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NASA FACILITY FOR THE STUDY OF SPACE RADIATION EFFECTS

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ABSTRACT

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Space particulate radiation from the Van Allen belts, solar flares, galactic cosmic, and manmade sources have energies and fluxes which are capable of producing damage in space mission payloads. NASA - Langley Research Center, Hampton, Virginia, has initiated the construction of a ground based Space Radiation Effects Laboratory which simulates most of the space particulate energy spectrum and which can be used in a radiation research program for minimizing or eliminating deleterious radiation effects. A 600-Mev proton synchrocyclotron of variable energy and electron accelerators from 1 to 10 Mev will be included in the laboratory for accelerated testing. The plan of the proposed test areas reflect the latest advances in the state of the art as it pertains to the engineering and basic experimental requirements in flexibility, radiation background levels, shielding, and isolation. The laboratory operational plan permits three Virginia institutions of higher learning to cooperate with the Langley Research Center in carrying out radiation programs.

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INTRODUCTION

The Langley Research Center of NASA, because of its programs involving the exploration of space, has a special interest in the space environment insofar as it influences the design of space vehicle systems. Included in the many hostile aspects of the space environment is the particulate radiation associated with cosmic rays, solar flares, and that trapped in the earth's magnetic fields. Early in 1960, Langley Research Center personnel initiated study and experimental programs, utilizing limited time in existing United States accelerator facilities, to assess the effects of this environment on space systems. As an outgrowth of this effort a Space Radiation Effects Laboratory (SREL) is now being constructed. Various aspects of this laboratory will be covered by this paper. The laboratory will simulate a large portion of the particulate space radiation environment and thus provide a means for running space radiation experiments under controlled conditions.

SUMMARY OF THE SPACE PARTICULATE RADIATION

A brief summary of our knowledge of flux and energy level of particulate radiation in space is given in table I.[1,2]

TABLE I.- SUMMARY OF THE PROTON AND ELECTRON SPACE RADIATION

TRAPPED PROTON SUMMARY

Low energy	High energy
120 Kev < E < 4.5 Mev	30 Mev < E < 700 Mev
Flux ≈ 10^8 p/cm^2/sec	Flux ≈ 2 - 4 × 10^4 p/cm^2/sec

Intensity can vary by a factor of 2 to 3 with solar activity.

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SOLAR FLARE PROTON SUMMARY

Low energy	High energy
$E < 40$ Mev	40 Mev $< E < 10$ Bev
Flux $\approx 10^5 - 10^6$ p/cm^2/sec	Flux $\approx 10^4 - 10^5$ p/cm^2/sec

TRAPPED ELECTRON SUMMARY

Low energy	High energy
110 Kev $< E < 1.6$ Mev	1.6 Mev $< E < 5$ Mev
Flux $< 10^8$ e/cm^2/sec	Flux $< 10^5$ e/cm^2/sec
$E > 10$ Kev	$E > 5$ Mev
Flux $\approx 10^9$ e/cm^2/sec	Flux $< 10^3$ e/cm^2/sec

Flux can vary by a factor of 50 to 100 with solar activity.

The data for table I were obtained in space flight through Explorer XII. The high-energy protons are generally encountered in the inner radiation region at about 10,000 kilometers from the earth's center whereas the low-energy protons are found between 20,000 and 30,000 kilometers.

The maximum integral energy flux of the solar flares varies between 10^5 to 10^6 protons/cm^2/sec with energies ranging from Kev's to about 10 Bev. By far, the largest number of these protons have energies less than 1 Bev.

The natural trapped electrons have their highest intensities at about 16,000 to 27,000 kilometers as measured from the earth's center. The electrons of the manmade belt caused by a high-altitude nuclear detonation in 1962 have been geographically located[3] in the position shown in figure 1. The naturally trapped protons and electrons of the radiation belts are also shown. The energies of both the manmade and naturally occurring electrons extend from a few Kev to less than 10 Mev.

SELECTION OF THE ACCELERATORS

The architect's rendering of the Space Radiation Effects Laboratory is illustrated in figure 2. It shows a support building in the front which includes the labs and controls and a larger experimental building in the rear. The major research tools associated with the laboratory are three particle accelerators. These are housed in the experimental building.

In selecting the accelerators for the laboratory two primary objectives had to be satisfied: (a) they should be operational in less than 3 years from start of construction and (b) they should simulate as much of the energy spectra as possible with sufficient intensities for accelerated test programs.

An analysis of the particulate space radiation environment indicated that ground simulation of a large portion of this environment could be accomplished with a proton accelerator with a maximum energy of less than 1 Bev and with an electron accelerator with a maximum energy of approximately 10 Mev.

