KEY CONSIDERATIONS IN THE CONVERSION TO LEU OF A Mo-99 COMMERCIALLY PRODUCING REACTOR: SAFARI-1 OF SOUTH AFRICA

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ABSTRACT

Apart from the technological demands and considerations associated with the conversion of a Mo-99 commercially producing reactor to LEU, a number of commercial challenges also need to be addressed. This is particularly the case when the reactor is primarily used as a source for the production, on an uninterrupted basis, of significant quantities of Mo-99 to satisfy long term commitments to a range of global customers. This paper highlights key business considerations which are applicable in the conversion process of firstly, reactor fuel to LEU and secondly target plates for Mo-99, also to LEU, using the SAFARI-1 reactor in South Africa as a typical example of such a commercially utilized reactor.

1. INTRODUCTION: SAFARI-1 REACTOR PROFILE

The SAFARI-1 reactor is a 20 MW tank-in-pool type materials testing reactor (of Oak Ridge Research Reactor design) which is operated by NECSA, the former Atomic Energy Corporation (AEC) of South Africa (Ltd) at its Pelindaba site near Pretoria. The name SAFARI is an acronym for the South African Fundamental Reactor Installation. It has a 8 x 9 core lattice which houses MTR-type fuel elements and control elements. The locally produced fuel elements are manufactured from ~ 90 wt% enriched uranium-aluminium alloy (HEU). The reactor has a wide range of in-core and poolside irradiation positions for experimental applications and isotope production. Several neutron beam lines are also available for research and industrial applications. Since its commissioning in 1965, SAFARI-1 has operated with an exemplary safety record having logged 1,5 million MWh in November 1999. (Of this, 0,5 million MWh were achieved over the last 5 years where commercial usage of the reactor was of importance).

The SAFARI-1 reactor is supported by an advanced on-site infrastructure consisting, amongst others, of a MTR fuel fabrication plant, hot cell facilities, an isotope production center, a pipe storage facility for the interim dry storage of spent fuel, a disposal site for low and intermediate radioactive waste, theoretical and experimental reactor physics, radiochemistry and radio-analysis groups.

2. COMMERCIALISATION PROGRAMME OF NECSA: SHIFTING ROLE OF SAFARI-1 REACTOR

During the past four decades, the development and transformation of NECSA evolved through various distinct phases. In each of these phases, the SAFARI-1 reactor played a unique and pivotal role.

- **Phase 1: Basic Research Era (1959 – 1970)**

  NECSA, then the former Atomic Energy Board, was instituted as South Africa's national nuclear authority responsible for basic nuclear research. During this early operating phase of SAFARI-1, valuable operating expertise and skills were built, whilst the utilization of SAFARI-1 was initially focused on basic research which involved materials studies, neutron activation analyses and small scale radioisotope production for local use.

- **Phase 2: Strategic Supply of Nuclear Fuel Era (1970 – 1990)**

  During this phase, NECSA was mandated by Government to establish front-end nuclear fuel production activities that would ensure the on-going supply of PWR fuel to the Koeberg Nuclear Power Station in the Western Cape. SAFARI-1 gradually developed into an applied research facility conducting neutron radiography studies and irradiation examinations of nuclear fuel rods.

- **Phase 3: Commersialisation and Diversification Era (1990 - 2000)**

  The opening up of global economies since the early 90s saw greater focus on privatization and international strategic partnerships and the need for enhanced efficiencies, leading NECSA to embark on a focused commercialization and diversification strategy. This involved the redeploy-ment of many existing facilities and the commercial exploitation of the organization's nuclear and related competencies in the fields of radiation, fluoride-based chemistry and systems engineering. Out of this strategic redirection, SAFARI-1's mission was defined as a multi-purpose commercial/ institutional role.

  The commercial repositioning created a new and challenging role for SAFARI-1, namely to maximize commercial income and to establish itself as an important international commercial isotope producer and provider of irradiation services. To this end, SAFARI-1 has achieved a remarkable performance over the last five years.

Based on its core competencies, NECSA has established three commercial divisions (Chemical, Systems Engineering and Nuclear Technology Products) with a total portfolio of more than 50 products and services which are currently sold in more than 20 international countries. Over the past year alone, about 33% of the total revenue emanating from the commercial divisions within NECSA, was generated via the sales of SAFARI-associated products and services. Currently more than 67% of SAFARI's operating costs are covered through service payments from commercial programmes. The remaining one third is subsidised by Government, allowing free access to the reactor's beam lines by the academic community for research and training purposes.

