BNL Radioisotope Research & Production Program

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Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY

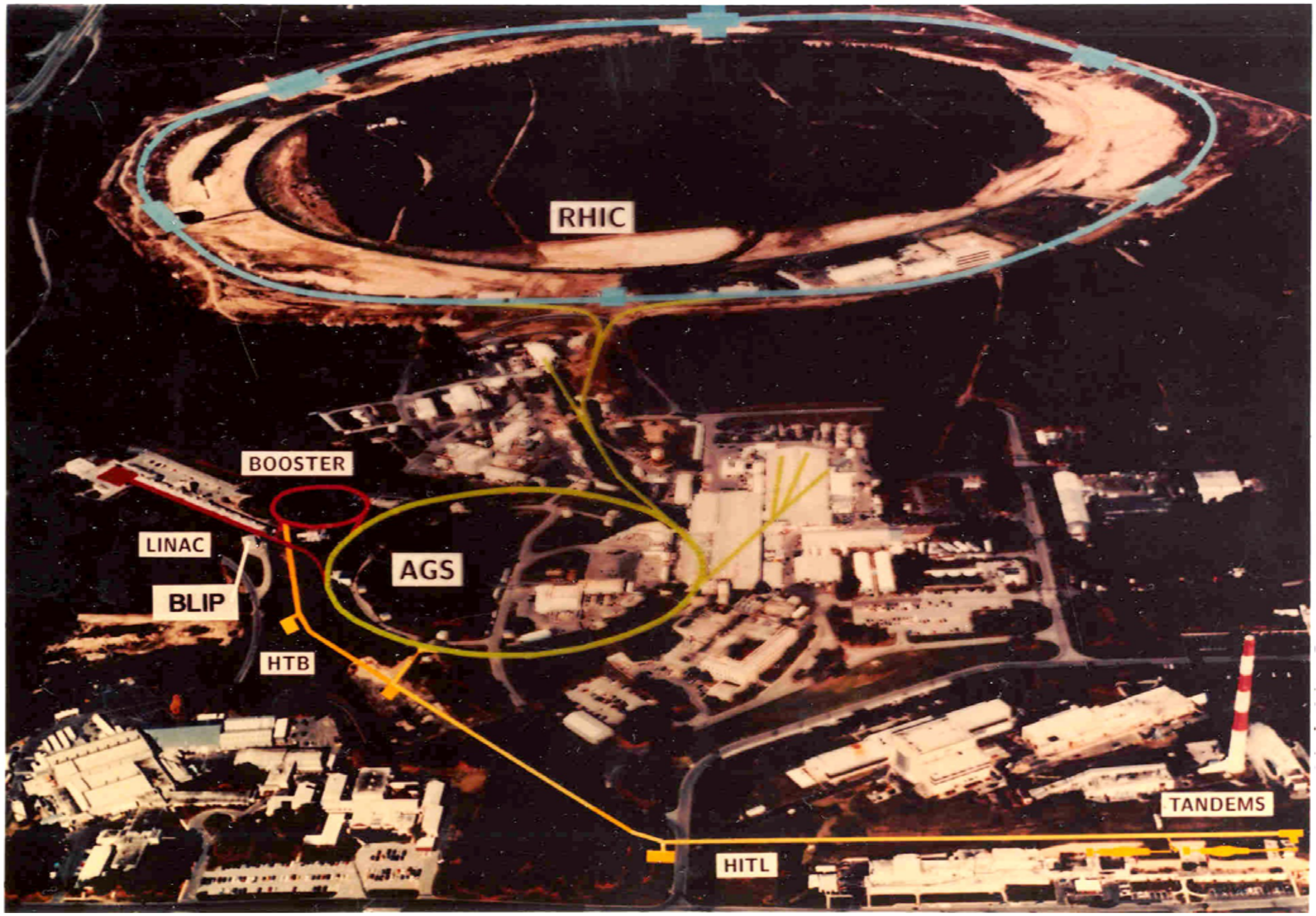
Radioisotope Program Components

- Isotope Production and Distribution at BLIP
  - **Distribution for sale; process & target development to improve quality & yield.**
  - **Sr-82/Rb-82 for human heart scans with PET**
  - **Ge-68 for calibration of PET devices**
  - **Zn-65 tracer for metabolic or environmental studies**
- Radioisotope R&D
  - **Sn-117m, Cu-67, for cancer therapy applications**
  - **Y-86 for cancer imaging**
- Radiation damage studies
  - **target and magnet materials for future high power accelerators, collaboration with BNL Physics & ES&T Departments**
  - **high temperature superconductors for FRIB, collaboration with BNL Magnet Division and ES&T Department**
- Training
  - **Support (space, equipment, faculty) for DOE funded Nuclear Chemistry Summer School, a 6 week undergraduate course in nuclear and radiochemistry**

Facility Description

- The Brookhaven Linac Isotope Producer (BLIP) was the world's first facility to seriously exploit the isotope production capabilities of a high energy proton accelerator.
