NASA SPACE RADIATION EFFECTS LABORATORY

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Abstract

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Space particulate radiation from the Van Allen belts, and from cosmic and manmade sources have energies and fluxes which have produced and are capable of producing damage in matter and living organisms which comprise space mission payloads. Laboratories in space for the study of radiation effects are not available. NASA, Langley Research Center, Virginia has proposed a ground based Space Radiation Effects Laboratory which simulates most of the particulate energy spectrum found in space and can be used in an effective, accelerated, radiation research program by means of which deleterious radiation effects can be minimized or eliminated. To achieve these results in a minimum time, a 600-Mev, proton, synchrocyclotron of proven design with variable energy and variable external beam size, as well as a 1 to 30 Mev electron accelerator with the same capabilities have been incorporated into the proposed facility. Although these devices will be used as engineering tools, provision has been made to maintain the basic research capabilities of these accelerators. This will provide three Virginia institutions of higher learning, who will operate the laboratory jointly with the Langley Research Center, with the instruments necessary to conduct a basic research program. The plan of the proposed test areas reflect the latest advances in the state of the art as it pertains to both the engineering and basic experimental requirements in flexibility, radiation background levels, shielding, and isolation. NASA, Langley Research Center, Virginia, has been engaged in particulate radiation effects research in materials, components, dosimetry, devices, and instrumentation used in space missions. These efforts have been handicapped by the limited availability of time in existing accelerators which are being used for basic physics experiments. The proposed Space Radiation Effects Laboratory will provide the necessary facilities for conducting an expanding radiation effects research program using particulate radiation which simulates the space spectrum.

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Introduction

The Langley Research Center of NASA has had a special interest in the space environment insofar as it influences the design of space vehicle systems. Scientific exploration of space has revealed a number of hostile aspects of the environment. Perhaps the most significant of these is the particulate radiation associated with cosmic rays, solar flares, and that magnetically trapped in the radiation belts. The Langley Research Center has proposed a Space Radiation Effects Laboratory in which the particulate space radiation can be simulated, accelerated testing performed, and fundamental studies made in this problem area.

Particulate Radiation in Space

A brief review of our knowledge of the particulate radiations in space is appropriate and, as cosmic rays are familiar, they are used as a basis of comparison in figure 1.[1] The cosmic ray flux is comprised of approximately 85 percent protons, 13 percent helium nucleii and the remainder, heavy ions.[2] Only the proton spectrum is shown. Although the flux is low, protons from this source attain extreme energies in the Bevs. The upper energy limit has not been determined but there is reason to believe that it is much in excess of 10^6 Bev.

The proton spectra of three solar events are shown with an indication of their time variation. The dotted portions of the curves are extrapolations. Energies of 10 Bev may be attained but flux values for these high energies are very low. Integrated, instantaneous, omnidirectional fluxes down to a few Mev may exceed 10^6 protons/cm^2/sec. The solar event of February 23, 1956 would indicate that both flux and energy decrease with time. It is more commonly believed, however, that the event of November 12, 1960 is the more likely occurrence.[3] For this event, the flux values of the lower energies increase, as those of the higher energies decrease with time.

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[1] Trutz Foelsche, Current Estimates of Radiation Doses in Space, NASA TN D-1267, 1962.

[2] F. B. McDonald, ed., contributed by G. E. Fichtel, D. E. Guss, H. H. Malitson, K. G. McCracken, K. W. Ogilvie, and W. R. Weber, Solar Proton Manual, NASA TR R.

[3] George J. Jacobs, ed. (With Appendix A by J. R. Winckler), Proceedings of Conference on Radiation Problems in Manned Space Flight, NASA TN D-588, 1960.

The protons trapped in the inner radiation belt have omnidirectional fluxes ranging from over 10^4 protons/cm^2/sec at energies greater than 40 Mev to fluxes of the order of 10^3 protons/cm^2/sec at energies greater than 550 Mev.

It is assumed that the electron fission energy spectrum shown in figure 2 would be obtained for manmade detonations of nuclear devices. The spectrum[4] is expressed in relative differential values. If the spectrum is integrated and normalized it yields the following results: 55 percent of the electrons have energies $\leqq 1$ Mev and 91 percent of the electrons have energies $\leqq 3$ Mev. The maximum electron energy is about 7 Mev.

The recent explosion of a nuclear device produced the electron spectrum of figure 2 and these electrons have been geographically located[5] in the position shown in figure 3. The naturally trapped protons and electrons of the radiation belts as previously reported are also shown and may be used as a basis of comparison. It can be seen that the new manmade belt contributes much of its intensity in the region previously referred to as the inner belt and thus increases the radiation damage problems of low-altitude space missions. The peak intensities of the electrons of this artificial belt equal if not exceed the maxima of the natural outer region when the latter's intensities are increased by magnetic storms.

The outer region is seen to be of a transient character and has variations in flux and energy due to solar activity. By far the greatest number of these electrons have energies below 1 Mev.[6] As indicated previously, however, the manmade belt has about 45 percent of its electrons with energies between 1 and 7 Mev. The addition of any manmade trapped electron radiation may pose an even greater hazard than that which is already present from the natural belt electrons.

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[4]R. E. Carter, F. Reines, J. J. Wagner, and M. E. Wyman. Free Antineutrinos Absorption Cross Section. II. Expected Cross Section From Measurements of Fission Fragment Electron Spectrum. Phys. Rev., Vol. 113, No. 1, p. 280-6, January 1, 1959.

[5]Artificial Radiation Belt Discussed in Symposium at Goddard Space Center, W. N. Hess, P. Nakada, Science, Vol. 138, No. 3536, October 5, 1962, pp. 53-54.

