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RESEARCH OPPORTUNITIES WITH PROTOTYPE ACCELERATORS FOR AN ACCELERATOR BREEDER

G.A. Bartholomew

Atomic Energy of Canada Limited
Research Company
Chalk River Nuclear Laboratories
Chalk River, Ontario K0J 1J0

Abstract

Three stages of the prototype cw proton accelerator required to develop a pilot accelerator breeder provide opportunities for neutron research. New spallation yield measurements at 100 MeV in Pb, together with known yields above 400 MeV confirm that the second stage device, a 70 mA 200 MeV linac, coupled to a Pb-Bi target could provide beam tube fluxes of $\approx 10^{15}$ cm^{-2} s^{-1}. The pilot breeder is visualized to be located in a nuclear energy centre whence users might enjoy reduced costs owing to shared use of the accelerators, cheaper electricity and the possibility of output heat reclammation.

RESEARCH OPPORTUNITIES WITH PROTOTYPE ACCELERATORS FOR AN ACCELERATOR BREEDER

G.A. Bartholomew

As many in the audience will know, CRNL has not had the same goals in R and D for intense accelerator neutron sources as other laboratories in ICANS. The other laboratories have been interested in developing neutron sources primarily for fundamental research while in recent years we have been interested in developing them for accelerator breeding of fissile fuel[1]). I would like to tell you in what directions our planning is leading us as from this different vantage point. Although our thinking in spallation sources for research goes back to ING, we have only in the last year or two begun to think seriously of such sources as opportunities arising ready made from our accelerator breeder program and our concepts are still not very detailed. At Karlsruhe Dr. Chidley will describe our current accelerator development work. For some years we have also done target neutron yield and blanket fissile yield studies in collaboration with Dr. Thorson and others at TRIUMF and in the last year there has been a small scale effort on liquid-metal target concepts.

By way of background, let me mention that Canada is in the rather unique position in its nuclear power program in not needing a fast breeder reactor to extend its fissile fuel supply. With the CANDU reactor we could meet electricity needs for a very long time on the thorium fuel cycle[2]). In principle, the CANDU-thorium reactor could operate as a thermal breeder with a breeding ratio of unity but in practice it would be more economic to use some "topping enrichment" from outside the cycle. Extra fissile material would also be needed as initial inventory to start new reactors to expand the system. One can foresee a time when it may be economic to produce this makeup fissile material by means of a local auxiliary breeder and in a review just completed at CRNL we have confirmed our view that the accelerator breeder is, for us, the leading option to fill this role. So we visualize the accelerator breeder as a relatively small auxiliary supply system working in conjunction, or symbiosis, with a very much larger system of thermal reactors which will be the same CANDU advanced converter reactors we now have.

It has been determined[3]) that an optimized accelerator breeder would require a 1 GeV proton accelerator at 300 mA cw (Table 1). The beam would bombard a lead bismuth target surrounded by a blanket of fertile material and would produce something like 3 kg per day of fissile material. This is all I want to say about the breeder itself because I want to concentrate on opportunities presented by the prototype accelerators that will be needed to develop the accelerator breeder.

Three major steps are foreseen in building the technological base for the electronuclear breeder demonstration plant as portrayed in Fig. 1. The first step is the zero-energy breeder accelerator (ZEBRA) which would produce the full accelerator-breeder beam current but at only 1% of the final energy. This is visualized as a laboratory test accelerator located at CRNL. It would be very much an experimental

TABLE 1 PARAMETERS OF ACCELERATOR BREEDER

Energy	1 GeV
Beam Current	300 mA protons cw
Accelerator	0-50 keV injector 0.050-2 MeV RFQ 2-200 MeV DTL 200-1000 MeV coupled-cavity
Target	Pb-Bi (distributed)
Blanket	uranium or thorium
Target/Blanket Power	1800 MWth
RF Power	370 MW
Fissile Output (80% availability)	≈3 kg/day

