ANL/ASD/CP-93340
CONF-970885--

STATUS OF THE ADVANCED PHOTON SOURCE LOW-ENERGY UNDULATOR TEST LINE

Stephen V. Milton, Efim Gluskin, Ned D. Arnold, Steven Berg, William Berg, Yong-Chul Chae, Edwin A. Crosbie, Roger J. Dejus, Patric Den Hartog, Horst Friedsam, John N. Galayda, Arthur Grelick, Justin Jones, Yoon Kang, Suk Kim, John Lewellen, Alex H. Lumpkin, James R. Maines, Gregory M. Markovich, Elizabeth R. Moog, Ali Nassiri, Emil Trakhtenberg, Isaac Vasserman, Nikolai Vinokurov†, Dean R. Walters, Ju Wang, and Bingxin Yang

Advanced Photon Source
Argonne National Laboratory
9700 S. Cass Ave.
Argonne, IL 60439, U.S.A.

The low-energy undulator test line (LEUTL) is being constructed at the Advanced Photon Source (APS). Its first purpose is to fully characterize innovative, future generation undulators, some of which may prove difficult or impossible to measure by traditional techniques. Second, LEUTL will act as a test line to investigate the generation of coherent radiation at wavelengths down to a few tens of nanometers. The line will use a high-brightness rf electron gun as its source and the APS linac to accelerate these electrons up to > 650 MeV. This beam will then be directed into a new enclosure that is nearly 50 m long and will accommodate beamline components, diagnostics, and undulators. This region is wide enough to house two separate beamlines. In addition, there is an external end station appropriate for housing the equipment necessary to directly study the generated light outside of the radiation environment. At present, the new enclosure and building are

DISCLAIMER

complete, the new rf electron gun is installed and operational, and a part of the necessary transport line is installed. An undulator cell prototype, suitable for testing the requirements of single-pass free-electron laser operation, is near completion and will be installed during the winter shutdown of 1997. This paper will describe the LEUTL project and its capability for exploring the self-amplified spontaneous emission process.

† Budker Institute

Keywords: Free-Electron Laser, Fourth-Generation Light Source

Introduction

The Low-Energy Undulator Test Line (LEUTL), presently under construction at Argonne National Laboratory's Advanced Photon Source (APS), was designed with two purposes in mind. The first is to characterize innovative, future generation undulators, some which may prove difficult or impossible to measure by traditional techniques. The second is to investigate the generation of coherent radiation at wavelengths down to a few tens of nanometers.

Lately, there has been tremendous interest in clearly defining what constitutes a fourth-generation synchrotron light source and also how it should be constructed [1]. One possibility is to use a high-brightness electron beam passing once through a very long undulator and subsequently producing coherent radiation via the self-amplified spontaneous emission (SASE) process. Here, a high-brightness electron beam is characterized by its simultaneous high peak bunch current, low energy spread, and low normalized transverse emittance. The key to the success with this method is in producing and accelerating the high-brightness beam and further guiding it with sufficient accuracy through the length of the long undulator.

As the desired wavelength decreases, the requirements on the electron beam quality become more difficult to meet and the length of the undulator grows. As an example, the SLAC linac coherent light source (LCLS) proposal is striving to reach 0.15 nm [2]. In order to achieve this, the beam quality must reach unprecedented levels of brightness (approximately 1π mm•mrad normalized emittance and 5 kA peak current), the beam energy from the linac must be nearly 15 GeV and the undulator length grows to nearly 100 meters.

To date, the shortest wavelength SASE demonstrations are in the 1 to 10 μm range with 1 to 2 m long undulators and beams of modest energies at a few to tens of MeV; however, there appears to be some ambiguity as to whether the results are due to amplified spontaneous emission or coherent spontaneous emission. The next step, that of reaching the UV to VUV wavelength range using the SASE process, will require many more experiments and an organized effort. Such intermediate case studies must be performed before attempting a 0.15 nm SASE FEL and will require a facility capable of producing a relatively high brightness beam accelerated to hundreds of MeV and guided down long undulator systems, longer than those ever assembled before. This is precisely one of the purposes of the LEUTL, to test undulator systems, some of which are designed with fourth-generation SASE-based synchrotron light sources in mind. As an added benefit, given the operating parameters of the LEUTL system and a suitable undulator, the SASE process itself can also be explored at wavelengths significantly shorter than have been achieved to date.

LEUTL Description

An overview schematic of the LEUTL system is shown in figure 1. In addition to the APS linac, which is easily capable of beam energies of 650 MeV, a number of modifications and additions to the APS were required. These included

- the addition of a high-quality, high-brightness, thermionic rf gun system with alpha magnet compression,

- an upgrade of the linac diagnostics for better control and diagnosis of beam quality along the linac,

- the addition of beam lines that bypass both the APS positron accumulator ring and booster synchrotron,
- construction of an undulator test line vault, and
- construction of an end station building.