Historically, it has taken from 4 to 8 years to design and put into operation proton accelerators in the hundreds of Mev range.[4] Therefore, from the outset it was realized that an existing accelerator would have to be copied as closely as possible to meet the construction schedule. Basically, there were three types of highly developed proton accelerators considered for the laboratory, the fixed-frequency cyclotrons, the frequency-modulated cyclotrons or synchrocyclotrons, and the alternating gradient synchrotrons. The fixed-frequency cyclotrons were eliminated because the maximum attainable energy for this type is approximately 20 Mev and the synchrotrons were eliminated because their external beam flux was insufficient for accelerated space simulation studies. The synchrocyclotron was chosen and considerations of downtime and overall proven reliability were additional factors in its favor.

There are four synchrocyclotrons in the world with energies of about 600 Mev or greater. Two of these are located behind the iron curtain and were not considered. The others are the 730-Mev machine at Berkeley, California, and the 600-Mev machine at CERN, Geneva, Switzerland. Of these two the CERN machine was chosen as being more applicable. The CERN machine was designed from its concept for its stated energy and incorporated the most advanced accelerator design concepts of the day.

In order to cover the electron spectra two accelerators were required. Various companies in this country had manufactured machines which were more than adequate for the contemplated research programs. These requirements will be satisfied by a Dynamitron with an energy range of about 0.5 Mev to 3 Mev and a Linac with an energy range of about 3 Mev to 10 Mev. The higher energy machine has provisions for extending its range to 30 Mev if desired at a later date.

ACCELERATOR CHARACTERISTICS

Synchrocyclotron

Figure 3 is a photograph of the 600-Mev synchrocyclotron at CERN near Geneva, Switzerland and is the basis of the proton accelerator for SREL. The magnet weighs 2,500 tons and is 36 feet wide, 21.3 feet deep, and 20 feet high.[5] The magnet gap varies from 17.7 inches at the center to 14.7 inches at the outer edge. The beam is extracted from the horizontal center line of the gap which is 4.1 feet from the floor. The coils are made of water-cooled aluminum and when energized require approximately 1,500 kva of electrical power. They are about 25 feet in diameter and weigh 60 tons each. The upper coil can be seen in figure 3. A coil assembly is constructed of nine "pancakes" assembled in a coil-former and connected in series electrically. A "pancake" consists of two layers of hollow rectangular conductors spirally wound from one continuous extrusion. The magnetic field has a flux density of about 20,000 gauss.

The radio-frequency system, on which the reliability of the whole synchrocyclotron depends, can be regarded as a coaxial transmission line as shown in figure 4. The outer conductor of the transmission line, which includes the dummy Dee, is at ground potential. A water-cooled tuning-fork modulator is used to vary the capacitance of the oscillator. It modulates the r-f frequency between 29 and 16.5 megacycles at 55 cps with Dee voltages varying from 6 to 25 kilovolts. The tuning fork is the unique feature of the r-f system and the prongs or blades, which is more descriptive, are approximately 80 inches wide and from the closed to open position vary the modulator capacitance by a factor of 10.

The vacuum in the accelerating chamber, which is about 10^{-6} torr, is maintained by two roughing and two 32-inch oil diffusion pumps.

The ion source, which introduces the protons into the center of the accelerating chamber, is a cold cathode type; it receives a 1,000-volt d-c pulse at the repetition frequency of the r-f system.

The internal beam current of the synchrocyclotron is approximately 0.3 microamp but with an extraction efficiency of 6 percent the external beam is reduced to 0.018 microamp or approximately 10^{11} protons per second.

Figure 5 is a plan view of the cyclotron showing the relative position of the r-f system, the vacuum tank, the Dees, the ion source, the proton extraction system, and the internal target arrangement. The eight flip targets noted are used to produce neutrons of different energies. The universal target is used to produce mesons.

Dynamitron

The Dynamitron will be capable of accelerating electrons with energies from 0.5 to 3 Mev with a variable external beam current from 1 microamp to 10 milliamps. A magnetic scanning system will be provided that is capable of controlling the external beam pattern to a maximum of 2 inches wide and 24 inches high. The Dynamitron is approximately 7 feet in diameter, 20 feet long, weighs 20,000 pounds, and requires 160 kva of electrical power. A large tank maintained at 10^{-5} torr houses the cascaded rectifier accelerating mechanism.

Linac

The Linac shown in figure 6 is a traveling wave linear electron accelerator with an energy range from 2 to 10 Mev. The average d-c beam current is a maximum of 1 milliamp at 7 Mev and varies linearly down to about 0.4 milliamp at 3 Mev and 10 Mev. The beam pulse length will vary continuously from 0.1 to

6 microseconds and stepwise to a pulse length of 0.01 microsecond. The 0.01 microsecond pulse will have a rise time of 5 nanoseconds, a duration of 10 nanoseconds, and a decay time of 5 nanoseconds. The pulse repetition frequency will be continuously variable from 1 to 720 pulses per second. Single-pulse operation will also be available. The radio-frequency system uses an L-band klystron amplifier to provide the microwave energy for the waveguide. The Linac requires about 200 kva of electrical power.