  - The use of higher energy particles allows the use of relatively thick targets, where the large number of target nuclei can compensate for the generally smaller nuclear reaction cross sections compared to low energy reactions.
  - The BLIP, built in 1972, utilizes the excess beam capacity of the 200 MeV proton Linac that injects into larger synchrotrons (Booster, AGS, RHIC) at BNL. (Figure 1,2) A 30m long transport line delivers the protons to a shielded target area for radioisotope production. (Figure 3,4). The facility has been upgraded twice, in 1986 and 1996.
  - The target area consists of an underground 2.44m diameter tank containing sand shielding, a water filled 40cm diameter shaft, 9.2m high, and a 20cm diameter inspection shaft. (Figure 5)
  - The target assembly is immersed at the bottom of the shaft and cooling water is forced individually past the faces of the target disks. (Figure 6)

Figure 1. BNL Accelerator Complex (AGS=Alternating Gradient Synchrotron, RHIC=Relativistic Heavy Ion Collider)



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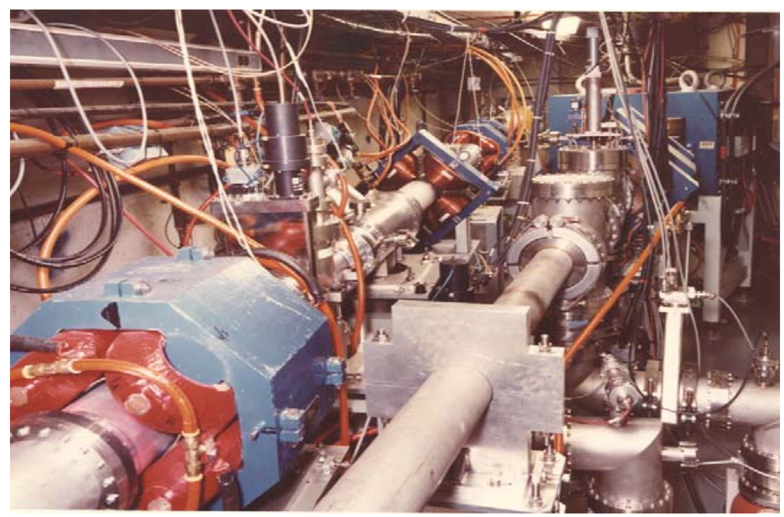
Brookhaven LINAC Isotope Producer (BLIP)

Figure 2. The LINAC supplies protons to the Booster for high energy physics. Excess pulses (~85%) are diverted to BLIP. Energy is incrementally variable from 118-202 MeV.