Apart from SAFARI-1's institutional activities, which include a programme of outreach to higher education institutions, research via neutron beam lines and increased involvement in IAEA/AFRA initiatives, SAFARI-1 has established two key international commercial export programmes, namely the production of fission Mo-99 and the irradiation of high purity single crystal silicon ingots (NTD-Si) for the semiconductor industry.

With the aid of SAFARI-1 and its supporting infrastructure, NECSA has, since 1994, succeeded in penetrating the international Mo-99 market. It currently supplies approximately 12% of the world demand of Mo-99, classifying NECSA as one of the four leading suppliers in the world and a collaborative agreement has been established with IRE of Belgium. The relative growth in volume, product range and customer base of Mo-99 is depicted in the table below:

SAFARI-1: Mo-99 Programmes	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Mo-99 growth (Base 1994 = 100)	100	200	900	1200	4100	5400
Production per employee (Base 1994 = 100)	100	161	483	943	1707	1780
Number of export countries	1	1	5	6	7	9

SAFARI-1 has succeeded in providing international customers the opportunity to implement a diversified Mo-99 procurement strategy which limits the risk of unavailability of nuclear medicine globally.

Since 1995 SAFARI-1 has also been playing a key role in the neutron transmutation doping of silicon for international clients within the semiconductor industry. Growth in this market is indicated in the table below:

SAFARI-1: NTD Programme	1996	1997	1998	1999
NTD-Si production growth (Base 1996 = 100)	100	400	600	1000

NECSA is currently investigating the formation of a strategic alliance with Studsvik of Sweden in the fields of radio-pharmaceuticals and other nuclear products. This potential partnership venture would significantly enhance the business growth and commercial positioning of SAFARI-1 and generate substantial forex over the next ten years.

3. REQUIREMENTS FOR THE CONVERSION OF FUEL TO LEU FOR SAFARI-1

As NECSA continues with the second phase of its strategy of commercialization, emphasis is directed at sustainable market growth, fostering of international collaboration, partnerships and cost-effective and reliable delivery of products and services based on client needs. To these ends, strategic decision-making within NECSA, which may impact on processes, projects or policies, are largely dominated by economic, market and client considerations and only focuses on technological issues on a secondary basis.

In the case of SAFARI-1, the conversion of fuel to LEU silicide fuel should be viewed from a focused business perspective where economic, market and client requirements prevail. In this regard the following business criteria have to be met:

3.1 The conversion to LEU fuel should avoid any detrimental influence on the present level of business risk associated with the supply-chain of activities surrounding SAFARI-1. To minimize the commercial risk, the reactor fuel conversion process should focus on the following:

a) **Transfer of already developed and well-proven fuel technologies**. Building up of an international track record of operating reactors that use converted LEU fuel and where favorable performance, safety and economic usage have been clearly demonstrated are of importance here.

b) **Interchange of experience from reactors undergoing (or having completed) conversion**. In the case of a commercially-oriented reactor immediate and guaranteed access to upgraded LEU fuel and other technical improvements in associated systems and hardware, are essential to speed-up the learning curve and to enhance economic efficiencies of reactor operations. International access to a data-base of relevant and successful operational statistics involving LEU fuel, would be an incentive to a commercial operator.

c) **A well-designed phased-in process of fuel conversion.** The change-over process to LEU fuel may not compromise the availability of a commercial reactor, even on the short term. Any unscheduled interruption in reactor irradiation services severely jeopardizes the production of commercial products such as Mo-99 and NTD-SI, impeding sound customer/client relationships.

3.2 For LEU fuel conversion to support and adhere to sound business yield principles, one would need assurance in respect of the following matters to comply with existing supply contracts with established clients:

a) **Limited loss (preferably none) in the maximum production capacity associated with the reactor**. A significant setback in this area may not only hamper economies of scale, but may erode the long term strategic intent of the reactor. Very often, the establishment of potential strategic alliances and partnerships with multinational organizations are based on a sound analysis of reactor production capacities, which in turn become the premise of a comprehensive business plan for the venture. Fundamental changes in these parameters may affect the viability of the venture.

b) **No violation in any of the prescribed safety limits of the operating license of the reactor**.

d) **No increase in the fuel cost per production unit** (Mo-99 would be a typical example in the case of SAFARI-1.