PLAN OF THE SPACE RADIATION EFFECTS LABORATORY

Figure 7 is a plan view of SREL showing the experimental building and the first floor of the support building. The first floor of the support building contains the control and readout rooms as well as office and shop space for the operating staff. The second floor contains the office and laboratory space required to support the researchers using the accelerators. The right-hand wing of the support building houses the building utilities and the auxiliary mechanical and electrical equipment associated with the accelerators. The total floor area of the support building is approximately 21,000 square feet.

The experimental building contains the setup area, two large target areas, a magnet hall, the proton accelerator cave, the two electron accelerator caves, and is characterized by the massive concrete shielding surrounding these spaces. The concrete shielding varies in thickness from 7 to 24 feet. The shielding shown crosshatched is made from movable blocks to provide flexibility in target area arrangements. The shielding will permit personnel to be in one experiment setup area while irradiation is in progress in the adjacent area.

The engineering application requirements for SREL resulted in two unique features not normally found in cyclotron facilities. One is the requirement of variable energy to partially simulate the space proton spectra and the other is the requirement to irradiate larger than normal targets. In addition to the 600-Mev external beam, the design of a lower energy beam extraction system will be attempted. If successful, a primary 180-Mev external beam with a flux of at least 10^{11} protons per second will be available. Absorbers will be used to attenuate the primary beams from 600 to 200 Mev and from 180 Mev down to about 70 Mev. Beam fluxes of at least 10^{10} protons per second will be available at the target. A magnetic beam spreading system will permit a continuously variable beam area of 15 cm^2 to 900 cm^2 at the target plane. The proton beam handling system required to transport the beam from the synchrocyclotron to the target areas utilizes a series of quadrupole focusing magnets, bending magnets, and collimators. The system will require approximately 2,000 kva of electrical power.

The beam handling system for the electron accelerators will permit target electron irradiation in the cave with the accelerators or will transport the beam to a nearby target area where experiments will be conducted using combined electron and proton beams.

A mobile evacuated target chamber will be provided which will be a right circular cylinder 5 feet in diameter by 3 feet high with a vacuum capability of 10^{-9} torr. In this chamber the combined effects of radiation, pressure, and temperature can be studied.

Figure 8 is a section view of the experimental building through the cyclotron cave. It shows the headroom for the crane and the utility tunnel. Details of the overhead shielding in the cyclotron cave are pictured. Overhead shielding will be required for all shielded areas to minimize the background radiation in the target areas as well as to provide protection for personnel in other building areas.

The experimental building will be designed with provisions to enable the addition of future target areas adjacent to the magnet hall and the cyclotron cave to fully exploit the capabilities of the accelerators.

PROPOSED USE OF SREL

The success of the NASA space exploration programs depends to a great extent on NASA's ability to determine the effects of, and the corrective measures required to minimize the hazards of particle radiation encountered in space flights. The technology gained from the contemplated research programs for the Space Radiation Effects Laboratory will make vital contributions toward solving these problems. Of prime importance is the fact that months and years of space travel can be simulated in the facility in hours and weeks. The effects of a wide range of energy and intensities levels can be accurately determined. Transient and permanent effects can be more easily separated. Proton and electron radiation effects in combination with other space parameters, such as pressure and temperature, can be investigated. In addition the facility will be used to upgrade the educational level of people working in the radiation field and by doing so improve NASA's rate of progress in handling these problems.

RESEARCH PROGRAMS

A broad radiation effects program has been outlined to study radiation effects on critical items which comprise space vehicles. The more prominent programs, some of which are already underway, are in the following areas: materials for rigid and inflatable vehicles; shielding including electrostatic, electromagnetic, and bulk methods; electronic devices, assemblies, subassemblies and their constituent materials; ablation and heat balance coatings; physiological instrumentation and life support systems; and radiation sensors including design, development, testing, and calibration.

OPERATION OF LABORATORY

The tentative operational plan for the SREL provides for William and Mary, the University of Virginia, and Virginia Polytechnical Institute organized as a partnership called The Virginia Associated Research Center (VARC), to supply the operational staff for SREL. Both NASA and people from the three schools will design research programs and construct the associated equipment. The VARC operational people will then in turn collect the data as directed and return it to the experiment designer for analysis and workup. The participating universities of VARC will also establish a basic physics research program sponsored by government or industry grants, or self-initiated. Other institutions requiring a facility with high-energy capability for basic research will deal directly with VARC. The Langley Research Center will conduct the engineering, applications, and basic research phases associated with the space environment. Other NASA Laboratories, government agencies, and industry under NASA contract will deal directly with the Langley Research Center.

With this plan it is hoped that many of the problems now associated with outer space radiation may be either minimized or eliminated.

