THE CANADIAN INTENSE NEUTRON-GENERATOR

by

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The proposed Intense Neutron-Generator[1] is a multi-purpose facility. It would produce intense beams of thermal neutrons for solid-state and low-energy nuclear physics studies and provide irradiation facilities for advanced research in nuclear chemistry, in materials science and for production of radioisotopes of research and commercial value. It would also provide copious sources of mesons and energetic nucleons for intermediate-energy nuclear-structure studies.

The primary neutron source, $\sim 10^{19}$ sec^{-1}, would be generated by bombarding a lead-bismuth target with a continuous 65 mA beam of 1 GeV protons. The same beam, and at a later stage of development, an auxiliary H^- beam, would be used simultaneously for producing secondary beams of π- and μ-mesons and energetic nucleons.

The overall plan, shown in Fig. 1, divides naturally into linear accelerator and beam-applications areas. The latter area, shown in more detail in Fig. 2, was planned to be easily modified and extended. The basic system includes a thin meson target traversed by the full 65 mA beam and, at the end of the transport system, the thermal-neutron target which absorbs the full beam. Subsequent elaborations would provide a split-beam channel for H^- ions co-accelerated with the protons, and for other secondary beam channels into which part or all of the main beam may be diverted. Ample space is allowed for adding a second transmission meson target, more experimental floor area, extra shielding if needed, and possible future facilities, for example, a storage ring. All beams are enclosed in tunnels shielded by about 8 metres of sand.

The thermal-neutron target area is shown in more detail in Fig. 3. The proton beam enters the building near ground level, is bent upward and then vertically downward into the liquid lead-bismuth target. The latter, a circulating, cooled, eutectic mixture, is surrounded by a tank of heavy-water moderator to yield a flux of 10^{16} cm^{-2} sec^{-1}. Beam tubes and isotope irradiation facilities would be placed within and around the heavy water.

Fluxes near 10^{16} cm^{-2} sec^{-1} are difficult to obtain with fission reactors because of core heating and fuel consumption limitations. The spallation-evaporation process by 1 GeV protons has several advantages, notably liberating about 4 times less heat in the primary source per output neutron.* About 20 neutrons per proton are expected[4]. Only 39 of the 65 MW beam power appears in the liquid metal; the remainder is radiated by nuclear processes to the heavy-water and surrounding shield.

*This scheme for producing neutrons in large quantities is not new; an extensive development program, the MTA project, was pursued in the USA in the early 1950's[2]. Lewis[3] discussed potentialities in 1952.

The transmission meson target will probably be a falling curtain of liquid lithium, 0.1 gm/cm^2 thick. It would remove 0.2% of the main beam and have to dissipate about 15 kW of heat.

A Separated-Orbit Cyclotron to produce the proton beam was seriously considered[1]. However we have now chosen a linear machine, adapted from the design of the Los Alamos Meson Physics Facility[5] for 100% duty factor, for detailed study. Improved accelerating structures developed at Los Alamos[6] and advances in crossed-field microwave generators[7] influenced this choice.

Figure 4 and Table I illustrate the current design concept and main parameters of the machine. The injection system is a D.C. Duoplasmatron ion-source delivering 120 mA of positive ions, about 70% protons, accelerated to 0.75 MeV in a Pierce geometry column. With a double-drift-space harmonic buncher we expect 85% capture efficiency into the linac. A drift-tube structure consisting of 9 tanks and operating at $268\frac{1}{3}$ MHz accelerates the beam to 106 MeV. The first tank will be a $2\beta\lambda$ structure to ease quadrupole design problems in containing the transverse space-charge defocusing. At 106 MeV a transition is made to a coupled-cavity accelerator operating at 805 MHz consisting of 322 tanks driven in pairs by 0.5 MW RF generators. The 3:1 frequency ratio is dictated by a desire to be capable of simultaneously accelerating about 1 mA of negative hydrogen ions with the 65 mA of protons. The negative ions could be easily separated from the protons by an analysing magnet at the out

The design concept of the radiofrequency generators is shown in fig. 5. While the crossed-field device used as an output stage has low gain it is responsible for most of the DC to RF conversion; an efficiency of 85% is believed achievable and indeed has been accomplished in magnetrons[8]. With this we expect to approach an A.C. line power to beam power efficiency of 50%.