3.3 Finally, any capital investment required for the conversion of SAFARI-1 fuel to LEU should eventually be supported by a sound return on investment. In the case of NECSA, a minimum net profitability of 10% of sales (after interest but before tax) is used as an investment norm, taking all opportunity costs into consideration.

4. REQUIREMENTS IN THE CONVERSION OF HEU Mo-99 TARGET PLATES TO LEU

As yet, no research or development on the production of Mo-99 from fission targets utilizing LEU instead of HEU has been undertaken by NECSA. However, since initiatives in this field are part of a worldwide trend to reduce international commerce in HEU and in the light of some recent international collaborative ventures in this area, it may be meaningful in the early development cycle of such a process, to provide a broad commercial framework to lay down a premise of key requirements for the conversion of Mo-99 target plates to LEU and thus help to steer future strategic decision making in this field of research.

At NECSA, the production of Mo-99 is the key process in the commercial value chain of activities of the SAFARI-1 reactor. It is therefore evident that any modification, new development or change of parameters that may affect the current Mo-99 production process, will have to be closely evaluated in terms of its overall impact on the total value chain. Within the focused commercial paradigm deployed at NECSA, the impact associated with a potential Mo-99 production process change, would typically comprise an early analysis of the following areas:

a) Economic value impact
b) Customer requirements (care) impact
c) Health, safety and environmental care (HSE) impact

Guidelines with respect to these factors above include the following:

4.1 Economic Value Impact

- A critical element for the generation of sustainable economic returns with regards to NECSA's Mo-99 production business, is assurance that a technically risk-free, well researched, scientifically understood and proven technological process is in place. Over the years, NECSA has succeeded in achieving a high level of technological reliability and cost-effectiveness in its process technologies and infrastructure for the current Mo-99 production via HEU target plates. In fact, NECSA's full scope of competencies in this area, that ranges from the manufacture of target plates right through to waste storage, is unique in the commercial Mo-99 industry and is one of the important cornerstones of the economic and market successes that have been achieved. Over the last few years, approximately US $1,0 million has been invested in establishing a reliable and safe Mo-99 technology process.

  To prevent additional business and economic risk, NECSA is of the opinion that it can only rely on a modified or new production technology of Mo-99, once thorough testing of the new process has been aptly demonstrated. In practice, it would imply at least two years of full scale pilot plant testing in parallel to current production capacity. The potential user of a new technology must be convinced that the reliability of the new process is at least equal to or better than the one currently in use, before commercial application can be confidently considered.

- It is further clear that many technological uncertainties with respect to the commercial usage of LEU targets for Mo-99 production still prevail, which need to be addressed in the near future. Two critical elements are:

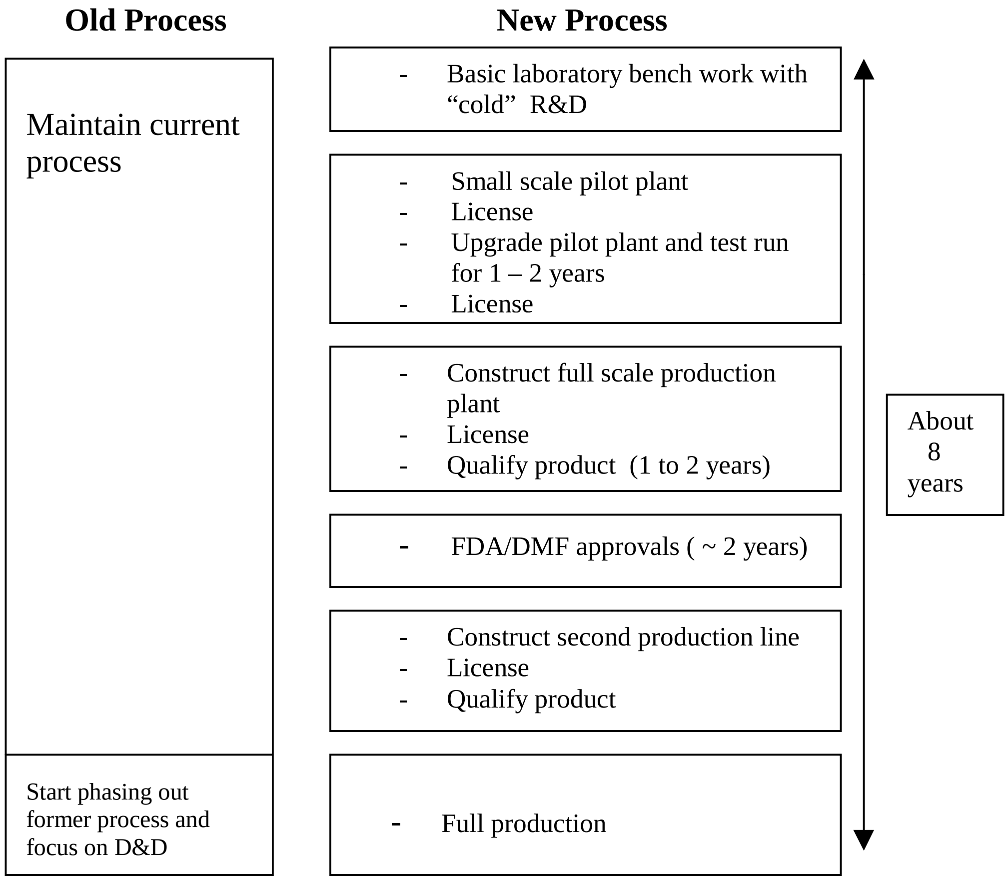
  - the ideal design of targets to be used on a commercial basis and
  - a routine commercial and cost-effective means of target dissolution, whether acidic or basic. Ideally, this dissolution process should be the same as before the conversion to limit any further downstream recovery and purification activities.

In any event, to facilitate a smooth switch-over from HEU to LEU Mo-99 targets, equipment modifications, fabrication alterations and/or chemical process changes should be kept to an absolute minimum.

Any research and development funds and capital investment that may be required for the establishment of a new commercial process involving these and other elements can only be fully recovered through enhanced profits. In NECSA's case such a project will have to demonstrate an IRR (internal rate of return) in excess of 20% and achieve a payback period of less than five years to be deemed commercially viable. A measurable setback in the profitability of the Mo-99 business cannot be absorbed.

- A further significant challenge of potentially large economic proportions, associated with the implementation of a new Mo-99 production process, is the availability of additional hot cell facility space.

To ensure continuity of supply to clients, a switch-over to a new Mo-99 production technology would require a strategy of parallel production, i.e. whilst a new process is being installed and test run, current production capacity has to be maintained. The critical steps in such a strategy are illustrated in the diagram below.



Currently, NECSA operates two separate Mo-99 production lines with four hot cells allocated to each line and one cell which is shared between the two lines. The past investment of about US $4 million for the current hot cell facility at NECSA will have to be supplemented by further capital to provide additional hot cell space which will be needed only for the interim whilst a new Mo-99 process is being installed and test-run for a considerable period. This new investment will soon become obsolete once the "old" Mo-99 production processes are successfully phased out and the hot cells become available. This extra capital investment will, therefore, have to be written off against future profits with the new process, demanding a higher profitability potential with the new process.

4.2 Impact on Customer Requirements

In the highly competitive Mo-99 business environment, meeting customer requirements is of paramount importance. Apart from the traditional non-negotiable customer care principles (supplying the right product at an agreed, competitive price and on schedule), one of the more pivotal elements of customer care in this field is the absolute, uninterrupted conformance to stringent regulations governing the production of pharmaceutical drugs. This is obtained via a lengthy licensing procedure which applies across the whole customer supply chain.

Any minor change to the current Mo-99 production process (targets and/or process technology) may have major licensing ramifications for the Mo-99 producer and may even extend to the Technetium-99 manufacturer, bulk dealer, distributor and targeted customer within a defined geographic location. For example, in the event of a potential change in the Mo-99 production process, NECSA is obliged to re-apply for its production license which involves a process of formal approval from the local pharmaceutical regulatory authorities (Department of Health) and the local National Nuclear Regulator (NNR). Very recently an opinion was expressed by a large Canadian producer of Mo-99 that the conversion of the Maple research reactor to use LEU targets for Mo-99 production would require various qualifications to satisfy regulatory requirements and that such a process was envisaged to take up to at least three years.