Although more complete descriptions of these various new additions can be found in earlier reports [3,4], some of this information will be presented here in order to provide a complete general overview of the project to date.

The Thermionic RF Gun and Alpha Magnet System

This electron gun system is similar to that found at the head of the SLAC/SSRL injector [5]; however, a number of improvements have been made in order to achieve a higher brightness beam delivered to the APS linac [6]. Figure 2 shows the layout of the rf gun and alpha magnet system. Although thorough testing is not yet complete, the system is presently installed and operational. Its simulated performance parameters are given in table 1.

Linac Diagnostics Upgrades

The diagnostics upgrades to the APS linac consisted primarily of placing additional optical transition radiation (OTR) screens at strategic locations along the linac as well as upgrading the beam position monitoring system's electronics to make them compatible with the higher peak currents expected from the new rf gun. Although this upgrade is not yet fully complete, testing of some of the installed components is already underway, most notably from an OTR screen located at the high energy end of the linac [7]. The remainder of the upgrades will be complete by the end of this calendar year.

Bypass Beamlines

There are two additional beamlines needed: one to bypass the positron accumulator ring (PAR) and the other to bypass the booster synchrotron. Figure 3 shows the PAR bypass beamline. The most notable feature about this line are the four OTR screens positioned in a region entirely free of magnetic quadrupoles. This screen system will allow for unambiguous measurement of the expected very small beam emittances and will be capable of determining a normalized emittance of $\varepsilon_n = 10\pi \bullet$ mm-mrad to approximately 6% and $\varepsilon_n = 1\pi \bullet$ mm-mrad to approximately 20%. Interference OTR will also be possible. The PAR bypass beamline is nearing completion and will be commissioned late this autumn.

The design of the second additional beamline, the one that bypasses the booster synchrotron, is conventional and straightforward. Its sole purpose is to guide the beam through the booster vault and on into the LEUTL enclosure. Construction and installation is just now beginning, with commissioning slated for the end of this year into the beginning of 1998.

The LEUTL Building

Figures 4 and 5 show both the plan and cross-sectional drawings of the new LEUTL building. It consists of two parts: an earth-berm covered concrete enclosure for the electron beamline, undulator, and beam dump, and an end station building that houses the diagnostics for characterizing the light produced by the undulators. The beamline enclosure has nearly 50 m of available length and is 3.7 m wide. Provisions have been made to house two separate beamlines, one straight ahead relative to the APS linac and the second offset by 1.5 m horizontally. The end station building has approximately 110 square meters of available floor space and can be occupied while beam is being delivered to the LEUTL enclosure. Both parts are now complete and awaiting installation of technical components.

LEUTL Capabilities in SASE Mode

Both analytic and simulation studies based on the use of the anticipated beam properties from our initial thermionic rf-gun source have shown that there exists the possibility of achieving SASE-mode operation at wavelengths of near 100 nm with the LEUTL system. An undulator system was designed for this mode of operation and was optimized for an initial wavelength of 120 nm using a 400-MeV beam [8]. Table 2 lists the principle parameters.

A planar undulator with separated-function external focusing and a fixed gap was chosen as the nominal design due to its simplicity. The single undulator cell is 2.4 m long with 2.0 m of undulator and the remaining 0.4 m used for the necessary external focusing, particle and photon beam diagnostics, as well as the required vacuum pumping systems. The schematic of a single cell is shown in figure 6.

The full undulator, comprising a series of cells with gaps between undulator sections and periodic focusing, represented a difficult or impossible problem for previously available SASE-mode simulation codes. Rather than using existing FEL codes, a new computer program was written to simulate the SASE process and to confirm the required specifications for the undulator. Figure 7 shows the result of this simulation for both the case of a continuous undulator with constant beta function and the proposed undulator cell system with gaps between undulators. The gaps and periodic focusing are expected to not have a significant effect on the SASE process, and the overall length of undulator required to reach saturation is only slightly longer than if the undulator were one continuous section.

Nevertheless, the required undulator length is indeed quite long, and it is desirable to shorten the overall length. Using a parameterization of the SASE process [9], one can create a contour plot of the saturation length as a function of both the peak current and normalized emittance. The result for the 120 nm case, after optimizing the beta function within the undulator, is shown in figure 8. This parameterization was checked by simulation using the program GINGER [10] and found to be in good agreement. It is clear by the gradient of this plot that the greatest improvement in performance is achieved by increasing the peak current of the initial bunch. With this in mind, a separate project is underway at the APS that attempts to compress the electron bunch directly out of an rf gun using ballistic bunch compression [11].

The LEUTL beam energy can be raised to 700 MeV with a commensurate reduction in the output wavelength. This energy increase, along with the use of a planned rf gun upgrade, was considered during the optimization process of the undulator. At higher energies with the same undulator, the LEUTL system will be capable of achieving saturation at a wavelength of approximately 40 nm.

Present Status and Schedule

The present schedule (August 1997) of the LEUTL project is as follows. First testing of beam into the LEUTL vault is scheduled for early 1998. First measurements within the LEUTL vault of the prototypical undulator should begin in 1998. Upgrade to a high-brightness gun is planned for sometime late in 1998 to early 1999.

