G. High-Current Accelerators for Fissile-Fuel Production, J. S. Fraser, CRNL

For many years, Canada has maintained a modest program designed to develop accelerator-breeder technology as an adjunct to the nuclear power fuel cycle. Our long-range objective is to develop an alternative scheme to extend the usefulness of uranium and thorium resources. At the present time, electronuclear breeding is not economically attractive, but the time may well come when the cost of uranium rises to say, $300/kg (in 1979 dollars). When and if that happens, the accelerator breeder will have an economic attraction. In the meantime we plan to develop the accelerator and, to some extent, the target technologies so that they are available if needed.

The idea of accelerator-produced neutrons for fissile-material production is not new. An extensive development program on the MTA[1] accelerator was undertaken in the USA in the early 1950's to produce plutonium[2,3] but was terminated when sufficient uranium ore was found in Colorado to supply the Savannah River reactors. A 500-MeV, 320-mA, 50-MHz deuteron accelerator, with a primary beryllim target surrounded by a secondary depleted uranium target, was expected to produce about 500 kg of plutonium a year at $124/g (~$300/g, 1976 $). The concept of bombarding a heavy element target with energetic nucleons was also recognized by W. B. Lewis[4] at Chalk River around 1950. Lewis made some remarkably foresighted comments on the role accelerators might play in a nuclear energy system.

Canadian interest in spallation-neutron sources continued through the 1950's with measurements at the McGill cyclotron[5] and using cosmic ray neutrons.[6] The Intense Neutron Generator (ING) study[7,8] at CRNL was based on the concept of a high-power proton beam bombarding a liquid lead-bismuth eutectic target; its goal was the production of a high flux of thermal neutrons.

Although the ING study was terminated as a program for a scientific research facility, a small effort continued on the industrial application of accelerators for production of nuclear fuels.[9] The work was concentrated on two low-energy, high-current, 100% duty-factor accelerator experiments[10,11] and a study of efficient radio-frequency generators.

An economically competitive accelerator breeder would require a beam power of the order of 300 MW, typically a beam current of 300 mA at 1 GeV. This high-current level has been achieved in proton linacs - the high power is a consequence of extending the duty factor to 100%. It is precisely for that reason that we are carrying out several low-energy, high-current, cw accelerator experiments.

The first of these experiments is a low-energy proton linear accelerator designed to accelerate protons up to 3 MeV. The starting point is a duoplasmatron ion source for protons located in the terminal of a high-voltage set, a standard Cockcroft-Walton accelerator operated as a dc terminal. The ion source has delivered a dc proton current in excess of 100 mA with normalized emittance of 3.2 π•mm•mrad. This is a good quality beam. The beam is accelerated to 750 keV in a high-gradient column. It is then injected into a 3 MeV Alvarez accelerator tank. The ion source and high-gradient column have been operated successfully up to 45 mA.

Beam experiments are about to begin. These experiments will give us experience in the operation of a high-current injector and in the most difficult stages of the low-energy part of the breeder accelerator. In many aspects of this work we are opening up new ground. With the Alvarez structure itself we hope to gain information on the space-charge limits of operation of such a structure.

While the present dc injector is suitable for initial beam experiments in the Alvarez, advanced injector concepts will be tested separately in an injector-test experiment. This will include a duoPIGatron, cusp or picket-fence source, mass anlysis and differential pumping in the high-voltage terminal and ceramic insulators well shielded from bremsstrahlung. Currently we have a duoPIGatron operating at over 450 mA total current with a normalized emittance of about 10π.mm.mrad.

Like other intermediate-energy accelerators, the breeder accelerator would make a transition at, say, 100-150 MeV, to a different kind of structure which would be more efficient at higher energies, probably a biperiodic wave guide structure similar to the 800-MeV linac at Los Alamos. We have built an electron analog of this structure designed to carry out experiments on the field-level control under full-beam loading, the cooling of the structure, the operation of the safety, and beam-control devices all at 100% duty factor. It consists of a three-element electron gun, a buncher cavity, a graded-β pre-accelerator tank, and one main accelerator tank. The bunched and the graded-β tank have been operated successfully up to 20 mA and both tanks at 16 mA without difficulty. We have demonstrated that the structures and the control systems work well at the design level of power density and at 100% duty factor. Computer control of a cold start to beam ready condition in 10 min has been demonstrated.

For several years we have also carried out some target studies, including calculations and experiments. The calculations have been limited to simple geometries amenable to experimental verification. In the future we intend to tackle more complex assemblies which come a little closer to engineering reality.

The experimental program of measurements, called "FERFICON" for "fertile-to-fissile conversion," is currently under way at the TRIUMF cyclotron in Vancouver. These experiments are designed not only to verify earlier measurements on neutron production but to obtain data on fertile-to-fissile conversion rates.

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H. The TRIUMF Thermal Neutron Facility, I. M. Thorson, TRIUMF

The primary purpose of the TRIUMF Thermal Neutron Facility (TNF) is to stop the residual proton-beam downstream of the meson production targets in the main TRIUMF beamline. The nominal full current from the 500-MeV isochronous cyclotron is 100 μA; as much as 35% of this beam current is removed by the meson production targets. The remaining beam is used to produce a steady-state neutron source in a 13-cm-diam by 25-cm-long lead target of ~ 3×10^{15} n/s^{-1}, giving thermal flux levels of ~ 3×10^{12} cm^{-2}•s^{-1} in the surrounding H_2O and D_2O moderators. The target heat is dissipated by convection of the molten lead and nucleate water boiling at the outside of the 0.3-cm-thick stainless steel container.

The TNF is intended for use as both a neutron-beam and irradiation facility with hardware provisions for both having been installed. Two of the four neutron-beam tubes view the D_2O moderator below the lead target offset 15 cm from target centerline and at angles to the incident proton beam of 60° and 120°. The other two are offset by 30 cm from the target centerline and form a through-tube at the interface between the D_2O moderator and H_2O reflector. The access to the D_2O moderator compartment is through a 5-cm by 13-cm vertical tube from the top of the 45-cm diam by ~350-cm high H_2O moderator coolant column.

The thermal and epithermal neutron-flux distribution in the D_2O moderator has been measured by activation of gold foils, with integral proton-beam current estimated from the ^{24}Na activity induced in a thin aluminum foil mounted directly ahead of the target. The results are shown on the lateral cross-section view of the assembly in Fig. I.H-1. Measurements were also made with H_2O in the D_2O moderator tank. The