Conf- 9108118--26

LA-UR-91- 3164

LA-UR--91-3164

DE92 002442

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE: ENGINEERING CONSIDERATIONS OF THE ADVANCED FREE ELECTRON LASER FACILITY

AUTHOR(S): Karl L. Meier

**SUBMITTED TO: Thirteenth International Free-Electron Laser Conference
Santa Fe, NM
August 25-30, 1991**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

MASTER
1/2

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

ENGINEERING CONSIDERATIONS OF THE ADVANCED FREE-ELECTRON LASER FACILITY*

Karl L. Meier

**Los Alamos National Laboratory
Los Alamos, NM 87545**

ABSTRACT

The Advanced Free-Electron Laser (AFEL) is being built at Los Alamos inside a large laboratory building. In addition to cost and available space considerations, several engineering issues affected the design of the AFEL and its facility. The 1300-MHz, 20-MeV electron linac required extensive radiation shielding and a short rf-waveguide run. Free-Electron Lasers (FEL) and photocathode-drive laser optics required a clean, constant temperature environment. New environmental, health, and safety (ES&H) regulations placed constraints on the facility design and layout. In the past, many ES&H regulations did not apply to pilot-scale experiments such as the AFEL; compliance is now mandatory. The facility design included an earthquake restraint system for the radiation shielding, full compliance with the National Environmental Protection Act (NEPA), and minimization of airborne emissions.

I. INTRODUCTION

The AFEL is a Los Alamos National Laboratory internally funded research project. As a multipurpose project, the AFEL will perform research experiments for photolithography, medical purposes, and defense applications. As shown in Fig. 1,

*Work supported by Los Alamos National Laboratory Institutional Supporting Research, under the auspices of the United States Department of Energy.

the AFEL consists of a 20-Mev, 50- μ average, 1300-MHz, rf-driven electron LINAC with a photocathode injector. The electron beam is directed by permanent magnet dipoles and focused by permanent magnet quadrupoles to a beam spot size of 0.25-mm diameter at the entrance to the 30-cm-long wiggler. Electron-beam diagnostic devices consist of current and positron monitors, a spectrometer, and several optical transitron radiation (OTR) emittance monitors. In conjunction with the wiggler, the 1.5-m spherical resonator is capable of producing FEL light in the range of 0.4 to 4 μ m when lasing at higher harmonics.

II. AFEL FACILITY

The AFEL is being constructed inside of a large laboratory building. Because the available space was 76 by 38 feet, many cost and space trade-offs were required to achieve a workable facility design and layout. Competing for the available space were the experimental vault, radiation shielding, drive laser, FEL diagnostics, control and data systems, mechanical staging, large equipment, and access aisles. Interior vault dimensions of 12 by 25 feet were needed to house the photocathode insertion system, the linac, and the 10-feet-long optical table on which are mounted the beam transport system and FEL optics.

To maintain safe working conditions for personnel, 6 feet of ordinary concrete and 4 inches of lead shielding are required.[1] An important cost-versus-space trade-off was made early in the facility design when high-cost magnetic concrete was incorporated rather than less-expensive ordinary concrete. Through the use of magnetite, shield wall thicknesses were reduced to 4 feet; a saving of 2 feet on each vault wall.

Optimum rf system operation and control mandates a short waveguide run. Because the klystron and rf system were preexisting, the vault was placed in the

northeast corner of the facility, as shown in Fig. 2. The waveguide run is 25 feet, allowing excellent control of the rf system.

The cesium, potassium, and antimony photocathodes are prepared in the staging area. The photocathodes are transported to the vault in an evacuated chamber and are then loaded into the insertion chamber. When needed for AFEL operation, the preprepared cathodes are inserted into the low energy end of the linac.

The laser room was located adjacent to the vault to minimize the optical path lengths. The YLF drive laser exits the laser room, passes through the concrete shield wall and into the linac in the vault. The FEL light beam returns back from the vault, passes through the shielding, and into the laser room. FEL diagnostics and experiments will be conducted in the laser room as shown in Fig. 2. For a more detailed description of the AFEL, see references 2 and 3.

Situated on the west side of the vault and laser room is the control room. This nearly ideal central location allows 1) easy access to the AFEL linac and optical system in the vault, 2) quick coordination with the drive laser and FEL experiments, and 3) interaction with the rf system operator when needed. The control room contains the computer control system, data acquisition system, and most of the electronic apparatus for the AFEL.

III. SHIELDING

The vault-wall radiation shielding consists of 4-foot-thick magnetite concrete blocks, 4 feet thick. In the forward section, an additional 4 inches of local lead shielding is required around radiation areas, such as dipoles, wiggler, and beam stop. Most of the magnetite blocks are approximately 4 by 4 by 2 feet in size and weigh about 4 tons each.

