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The Feasibility of Short-Lived Radionuclide Production at Fermilab

to be presented by

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The Fermi National Accelerator Laboratory (Fermilab) is operated by Universities Research Association, Inc. under contract with the Department of Energy (DOE contract #DE-AC02-76-CH3000). The laboratory's purpose is to explore the basic structure of matter through high energy physics (HEP) research. When appropriate, activities such as treating cancer patients with neutrons can harmoniously coexist with that primary mission. Additionally, a group known as the Fermilab Industrial Affiliates has recently been formed to stimulate the transfer of spin-offs from Fermilab's basic research to private industry. Areas of technological development have included superconductivity, cryogenics, data processing, computer hardware processing, computer controls, fast electronics, ion beams and sources, high power radiofrequency designs, cryogenic vacuum technology, and particle detectors. Further information about the Fermilab Industrial Affiliation may be obtained from John A. McCook at the Director's Office.

The present 400 GeV proton accelerator system is actually composed of four accelerators working in series. Electrons are added to hydrogen atoms in an ion source contained in a Cockcroft-Walton generator. The H^- ions emerge with an energy of 750 keV and enter a 500 foot long linear accelerator (linac), which accelerates them to 200 MeV. Next, the ions are injected into the Booster synchrotron, they are stripped of their electrons, leaving protons. This synchrotron is a circular, rapid-cycling machine approximately 154 m in diameter. The protons are accelerated to 8 GeV and then extracted and injected into the main synchrotron, which is 2000 m in diameter, where they are accelerated to 200-500 GeV.

Neutrons for cancer therapy are obtained by extracting 66 MeV H^- ions from the linac and having them impinge upon a Beryllium target 22 mm thick. This is accomplished approximately midway down the linac by means of a bending magnet (See Fig. 1). That is also the location where ions would be removed for production of short-lived radionuclides (SLR), although they would be extracted in the opposite direction (antiparallel) to that of the beam going to the neutron target. This new beam would have to pass through the linac housing walls. Then, a facility would have to be constructed to utilize the H^- beam. The beam extraction would be accomplished by replacing the present unilateral 58^o bending magnet by a "Y" shaped bilateral extraction magnet and constructing another beam line complete with 32^o magnet and quadrupoles.

Operation of the neutron therapy facility (NTF) or a SLR facility in conjunction with the primary laboratory mission of HEP is possible due to the main accelerator cycling time of 10-20 seconds, dictated by physical considerations and electrical power consumption (See Fig. 2). Except when accelerating particles to fill the booster, the linac and ion source are on standby waiting for the main accelerator cycle to be completed. During those intervals, beam is extracted from the linac for the NTF. With an appropriate beam line, 66 MeV H^- could be made available for other purposes such as ^{123}I or other high threshhold radionuclide production. The booster requires one second of linac operation per main ring cycle. The NTF bending magnet requires one second to ramp up or down. Therefore, out of each main ring cycling time, only three seconds are unavailable for other uses. Of course, during those periods when the main accelerator program is not operating the linac is available without interuption, except for scheduled maintenance.

The linac produces a pulsed beam at a rate of 15 pulses per second. Beam pulses are 45-50 μsec in duration and have peak currents of 16-32 mA. Therefore, typical average currents available for the NTF or SLR production are in the range of 12-22 μA when the HEP program is not running and are reduced by at most 50% when the main accelerator is in operation.

Modifications required for construction of a beam line for a SLR production facility include fabrication of the $\pm 58^{\circ}$ and the 32° magnets previously mentioned as well as the purchase of 6-12 quadrupole magnets and a complement of power supplies. Also, installation of a vacuum system from the linac through a hole in the existing linac berm would be required. Furthermore, a shielded target enclosure outside the linac shielding would need to be constructed. The facility would be located next to a parking lot in an area with a high water table requiring shielding not only laterally and above but also below. Other considerations include controls, electrical power and water, as well as construction of a temporary facility for housing personnel and some dry chemistry. Initial "back of the envelope" computations estimate the cost of constructing such a facility in 1982 dollars to be between 0.2 and 0.3 M$ not including contingencies, chemical paraphernalia, or targets. Operational costs have not been estimated.

The feasibility of establishing a facility for SLR production hinges on the availability of the linac and on how such a program would fit in with the primary mission of the laboratory. The linac is available 168 hours per week except for scheduled maintenance, which typically does not excede one to two shifts per week, and HEP requirements. The laboratory may be reluctant to make a commitment for the routine production of SLRs however, due to its understanding of the requirements for reliable scheduled delivery of targets. But, the laboratory is also quite interested in establishing industrial liasons. It would be willing to explore feasible industrial proposals, especially with regards to developing a research-type facility where the technology and methods developed at Fermilab could be utilized elsewhere. Inquiries about this possibility should be directed to Mr. John A. McCook.