Acknowledgments

Work supported by U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

REFERENCES

[1] 4th Generation Light Sources, 10th ICFA Beam Dynamics Panel Workshop, Grenoble, January 1996.

[2] M. Cornacchia et. al., in: Free-Electron Laser Challenges, eds. P. O'Shae and H. Bennett (SPIE Proc. Vol. 2988, 1997) pp.2-14.

[3] S.V. Milton, in: Free-Electron Laser Challenges, eds. P. O'Shae and H. Bennett (SPIE Proc. Vol. 2988, 1997) pp.20-27.

[4] S.V. Milton, J.N. Galayda, and E. Gluskin, 1997 IEEE Particle Accelerator Conference, Vancouver 1997, in press.

[5] M. Borland et. al., Proc. of the 1990 Linear Accelerator Conference (1990).

[6] M. Borland, 1993 IEEE Particle Accelerator Conference (1997) pp. 3015-3017.

[7] A.H. Lumpkin et. al., Preliminary Tests of the Optical Diagnostics for the APS Low-Energy Undulator Test Line Particle Beam, these Proceedings.

[8] N.A. Vinokurov, in: Free-Electron Laser Challenges, eds. P. O'Shae and H. Bennett (SPIE Proc. Vol. 2988, 1997) pp. 64-68.

[9] M. Xie, 1995 IEEE Particle Accelerator Conference (1995) pp. 183-185.

[10] R.A. Jong, W.M. Fawley, and E.T. Scharlemann, in: Modelling and Simulation of Laser Systems, (SPIE Proc. Vol. 1045, 1989) pp.18-27.

[11] S.V. Milton and J. Lewellen, A High-Brightness Beam Bunch Compression Test Stand, these Proceedings.

TABLES

Table 1: Expected Thermionic RF Gun Performance

Energy	3 MeV
Peak current	150 A
Normalized emittance	$5\pi \bullet$ mm-mrad
Energy spread	1%

Table 2: Parameters for Initial LEUTL SASE-mode Operation

Wavelength	120 nm
Electron energy	400 MeV
Normalized emittance	5 π mm-mrad
Energy spread	0.1%
Peak current	150 A
Undulator period	27 mm
Magnetic field	1.2 T
Undulator gap	5 mm (fixed)
Focusing	separated quadrupoles
Gain length	1.5 m
Undulator length	15 × 2.4 m

FIGURE CAPTIONS

Figure 1: An overview of the LEUTL system.

Figure 2: Drawing of the installed thermionic rf gun and alpha magnet bunch compression system used in the LEUTL.

Figure 3: The PAR bypass line showing the OTR screen layout. Much of the beamlines leading to and from the PAR and the PAR itself have been removed for clarity.

Figure 4: The LEUTL floor plan showing both the LEUTL enclosure and the LEUTL end station building.

Figure 5: A cross section of the LEUTL enclosure showing an undulator in place.

Figure 6: A single undulator cell on the support structure.

Figure 7: Simulated output power vs. undulator length for two cases. The dashed line is for the case of a continuous undulator with no gaps and the dotted line shows the power gain for an undulator with gaps between cells.

Figure 8: Saturation length of the SASE process vs. peak current and normalized transverse emittance. The beta function has been optimized to achieve the minimal length.