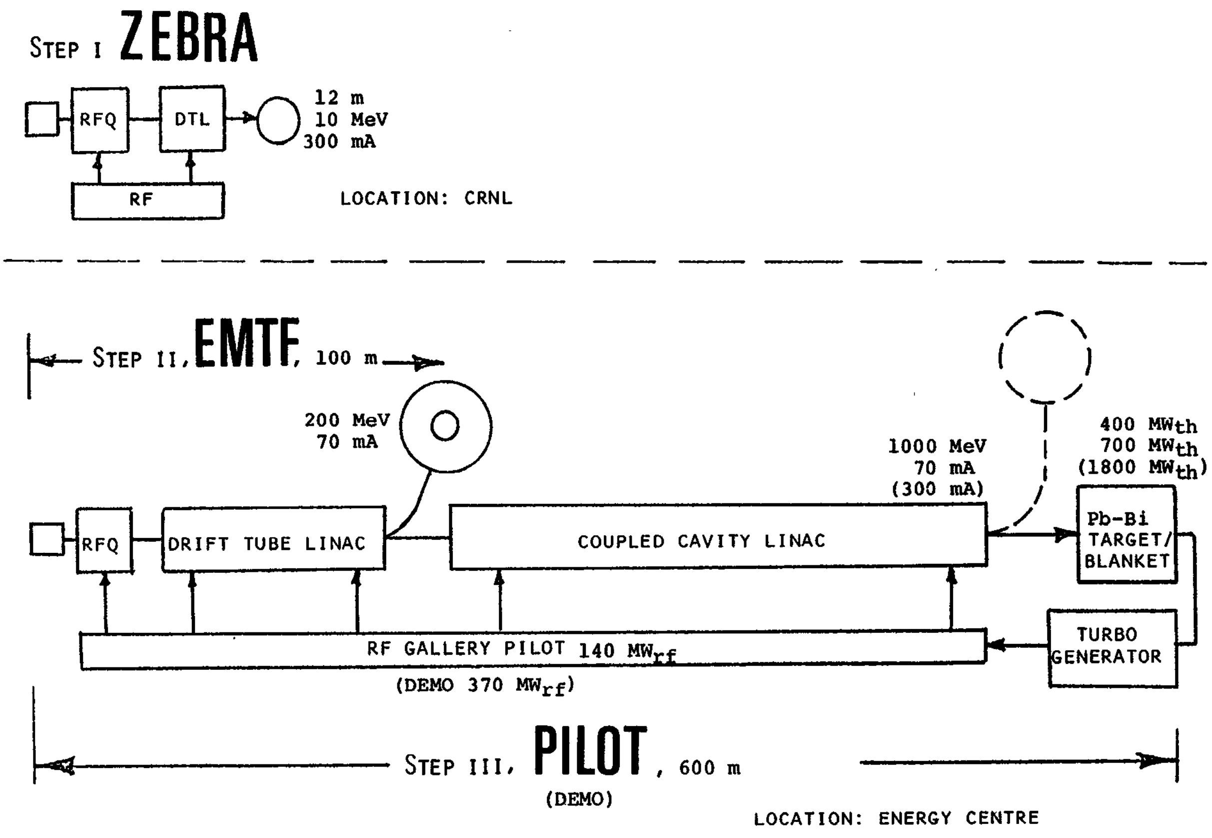

Fig. 1 Schematic representation of three modular steps in development of accelerator breeder from Zero Energy Breeder Accelerator (ZEBRA) to Electronuclear Materials Test Facility (EMTF) to PILOT Breeder. Subsequent upgrading from PILOT to DEMO would be accomplished by increasing the radiofrequency power.

prototype heavily instrumented to diagnose accelerator performance at high currents and low energy; this would be its main reason for existence. ZEBRA would involve an ion source and injector to about 50 keV, then a radiofrequency quadrupole to 2 MeV followed by a drift tube linac to 10 MeV. I will return to the output and possible experimental uses later.

The second step is an Electronuclear Materials Test Facility (EMTF) which, as indicated in Fig. 1, would accelerate a 70 mA proton beam to 200 MeV. This facility is envisaged to be located within the exclusion area of a nuclear energy centre because it is planned ultimately that it would be the front end of a full-demonstration breeder and the breeder would be best located near fuel reprocessing and storage facilities and also near the turbo generators of a CANDU station all of which we envisage to be located in the energy centre. However at the EMTF stage the beam would be stopped in a Pb-Bi target to form a neutron source. The beam parameters were chosen to give a thermal neutron flux of $\approx 10^{15}$ cm^{-2} s^{-1}. The accelerator might be planned so that 200 MeV is the transition energy between the drift-tube linac section and the coupled-cavity section. I will return to target characteristics in a moment.

In the third or PILOT stage the EMTF accelerator would be extended to 1000 MeV and 70 mA. This beam is considered the minimum to provide a full demonstration of the accelerator breeder target-blanket system, in particular to test performance at heat fluxes and neutron fluxes of interest to the reactor physicists and fuel engineers who would develop the blanket. It would be advantageous at this stage to reclaim the power developed in the target and blanket which might be of the order of 700 MW - the exact value would depend on the equilibrium fissile concentration permitted in the blanket. Beam splitting could be arranged to maintain both the EMTF and PILOT in service at the same time. By uprating the 200 MeV section to deliver 140 mA both could enjoy a 70 mA beam.

