<u>COBALT-60 PRODUCTION IN CANDU® POWER REACTORS</u>

G.R. Malkoske
MDS Nordion
447 March Road
Kanata, Ontario, K2K 1X8, Canada
613-592-2790
gmalkoske@mds.nordion.com

J. Slack
Atomic Energy of Canada Limited
2251 Speakman Drive
Mississauga, Ontario, L5K 1B2, Canada
905-823-9060
slackj@aecl.ca

J.L. Norton
MDS Nordion
447 March Road
Kanata, Ontario, K2K 1X8, Canada
613-592-2790
jnorton@mds.nordion.com

ABSTRACT

key words: cobalt, reactor, CANDU®

MDS Nordion has been supplying cobalt-60 sources to industry for industrial and medical purposes since 1946. These cobalt-60 sources are used in many market and product segments, but are primarily used to sterilize single-use medical products including; surgical kits, gloves, gowns, drapes, and cotton swabs. Other applications include sanitization of cosmetics, microbial reduction of pharmaceutical raw materials, and food irradiation.

The technology for producing the cobalt-60 isotope was developed by MDS Nordion and Atomic Energy of Canada Limited (AECL) almost 55 years ago using research reactors at the AECL Chalk River Laboratories.

In order to produce cobalt-60 in CANDU® power reactors, the stainless steel adjusters are replaced with neutronically equivalent cobalt-59 adjusters. With its very high neutron flux and optimized fuel burn-up, the CANDU® has a very high cobalt-60 production rate in a relatively short time.
Many design considerations and requirements for the production of cobalt-60 in CANDU® must be assessed, such as; operator and public safety, minimum impact on station efficiency and reactor operations, shielding requirements during reactor operation with cobalt-60 adjusters and removal of the cobalt-60 adjusters from core, transportation within the station, and finally the processing and shipment off-site. This Canadian technology for cobalt-60 production in CANDU® reactors, designed and developed by MDS Nordion and AECL, has been safety, economically and successfully employed in many CANDU® reactors with over 195 reactor years of production.

This paper will describe, at an overview level, the MDS Nordion proprietary technology and know how that is used to provide CANDU® reactors with a safe and economical capability to produce cobalt-60.
CANDU® (CANada Deuterium Uranium) is a registered trademark of Atomic Energy of Canada Limited (AECL).

1. BACKGROUND

MDS Nordion has been supplying cobalt-60 sources to industry for industrial and medical purposes since 1946. These cobalt-60 sources are used in many market and product segments. The major application is in the health care industry where irradiators are used to sterilize single use medical products. These irradiators are designed and built by MDS Nordion and are used by manufacturers of surgical kits, gloves, gowns, drapes and other medical products. The irradiator is a large shielded room with a storage pool for the cobalt-60 sources. The medical products are circulated through the shielded room and exposed to the cobalt-60 sources. This treatment sterilizes the medical products which can then be shipped to hospitals for immediate use. Other applications for this irradiation technology include sanitization of cosmetics, microbial reduction of pharmaceutical raw materials and food irradiation.

The cobalt-60 sources are manufactured by MDS Nordion in their Cobalt Operations Facility in Kanata. More than 75,000 cobalt-60 sources for use in irradiators have been manufactured by MDS Nordion. The cobalt-60 sources are double encapsulated in stainless steel capsules, seal welded and helium leak tested. Each source may contain up to 14,000 curies. These sources are shipped to over 170 industrial irradiators around the world.

This paper will focus on the MDS Nordion proprietary technology used to produce the cobalt-60 isotope in CANDU reactors.

Almost 55 years ago MDS Nordion and Atomic Energy of Canada developed the process for manufacturing cobalt-60 at the Chalk River Labs, in Ontario, Canada. A cobalt-59 target was introduced into a research reactor where the cobalt-59 atom absorbed one neutron to become cobalt-60. Once the cobalt-60 material was removed from the research reactor it was encapsulated in stainless steel and seal welded using a Tungsten Inert Gas weld. The first cobalt-60 sources manufactured using material from the Chalk River Labs were used in cancer therapy machines. Today the majority of the cancer therapy cobalt-60 sources used in the world are manufactured using material from the NRU reactor in Chalk River.

The same technology that was used for producing cobalt-60 in a research reactor was then adapted and transferred for use in a CANDU power reactor. In the early 1970s, in co-operation with Ontario Power Generation (formerly Ontario Hydro), bulk cobalt-60 production was initiated in the four Pickering A CANDU reactors located east of Toronto. This was the first full scale production of millions of curies of cobalt-60 per year.