Two other vault-shielding configuration schemes were considered during the facility design, an underground vault beneath the existing floor and poured-in-place concrete walls. The underground vault scheme presented problems for the existing building structure and foundation. Access for large items was also difficult. Both the poured-in-place walls and underground structure limited possibilities for later expansion. These two schemes represented major, permanent construction projects and required extensive, time-consuming permits and design reviews. These two schemes also required the use of nonrecoverable resources. A block-type structure avoided all these disadvantages. In addition, a block-type structure is removable and reusable, an advantage that will be discussed in later sections of this paper.

The 4 by 4 by 2 feet blocks represented a near-optimum size and were stacked with a forklift. Larger blocks could not be used because large forklifts could not get into the existing building. Small-12-by-12-by-8 inch--interlocking blocks are relatively expensive and are costly to hand stack. With a density of 230 lb/ft^3 , the magnetite concrete blocks can provide adequate shielding in a 4-feet-thick configuration, whereas ordinary concrete with a density of 150 lb/ft^3 requires a 6-feet-thick wall. Each block is fitted with steel angles on all edges to prevent chipping during handling.

A 33 ton moveable shield door separates the vault from the control room. When closed during linac operation, the door protects personnel from neutron and bremsstrahlung radiation, activated air, and ozone. The door is constructed of 12 magnetite concrete blocks welded together on their edges and welded to a reinforced concrete base. Mounted on four sets of Hilman rollers and guided by tracks on the floor, the door is opened and closed by hydraulic piston.

Because sky-shine radiation emanates from the vault, roof shielding was required to protect personnel. Sky-shine radiation is orders of magnitude less than direct radiation and requires less thickness to reduce radiation to safe levels. Steel slabs 6 inches thick span the vault to shield against bremsstrahlung. In addition, local lead shielding 2 inches thick is required over radiation sources in the beam transport system. Borated water in 5-gallon cans is placed on top of the steel slabs to absorb neutrons. Although the total radiation level on top of the roof is 100 mr/h and is an exclusion area during AFEL operation, the sky-shine radiation is 0.1 mr/h at ground level.

IV. HEATING, VENTILATING, AND AIR CONDITIONING

Although most of the equipment that generates large amounts of heat, such as water chillers and magnet power supplies situated outside the enclosed areas, an appreciable amount of heat must be removed from the vault, laser room, and control room. The heating, ventilating, and air conditioning (HVAC) system removes as much as 20 kW of heat generated by electrical and electronic equipment, lights, and personnel. In addition, the HVAC system maintains a year-round temperature of $72^{\circ} \pm 2^{\circ}\text{F}$. The tightly controlled temperature range of $\pm 2^{\circ}\text{F}$ is required for proper operation of the drive laser and FEL optical systems in the vault and laser room.

A high efficiency particulate air (HEPA) filtration system is an important part of the HVAC system. Dust contamination is particularly troublesome to the optical components of the AFEL. The HEPA filters reduce the air particulate level to near the class-100 level and provide a very clean environment for the optical systems.

Because linac operation creates small amounts of activated air, nitrous oxides, and ozone, the vault HVAC is completely separate from the HVAC of the laser and control rooms. Even though the entire vault inventory of activated air, is a few microcuries[4], it

was thought best for safety reasons to prevent any of this air from being circulated into the laser or control rooms during operation. A 400-ft³/min exhaust fan removes the activated air, nitrous oxides, and ozone from the vault during operation and before personnel entry. With a 400-ft³/min exhaust rate, the average residence time of air in the vault is 6 minutes.

V. BEAM STOP

The largest source of radiation in the vault is the beam stop. Therefore, the beam stop was designed to minimize the amount of bremsstrahlung and neutrons created in it. As shown in Fig. 3, the beam stop is made of graphite and is located underground to minimize the amount of radiation coming from the beam stop into the vault. The beam stop has two sections: 1) a water-cooled graphite cylindrical section for stopping the electron beam and 2) a graphite cylinder for absorbing about 90% of the bremsstrahlung created by the electrons. With a density of 1.7 g/cm³, the range of 20-MeV electrons in graphite is 6.3 cm. The design current level is 50-μ-Amperes average, resulting in an electron beam of power of 1 kW. Because future AFEL upgrades may double the electron energy and also increase the beam current, large design margins were built into the beam stop. At the design water flow rate of 2 gal./min, 1 kW of beam power results in a 2°C water-temperature rise.

