many RRs look towards generating income for sufficiency of funds in various ways:

- **Isotope Manufacture** is generally a good justification for utilisation of the RR, particularly when involving a local market, but can become extremely competitive on an international forum and often requires considerable marketing drive on behalf of the facility.
- In conjunction with the above it is often necessary to have Isotope **Processing Facilities** established (e.g. hot cell facilities) and licensed.
- The **promotion** of an RR's utilisation to improve its commercial program, depends on the products **and** services available and the ability of responsible personnel to convince potential clients of the benefits in using the facility. Such **marketing** persons must be willing and able to propagate related products and services and in most cases will require appropriate training. The history regarding the reliability of a quality service by the facility is essential and can be greatly assisted by ensuring implementation and subsequent certification of a Quality Management System (QMS) such as ISO 9000.
- Evaluation of the commercial program must obviously be thorough and it is essential that, particularly where commercial intentions prevail, a ring-fenced budget identifies the **profitability** of the service or product provision. The question to be answered is:

"Can we sell the product / service at an income greater than the cost, taking all considerations into account – including for example waste disposal?"

- **Irradiation Services** are generally the most appealing type of commercial action due to the low labour and processing costs and are basically an efficient in-out system. Any aspirations should however be clearly evaluated, since seemingly attractive commercial projects such as Neutron Transmutation Doping (NTD) of Silicon have several complexities that can be cost penalising if not thoroughly addressed.
- In the case of larger RRs and where a national or cooperative program justifies the cost, **Materials Testing** could be a good commercial attraction, bearing in mind that the cost implications of irradiation rigs and supportive devices can be significant. In addition the technical ability of support staff and equipment should be able to meet the needs of both irradiation and post irradiation examination programs as required.

3.4. Institutional

For the purpose of this paper, "institutional" interest is regarded as all programs relating to stakeholders who have access to the utilisation [4] of the facility at no charge or at minimal cost. Selective support from such stakeholders is often very relevant to the justification of existence of the RR based on the level of utilisation:

- An immediate responsibility of accessible RRs is the **academic** or educational role the RR can play with regard to promotion of nuclear technology to scholars, the public, interested parties from industry, the government etc., by open-days, tours, information sessions, etc.
- The role of the RR regarding its utilisation in **tertiary education** is usually very relevant where the RR is owned/funded by the university or institute where it is placed and where dedicated equipment and experimental facilities are made available for the advancement of studies and research and development in the interest of the institute and it students and/or personnel. In particular the opportunity for international student exchange regarding post graduate and doctoral studies is a recognised form of beneficial utilisation.
- The opportunity of the RR to assist with **Governmental / Industrial projects** relating to amongst others, agriculture, water conservation, insect control, mining, or industrial challenges, etc. is obviously also a major application for the utilisation of a RR in many countries, particularly where the need is to address such problems academically.

3.5. RERTR

The international concern regarding proliferation of materials is obviously the main focus of this conference [5] and little more need be mentioned regarding the expectation that all RRs will at some stage or other convert their facilities to operate on Low Enriched Uranium (**LEU**) fuels. Although in most cases the **conversion** of the RR is normally readily achievable, there are obvious penalties that can be expected in terms of operational efficiencies, flux ratio variations (thermal to fast), material disposal abilities, adaptation of manufacturing processes in the case of in-house or local fuel manufacture. Although current conversion expectations are mainly applicable to fuel and control rod configurations, the indications are that such programs will necessarily extend into the regime of isotope production e.g. ^{99}Mo targets. In this case, availability of alternative processes with equivalent, if not better, yields, waste-volumes and overall cost-impacts are still under discussion / development for large-scale commercial plants. Initiatives to convert a reactor and, where feasible, the isotope production process, are currently led by the Argonne National Laboratory and IAEA. Assistance programs for those facilities that require for example core management calculations, verification or feasibility studies, assistance in fuel manufacturing methods and new developments in isotope processing, is readily available from these institutes.

3.6. Security (Physical Protection)

A major concern in the current age, due to the international awareness of proliferation, is the potential threat of **theft**, firstly of fresh Highly Enriched Uranium (HEU) bearing materials and secondly the availability of irradiated materials that can be used for dispersion devices in acts of terrorism. Concern is obviously present where a RR does not have sufficient physical protection (security) in place to ensure that such acts of theft are readily detected and deterred.

Just as significant to theft detection, is the ability of the RR to detect and prevent **sabotage** of any sections of the facility, bearing in mind that such acts of sabotage require faster detection by the resident forces. Although it is generally perceived that sabotage of a lower power RR will not necessarily result in significant environmental threat to the public or surroundings, the loss of continuity of operation as well as the negative impact on an environmentally aware public could be quite significant.

