Atomic Energy of Canada Limited

# THE INTENSE NEUTRON GENERATOR STUDY

DL-70

by

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Chalk River, Ontario

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L'étude du générateur de faisceaux intenses de neutrons

par W. B. Lewis

Rapport sur l'état d'avancement de l'étude en question ayant été présenté au Congrès de l'Association nucléaire canadienne qui a eu lieu du 30 mai au 1$^{er}$ juin 1966 à Winnipeg, Manitoba.

Résumé - L'étude a confirmé qu'un faisceau de 65 mA de protons à 1 000 MeV frappant une cible de plomb-bismuth fondu, entourée d'eau lourde modératrice, donnerait le flux désiré de $10^{16}$ neutrons thermiques par $cm^2$ et par seconde, pour fournir des faisceaux intenses de neutrons et aussi pour produire des radioéléments. En traversant une cible auxiliaire mince le faisceau de protons produirait également des faisceaux de mésons. Les plans et la fabrication de la source d'ions, de l'injecteur, de l'accélérateur, de la cible et des dispositifs auxiliaires donnent lieu à des problèmes techniques qui sont de véritables défis. De plus, les développements continus qui visent à rendre les systèmes plus durables et plus économiques sont très prometteurs. Les faisceaux intenses de neutrons serviront pour les recherches en physique des états solide et liquide et aussi pour la physique nucléaire. On s'attend à ce que les universités et les entreprises industrielles participent largement au développement du générateur de faisceaux intenses de neutrons et à son utilisation.

Chalk River, Ontario

Mai 1966

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by W.B. Lewis

A report on progress presented to the
Canadian Nuclear Association Conference,
May 30 to June 1, 1966
at Winnipeg, Manitoba


## Summary

The study has confirmed that a beam of 65 mA of protons at 1000 MeV, striking a molten lead-bismuth target surrounded by heavy water moderator, would give the desired flux of $10^{16}$ thermal neutrons per $cm^2$ per second to provide intense beams of neutrons and also to produce radioisotopes. The proton beam passing through a thin auxiliary target would also produce beams of mesons. The design and construction of the ion source, injector, accelerator, target and auxiliaries present challenging technical problems. Moreover, continued development for improved life and economy promises to be rewarding. The high neutron intensity is sought for research in solid and liquid state physics and also for nuclear physics. Participation by universities and industry, both in development and use, is expected to be extensive.


Chalk River, Ontario
May, 1966

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# THE INTENSE NEUTRON GENERATOR STUDY

by W.B. Lewis

Experience teaches that in a ten-minute speech only one point can be communicated to all the members of a large audience, but I am optimistic and hope to make two points; namely, that a large number of people with very many different outlooks and specialities have great expectations from ING, and second that projects of this type and the ING project in particular would be very good for the economy and for science in Canada.

I should make it clear that so far the project has been only a study; very shortly there will be a proposal and in view of its promise we hope and expect that a development and construction project will result.

The idea began quite simply from the fact that we have been able to do so much and find so many uses for the high neutron flux and intense neutron beams from the $57 million NRU reactor that we would like to go one better. Others in the world also want to go one better, in fact the USSR and USA already have reactors with higher fluxes and more intense beams than our NRU reactor. We, however, rejected the reactor route which requires the consumption of highly enriched or pure fissile material at a very rapid rate. The reasons for rejection were not only that such fuel is expensive but also that a limit is finally set by the large amount of heat that has to be taken from a relatively small volume. Moreover, other nuclear reactions exist that yield more neutrons with less heat than from fission.

Let us be quantitative; we are seeking a flux of $10^{16}$ n/cm$^2$/sec, fifty times higher than in NRU. In such a flux uranium-235 with an effective cross section of 650 barns would have a mean life $1/\phi\sigma = (1/0.65) \times 10^5$ seconds or about 1.8 days. So one would need a very special reactor with an almost continuous fuel feed.

Our study has confirmed that we can obtain the required neutron flux of $10^{16}$ n/cm$^2$/sec from a beam of protons of 65 mA at 1000 MeV or 65 megawatts striking a target 21 cm diameter by 60 cm long of molten lead-bismuth eutectic (45% Pb, 55% Bi) surrounded by heavy water moderator. Moreover, the total energy dissipated in the target is only 40 megawatts because the nuclear reaction has little effect on the energy balance and the energetic particles and neutrons, fast or slow, that escape deliver the residual energy to the surrounding moderator, neutron absorbers and shield.

It is of interest to note that the neutron yield is about twenty neutrons per proton so 65 mA of protons will produce $8 \times 10^{18}$ n/sec which comes to 1.2 g neutrons per day. A fission reactor producing the same number of spare neutrons (at 1 spare neutron per U-235 atom destroyed) would consume 275 g U-235/day, giving a power of 220 megawatts and costing, for fuel alone, at least \$4000/day or \$1.2 million/year of 300 days. In practice, a reactor designed to yield both 1.2 g neutrons/day and a flux of $10^{16}$ n/cm$^2$/sec to several large beam tubes would have to operate at 400 to 600 MW with an annual fuelling cost of at least \$2.5 million to \$3.5 million.