Figure Captions

<u>Figure 1</u> Plan View of NTF beam line showing linac tanks 4 and 5, beam transport system, target collimator holder, and shielding. For SLR production the 58^{o} bending magnet could be replaced by a "Y" shaped $\pm 58^{o}$ magnet and a new beam line would be constructed antiparallel to the NTF line.

<u>Figure 2</u> Illustration of how linac time is divided between HEP, transition times for the 58^{o} bending magnet, and neutron therapy. The main ring cycle depicted is 10 seconds long; however, this time may vary from 8-23 seconds depending upon energy, length of flat top (extraction time), and time of day (which affects the cost of electrical power).

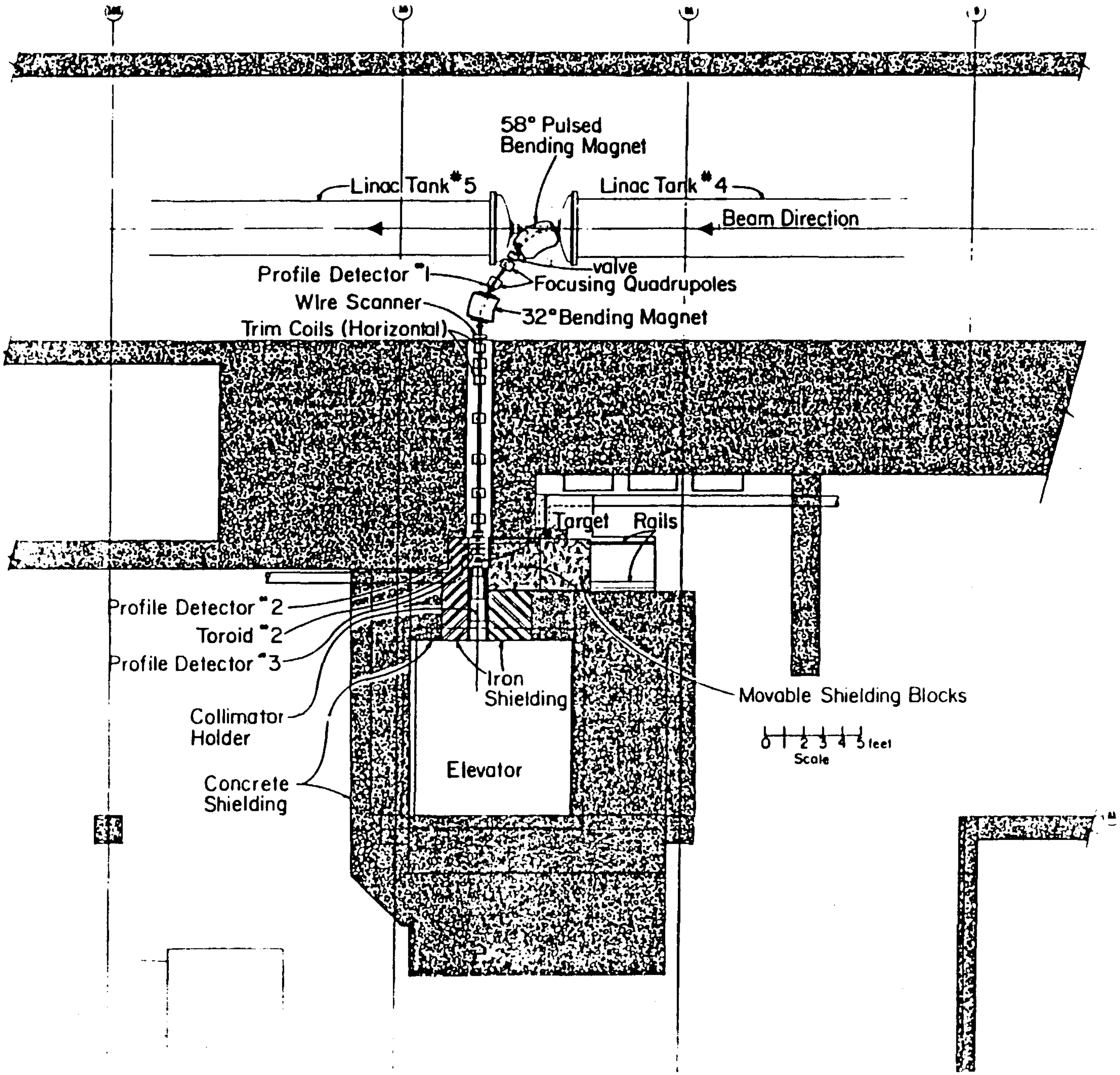
58° Pulsed
Bending Magnet
Linac Tank #5
Linac Tank #4
Beam Direction
valve
Profile Detector #1
Focusing Quadrupoles
Wire Scanner
32° Bending Magnet
Trim Coils (Horizontal)
Target
Rails
Profile Detector #2
Toroid #2
Profile Detector #3
Iron
Shielding
Movable Shielding Blocks
Collimator
Holder
0 1 2 3 4 5 feet
Scale
Elevator
Concrete
Shielding