3.7. Environmental Responsibility

Besides the immediate responsibility to personnel and public to ensure safe radiological control and environmental care, it remains a major challenge for a RR and associated nuclear facilities to ensure that the public perception regarding these facilities remains positive. In particular information negating the typical concerns relating to any form of potential environmental pollution should be communicated. A well-established Environmental Management System (EMS) that ensures controlled operation with regard to **gaseous, liquid and solid waste discharge**, is strongly advised for all RRs. Controlled usage of resources (water, electricity, consumables, etc.) is an efficiency requirement in terms of an environmental program and in particular certification of the EMS to ISO 14001 and resultant regular communication of this by means of media coverage and public relations communication is advantageous.

3.8. Waste (Back-end Storage / Disposal)

RRs and associated nuclear facilities need to establish means of long-term nuclear waste disposal for all levels of waste. In particular, although most reactors can accommodate **spent fuel** in the allocated storage areas, the problem of **final disposal** of high level spent fuel and associated waste (HLW) is a major concern. The need for interim disposal to accommodate spent fuel pool capacity limits (e.g. in underground pipe storage facility), or confirmation of a take back program (US or Russia) to meet the RR's needs until final disposal alternatives are solved, are challenges threatening premature shutdown of potentially useful RRs. The dilemma regarding the ability of various fuel types (e.g. UAl and USi) to be processed and diluted by chemical methods and then packaged, e.g. by vitrification to enable treatment as Low or Medium Level Waste, needs to be sorted out internationally for those countries that do not have the assurance of a disposal facility planned (e.g. based on power-plant needs). The possibility of regional depositories is a concept that might offer suitable solutions to this dilemma, provided that public and, in certain cases, political and environmental resistance can be overcome.

3.9. Refurbishment (Life Extension)

It is a known fact that most of the RRs in operation are ”aged”, i.e. typically in operation for more than 35 years. In many cases the desired extension of lifetime of an RR is based on the high replacement costs of the facility – it is more cost effective to maintain the facility in a good running condition than to consider replacement. The need to continuously provide the necessary preventive maintenance to plant and instrumentation to ensure extended life is obviously also a safety aspect. A maintenance and refurbishment schedule as well as involving In-Service-Inspection (ISI) of selective important components such as core components, plant pumps and piping, etc., should be part of strategic planning and implemented and subsequently preferably monitored by an external body, e.g. the regulator.

3.10. D&D Liability

It is evident that a significant portion of RR Management relates to present day operation and possibly involves planning for an extended period e.g. 5-10 years. Regrettably one of the issues of concern to many authorities is the implications of Dismantling and Decommissioning (D&D) of the RR and associated facilities at end-of-life, often neglected by facility managers. Many regulators are now insisting that the D&D plan of RRs be established as a licence requirement. The various options of D&D may have diverse impacts in terms of desirability, feasibility and cost e.g.: Entombment (not encouraged by IAEA), Long Term Storage (Deferment) or the preferred option, viz. Immediate Dismantling. It is also evident from the status of many RRs that have been shut down that a large majority remain in an indeterminable state of deferment, mainly because no stakeholder accepts the corresponding financial liability of the D&D project. This should be a lesson learnt and it should be mandatory for the responsible stakeholder to identify with the current costs of D&D and to accept this responsibility.

4. SAFARI-1: Status of 10 Point Evaluation

The above model has over the years been selectively evaluated and applied at SAFARI-1. The status of implementation is given below in a summarised version, using Figure 1 as a chronological indicator of the various levels of utilisation over the past ~40 years:

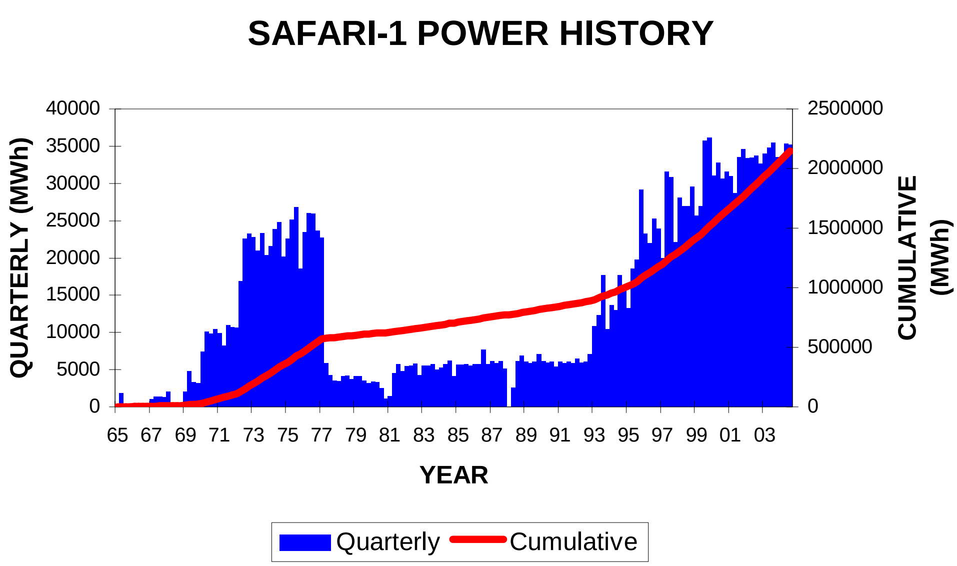

Figure 1: SAFARI-1 Power History (Megawatt hours/quarter and Cumulative)

4.1. Operational Ability

Assurance of the technical ability of staff by means of regular training and guidance is ongoing. The loss of expert personnel due to normal attrition (e.g. retiring aging experts) receives constant attention by means of in-house training and skills development programs.
Whereas SAFARI-1 operation was initially fully funded by the South African government during the first 25 years of its lifetime, the current requirement is that at least 70% of the

operational costs must be recovered from a commercial program. This is currently readily achievable.