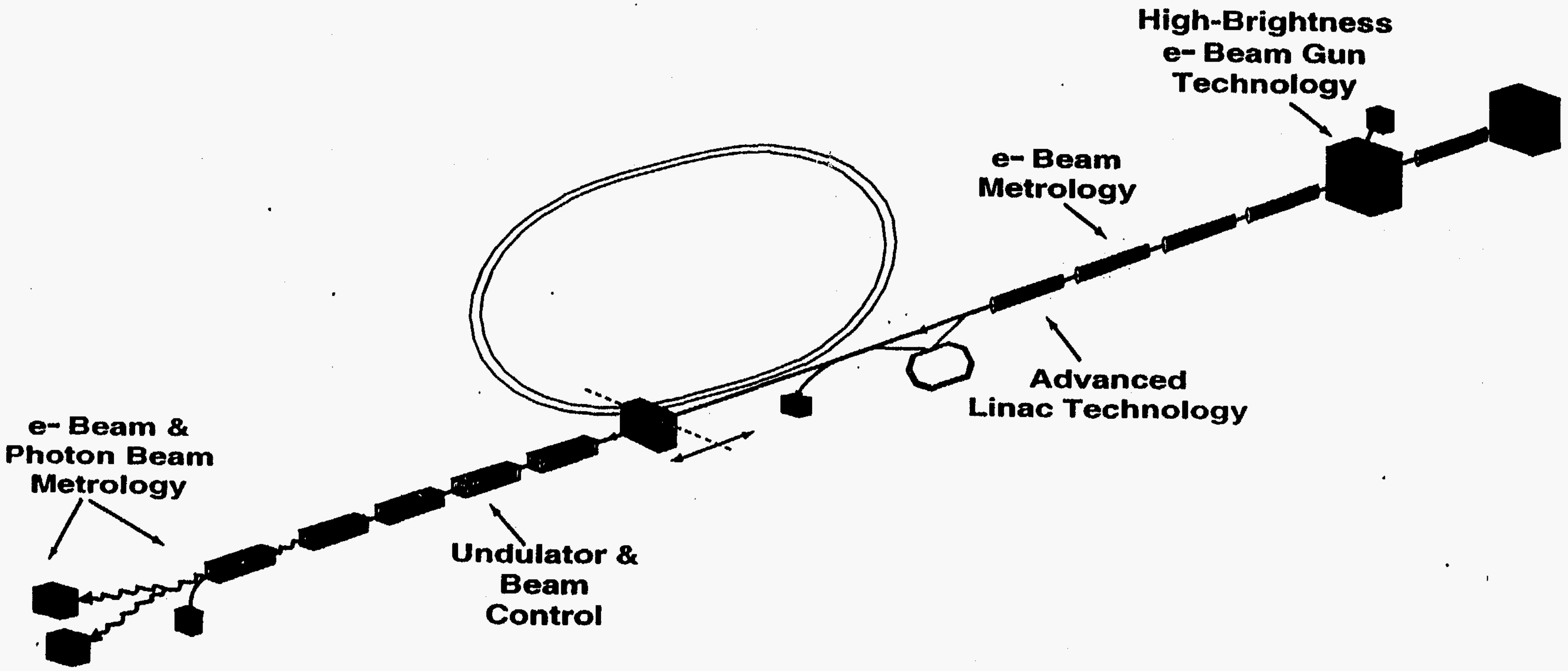

High-Brightness e- Beam Gun Technology
e- Beam Metrology
Advanced Linac Technology
e- Beam & Photon Beam Metrology
Undulator & Beam Control