Our current programme includes studies of particle dynamics and beam stability in the machine, development and testing of ion sources and experimental radiofrequency tubes, and design and testing of accelerator structures. We propose to construct an experimental injection system and first drift-tube tank to accelerate a 65 mA beam to 5 MeV and verify the beam behaviour in the beginning of the machine. We also propose to construct a short section of the main coupled-cavity accelerator as a prototype engineering and systems test. The section will be loaded with 65 mA of electrons and accelerate them to 6 MeV.

The Science Council of Canada was asked to review our proposals and has reported favourably. So far funding has permitted only a study with limited experimental work.

If the project is approved in the near future completion of the first phase by 1974 at a cost of about $130M U.S. is envisaged. Other facilities could be added during the following 5 years.

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DISCUSSION (condensed and reworded)

J.P. Blewett (Brookhaven): Could you clarify what you meant by the first phase?

Tunnicliffe: This would consist of the main thermal neutron target, one transmission meson producing target and a relatively small experimental area.

J.M. Peterson (LRL): Why do you prefer to accelerate negative ions, i.e., H^-, in preference to splitting the proton beam?

Tunnicliffe: We have come to the conclusion that the present state of the art in fast beam switching systems would not allow us to split the beam with a tolerable beam loss. However the negative ion beam is quite easily separated.

K.H. Reich (CERN): You discussed the use of a different design for the first tank. Have you compared this with the use of a higher energy pre-accelerator?

Tunnicliffe: Yes, this appears to be a compromise between reliability and complexity of tank design.

TABLE I

Linear Accelerator Design Parameters

Output energy	1000 MeV
" " spread	~ ± 3 MeV
Output current, positive ions (basic machine)	65 mA
" " negative ions (full machine)	~ 0.5 mA
Length	1540 m.
Injection (basic machine)	
Positive ion source type	Duoplasmatron
Positive ion source current	120 mA (70% protons)
D.C. accelerating voltage	750 kV
Buncher (double-drift harmonic type)	34 kV fundamental 15 kV 2nd harmonic 0.78 metre drift space
Capture efficiency into linac	86%
Alvarez Section	
Injection energy	750 keV
Output energy	106 MeV
Operating frequency	268.3 MHz
Length	110 metres
Input admittance invariant	7.6π mm. mrad.
Input energy spread	± 15 keV max.
Number of tanks	9
Tank 1	2 $\beta\lambda$ design, length 6 metres Energy gain 4 MeV Quadrupole magnets in every drift tube, gradients 5 to 2 kg/cm, $\cos\varphi_s = 0.82$
Tanks 2-9	$\beta\lambda$ design, length ~ 12 metres Quadrupole magnets in alternate drift tubes, gradients 4 to 2 kg/cm in tank 2, others 1 kg/cm, $\cos\varphi_s = 0.9$
Tank diameter	~ 70 cms.
Drift tube diameter	~ 12 cms.
Drift tube bore	1.5 to 3.0 cms.
Tank separation ($2\beta\lambda$)	22 to 82 cms.
R.F. power requirements (approx.) (beam + loss)	0.4 MW tank 1 1.2 MW tanks 2-9
R.F. generators	1.2 MW/unit (one/tank) (tank 1 - special)
Total R.F. power	10.0 MW
Total R.F. losses	3.5 MW

continued - - -

TABLE I (continued)