CONCLUDING REMARKS

The Space Radiation Effects Laboratory will be located in the city of Newport News, Virginia on state route 143 a few miles south of the Patrick Henry Airport. It will be about 10 miles from the Langley Research Center on a 100-acre site. As previously stated, the primary purpose of SREL is to provide a facility to study the effects of the space radiation environment on space vehicle systems. As the project has now evolved, the Laboratory will serve a dual function. In one capacity it will support an engineering program aimed at increasing the reliability and safety of spacecraft and missions. In the other, it will provide our universities and colleges with the instruments by which they can conduct basic research in high-energy physics as well as expanding their graduate program in this field. Thus, by providing a facility whereby both these endeavors can be conducted concurrently, two vital needs are simultaneously fulfilled.

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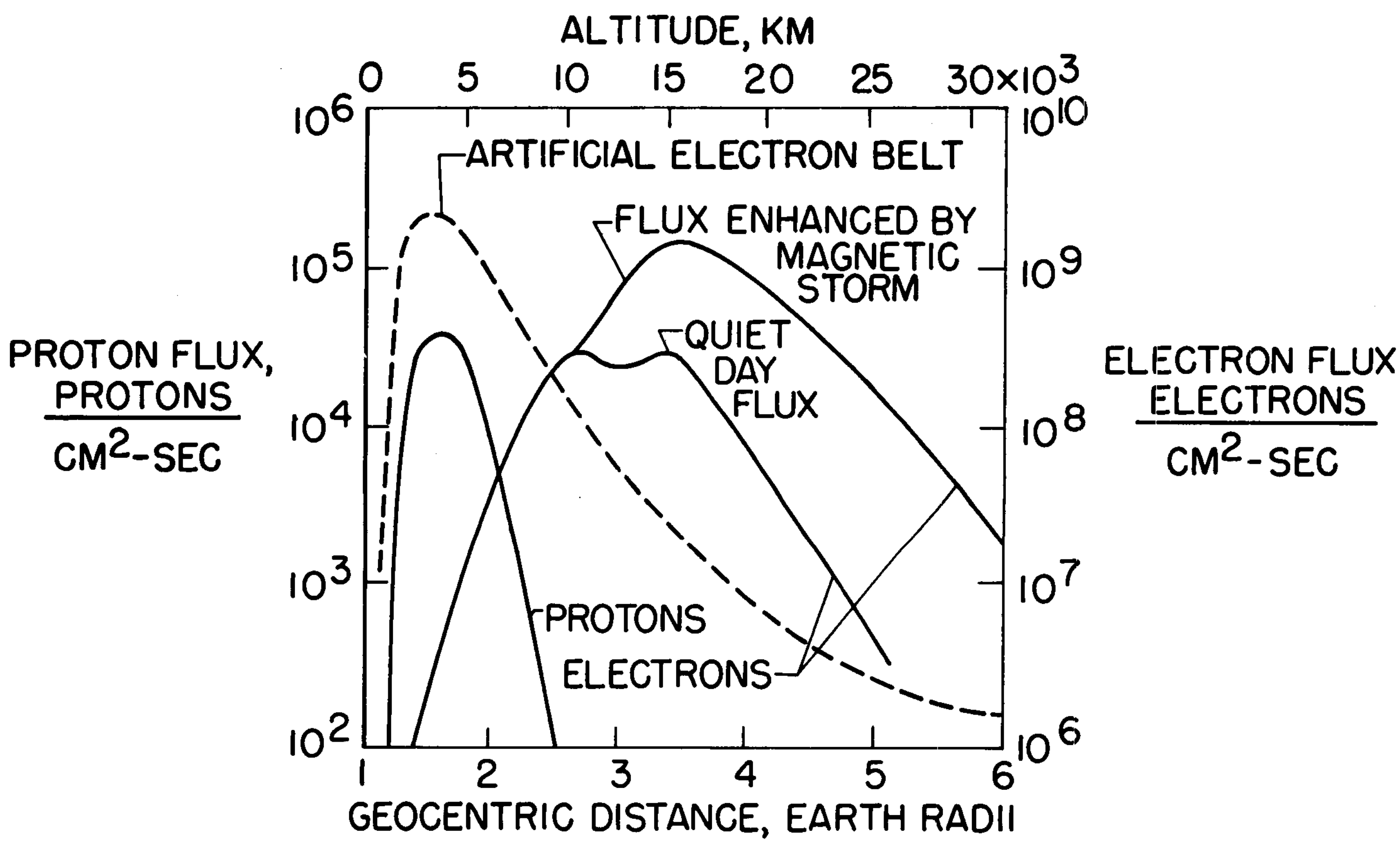

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Figure 1.- Manmade electron belt shown relative to the existing electron and proton distributions. (From ref. 3.) The approximate variation of flux with geocentric distance and altitude in the plane of the geomagnetic equator is depicted.

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Figure 2.- Architects' perspective rendering of the Space Radiation Effects Laboratory.