Graphite is an excellent beam-stop material for 20-MeV electrons because only bremsstrahlung radiation is created when the electrons are stopped.[5] Over 90% of the bremsstrahlung is highly forward directed and is contained within a half cone angle of 15°. Using the rule-of-thumb for average bremsstrahlung energy, $E_\gamma = 1/3$ of the electron energy. Therefore, in this case $E_\gamma = 6.7$ MeV. For a 70-cm thickness of graphite, 96% of the bremsstrahlung inside the cone angle is absorbed. Taking into

account the bremsstrahlung outside of the cone angle, nearly 90% of all the bremsstrahlung is absorbed in the two parts of the beam stop.

The photoneutron production threshold in graphite is 18.7 MeV[5]. With an average bremsstrahlung energy of 6.7 MeV, very few neutrons are produced in the graphite. Because most of the bremsstrahlung is absorbed in the graphite, photoneutron production in the stainless steel container and the surrounding rock is expected to be relatively small. Monte Carlo beam-transport calculations will be performed to determine the actual bremsstrahlung and neutron fluxes that originate in the beam stop in the vault.

When used as a beam stop for 20-MeV electrons, graphite produces very little or no induced radioactivity. Los Alamos' 20-MeV electron experiments such as APEX and HIBAF have shown no detectable induced radioactivity in a graphite beam stop after many hours of operation.

IV. ENVIRONMENT, HEALTH, AND SAFETY

New and stringent ES&H regulations have recently been placed on all DOE projects and facilities. In the past, relatively small pilot-scale experiments such as the AFEL were not required to comply with many ES&H regulations nor were they required to prepare lengthy ES&H documentation.

In February 1990 all DOE projects and facilities were directed to comply fully with ES&H regulations. An attempt was made in November 1990 to allow pilot-scale experiments such as the AFEL to obtain a categorical exclusion from some regulations such as an environmental assessment (EA). This request has been denied by the DOE. In fact, all operations of electron accelerators are specifically required to request and obtain approval of an EA.

Table I is a list of the ES&H documents, evaluations, and permits to be obtained for the FEL.

TABLE I
ES&H DOCUMENTS, REVIEWS, ASSESSMENTS, AND PERMITS
REQUIRED FOR THE AFEL

1. Environmental Assessment (EA)
2. Resource Conservation and Recovery Act Review (RECRA), (hazardous waste)
3. Airborne Radioactive Emissions Permit
4. Nonradioactive Airborne Emissions Permit
5. Safety Assessment (hazard classification)
6. Preliminary Hazard Assessment (PHA)
7. Facilities Quality Control Review
8. Occupational Radiological Hazard Assessment
9. Occupational Safety Review (OSHA)
10. Industrial Hygiene Review
11. Standard Operating Procedure (SOP)
12. Seismic Analysis of Vault-Shield Block Configuration

Most of the 12 documents must be written and approved before running significant amounts of electron beam in the experiment. Some of the documents are approved internally at Los Alamos, but some require Department of Energy Headquarters (DOE-HQ) approval.

An EA is a short environmental impact statement (EIS). The AFEL EA, after programmatic review and revisions, is 14 pages long compared to an EIS that could be several-hundred pages long. The main purpose of the EA is to show that the AFEL produces no significant impact on the environment. Included in the EA is documentation to show that the AFEL project will comply with NEPA. If DOE-HQ affirms that NEPA compliance exists, a finding of no significant impact (FONSI) will be

issued. When the FONSI is issued, the project can begin to commit nonrecoverable resources.

Because the EA preparation, review, and approval process is slow, and no FONSI has yet been issued, it has been important to avoid committing nonrecoverable resources to the project. Significant programmatic delays would have occurred if no facility fabrication had been allowed until FONSI issuance. Facility fabrication has begun by using recoverable and reusable materials. Constructing the vault from reusable blocks rather than poured-in-place concrete walls or a below-ground structure is an example of a recoverable resource. The shield blocks can be disassembled and used on other projects in the future. The vault roof is constructed of reusable steel slabs. The control and laser rooms are modular office enclosures. Being easy to disassemble, the walls and ceilings can be reused in another location if desired.

AIRBORNE EMISSIONS

A small percentage of the electron beam will be lost in the beam-transport system during normal operation. Likely sources of loss are at the dipoles and the wiggler. These beam losses will produce bremsstrahlung and neutrons, which when combined with radiation from the beam stop will activate the air in the vault. Because activated air is produced[4] it is necessary to determine the rate of production and then calculate its dispersal pattern in the atmosphere. These data are then used to calculate a very conservative maximum dose to the public[7]. Because the calculated dose to the public is less than 0.1 mr/yr, no Environmental Protection Agency permit is required.