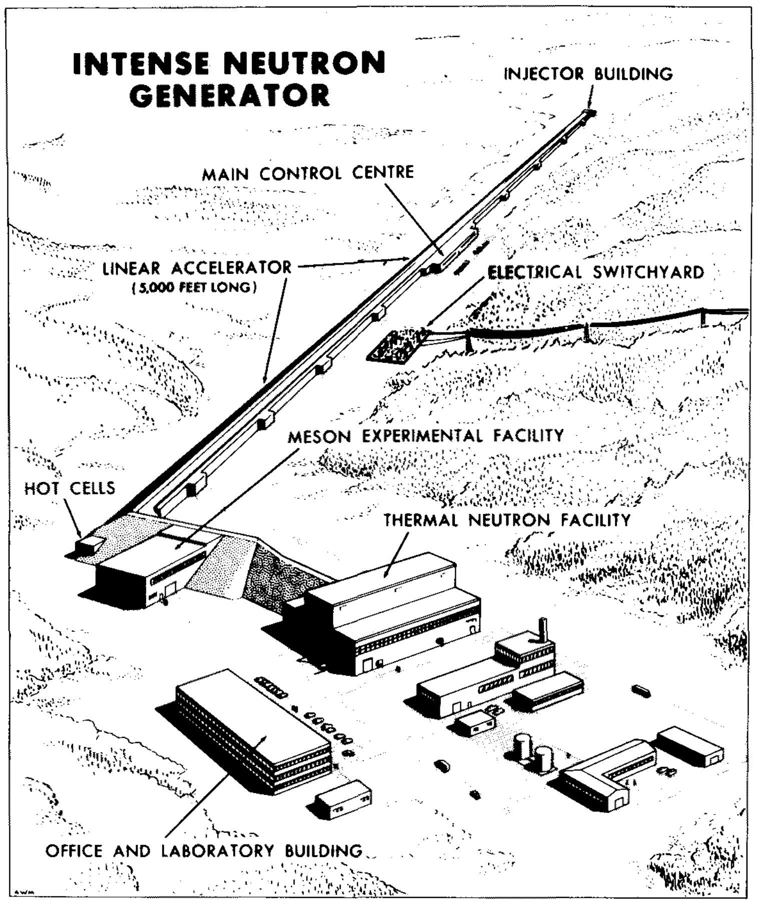
Waveguide Section	
Injection energy	106 MeV
Output energy	1000 MeV
Operating frequency	805 MHz
Length	1430 metres
Number of tanks	322
Average energy gain/tank	2.8 MeV
tank length	3.4 metres
tank diameter	28 cms.
beam hole diameter	3.8 cms.
power/tank	0.25 MW
$\cos\varphi_s$	0.9
Tank spacing	~ 1 metre
Focusing	1 quadrupole triplet/tank interspace quadrupole gradient - 3 kg/cm
R.F. generators	0.5 MW (one/2 tanks)
Total R.F. power	80.5 MW
Total R.F. losses	22.4 MW

Shielding & Activation

Proton Energy MeV	Maximum beam spill allowing reasonable access 10 hours after shutdown	Shielding thickness metres of sand
10	500 nA/metre	2.3
50	50	5.0
200	10	7.6
1000	2	8.0

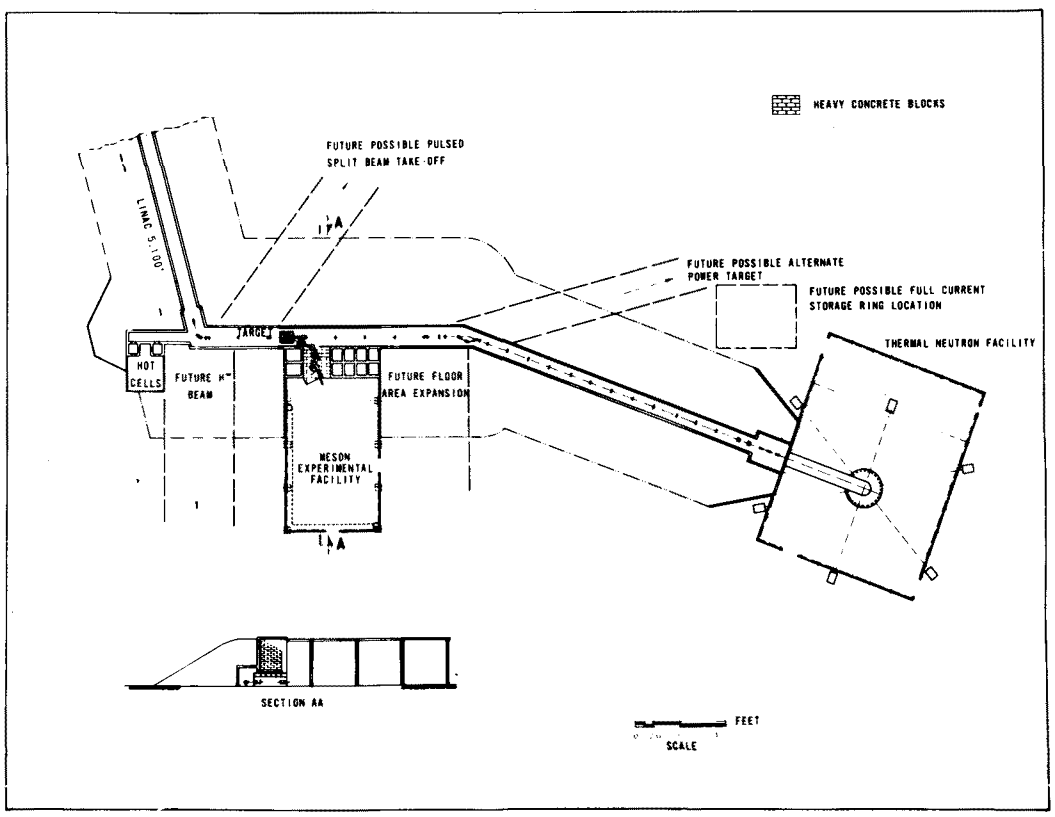
R.F. Power Supplies

Main power amplifiers	Crossed-field reentrant-beam devices (e.g. Amplitrons)
Driver amplifiers	Klystrons
D.C. power supplies	18 MW modules
Objective A.C. to R.F. conversion efficiency	80%