In later stages the rf supply of the pilot plant would be uprated to deliver the full 300 mA current required of a demonstration breeder plant and again I would think ways can be found to accommodate the research interests at the same time.

The facility represented by the broken line from the output of the 1 GeV accelerator in Fig. 1 would be a possible addition that would allow the 70 mA beam to be used, with a suitably uprated target of course, to provide a superb cw neutron source4) for research with a thermal flux of about 10^{16} cm^{-2} s^{-1}. We do not stress this possibility in present planning because it is too far in the future.

There is an obvious disadvantage in mixing the functions of a neutron source for research and a prototype breeder facility of interest to a utility. However, because the breeder is a pilot or demonstration device such a marriage may be rather more tolerable than attempting to share facilities with a fully committed commercial breeder. There could be compensating advantages, for example, in reduced operating costs for the research device because of close proximity to the power station and support services.

Now to return to ZEBRA one has to build a beam dump for 3 MW in any case and perhaps an argument could be made to go a bit further and install a falling liquid-lithium-stream target of a type similar to that for the Fusion Materials Irradiation Test (FMIT)[5]). We have not done a detailed design but we feel it may be possible to dissipate 3 MW with a flow of some 15-20 m/s in a jet several times thicker than the proton range (0.27 cm) in lithium. This flow may not be enough to prevent some vapour formation and cavitation by the beam, but it should be possible to arrange not to burn right through the Li jet. The proton beam would be about 10 cm in diameter to distribute the heat. The Li(p,n) yield at 10 MeV is known[6]) to an accuracy of about 4%; for 300 mA the total yield is 5.6×10^{15} ns^{-1} over 4π. This source would have a white spectrum and would not be pulsed, which makes it unattractive for cross section measurements. However, there are likely to be some applications in radiation damage, activation analysis, and isotope production. Of course, one would also gain valuable experience with liquid metal systems.

In the case of the EMTF source, we first thought of using a Li target here also because it would have simplified the heat dissipation problem. In fact our first plan called for a 100 MeV EMTF with 300 mA beam onto a Li target. However the accelerator will cost the same and will produce twice the yield at 200 MeV 70 mA, i.e. half the beam power, if we use a lead-bismuth target. One could not use a lead target at 100 MeV 300 mA because the range is only about 1.5 cm in lead and the power density in the metal becomes too high. At 200 MeV, the range in lead is about 5 cm. We envisage some kind of falling Pb-Bi stream but have not settled on the geometry; it could be cylindrical or rectangular. In simple calculations assuming a 10 cm diameter proton beam, the 14 MW heat deposition can be removed with a 15 m/s flow rate. The neutrons would be moderated to thermal energies and there would be space for a number of beam tubes in the high flux region.

When we started to study EMTF prospects as a neutron source we found that the total neutron yields for proton energies in the range from 25 MeV to 400 MeV were not measured for lead and other heavy metals. Only in this last month, as a direct result of our requirement an integrated yield measurement at 100 MeV has been carried out by a collaboration of CRNL and McGill University scientists using the McGill cyclotron[7]). The technique employed was quite standard, involving a large water bath in which are placed gold foils to give an integral flux measurement from which, and a measurement of the beam current, one calculates the yield. The lead target in the experiment was 5 cm in diameter and 1.5 cm thick. The Pb yield between 25 and 400 MeV was previously only known from calculations using the NMTC code[8]). The yield curve is shown in Fig. 2. Data points from previous results are shown above 400 MeV. The new results from McGill confirm the calculated yield at 100 MeV and therefore greatly improve confidence in the yield calculated for 200 MeV. The estimated yield at 200 MeV is $\approx9\times10^{18}$ ns^{-1} A^{-1} from which the thermal flux from EMTF can be estimated to be $\approx10^{15}$ cm^{-2} s^{-1} at 5 cm from the 5 cm target diameter surface in a water moderator. At the target surface the flux is $\approx2\times10^{15}$ $cm^{-2}.s^{-1}$. We have not tried to fix the geometries or moderators for this system at this stage.