Figure 1

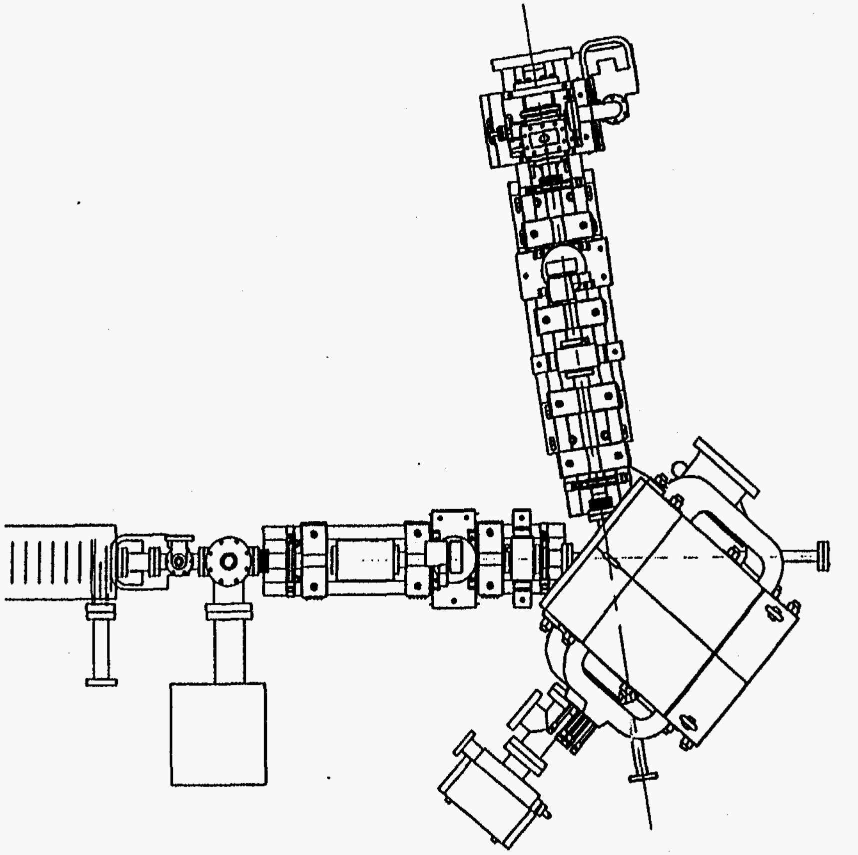


Figure 2