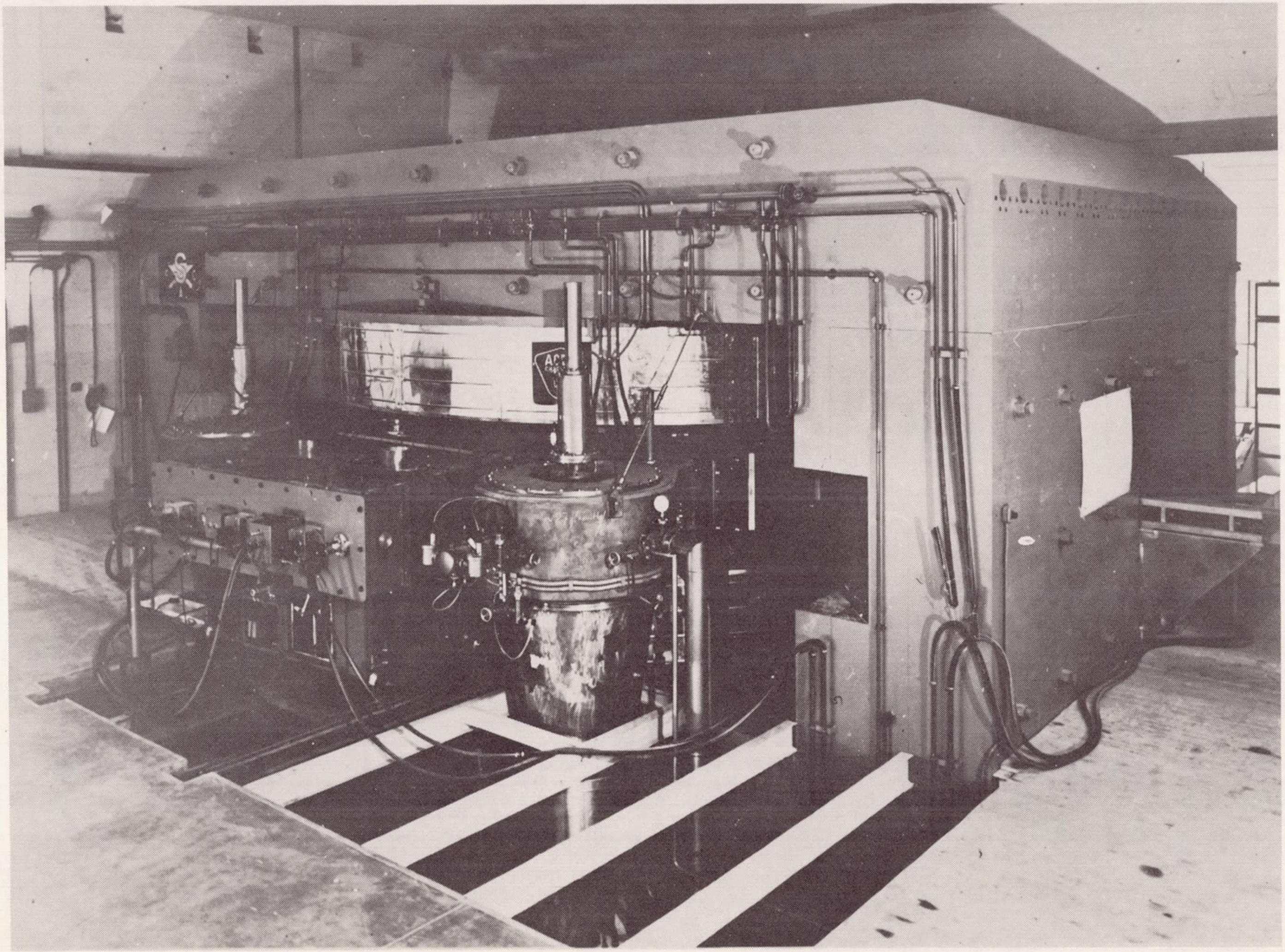

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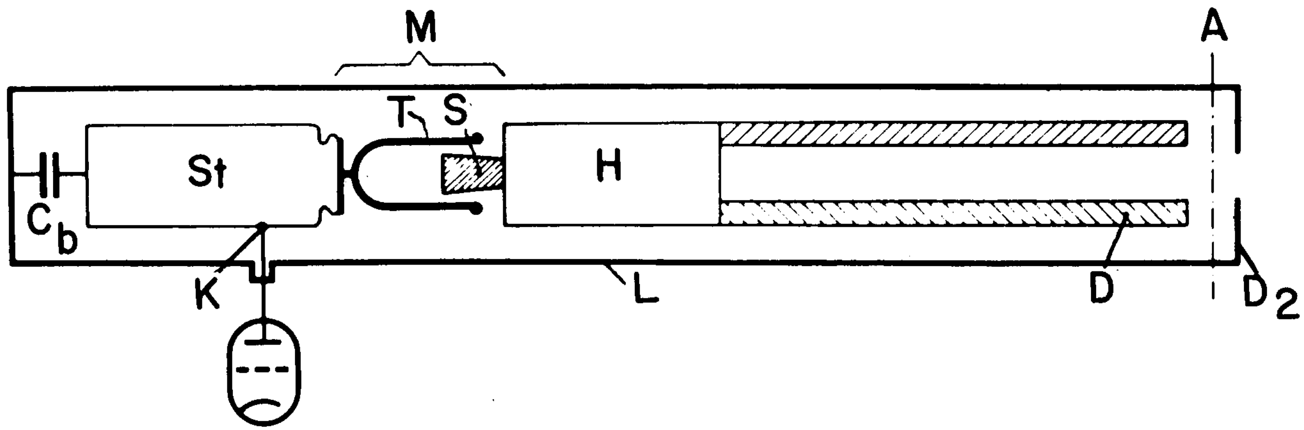
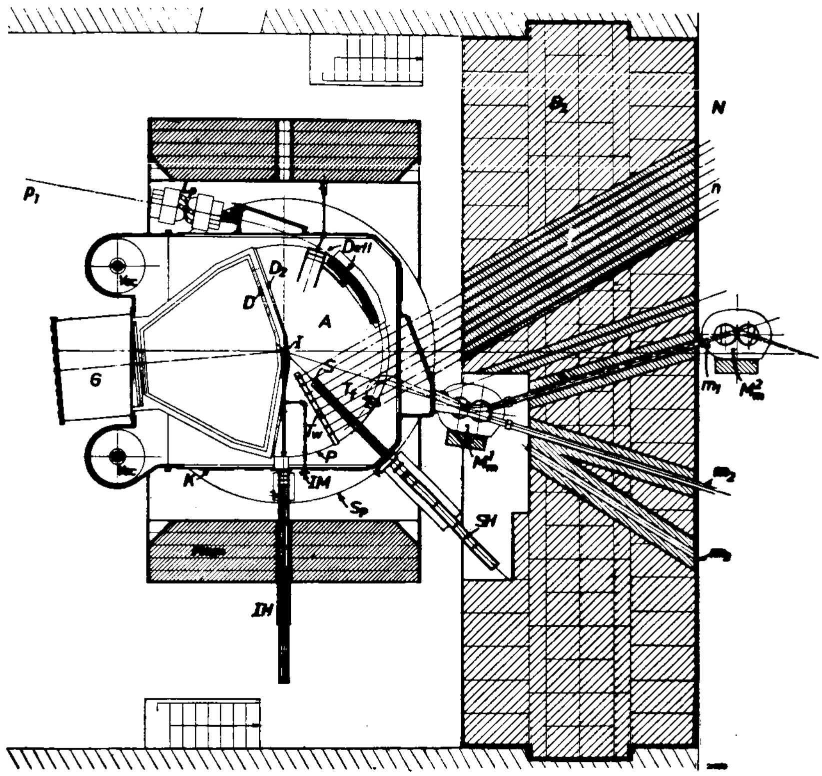
Figure 3.- CERN 600-mev synchrocyclotron.



A center line of the cyclotron. D dee. D_2 dummy dee. H stem of dee. M modulator, with tuning fork T and stator S. St "stub" (end section of transmission line). L outer conductor of transmission line. K coupling to anode of oscillating tube. C_b capacitor giving RF connection of stub to outer conductor.

Figure 4.- Schematic of the CERN synchrocyclotron radio-frequency system. NASA



A accelerating space in the vacuum chamber K. D dee. D_2 dummy dee. I ion source attached to arm IH. T_W eight "flip targets," which can be set upright for producing neutrons. S probe target fitted to arm SH. Defl magnetic channel for extracting the protons from the accelerating chamber. T_f Fermi trolley, i.e., universal target for producing mesons. Magn yoke of cyclotron magnet. P magnet pole. S_p energizing coil. Vac pumps. G radio-frequency source and tuning-fork modulator.