As the demand and acceptance of sterilization of medical products grew, MDS Nordion expanded its bulk supply by installing the proprietary Canadian technology in additional CANDUs. Over the years MDS Nordion has partnered with CANDU reactor owners to produce cobalt-60 at various sites. CANDU reactors that have, or are still producing cobalt-60, include Pickering A, Pickering B, Gentilly 2, Embalse in Argentina, and Bruce B.

AECL's CANDU® Reactor

AECL's CANDU® Reactor is unique among the power reactors of the world, being heavy water moderated and fuelled with natural uranium. They are also designed and supplied with stainless steel adjusters as part of the reactor regulating system, which is to shape the neutron flux to optimize reactor power and fuel burn-up, and to provide excess reactivity needed to overcome xenon-135 poisoning following a reduction of power. The reactor is designed to develop full power output with all of the adjuster elements in the core.

For cobalt-60 production, the reactor's full complement of stainless steel adjusters is replaced with neutronically equivalent cobalt-59 adjusters, which are essentially invisible to reactor operation. With its very high neutron flux and optimized fuel burn-up, the CANDU® has a very high cobalt-60 production rate in a relatively short time. This makes CANDU® an excellent vehicle for bulk cobalt-60 production.
Prior to a utility engaging in Cobalt-60 production, and notwithstanding the obvious initial change in licensing requirements and submissions, there are many engineering design considerations and requirements for the production of cobalt-60 in CANDU® which must be assessed. These include operator and public safety, minimum impact on station efficiency and reactor operations, shielding requirements during reactor operation with cobalt-60 adjusters, removal of the cobalt-60 adjusters from core, transportation within the station, and finally the processing and shipment off-site. Execution of the above mentioned results in the design and supply of the specialized equipment required for the production and handling of Cobalt Adjuster Rods.

CANDU Reactors currently produce many millions of curies per year of Cobalt-60 for MDS Nordion's use in industry and commerce. Following the removal and replacement of stainless steel adjusters with cobalt adjusters, the cobalt adjusters are removed from the reactor at approximately 2 year irradiation intervals, and transported to the remote Secondary Irradiated Fuel Bay (SIFB) for storage and processing. In the SIFB the cobalt adjusters are disassembled and the individual cobalt bundles prepared for offsite shipment to MDS Nordion in their purpose built and licensed transportation flasks.

In compliance with the above and to facilitate cobalt production, the Cobalt Adjuster Element

Processing System (CAEPS) was designed to permit the replacement of all of the cobalt adjuster rods during routine reactor maintenance shutdowns. The cobalt removal and transfer equipment was designed to be used intensively for relatively short periods of time and to function quickly and reliably so that the limited time "window" available for the replacement process would not be missed. The cobalt removal and transfer system is mechanized extensively in order to minimize labour and operator skills required. The system is designed for high productivity, to minimize the demands upon the station maintenance staff during the critical maintenance interval, and to increase the profitability of the operation.

Cobalt Adjusters

As previously stated a set of cobalt adjuster rods are provided in the reactor as part of the Reactor Regulating System (RRS). Initially, the design provided for D_2O cooling of the adjuster to address perceived thermal requirements. However, D_2O cooling has since been demonstrated as unnecessary and the system valved out.

The requirements for flux flattening in the core result in a number of different types of adjuster rods. Each cobalt adjuster rod assembly consists of a number of bundles, each bundle containing up to 6 cobalt pencils. The adjuster rods are assembled from standard design components. Only the centre rod and stainless steel cable lengths are special for each adjuster application, as determined by the number of bundles required due to its location in the reactor.

The cobalt bundle assembly is the basic building block of an adjuster rod. It consists of two circular end-plates held apart by two welded support tubes. The plates feature an outer ring of holes, which are precisely aligned so that one to six pencils can be inserted into them as required. Once inserted, the pencils are held in position by a snap ring, secured by a groove in the upper end plate and a shoulder on the bottom end plate.

The pencils are seal-welded zircaloy tubes filled with cobalt slugs. They are standardized components, made to suit service conditions as well as reactor requirements. The cobalt in the pencils constitutes the bulk of neutron absorbing material, the rest of the adjuster assembly being built mostly of zircaloy and designed for the smallest practical neutron absorption. The pencil and bundle lengths are matched so that the pencils, acting in compression, add to the bending structural stiffness of the bundle assembly.