Figure 3. The BLIP beam line directs protons up to 105μA intensity to targets; parasitic operation with nuclear physics programs



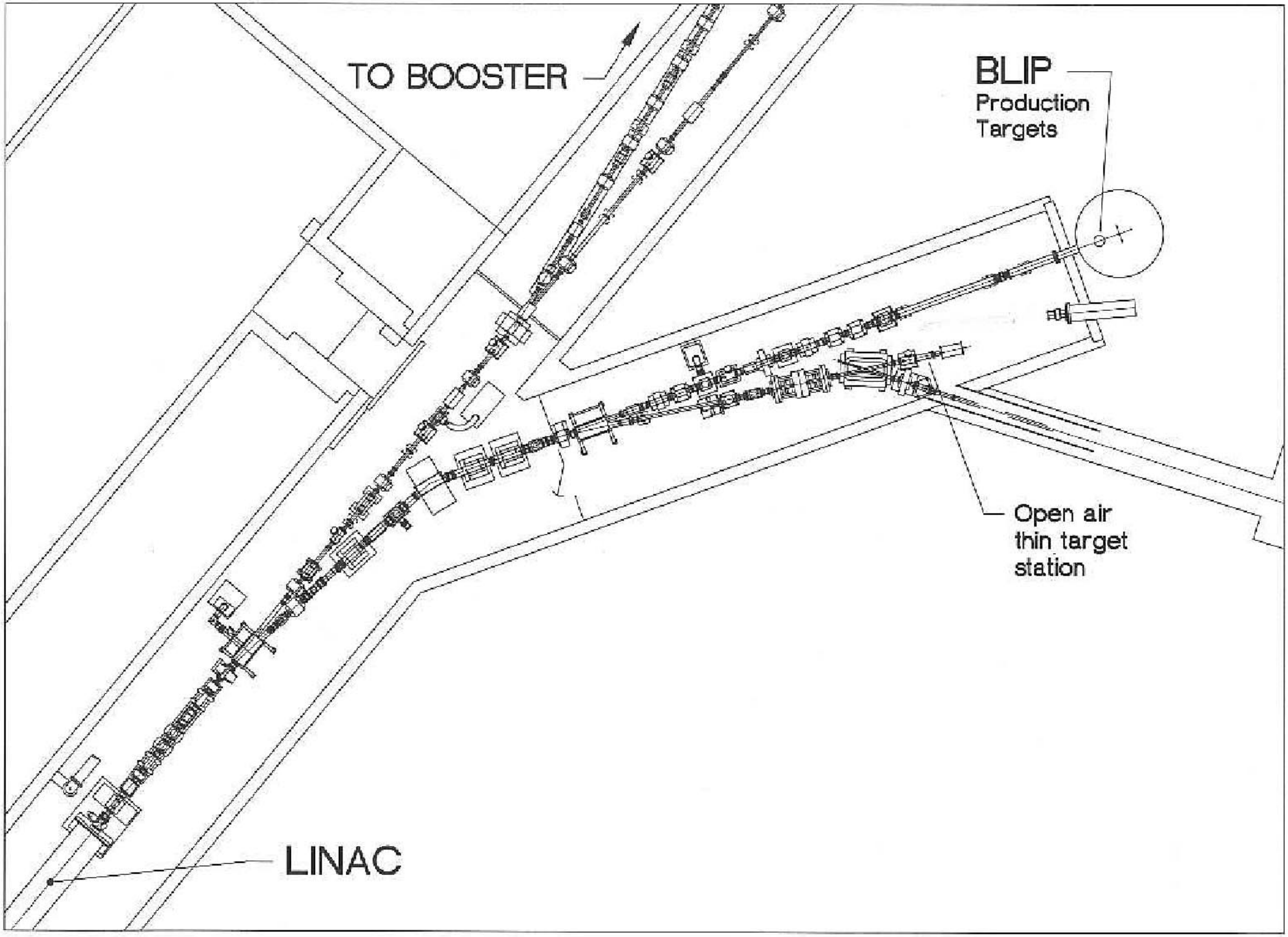


Figure 4. Schematic of