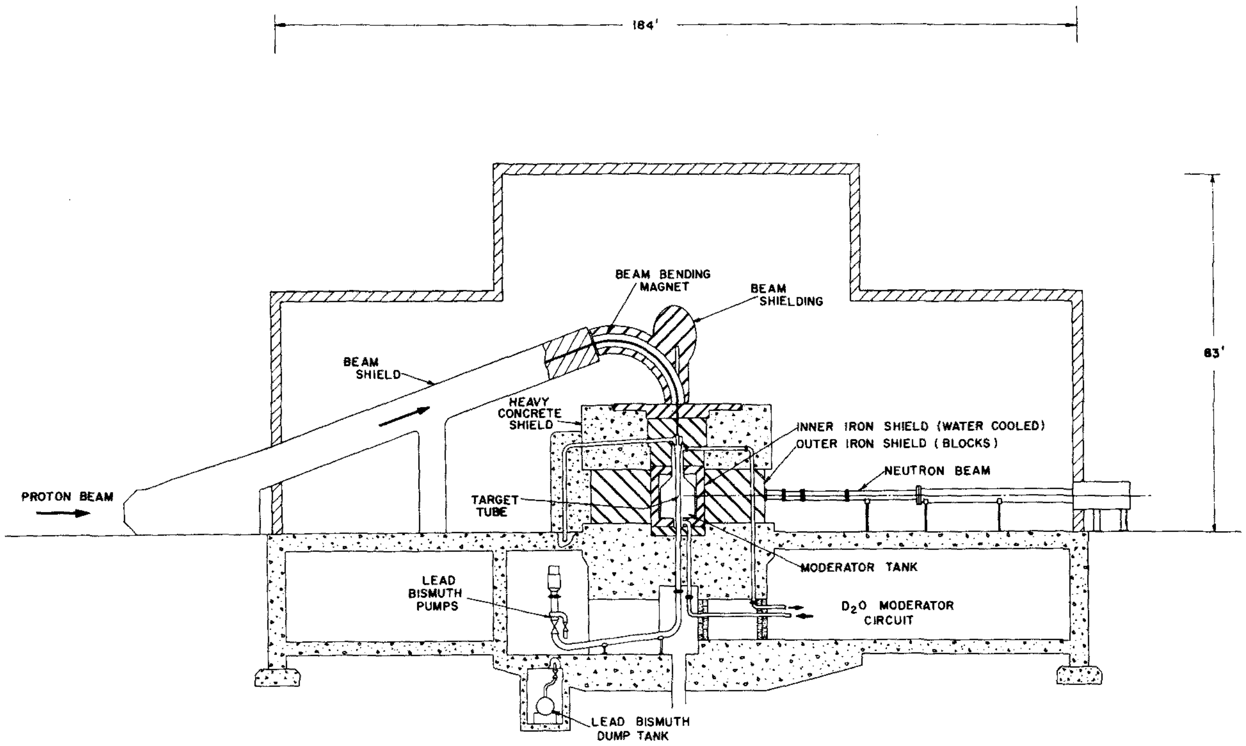
Perspective View of ING Project

Figure 1

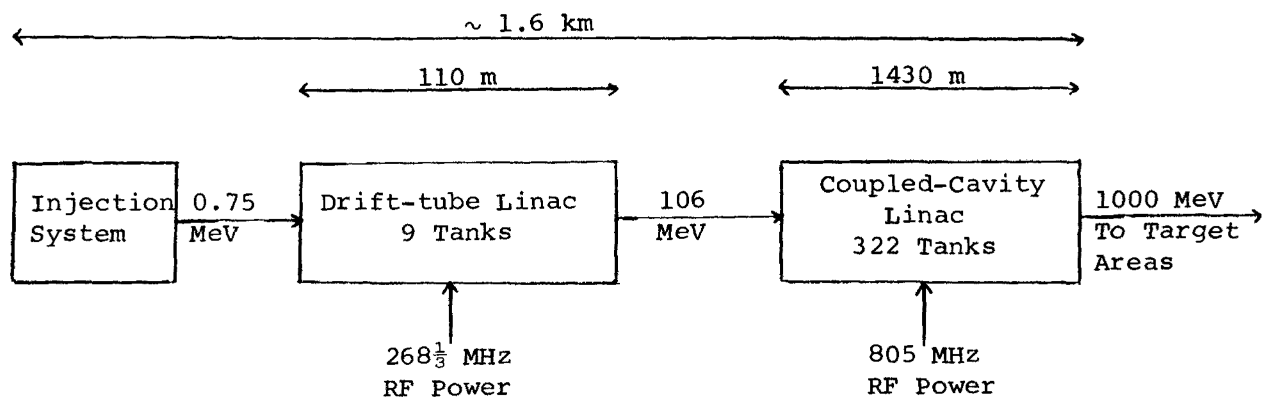


GENERAL ARRANGEMENT OF EXPERIMENTAL AREAS

Figure 2



Cross Section Thermal Neutron Target
Figure 3



ACCELERATOR PARAMETERS

ION SOURCE: DC Duoplasmatron, Current 120 mA

INJECTOR: DC Voltage 750 kV

BUNCHER: Double-drift harmonic

LINAC SECTIONS	*DRIFT-TUBE SECTION*	COUPLED-CAVITY SECTION