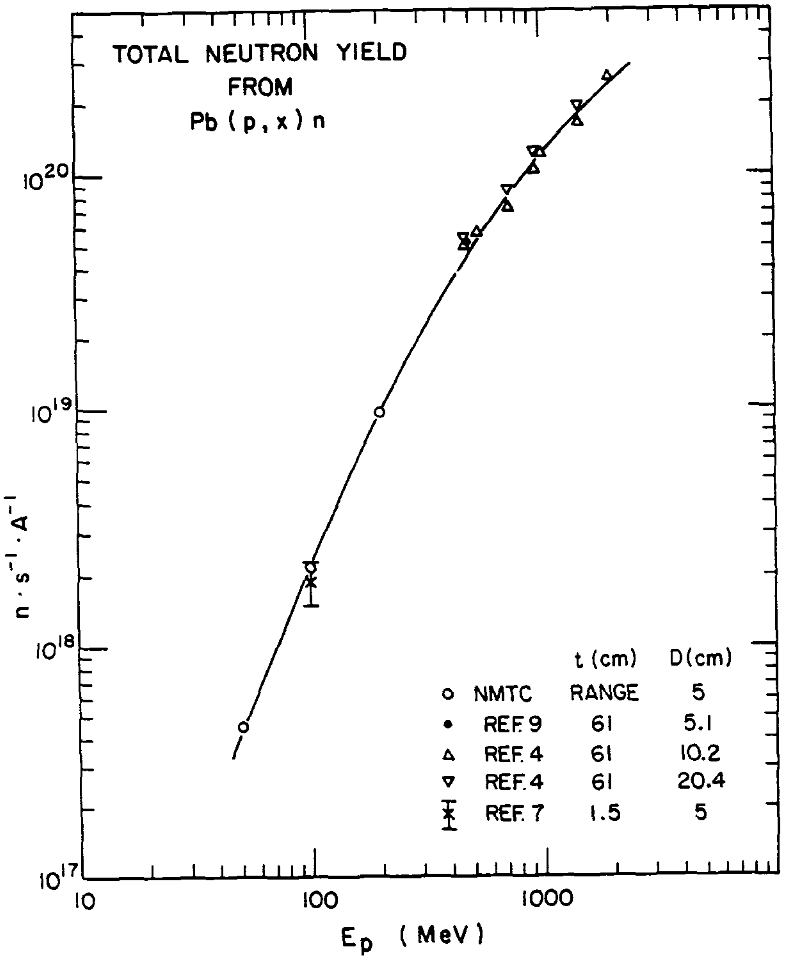

Fig. 2 Total neutron yield from bombardment of lead with protons. The recent experiment at 100 MeV (ref. 7) confirms the NMTC calculation at that energy.

Some uses of EMTF are listed in Table II. I should emphasize that one of the main justifications for EMTF is to study materials problems associated with the accelerator-breeder target/blanket assembly. For this purpose the spallation spectrum at 200 MeV is near ideal since its shape at low energies is a close approximation to the evaporation spectrum from 1 GeV protons; only the high energy cascade tail above 200 MeV is missing.

TABLE II EMTF USES

A. Programmatic:

1. neutron source with intensity and spectrum needed for testing of accelerator breeder target/blanket materials
2. liquid Pb-Bi target design and operating experience
3. accelerator tests cw, to 200 MeV

B. Spin-Off

1. high-flux ($\approx 10^{15} cm^{-2} s^{-1}$) steady state thermal neutron source for neutron solid state research
2. industrial opportunities in new liquid metal technology, new materials, new cooling systems, new components
3. complementary neutron damage studies for fusion
4. isotope production by fast neutrons
5. intense proton beam applications

In practical tests with the EMTF target one would be limited by practical flow rates of the liquid metal and by desire to avoid turbulent flow conditions caused by excessive vapour formation in the body of the metal. Of course several ICANS projects will provide valuable experience in high power targets. With EMTF there would be incentive to explore even more extreme conditions and press beyond 70 mA to breeder-type targets. You will realize of course that the target for a breeder would not necessarily be one useful for a high flux application; a breeder target might consist of a large number of jets and the proton beam would probably be widely spread to accommodate the heat load and to provide the distributed source required for the blanket. Experiments with a liquid lithium target system at 200 MeV energy might also be substituted in EMTF if desirable. Incidentally it is planned to extend the McGill total neutron yield experiments at 100 MeV to lithium and other targets.

Finally, I should mention that we do not yet have approval to build ZEBRA. We are still in a pre-ZEBRA development phase. We hope to obtain approval to build ZEBRA in 1983-84 and begin tests with it about 1987-89. The earliest we can imagine building EMTF is 1991-92 with first beam in 1995. We are not at this stage considering details of any neutron sources for research that might become available in later stages of the accelerator breeder development.

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