Figure 5.- Section, CERN 600-mev synchrocyclotron. NASA

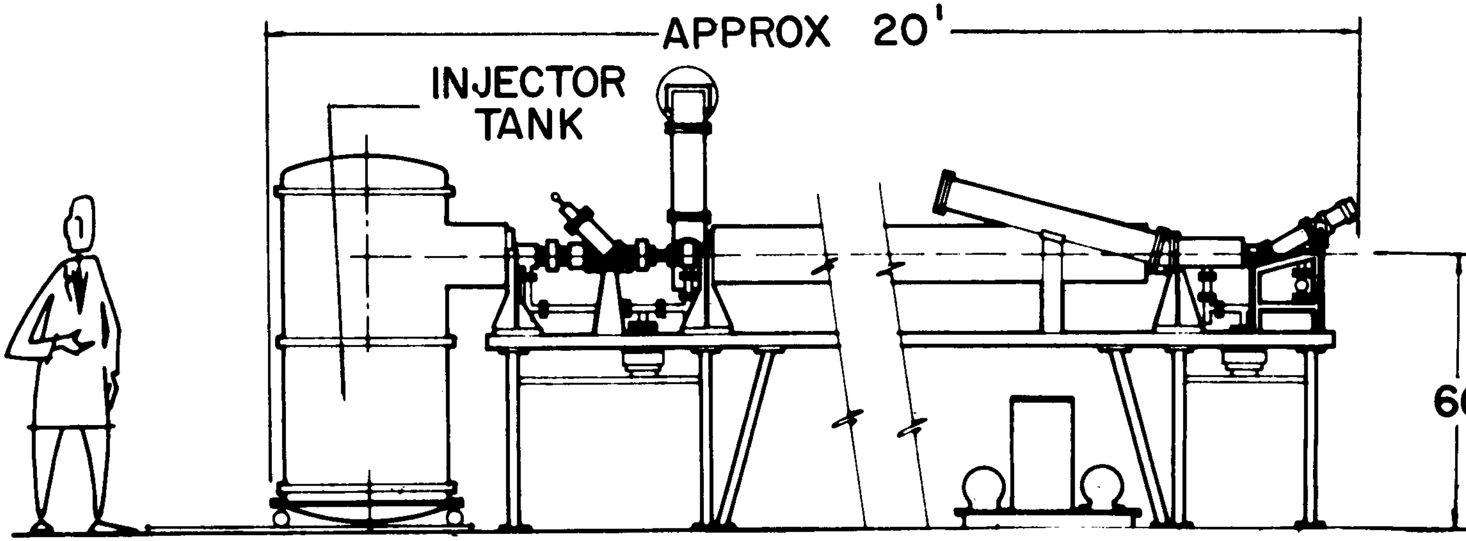


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Figure 6.- Side view of a 10-mev electron linac.