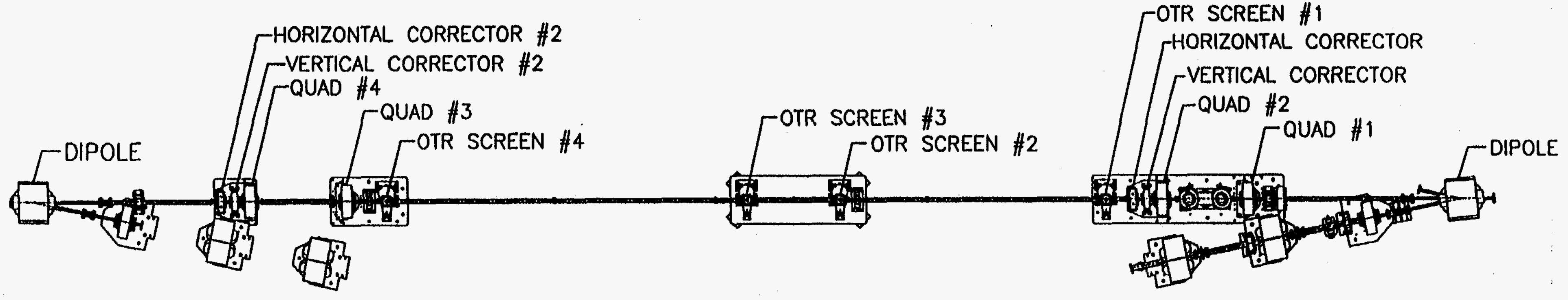


Figure 3

SMILTON

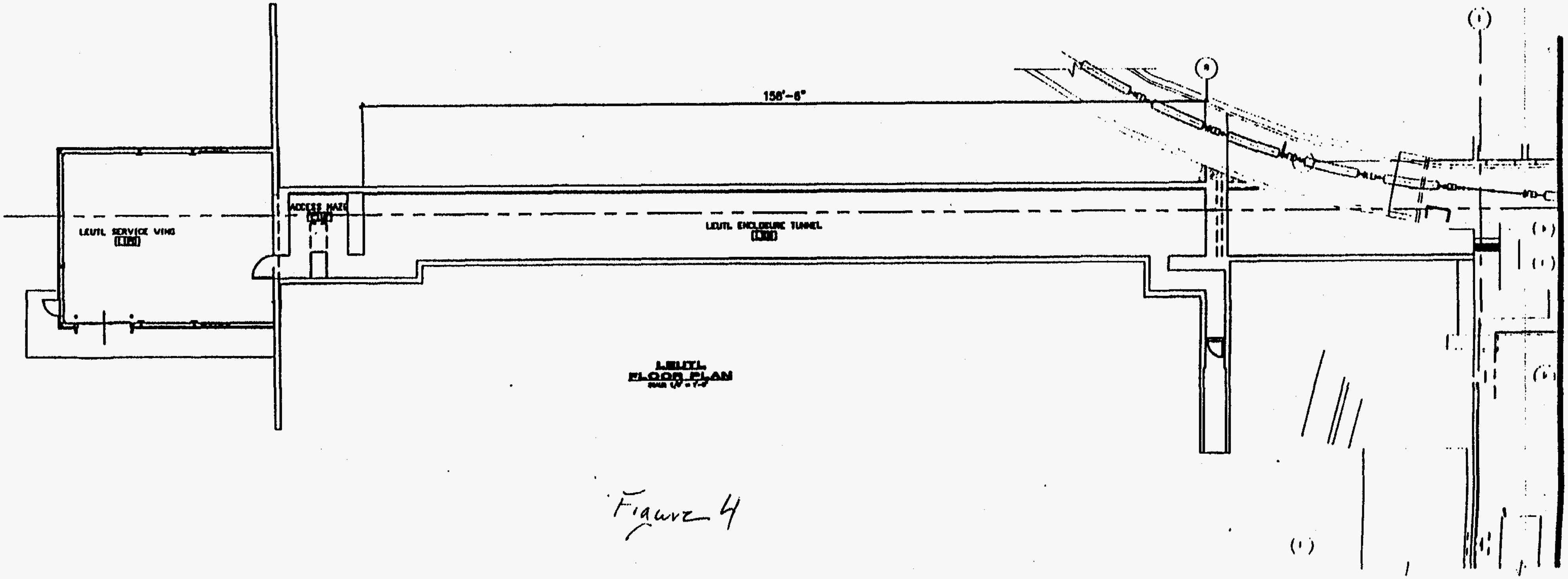
