ABSTRACT
MDS Nordion supplies the majority of the world's reactor-produced medical isotopes. These isotopes are currently produced in the NRU reactor at AECL's Chalk River Laboratories (CRL). Medical isotopes and related technology are relied upon around the world to prevent, diagnose and treat disease.

The NRU reactor, which has played a key role in supplying medical isotopes to date, has been in operation for over 40 years. Replacing this aging reactor has been a priority for MDS Nordion to assure the global nuclear medicine community that Canada will continue to be a dependable supplier of medical isotopes.

MDS Nordion contracted AECL to construct two MAPLE reactors dedicated to the production of medical isotopes. The MDS Nordion Medical Isotope Reactor (MMIR) project started in September 1996. This paper describes the MAPLE reactors that AECL has built at its CRL site, and will operate for MDS Nordion.

1. MAINTAINING AN ESSENTIAL SOURCE OF GLOBAL SUPPLY
This paper describes the role of MDS Nordion and AECL in providing a secure global supply of medical isotopes. The first part of the paper discusses the uses of medical isotopes, their importance to the medical community, and the benefits to patients of a secure supply of medical isotopes. The second part describes the new MAPLE reactors being commissioned at AECL's Chalk River Laboratories to meet the world market demand for medical isotopes for the next 40 years.

MDS Nordion is the world's leading supplier of medical isotopes. The company is in the business of supplying isotopes used to conduct some 34,000 nuclear medicine procedures performed every day around the world, such as determining the severity of heart disease, the spread of cancer, and diagnosing brain disorders.

There are currently more than 100 medical applications for radioisotopes, with 80% of nuclear medicine procedures relying on just one isotope, molybdenum-99. Some of these procedures are performed using medical isotopes that have left the reactor only 41 hours earlier. This is truly a just-in-time business and a global endeavour. As the radioisotope decays, MDS Nordion must deliver the product to the customer as quickly as possible. Moreover, 5000 hospitals in North America depend on this supply each week. Other examples of hospitals around the world that rely on the supply of medical isotopes currently produced at AECL's NRU reactor include 850 hospitals in Germany, more than 1000 hospitals in Japan, and 250 hospitals in Argentina.

MDS Nordion's medical isotope business is also creating exciting new applications in radioimmunotherapy. Today, molybdenum-99 is the most extensively used isotope. However, new medical techniques are providing opportunities for iodine-131, and iodine-125 and xenon-133 usage is also growing. For example, novel ways of using radioisotopes are being developed to treat diseases such as non-Hodgkin's lymphoma, a blood-borne cancer. These developments will expand the horizon for applications of medical isotopes.

The NRU reactor owned by AECL at Chalk River has operated since 1957 and has been producing molybdenum since the early 1970's. Today the NRU also supplies other medical isotopes, including cobalt-60.

In 1996, MDS Nordion and AECL responded to the concerns of the nuclear medicine community about the long-term, secure supply of
molybdenum-99, and announced an agreement that will ensure a reliable and economic supply of radioisotopes to hospitals and clinics worldwide.

The agreement provided for the construction of two MAPLE reactors and a high-volume, commercial, first-stage processing facility at AECL’s Chalk River Laboratories. MDS Nordion will own the reactors and processing facility, and be responsible for managing the business and planning activities of isotope production. AECL has been contracted to design, build, and operate the facilities on behalf of MDS Nordion.

The MAPLE reactors will be the only reactors in the world totally dedicated to the commercial production of medical radioisotopes. MDS Nordion’s significant investment in the AECL site at Chalk River will capitalize on the extensive infrastructure, expertise and experience of AECL for the reliable, continuous production and supply of medical isotopes.

2. THE MDS NORDION MEDICAL ISOTOPE REACTOR (MMIR) PROJECT

In August 1996, MDS Nordion contracted AECL to build two MAPLE reactors and an associated isotope processing facility at AECL’s Chalk River Laboratories. The MMIR Project started in September 1996. The objectives of the project were to design, build, and commission two identical 10 MW MAPLE reactors and a processing facility that would start commercial production of medical isotopes in calendar year 2001.