The cobalt bundles, loaded with pencils as required, are threaded onto the center rod in a sequence to match the negative reactivity requirements for each adjuster type, due to its particular location in the reactor core. A special nut is screwed onto the upper end of the center rod. To provide a shoulder for a compression spring to apply tension to the center rod. The cobalt bundles are thus kept under reasonable constant load despite varying tolerance and thermal expansion effects. The upper nut and lower fitting on the center rod are designed to permit tensioning, and the lower fitting is designed to rupture the center rod at the bottom rivet for disassembling the element in the SIFB.

Removal of Cobalt Adjusters from the Reactor

A.General

Heavily shielding apparatus is required to safely discharge and transfer the irradiated cobalt adjusters from the reactor adjuster position to the designated section of the SIFB. Prior to commencing the cobalt production program, and as a primary requirement, the reactivity mechanism decks were provided with extra shielding to facilitate the handling of the irradiated cobalt elements.

The following items of CAEPS equipment are supplied or are used to safely unload the cobalt adjusters from the reactor, transport them to the SIFB and process them in the SIFB.

1. Flask and Pedestal
2. Reactor Building Crane (existing)
3. Flask Positioner
4. Transporter/Erector
5. Discharge Port
6. Element Processing and Handling in the Bay

B.Flask and Pedestal

The flask was designed to safely contain one irradiated cobalt adjuster on its suspension cable plus the lower shield plug. The flask shielding is sufficient as to give a surface contact dose rate on the outside of the flask of 50 mR/h or less during normal operations. Special appendages on the flask permit its safe transport by the reactor building crane and the CAEPS transporter/erector.

The CAEPS pedestal is designed to bridge the gap between the adjuster thimble and the flask, and provide a shielded passage for the cobalt adjuster during its removal from the reactor. The pedestal is dimensioned such that it fits within the confines of adjacent Reactivity Control Units which are closely pitched on the reactivity mechanism deck. The pedestal is mounted in and positioned around the adjuster thimble by the positioner. The shielding provided by the pedestal is designed to minimize man-rem exposure to the operator. Auxiliary shielding blocks are used to improve local shielding effectiveness within the space restrictions caused by adjacent Reactivity Control Unit mechanisms and which vary from position to position. The number and complexity of assembling these is minimized so as to not impede the cobalt adjuster discharge process. Both the flask and pedestal are capable of being used in turn on all reactor units as required.

C.Flask Positioner

The CAEPS flask positioner is designed to accept, carry and position the flask and pedestal at each of the adjuster thimble positions on the reactivity mechanism deck. Its high accuracy of positioning of the pedestal is essential to avoid damaging the thimble when lowering the pedestal into the deck. The flask positioner is very similar to a crane and runs on rails located approximately 3 meters above the reactivity mechanism deck. Due to the use of the positioner in the cobalt adjuster replacement process, only a few CAEPS operations require the use of the overhead reactor building crane.

D.Transporter/Erector

After each irradiated Cobalt Adjuster Rod is removed from the reactor into the CAEPS flask, the boiler room crane is used to lift the flask from the positioner and to lower it into the Transporter/Erector. The Transporter/Erector is comprised of a simple tractor drawn carriage on which a mechanized cradle is mounted to support and elevate the CAEPS flask. The Transporter/Erector is used to safely transport the CAEPS flask, containing the cobalt adjuster rod, between the reactor building and the secondary irradiated fuel bay (SIFB). It is thus designed to function both indoors and outdoors and travel anywhere within the reactor site.

The Transporter/Erector is equipped with an integral erecting mechanism which is fully power operated and fail safe to prevent any uncontrolled or unintended movement of the flask during any operation. Stabilizing devices are provided on the Transporter/Erector, to ensure the basic stability of the Transporter/Erector whenever the flask is in a partially or fully raised position. The stabilizers are equipped with interlocks to the elevating mechanism such that no erecting or lowering motion can be effected unless the Transporter/Erector is fully stabilized.

At the SIFB, and depending upon the reactor site configuration, the positioning of the flask onto the discharge port is performed by the SIFB service crane and/or the Transporter/Erector. The Transporter/Erector is required to park, be stabilized, and then erect the flask to the vertical position. The flask is then held vertical by the crane or the Transporter/Erector until discharging of the cobalt adjuster into the bay via the discharge port is complete.