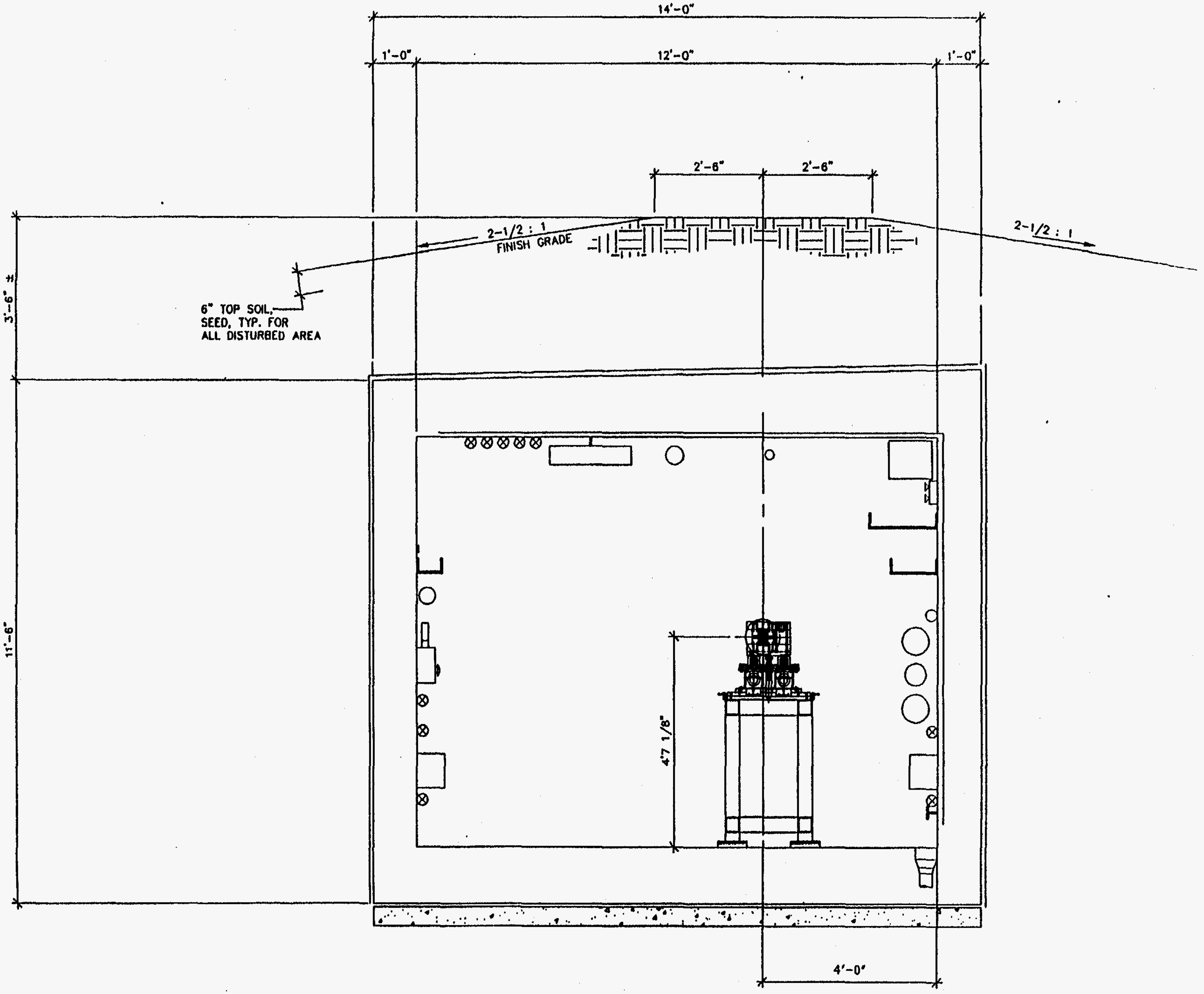
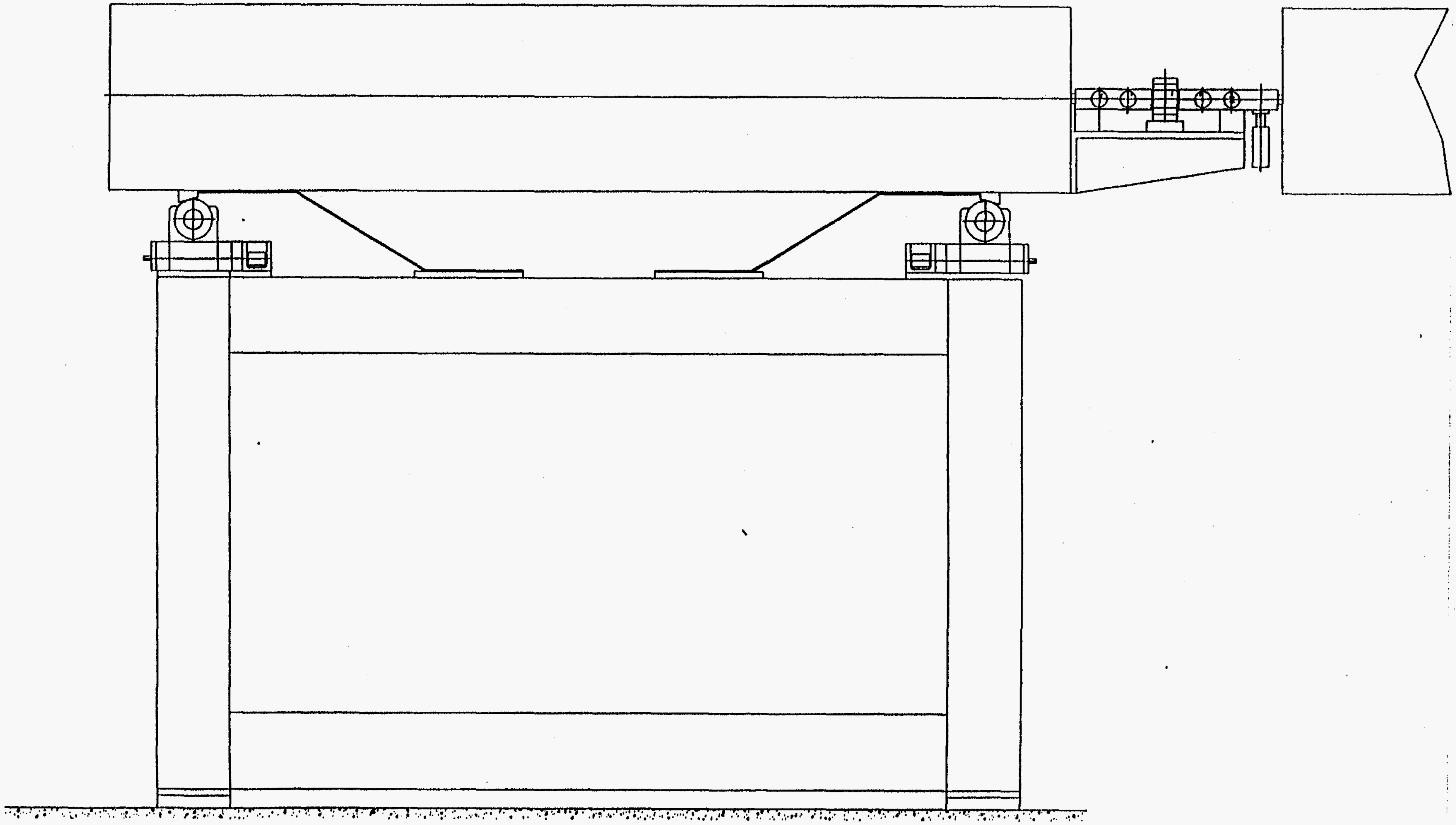