The environmental assessment for the project was approved in April 1997, construction approvals were granted in December 1997, and all construction work was completed in 29 months by May 2000. Figure 1 shows the MAPLE reactor and the isotope processing facility buildings (these are the buildings with beige siding). The photograph also shows the NRU reactor in the background and the NRX reactor, which was shut down in 1992, to the right in the photograph.

Operating licences for the MAPLE 1 reactor and the processing facility were granted in August 1999. The licence was amended in June 2000 to include the MAPLE 2 reactor. Commissioning of the facility systems started in June 1999 and overlapped the construction phase. The MAPLE 1 reactor achieved its first sustained chain reaction in February 2000, just 41 months after the start of the project.

Active commissioning of the facilities has been on hold since July 2000 after problems were encountered during testing of the MAPLE 1 shut-off rod operation. Investigation into the root cause of the problems identified some workmanship issues in the construction of the facilities that had not been captured by the quality management system in place during construction. This led to the detailed re-inspection of all MAPLE reactor and processing facility systems. Since July 2000, activities have been underway to correct the problems with the operation of the shut-off rods, and to address the workmanship issues that were identified. These activities are nearing completion. At no time was there any impact on safety to workers, the public or the environment.

Commercial production of medical isotopes in the new facilities is now scheduled for 2003, more than two years later than the original project objective.
3. THE MAPLE REACTORS

Figure 2 shows a cross section of the MAPLE reactors. The reactors are open pool-type reactors, each with a thermal power of 10 MW, designed for the sole purpose of producing medical isotopes.

The reactors are fuelled with Low-Enriched Uranium (LEU) silicide fuel dispersed in an aluminium matrix. The fuel is manufactured by AECL. The reactors are licensed to irradiate Highly Enriched Uranium (HEU) targets in their core to produce the following medical isotopes as fission products of uranium-235: molybdenum-99, iodine-131 and xenon-133.

Fuelling and target removal operations are performed manually from the top of the reactor pool with the reactor shut down. The reactor core, which measures about 400 mm in diameter and 600 mm in height, is near the bottom of a 10 m deep pool.

Figure 3 shows the MAPLE reactor core during low-power commissioning. The core has 19 fuel sites, consisting of 13 hexagonal and 6 circular sites. Nine hexagonal sites contain 36-element LEU fuel bundles, and the remaining four contain HEU isotope production targets. The six circular sites contain 18-element fuel bundles. A heavy water reflector surrounds the core and contains irradiation sites for the production of iodine-125.

Each MAPLE reactor core, including the LEU driver fuel and HEU targets, contains a nominal uranium-235 content of about 5 kg.

The LEU fuel is aluminium that contains 61% (weight) uranium-silicide. The uranium is enriched with 19.75% (weight) uranium-235. Each fuel element contains an 11.85 g uranium-235 cylindrical core, 6.35 mm in diameter by 600 mm in length, in an aluminium cladding surrounded by eight cooling fins at 45° intervals.

The HEU targets each contain 18.5 g of uranium-235 in the form of uranium dioxide with 93% (weight) uranium-235. The targets are a thin annulus of uranium dioxide crush-compressed between two concentric zircaloy tubes. The nominal dimensions of the targets are 15.2 mm OD, 13.2 mm ID, and 482.6 mm length.

The average linear power is 32 kW/m for fuel elements and 140 kW/m for targets. Figures 4 a) through 4 c) show the peak thermal neutron flux distribution in the reactors and the typical axial profile, based on measurements at 1 kW and normalized to 10.252 MW.
The reactor core is cooled by forced water flow. Water, circulated by the primary cooling pump, enters the inlet plenum (see Fig. 2) and flows vertically upward through flow tubes that contain fuel or targets. The water exits from the flow tubes into the chimney, where it mixes with a descending flow of pool water. The combined flow leaves the chimney through two outlets and then returns to the suction side of the pump. The pump directs the flow through a heat exchanger, where heat is rejected to the process water system. The total water flow through the core is 320 kg/s, and the maximum outlet pump pressure is 705 kPa (g). The core inlet water temperature is 30°C, and the core outlet temperature is 37°C.