The intense neutron generator may cost as much as the special reactor but instead of pressing against the limit of design for fuelling and heat removal it opens up a new technique that could probably go much further. A major contribution both to the capital and operating cost would come from the need to supply about 100 megawatts of radiofrequency power for the accelerator; 100 MW for 7000 hr/yr at 5 mill/kWh amounts to \$3.5 million/yr. Some estimates for RF power equipment have been as high as \$500/kW (50¢/W) or \$50 million for 100 MW, but we hope it would prove possible to cut this capital cost by half. The total installation might cost \$100 million, but there is considerable incentive for the project because it would satisfy such a large number of interests.

A list of just some of those people with expectations would include:

(1) Isotope producers, technologists and users: a large increase in the use of isotopes as power sources, particularly with thermoelectric converters, is foreseen; another hope is that portable and reasonably lasting (60-day half-life) neutron sources made of Sb-124 + Be, of much higher intensities than now available, will give sufficient neutron intensity to capture some of the growing practice of neutron activation analysis. Canada still has a short lead in the lithium-drifted germanium detectors that make neutron activation analysis so powerful.

Revenues from isotope and associated equipment supplies alone might even repay a large part of the capital cost of ING.

(2) One hears often that industrial technology depends on materials science, but this is more of a hope than a fact because materials science has to grow very far in depth and complexity. Studies of the "inelastic scattering of neutrons" made with the NRU reactor have told us so much about phonons and lattice vibrations in general that a prime reason for ING is to give even better facilities to solid (and liquid) state physicists.

(3) Our study suggests that we need about a hundred megawatts of continuous radiofrequency power at high efficiency and this proves to be a tremendous challenge to present-day radiofrequency engineers. It should be practicable to achieve but attempts so far fall considerably short on efficiency and life of generators.

(4) Our newspapers keep us aware of the current interest in accelerators. Many of those concerned would envy the ion source and the injector we hope to develop for the ING accelerator. Moreover, it might include a 10 million volt d.c. generator delivering 130 mA or 1.3 megawatts, and the process might be of interest to those concerned with d.c. power transmission.

(5) In the last two or three years the major principles have been established for the design and engineering of large superconducting magnets. We find superconducting magnets, both large and small, very attractive for guiding and transporting the proton beam. There are also possibilities for superconductors to save power in the radiofrequency system, but that is relegated to the future in the forthcoming proposal.

(6) Nuclear scientists have at least two main fields of interest in the ING. They are interested both in the neutrons and in the $\pi$, $\mu$ and K mesons that the generator will produce. The neutrons and $\pi$ mesons are specially valuable as tools with which to explore the structure of atomic nuclei and more generally the properties of "nuclear matter".

(7) The list is not by any means complete (I am leaving out those interested in pumps, valves and couplings for liquid metal systems, and many others) but I must mention a special interest of Atomic Energy of Canada Limited in the broad field of nuclear energy. Neutrons are recognized as a sort of technical currency; neutrons produce fissile material and thermonuclear material (tritium) and also release nuclear energy in fission. The ING indicates a means of producing neutrons in gram or kilogram quantities independently of any existing stock

of fissile material. Devices that increase the stock of fissile material have been called "breeders" so Alvin Weinberg has called the ING an electrical breeder. If we keep up the development we may arrive at more efficient and less costly accelerators that could eventually be of economic significance.

Having mentioned all this interest I must add a note of caution. Even the ING with only 40 megawatts in the target produces such a high intensity of penetrating radiation that the problems of radioactive activation appear severe even to those accustomed to reactors operating at hundreds of megawatts. Radiation fields limit access to the accelerator even when shut down and the target tube itself is exposed to such intense radiation that it may have to be replaced every few weeks.

Perhaps you are wondering why I have not used my time to tell you what ING is; the reason is that we do not know exactly. The study has certainly kept its feet on the ground and the concept and design of the target has advanced considerably. Careful experiments with high energy protons and deuterons with the Cosmotron at Brookhaven and the proton synchrotron at Birmingham have established that 1000 MeV protons in a beam of 65 mA will in fact give the thermal neutron flux and beams we look for. It seems feasible to let the beam plunge down from a vacuum directly onto the surface of liquid lead-bismuth eutectic flowing down and away to a heat exchanger. The target and tubes for neutron beams have been mocked up with a neutron source in a special study in the ZEEP reactor vessel at Chalk River. The required intensity and constriction of the proton beam has received a lot of study and appears to be comfortably within the range of experimental practice. Experiments, however, on such beams relate only to short pulses and not to continuous - but RF bunched - beams. Either the separated orbit cyclotron or the linear proton accelerator design appears feasible but either would be costly. Different types of radiofrequency generators have been studied for the two types of accelerator but, as I have mentioned, further development is required to assure long life at high efficiency. We would expect our study, augmented by experimental work, to continue for another year before deciding the main features of the ion source, injector and accelerator. We would be seeking especially cost reduction and technical assurance of adequate life.

I mentioned that we expect the project to be good both for the economy and for science in Canada. Throughout the study we have been building up close participation by those in industries and universities who are interested either in the challenging developments of the advanced technology involved or later as users of the outstanding facilities for research experiments that the device offers. Although when we started no one else in the world had a similar proposal, our friends at the Oak Ridge National Laboratory in Tennessee have adapted their earlier proposal for a meson facility to one closely similar to ours. I hope we can look forward to the stimulus of competition and mutual assistance in overcoming the many technical challenges.

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