BLIP Beam Line

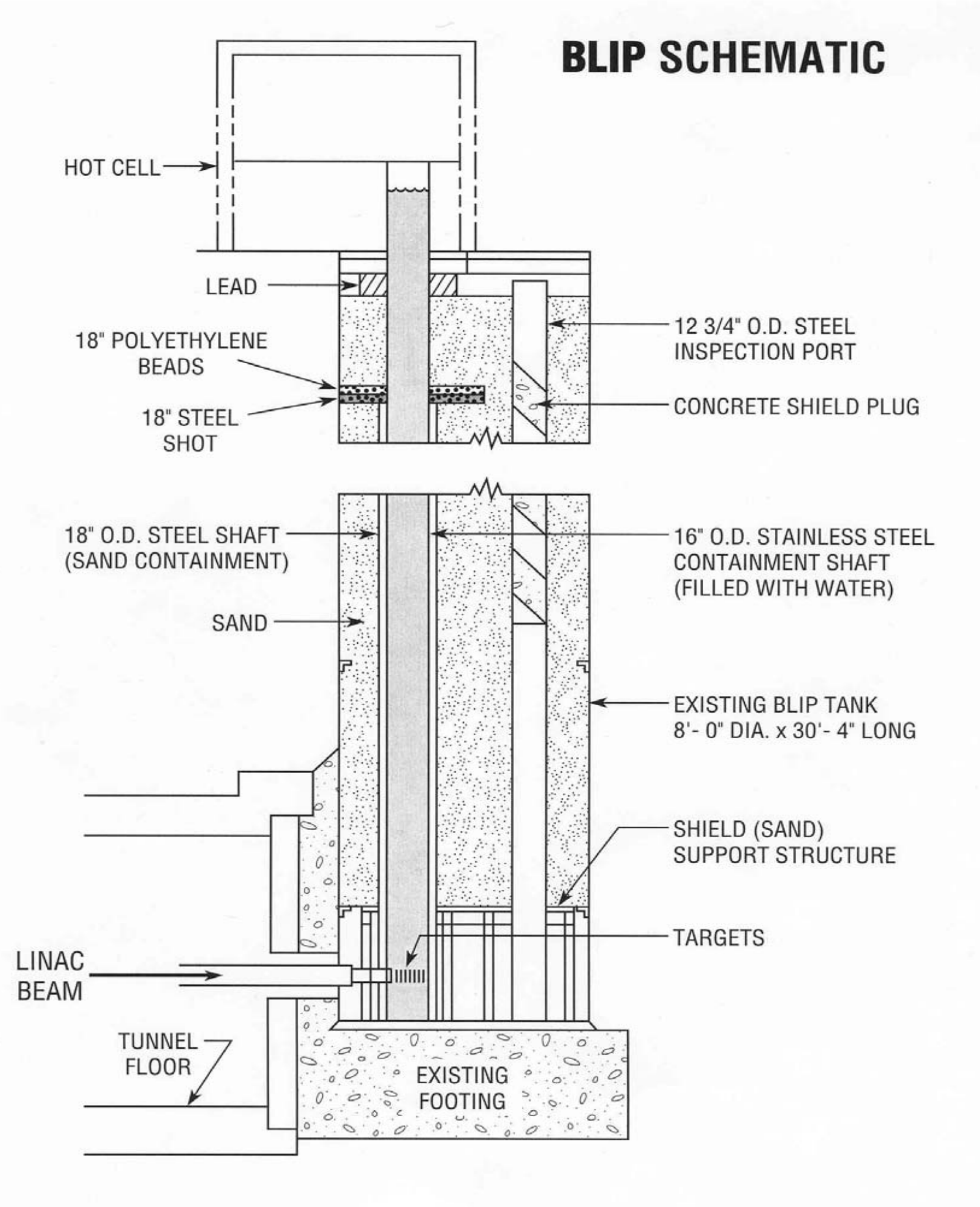
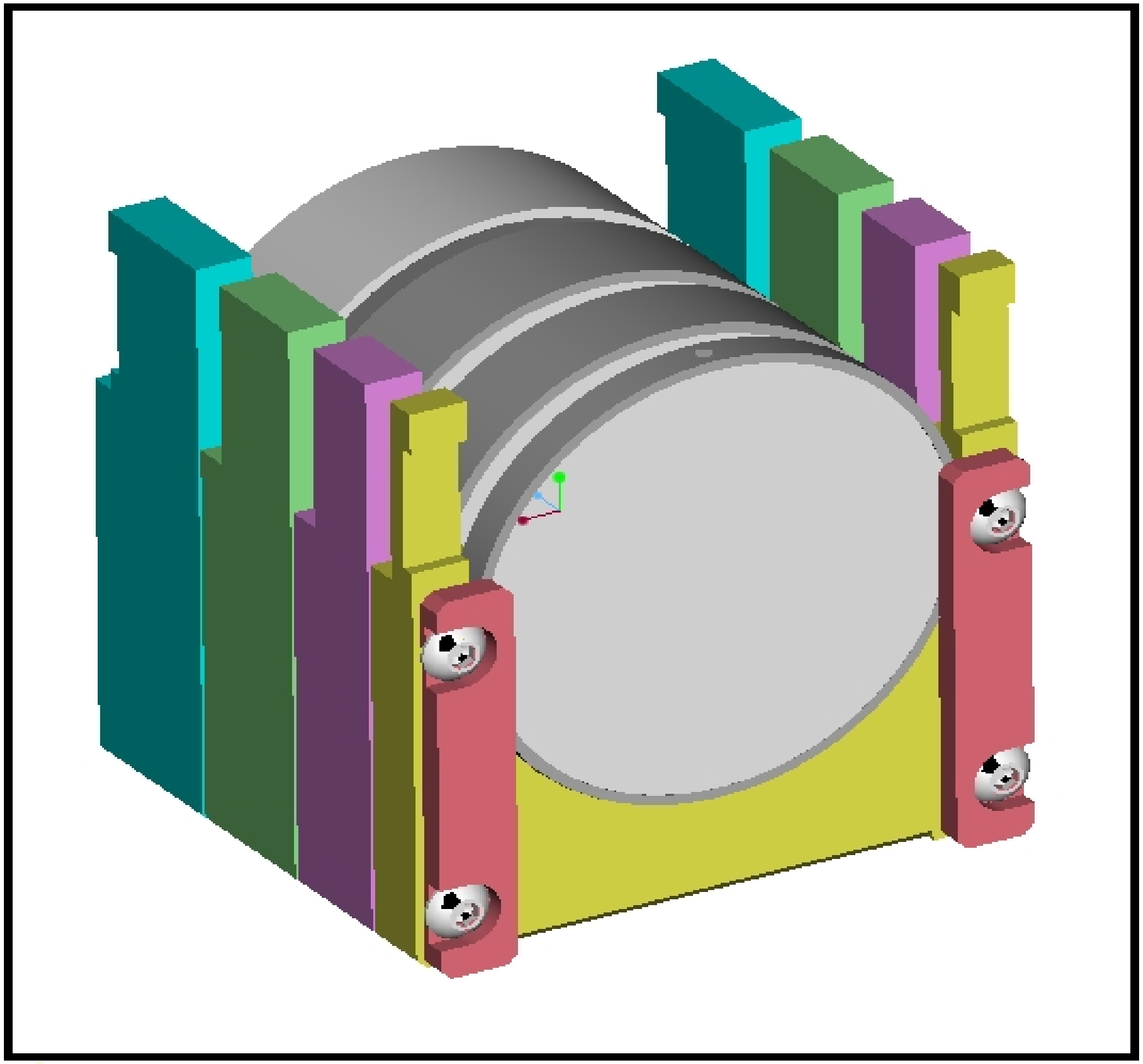