An analysis was performed to determine the amount of nonradioactive emissions from the AFEL during operation. Ozone is produced at the rate of 0.1 g/h and nitrous oxide at the rate of 0.05 g/h[8]. No other air contaminants are produced. Because the

New Mexico Air Quality Control Regulation 702 requires a permit for facilities producing over 10 pounds of emissions per hour, the AFEL does not need a permit to operate.

The airborne emissions calculations were complete. Because of the low levels of emissions from the AFEL, no permits are required. However, several months were required to complete the calculations and determine that these permits were not required. In the design of an experiment, it is quite important to minimize airborne emissions. If emissions are so high that they require a permit, years of operational delay could result.

VIII. PRELIMINARY HAZARD ANALYSIS

A Safety Assessment was made to determine the hazard level of the AFEL. After a finding of "low hazard" by Los Alamos safety personnel, the AFEL was directed to prepare a PHA. The AFEL is fortunate to require only a 30- to 50-page PHA. The "low-hazard" classification allows preparation of a PHA rather than a safety analysis report (SAR). A proton linac experiment at Los Alamos that is currently in its start-up phase has a "moderate hazard" classification. This classification requires an SAR. The SAR is a few thousand pages long and has been in preparation for over 2 years.

IX. SEISMIC ANALYSIS OF VAULT BLOCKS

In June, 1990, Los Alamos was directed to comply with a new set of guidelines for natural phenomena hazards, UCRL-15910⁹. Of the natural hazards--wind, flood, and earthquake--only the latter applies to the AFEL. In particular, the stacked shield blocks and steel slab roof must have a seismic analysis and be fitted with a restraint system to withstand a design-basis earthquake. Los Alamos is in a Seismic Zone 2. Because

the AFEL is a low hazard facility, UCRL-15910 indicates that a seismic restraint system must be built that prevents movement of the vault blocks, roof, and floor under a horizontal acceleration of 0.22 g (1.0 = acceleration of gravity). The probability of exceeding 0.22 g is 1×10^{-3} .

A conservative loads analysis was performed on the vault blocks and roof configuration. A restraint system was designed for the theoretical maximum earthquake of 0.22 G within a period of 1000 years. As shown in Fig. 4, the restraint system consists of block-to-block welds on the steel angle edges of each block and additional steel angles at the floor and roof. The block-to-block welds convert the shield blocks into a monolithic structure for the design-basis earthquake. The steel angles anchor the blocks to the concrete floor to prevent horizontal movement or tipping and steel angles connect the steel slab roof to the blocks. The borated water cans on the roof are banded together to prevent their falling to the ground.

X. CONCLUSIONS

New projects at DOE facilities that were once considered small, pilot-scale, or low-hazard are now required to comply with new and stringent ES&H regulations. Such projects are no longer exempt. Careful planning of facility design at an early stage can help meet the new requirements. A proper beam-stop design can reduce the radiation levels in the facility to decrease ES&H risks, emissions, and hazardous waste.

REFERENCES

- [1] M. Howe, "Compact FEL Shielding Estimates," Los Alamos National Laboratory memorandum, (May 29, 1990).
- [2] K. C. D. Chan, et al, "Los Alamos Free-Electron Laser," Thirteenth International Free-Electron Laser Conference, August 25, 1991.
- [3] K. C. D. Chan, K. L. Meier, et al., "Compact Free-Electron Laser at the Los Alamos National Laboratory," SPIE 1991 International Symposium on Optical and Optoelectronic Applied Science and Engineering, San Diego, California, July 21, 1991.
- [4] W. B. Wilson, "AFEL Air-Activation Calculations," Los Alamos National Laboratory memorandum, T-2-M-3258, (November 13, 1990).
- [5] W. P. Swanson, "Radiological Safety Aspects of the Operation of Electron Linear Accelerators," IAEA Technical Report Series No. 188, pp. 69 and 81.
- [6] K. C. D. Chan, M. A. Lowe, S. E. Adams, and P. Y. Wang, "Bremsstrahlung and Photoneutron Yields from 5-25 MeV Electrons on Thin Slabs of Al, Fe, Cu, and Pb," Nuclear Instruments and Methods B10/11, 419, (1985).
- [7] T. Buhl, "Review of the Advanced Free-Electron Laser Project under 40 CFR Part 61, Subparts A&H, National Emissions Standards for Hazardous Air

Pollutants," Los Alamos National Laboratory memorandum, HSE-8:91-436, (March 26, 1991).

- [8] C. Eberhart, "Advanced Free Electron Laser Nonradioactive Air Emissions Review," Los Alamos National Laboratory memorandum, HSE-8:90-1242, (November 30, 1990).

Fig. 1. AFEL Beamline.

Fig. 2. AFEL Facility.

Fig. 3. Beamstop.

Fig. 4. Seismic Restraints.

END

**DATE
FILMED**

12/05/91