156'-6"
LEUTL SERVICE WING
ACCESS MAZE
LEUTL ENCLOSURE TUNNEL
LEUTL
FLOOR PLAN

Figure 4



FEL IN THE TUNNEL

Figure 5



FEL - undulator cell on support stand

Figure 6

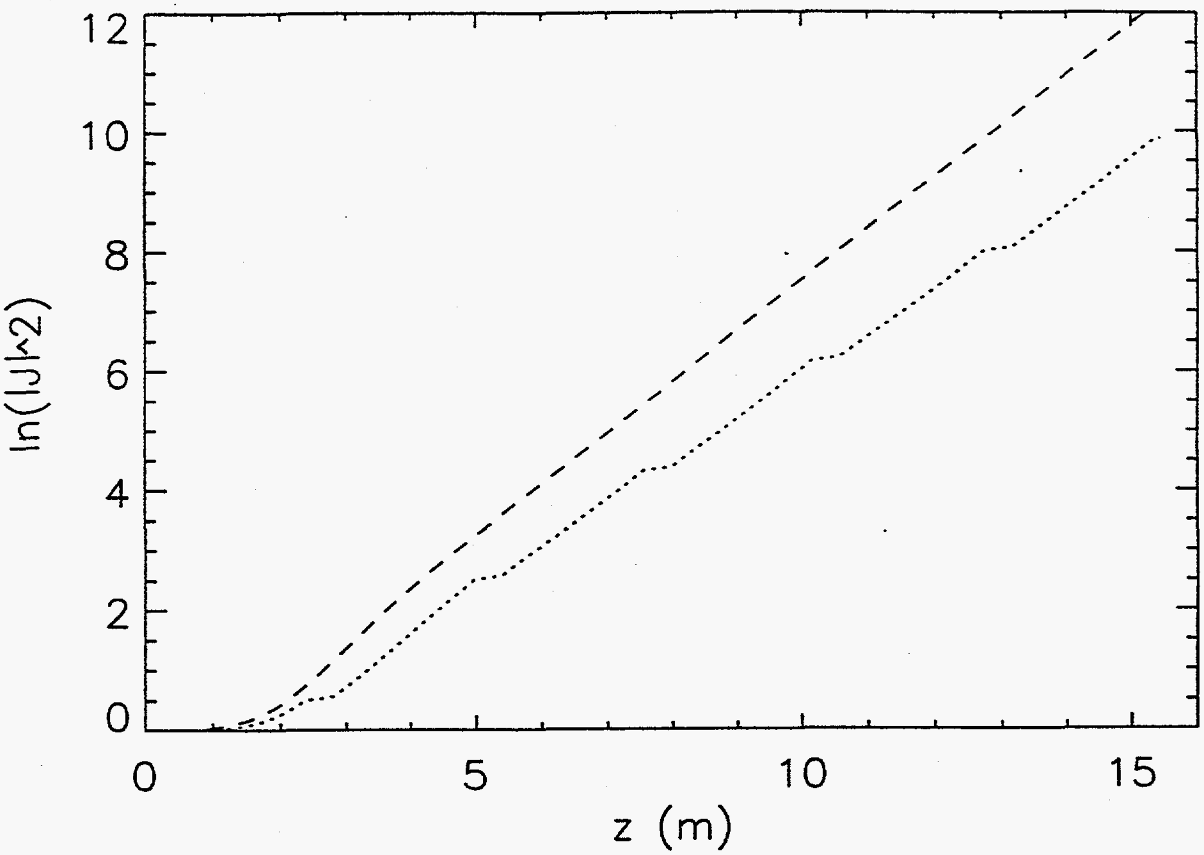


Figure 7

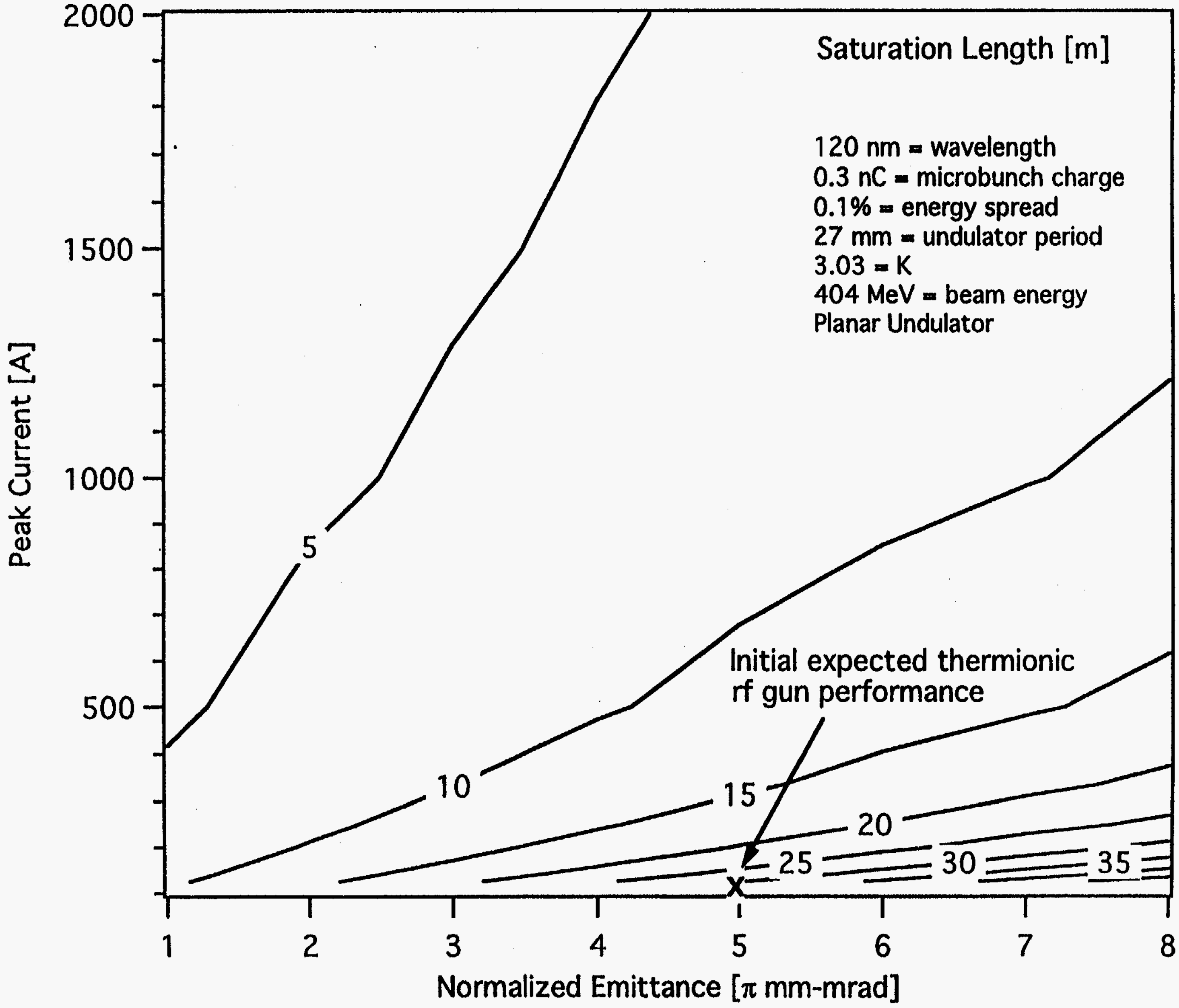

Saturation Length [m]
120 nm = wavelength
0.3 nC = microbunch charge
0.1% = energy spread
27 mm = undulator period
3.03 = K
404 MeV = beam energy
Planar Undulator
Initial expected thermionic rf gun performance
x
5
10
15
20
25
30
35
2000
1500
1000
500
1
2
3
4
5
6
7
8
Peak Current [A]
Normalized Emittance [π mm-mrad]

Figure 8