Beam Power (MW)	6.5	58.1
RF Losses (MW)	3.5	22.4
Magnet Power (MW)	0.5	1.2
Tank Length (metres)	~ 12 (1st special)	3.4
RF Unit Size (MW)	1.2 (one/tank)	0.5 (one/2 tanks)

Figure 4

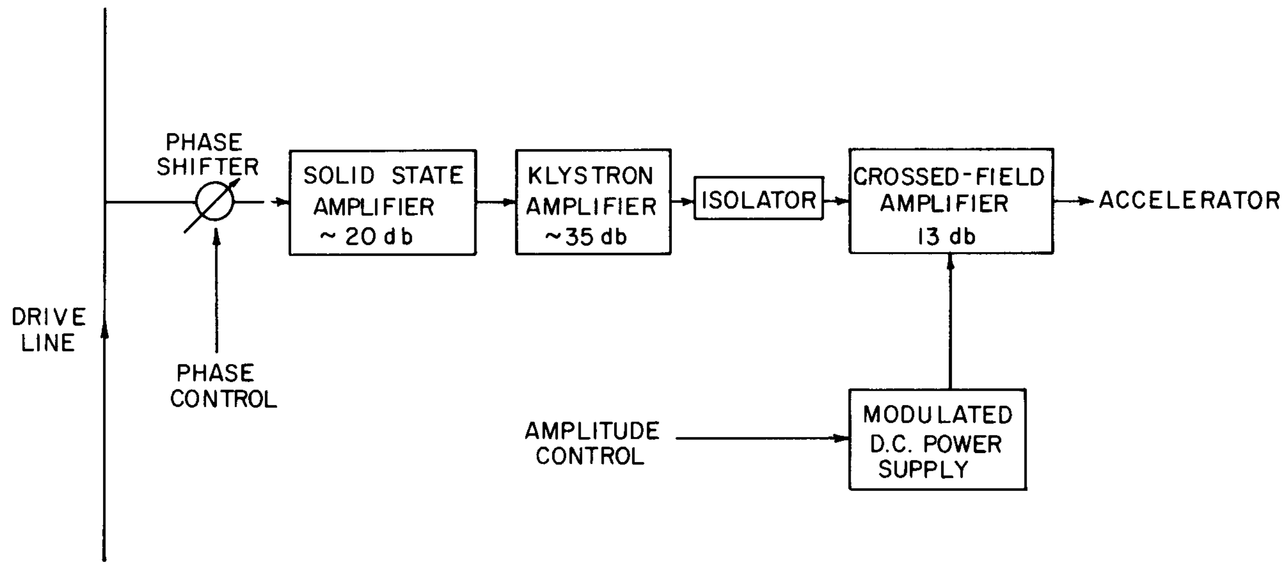

PHASE SHIFTER
SOLID STATE AMPLIFIER ~ 20 db
KLYSTRON AMPLIFIER ~35 db
ISOLATOR
CROSSED-FIELD AMPLIFIER 13 db
ACCELERATOR
DRIVE LINE
PHASE CONTROL
AMPLITUDE CONTROL
MODULATED D.C. POWER SUPPLY

Figure 5