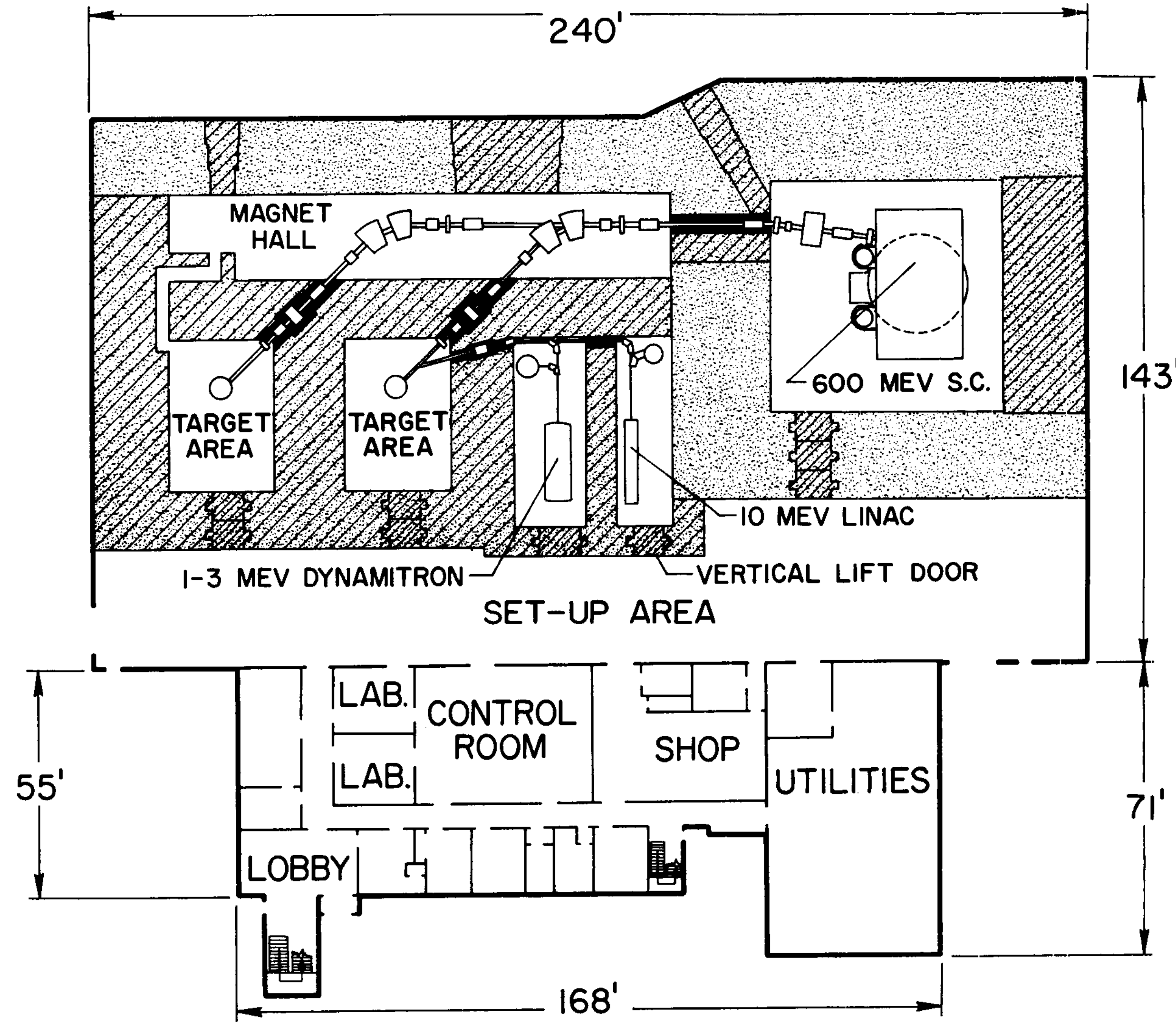

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Figure 7.- Plan of the Space Radiation Effects Laboratory.

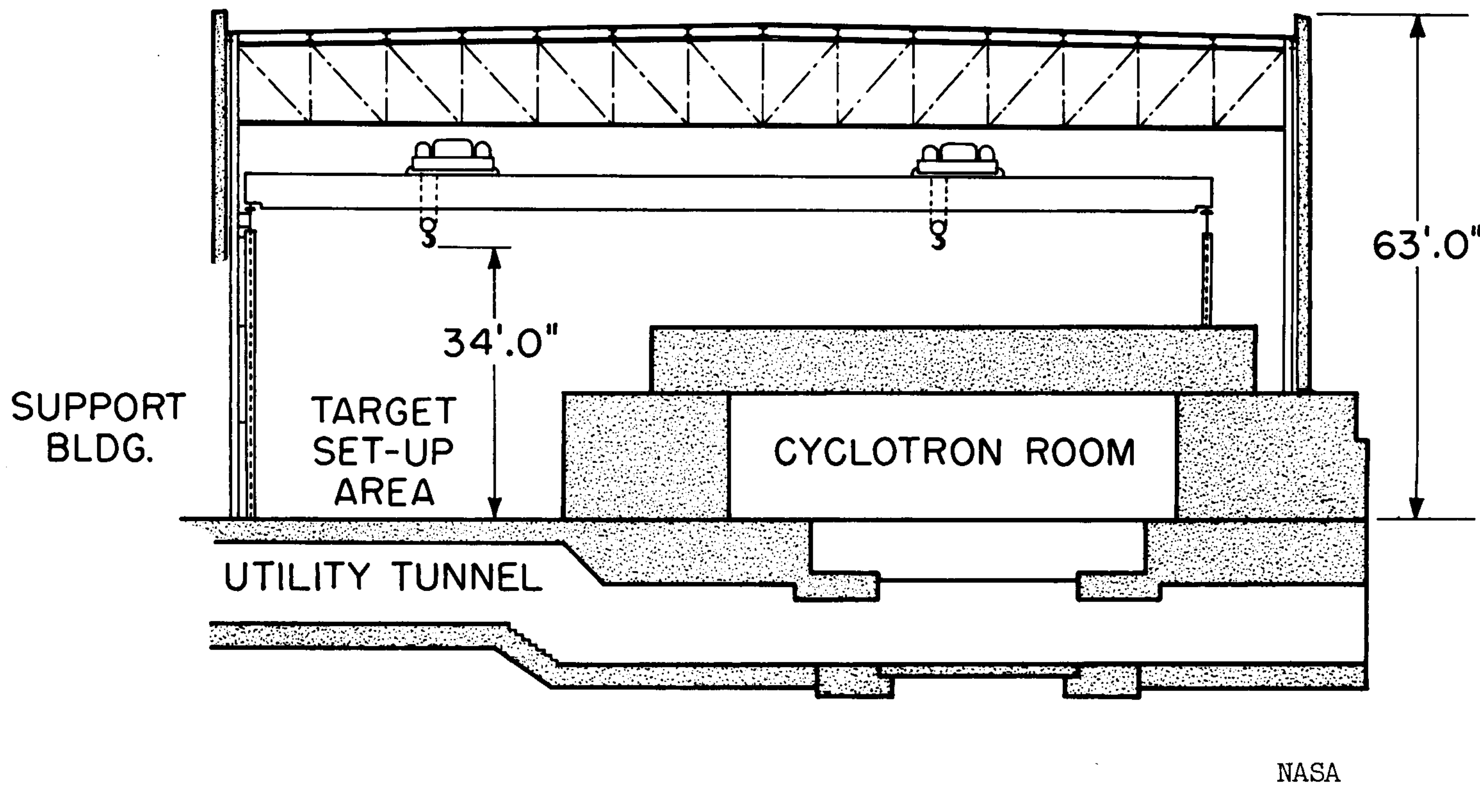

Figure 8.- Section, experimental building.

NASA-Langley, 1963