Furthermore, once process changes have been introduced, new Drug Master File (DMF) applications have to be submitted to the regulatory drug authorities within each targeted export country. Based on NECSA's current export client portfolio for Mo-99, more than 22 of these DMF applications to countries in Europe, USA and Asia will have to be renewed in the event of a change. NECSA's past experience has indicated that the licensing issue is an extremely costly exercise in terms of idle time and high level manpower involvement. A waiting time in excess of 18 months seems to be the norm in this industry.

In the final analysis, the benchmark of a new production technology for Mo-99 is embedded in the value that is perceived by the final consumer, in this case the patient. Ideally any improvement in the production process of Mo-99 should ultimately lead to greater affordability of the product, wider access and higher quality service to the patient.

4.3 HSE Impact

With regard to the waste associated with the current HEU target plate production of Mo-99, NECSA has implemented a nuclear waste management and control system in accordance with IAEA requirements which provides for the safe and skilful handling and storage of all liquid and solid Mo-99 waste.

The implementation of a new Mo-99 production process must be preceded by a comprehensive environmental impact assessment (EIA) conducted in a public and transparent manner, according to current legislation in South Africa. One of the important criteria of acceptance by the public from a HSE perspective, is a distinct indication that the volume or activity level of nuclear waste for disposal arising from a new process, will be equal to or less than that from the current production facility.

Early findings abroad in this regard are unfortunately to the contrary. Studies based on the LEU target conversion at another Mo-99 processing facility, indicate that greater volumes of waste may be expected with the usage of LEU target plates. In fact, the study further indicated that the speed at which the waste from the new process could be calcined, was a real limiting factor for the supply of LEU capability. It is apparent that more in-depth research on the waste associated with LEU targets for Mo-99 production, is required in order to arrive at a commercially viable process.

5. STATUS OF SAFARI-1 AND RERTR PROGRAMME

NECSA became involved in the Reduced Enrichment for Research and Test Reactor (RERTR) programme in September 1993 with the signing of a protocol agreement between the United States Department of Energy (DOE), Argonne National Laboratory (ANL) and NECSA. A first joint techno-economic study between ANL and NECSA on the feasibility of converting SAFARI-1 to LEU fuel was performed in 1994 and a final report issued in May 1995. No investigation was launched in this study into LEU target plates for Mo-99 production. The report indicated that it was technically feasible to convert SAFARI-1 to LEU fuel without violating any prescribed safety limits of the operating license. The results of the study with respect to fuel usage and fluxes in irradiation positions were used in a further economic feasibility study performed by NECSA in 1995, which indicated the following:

- The overall effect of converting SAFARI-1 to LEU fuel would result in a measurable fuel cost increase.
- A reduction in the incore neutron flux, would result in a certain loss of maximum potential production capacity for Mo-99.
- A concern for unquantified irradiation effects to NTD silicon ingots may exist, which could impact on to this commercial venture.

Based on these results, NECSA took a decision at the time to remain on HEU fuel until further studies could satisfactorily address these concerns.

In the light of international RERTR trends and in support of non-proliferation considerations, NECSA has recently committed itself to embark on a new joint techno-economic study with ANL concerning the conversion of SAFARI-1 to LEU fuel. The conversion of Mo-99 target plates to LEU has been excluded from this study, since NECSA is of the opinion that this conversion process still requires fundamental research and development work plus a very lengthy trial period before it is suitable for a committed commercial production environment. This new study makes provision for changes in the core configuration of SAFARI-1 and optimization of the core design for LEU fuel usage. The possibility of manufacturing LEU SAFARI-1 fuel on site (as is currently the case with HEU fuel) will also be investigated. This option was excluded in the initial study. A report on the second study is expected towards the end of 2000.

6. CONCLUDING REMARKS

NECSA remains totally committed to the fundamental principles and objectives of the RERTR programme. However, a final decision to convert SAFARI-1 to LEU fuel resides with the South African Government. From a holistic perspective it is, however, important to recognize that both technological and business considerations need to be satisfactorily addressed in the conversion process. This is particularly important in the case of Mo-99 target plate conversion to LEU where a very distinct business paradigm prevails.

References

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