4.2. Safety (Nuclear and Conventional)

SAFARI-1 operated virtually from initial start-up implementing a form of safety analysis, which was developed and regulated according to the requirements of the time. A fully revised Safety Analysis Report [3], based on IAEA guidelines [6], has been submitted and conditionally accepted by the National Nuclear Regulator (NNR) during 2003. Operational limits have been established and are regularly communicated to personnel during training. Specific programs addressing safety culture based on National Occupational Safety Assessments (NOSA) and Behaviour Based Systems (BBS) are applied on a corporate basis at Necsa, incorporating all SAFARI-1 personnel.

4.3. Commercial

SAFARI-1 has a well-established commercial program, originally initiated in the mid 90's, with the processing and marketing now controlled via NTP (Pty) Ltd at Necsa. This program involves isotope production (mainly ^{99}Mo) and irradiation services for selective clients. A successful NTD Si irradiation service is also in place. The success of the commercial drive can also largely be attested to the implementation of a QMS conforming to ISO 9001 for which both SAFARI-1 and NTP (Pty) Ltd are fully certified. A materials' testing ability and a fuel qualifications program at SAFARI-1, is currently under consideration in support of the development of the Pebble Bed Modular Reactor (PBMR) project in South Africa.

4.4. Institutional

Corporate visits to Necsa by academics and school-goers are encouraged and these regularly include visits to SAFARI-1. On the tertiary level, many projects for graduate and postgraduate students are functional, particularly on the neutron diffraction, radiography and more recently on the SANS facilities. Selective projects involving irradiation services are performed at SAFARI-1 in support of institutional requests for biological assays, mineral detection, etc. and for government and industry requests, at minimal charge.

4.5. RERTR

SAFARI-1 is, with Government approval, participating in a development program with ANL and the IAEA regarding feasibility of conversion to LEU and the financial impact on the reactor operation (efficiency and flux losses) as well as manufacturing technology adjustments and related costs. Two Lead Test Assemblies (LTAs) of LEU (USi) are being manufactured locally and are scheduled for testing in 2005. The actual authorisation to convert SAFARI-1 to LEU operation is awaiting approval from the DME.

4.6. Security (Physical Security)

The SAFARI-1 licence accommodates the security requirements for the reactor facility which are established according to international guidelines [7]. As such, the physical protection system is maintained to limit theft and sabotage threats, particularly in the reactor containment area. Ongoing evaluation is in place to ensure that requirements meet national and international guidelines according to a Design Basis Threat (DBT) evaluation [8], [9].

4.7. Environmental Responsibility

The QHSE management system for SAFARI-1 incorporates an EMS and as such SAFARI 1 is fully ISO 14000 certified since 2003.

4.8. Waste (Back-end Storage Dsposal)

SAFARI-1 spent fuel is stored in the reactor storage pool (part of the reactor pool) in a controlled environment with high quality water. Excess storage capacity is available at the Thabana Pipe Store on site – this is an underground dry storage facility licensed for 40 years storage. National consensus is awaited for the acceptance of a draft Nuclear Waste Policy to authorise commencement of a final HLW disposal site, identified in remote regions of South Africa.

4.9 Refurbishment (Life Extension)

Routine preventive maintenance of SAFARI-1 plant and equipment is performed and a controlled ISI program is in place. Refurbishment of selective plant e.g. secondary and primary piping and pumps as well as instrumentation and data acquisition systems are continuously implemented to ensure safe operation and to promote extended life expectations.

4.10. D&D Liability

A D&D plan forms part of the SAFARI-1 licensed condition and allows for Immediate Dismantlement at the end of life. Commitment from the major stakeholder (DME) ensures financial liability for the D&D of the reactor and associated facilities [10].

5. Conclusion

It should be evident to the management of a research reactor that it is no longer sufficient to merely have a well-utilised RR that is operated safely. Conformity with all the needs in view of the 10-point evaluation presented here is becoming more and more essential in view of international expectations and stakeholder demands.

Compliance with RERTR Developments, Physical Security, Backend Disposal, Environmental Aspects, Life-time Maintenance and D&D Liability should subsequently be ensured and allowed for in strategic planning, making use of international assistance (e.g. IAEA) as required.

6. References

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