BLIP SCHEMATIC
HOT CELL
LEAD
18" POLYETHYLENE BEADS
18" STEEL SHOT
12 3/4" O.D. STEEL INSPECTION PORT
CONCRETE SHIELD PLUG
18" O.D. STEEL SHAFT (SAND CONTAINMENT)
16" O.D. STAINLESS STEEL CONTAINMENT SHAFT (FILLED WITH WATER)
SAND
EXISTING BLIP TANK 8'- 0" DIA. x 30'- 4" LONG
SHIELD (SAND) SUPPORT STRUCTURE
TARGETS
LINAC BEAM
TUNNEL FLOOR
EXISTING FOOTING

Figure 5.

Figure 6. Target array drawing



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BLIP Operating Parameters

- Energy – incrementally variable from 118-202 MeV
- Pulse current 38mA, pulse rate 6.67 Hz, pulse width 420μs
- Maximum integrated current - 105μA, typical Integrated current (parasitic mode) -80μA
- Power – 7.4MW instantaneous, 21 kW integrated
- Target capacity – up to 8 simultaneously, dependent on beam energy & target thickness
- Schedule – Due to high operating costs BLIP generally runs in a parasitic mode, sharing pulses (~85% share), and costs (~30% share) with the driver nuclear physics programs at RHIC. The schedule and duration of Linac operation is largely determined by the plans and funding of the nuclear physics experiments, not isotope production needs.
  - Production coordination with other sites in Los Alamos, S. Africa, Russia has helped year round availability of longer lived, high value isotopes, such as Sr-82 and Ge-68.

The Target Processing Laboratory

- After irradiation all targets require chemical processing to separate the desired isotope from many others coproduced and from the bulk target material. To support this effort we have:
  - 9 hot cells
  - 8 radiochemistry development labs
  - Instrumentation lab for radionuclide and chemical assays
  - radwaste handling and storage facilities for both liquids and solids
  - Staff machine shop
  - For human use isotopes we maintain current good manufacturing practice (CGMP) registration with FDA

Figure 7. View of several processing hot cells

Associated BNL facilities

- Two small cyclotrons, 17 and 19 MeV
- Several PET scanners, and MRI
- Central fabrication facility with advanced capabilities
- Central hazardous and radwaste storage and disposal facility
- DOT trained isotope packaging & shipping group with assorted sizes of approved containers for radioisotope transport both domestically and internationally

Radioisotopes Developed at BLIP

Isotope	Half-life	Decay mode	Nuclear reaction	Typical application
^{7}Be	53.3d	EC	^{12}C(p,spall)	γ source
^{28}Mg	21h	β^-	Cl(p,spall)	Mg tracer
^{22}Na	2.6y	β^+	Al(p,spall)	γ source
^{47}Sc	3.4d	β^-	^{48}Ti(p,2p)	Radioimmuno-therapy (RIT)
^{52}Fe	8.3h	β^+(57%),EC	Ni(p,spall)	PET tracer, Fe metabolism
^{55}Co	17.5h	β^+(81%),EC	^{56}Fe(p,2n)	PET label
^{64}Cu	12.7 h	β^+/β^-	^{64}Ni(p,n)	PET label; RIT
^{65}Zn	244d	EC	^{69}Ge(p,αn)	Zn tracer
^{67}Cu	61.9h	β^-	^{68}Zn(p,2p)	RIT
^{68}Ge/^{68}Ga	271d/68m	EC	^{nat}Ga(p,2n/4n)	PET calibration
^{73}As	80.3d	EC	^{74}Ge(p,2n)	As tracer
^{81}Rb/^{81m}Kr	4.6h/13s	EC/IT	^{nat}Kr(p,4n)	Lung imaging