The handling and processing of cobalt adjusters are carried out at such depth in the SIFB as to provide sufficient water shielding and minimize radiation hazards to cobalt operations personnel. The equipment involved is primarily comprised of the discharge port, and cobalt adjuster storage and processing equipment.

E.Discharge Port

The cobalt discharge port is located in the SIFB cobalt discharge slot. The port provides shielding when the cobalt adjuster is lowered from the flask into the SIFB cobalt slot. The top section of the port is designed to allow the flask to be located and mounted to it. The cobalt then passes through a centrally located bore in the discharge port.

Beneath the discharge port resides the discharge trough, it is used to accept and provide visual confirmation that the cobalt adjuster has been fully lowered from the flask.
From the discharge trough, the cobalt adjuster is transferred to the storage rack via the transfer arm and monorail trolley, where it awaits processing.

F.Cobalt Adjuster Processing Equipment

The Cobalt Adjuster Processing Equipment is comprised of the Inspection Table, Bundle Separator, Center Rod Muncher and Control Panel.

G.Inspection Table

The inspection table provides an area for inspection of the cobalt bundles and storage for individual bundles and bundle carriers. In addition, the table provides support for the bundle separator, hydraulic cylinders, tubing and in case of separator malfunction, a manual adjuster cone cutting facility.

The table rests on the bay bottom and is secured to the edge of the bay by two straps. A cut-out at one end of the table provides for containment of the catenary hoses that connect the valve panel to the inspection table/bundle separator assembly hydraulics.

H.Bundle Separator

The bundle separator grips the cobalt adjuster assembly head cup and lower cone, placing the adjuster centre rod in tension. The tensile force applied is sufficient to fracture the centre rod at a designed weak point located at the lower cone area of the center rod. The fractured centre rod allows the adjuster to be disassembled into cobalt bundles and waste component.

A rotating shaft anchors the bundle separator to the inspection table. A hydraulic cylinder bolted to the inspection table enables the separator to be rotated from a horizontal to near vertical position for easy acceptance of the cobalt adjuster rod from the storage rack and monorail. The hydraulic cylinders and controlex cable of the separator inspection table assembly are remotely operated from the control panel located at the edge of the bay.

I.Centre Rod Muncher

The muncher, located on the bay bottom adjacent to the inspection table, consists of a pedestal, cutter assembly, storage bin, catenary hoses and a controlex cable. The storage bin receives adjuster waste components resulting from the adjusters disassembly.

The waste components from the bundle separator are discharged into the bin via a chute system located at the end of the bundle separator and under the inspection table. In addition, the bin receives lengths of the adjuster centre rod and cable fed through the cutter assembly. The cutter assembly is actuated by a double acting water operated piston, controlled from the control panel. The controlex cable actuates an indicator on the control panel which shows the position of the cutter assembly.

J.Control Panel

The operation of the bundle separator/inspection table and centre rod muncher hydraulics are manually initiated from the control panel. The working medium of the hydraulic system is demineralised water taken from and recirculated to the SIFB.

In addition, two controlex cable levers are located on the panel, one for operating the bundle shuffler control valve, and the second for position indication of the muncher cutter. The hand lever operated control valve of the muncher is also located on the panel.

K.Cobalt Bundle Shipping

After the individual cobalt bundles have been removed from the adjuster rod assembly, inspected, and measured for their curie content, they are placed in MDSN's F231 shipping flask for transportation to MDSN's processing facility in Kanata, Ontario. MDSN's F231 shipping flask, as used for transporting the cobalt, is a purpose built flask which is licensed by the CNSC for the transportation of up to 400,000 curies of cobalt 60.

SUMMARY

The technology for cobalt-60 production in CANDU reactors, designed and developed by MDS Nordion and Atomic Energy of Canada, has been safely, economically and successfully employed in CANDU reactors with over 195 reactor years of production.

Today over forty percent of the world's disposable medical supplies are made safer through sterilisation using cobalt-60 sources from MDS Nordion. Over the past 40 years, MDS Nordion with its CANDU reactor owner partners, has safely and reliably shipped more than 500 million curies of cobalt-60 sources to customers around the world.

MDS Nordion is presently adding three more CANDU power reactors to its supply chain. These three additional cobalt producing CANDU's will help supplement the ability of the health care industry to provide safe, sterile, medical disposable products to people around the world. As new applications for cobalt-60 are identified, and the demand for bulk cobalt-60 increases, MDS Nordion and AECL continue to identify additional CANDU reactor owners who recognise the mutual benefits of cobalt-60 production.

.