Figure 1

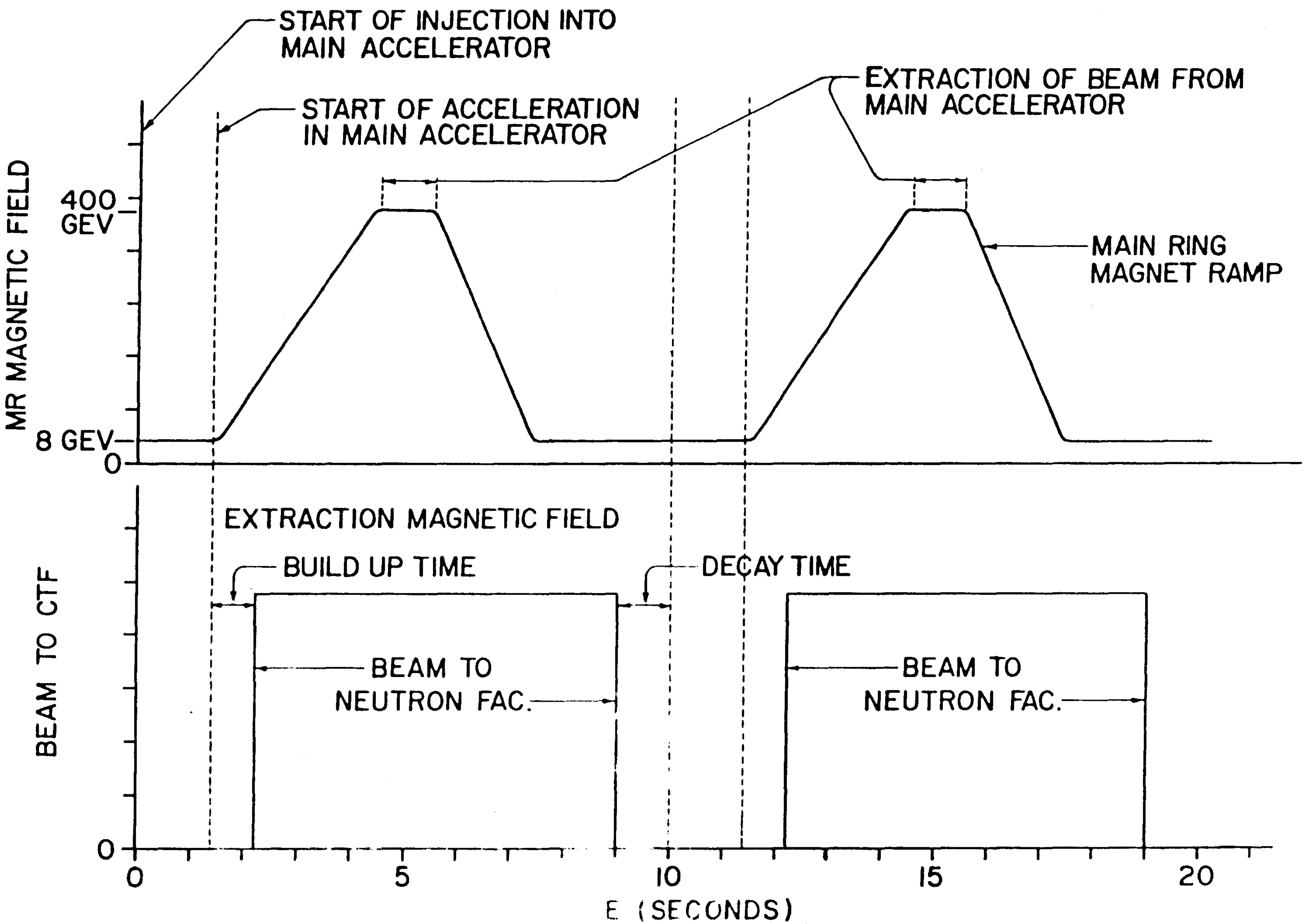
START OF INJECTION INTO MAIN ACCELERATOR
START OF ACCELERATION IN MAIN ACCELERATOR
EXTRACTION OF BEAM FROM MAIN ACCELERATOR
MR MAGNETIC FIELD
400 GEV
8 GEV
0
MAIN RING MAGNET RAMP
EXTRACTION MAGNETIC FIELD
BUILD UP TIME
DECAY TIME
BEAM TO CTF
BEAM TO NEUTRON FAC.
BEAM TO NEUTRON FAC.
0
0
5
10
15
20
E (SECONDS)

Figure 2