Each MAPLE reactor has two independent and diverse safety systems. (See Figures 2 and 3.):
- Safety System 1 - has three hydraulically actuated shut-off rods.
- Safety System 2 - has three electromagnet actuated control absorber rods and a hydraulically actuated reflector dump system.

Any two of the three shut-off rods that are dropped into the core will place the reactor in a stable sub-critical state. Similarly, any two of the...
three control absorber rods that are dropped into the core will place the reactor in a stable sub-critical state. The reflector dump system will also place the reactor in a stable sub-critical state.

During operation, the three shut-off rods are held out of the core by their hydraulic systems. The control absorber rods are used to control reactor power, and are driven by electric motors at the top of the reactor. When the reactor needs to be shut down (e.g., for fuelling), the control absorber rods are driven into the core, and the shut-off rods are left poised outside the core. Figure 5 shows the MAPLE reactor control room. Each MAPLE reactor is controlled by a programmable control system that includes control processors, input/output modules, communication components, a display system, printers, and a maintenance system. The Reactor Control Computer System (RCCS) senses the state of reactor systems by the signals it receives from field instruments. The RCCS achieves control by manipulating elements of the control system such as the position of control absorber rods, opening of valves, etc. The RCCS performs the following main functions:

- power regulation,
- process control,
- system monitoring and alarming, and
- historical data storage.

The power regulation function controls the reactor power level by adjusting the vertical position of the control absorber rods.

The process control function is achieved by turning pumps on and off, adjusting throttling valves, and opening and closing isolation valves for the primary cooling system, reflector cooling system and process water system. System monitoring consists of data collection from field instruments and from within the control algorithms. This data is available for display to the operator at the control console. Abnormal conditions initiate alarms and may also initiate the automatic shutdown of the reactor.

Selected data is recorded and stored by the display system. The data is available for display at the control console or may be exported for off-line analysis and/or permanent archiving.

Figure 5: MAPLE Control Room

4. CONVERSION TO LEU

Studies have been underway since 1999 to assess the feasibility of converting isotope production in these facilities from a high to low-enriched uranium target to address USA nuclear non-proliferation initiatives.

In concert with the global trend to utilize LEU in research reactors, MDS Nordion has launched a three phase LEU Target Development and Conversion Program for the MAPLE facilities. The three phases are:

- Initial feasibility study;
- Conversion Development Program; and
- Conversion Implementation Program.

Phase 1, the Initial Feasibility Study, completed by AECL in May 2000, identified the technical issues to convert the MAPLE reactor targets from HEU to LEU for large-scale commercial production. This phase indicated that the main challenge to conversion comes from producing five times more uranium waste with LEU than HEU.
The second phase of the LEU Target Development and Conversion Program was developed with extensive consultation and involvement of experts knowledgeable in target development, process system design, enriched uranium conversion chemistry and commercial scale reactor operations and molybdenum production.

MDS Nordion is currently engaged with AECL, Argonne National Laboratory (ANL), and the Société Générale pour les techniques Nouvelles (SGN) in a development program to assess options to manage the additional waste from medical isotope production using LEU. The Phase 2 Conversion Development Program will be completed in 2003, and will be followed by an assessment of the economic impact of converting the facilities to medical isotope production with LEU.

5. CONCLUSION
The MAPLE facilities are specifically designed for one purpose: the reliable, commercial production of medical isotopes. MAPLE 1 and 2 are the only privately owned reactors in the world that are designed exclusively to produce medical isotopes.

The combined strengths of MDS Nordion and AECL will capitalize on their extensive infrastructure, expertise and experience for the reliable, continuous production and supply of medical isotopes. The operation of the MAPLE facilities will be managed within an overarching culture of safety, superior performance, and a commitment to excellence.

AECL and the CNSC are engaged in a regulatory process that will ensure safety of design, an effective quality management program, reliability of operations, and protection of the environment. In fact, these will be the hallmarks of success for the project and its ongoing operations. Our strict adherence to such principles will enable Canada to remain as a premier supplier of medical isotopes to the international health care community.

Timely completion of the MAPLE project will ensure a secure, safe and reliable supply of medical isotopes, which is a priority for the global nuclear medicine community and for the patients who benefit from this technology. With the MAPLE facilities, Canada will continue to be the front-runner in medical isotope supply for many years to come.