HFBR-produced

Radioisotopes Developed at BLIP (continued)

Isotope	Half-life	Decay mode	Nuclear reaction	Typical application
^{82}Sr/^{82}Rb	25.4d/75s	EC/👓$^{+}$	^{nat}Rb(p,4n/6n)	PET studies of heart
^{88}Y	106.6d	EC	Mo(p,spall)	Y tracer
^{95m}Tc	61d	EC	^{103}Rh(p,spall)	Tc tracer
^{96}Tc	4.3d	EC	^{103}Rh(p,3p5n)	Tc Tracer
^{97}Ru	2.89d	EC	^{103}Rh(p,2p5n)	SPECT label
^{109}Cd	461.4d	EC	^{109}Ag(p,n)	☎ source
^{117m}Sn	13.6d	IT	^{117}Sn(n,n'☎)	Bone pain palliation
^{122}Xe/^{122}I	20.1h/3.6m	EC/👓$^{+}$	^{133}Cs(p,spall)	^{122}I generator
^{127}Xe	36.4d	EC	^{133}Cs(p,2p5n)	Lung/brain imaging
^{153}Sm	1.9 d	👓$^{-}$	^{152}Sm(n,☎)	Bone pain palliation
^{195m}Pt	4.0 d	IT	^{192}Os(✂,2n)	Rx Aug. emitter
^{203}Pb	51.9h	EC	^{209}Bi(p,2p5n)	RIT

HFBR-produced

Present Isotope Distribution

Isotope	Half- life	Typical application
Be-7	53.3d	γ source
Zn-65	244d	Zn tracer, multiple uses
Cu-67	61.9h	Radioimmunotherapy
Ge-68/Ga-68	271d/68m	PET calibration
As-73	80.3d	As environmental tracer
Sr-82/Rb-82	25.4d/75s	PET studies of heart
Y-88	106.6d	Y-90 tracer, γ source
Tc-95m	61d	Tc tracer

Radioisotope R&D

- Cu-67 is one of the most attractive isotopes for radioimmunotherapy (RIT) due to medium energy beta emission ($E\beta av$=116, 149, 184 keV), an appropriate half life (61.8h) for in vivo tumor uptake, as well as facile labeling chemistry. Effort is underway to significantly improve specific activity required for application in RIT using enriched Zn-68 target.
- Y-86 is of interest as a surrogate tracer for PET dosimetry assessment of Y-90 labeled therapeutic radiopharmaceuticals. Effort is underway to develop this short lived (14.7h) positron emitter by irradiation of enriched Sr-88.
- Sn-117m is also an attractive therapeutic isotope for certain applications such as bone cancer and treatment of vulnerable arterial plaque. Effort to produce this low energy electron emitter (internal conversion decay) in high specific activity is underway by irradiation of Sb target.
- Positron (Fe-52) labeled superparamagnetic ferric oxide nanoparticles are being developed to permit simultaneous PET and MR imaging of the same agent in a single study. This combines the spatial resolution advantages of MRI with the detection sensitivity of PET.

Cyclotron Isotope Research Center (CIRC)

- The high operating cost, constrained annual run time, and relatively low beam current at BLIP have limited our ability to provide a continuous and reliable supply of existing as well as novel radioisotopes to meet national needs.
- In response we have previously proposed to acquire, house and operate a new cyclotron to replace BLIP, dedicated to radioisotope research and production. This new facility would have much more capacity, flexibility and lower operating cost than BLIP. The proposed facility features:
  - proton energies variable from 30 to 70 MeV
  - proton beam current variable from 5 to 1000 microampere
  - dual simultaneous beam extraction
  - extracted alpha beam of 70 MeV, 35 microampere
  - four beam lines and target areas for isotope production, and new isotope/target development
  - existing high bay space with adequate power, cooling and crane capability will house the machine
- This BNL concept formed the basis for the Arronax cyclotron now under construction in Nantes, France.