[6]B. J. O'Brien, J. A. Van Allen, C. D. Laughlin, and L. A. Frank, Absolute Electron Intensities in the Heart of the Earth's Outer Radiation Zone. Jour. Geophys. Res. (Letter to the Editor), Vol. 67, No. 1, January 1962, pp. 397-403.

A brief summary of our knowledge of particulate radiation in space is given in table I.

TABLE I.- SUMMARY OF THE PROTON AND ELECTRON SPECTRA IN SPACE

PROTON SPECTRA

Low Energy	High Energy
Energy spectra $\leqq$22 Mev as obtained from Explorer XII data: 120 Kev < E < 4.5 Mev Flux (p/cm^2/sec) = 10^7 to 10^9	Energy spectra from 22 Mev to 700 Mev Total flux >2 × 10^4 p/cm^2/sec Intensity can vary by a factor of 2 to 3 with solar activity

ELECTRON SPECTRA

Low Energy	High Energy
Energy spectra <1.6 Mev E > 40 Kev, Flux < 10^8 e/cm^2/sec E > 600 Kev, Flux $\geqq$ 5 × 10^6 e/cm^2/sec	Energy spectra 1.6 < E < 6 Mev Flux ≈ 2 × 10^5 e/cm^2/sec Intensity can vary by a factor of 50 to 100 with solar activity

Electron data obtained from Explorer XII.

SOLAR FLARES

Proton energy approaches 10 Bev. Fluxes vary with maximum values between 10^5 to 10^6 p/cm^2/sec. The greatest intensities occur at the low-energy values.

The proton data are divided into low energy, high energy, and solar flares. The low-energy data were reported at the symposium on the scientific results of Explorer XII, January 1962, by L. R. Davis and J. M. Williamson of the NASA, Goddard Space Flight Center. The low-energy range given was from 120 Kev to 4.5 Mev. This has been extended arbitrarily to 22 Mev, the upper limit for fixed frequency cyclotrons. The integral flux in this range is between 10^7 and 10^9 protons/cm^2/sec.

The high-energy-range data were obtained with Pioneer III and Explorer VII.[7] The low end has been taken from 22 Mev and extends to 700 Mev, the integral flux being greater than 2×10^4 protons/cm^2/sec.

The maximum integral energy flux of the solar flares vary between 10^5 to 10^6 protons/cm^2/sec with energies ranging from Kevs to about 10 Bev. The natural belt electrons have their highest intensities (between 10^8 to 10^9 e/cm^2/sec) at about $2\frac{1}{2}$ to 4 earth radii as measured from the earth's center. The manmade belt electrons have peak intensities greater than 10^9 e/cm^2/sec occurring at about 1.6 earth radii. The energies of both the manmade and naturally occurring electrons extend from a few Kev to 7 Mev.

Concept of the Space Radiation Effects Laboratory

Threshold doses for functional radiation damage[8] are shown for various materials and devices in figure 4. Unfortunately, most of this data is obtained from fission radiation which neither simulates space radiation as regards energy or type of radiation. This information is still useful in that it gives relative orders of magnitude of damaging doses and provides some means for determining the fluxes needed for accelerated space radiation damage studies.

The Langley Research Center in pursuing its research program for the experimental investigation of the effects of particulate radiation on items used in space missions, found, as have other investigators, that very limited beam time is available for engineering research using high-energy proton accelerators. The existing ones are being used almost full time for basic physics research experiments. To overcome this shortcoming without interference with the high-energy physics research effort, LRC, NASA, proposed construction of a Space Radiation Effects Laboratory which would encompass most of the space particulate radiation and which would utilize proton and electron accelerators as engineering tools as well as physics instruments.

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[7]Guido Pizzela, C. E. McIlwain, and J. A. Van Allen, Time Variation of Intensity in the Earth's Inner Radiation Zone, October 1959 through December 1960, Jour. Geophys. Res., Vol. 67, No. 4, April 1962, pp. 1235-1253.

[8]S. N. Lehr, V. J. Tronolone, and P. V. Horton, Equipment Design Considerations for Space Environment, STL/TR-60-0000-09224, Space Tech. Lab, Inc., Sept. 1960.

Since over 90 percent of the space spectrum is below 1 Bev with fluxes less than 10^5 particles/cm^2/sec, and as the needs for the facility are immediate, a survey was made of existing accelerators having energies of this range and external beams which would permit accelerated space simulation for components with volumes of at least a cubic foot. The desire was to duplicate an existing, proven, design having the necessary features for accelerated space simulation, thus saving years of development time. The choice, based on availability, was narrowed to frequency modulated cyclotrons and alternating gradient synchrotrons. The synchrocyclotron design was chosen because its external flux was adequate for our purposes, whereas the external flux of the synchrotron machine was lower by about two orders of magnitude. Considerations of down time, beam extraction and overall proven reliability were additional factors in favor of the synchrocyclotron.

Particle Accelerators

There are four synchrocyclotrons in the world with energies of about 0.6 Bev or greater. The two behind the iron curtain were not considered. The other two are the machine at Berkeley, California (0.76 Bev) and the machine at CERN, Geneva, Switzerland (0.6 Bev). The CERN machine was designed for its stated energy and incorporated the most modern concepts of the day. The Berkeley machine has been redesigned and altered to bring it up from its initial lower energies to its present level and any design improvements of it and other existing accelerators were considered in the design of the CERN machine.[9] Since the CERN machine was the most modern, met our energy and flux requirements, and had a very good operational history, it was our final choice.

CERN Synchrocyclotron

Figure 5 is a photograph of the 600-Mev proton synchrocyclotron at CERN, Geneva, Switzerland. The overall size of the magnet is 36 feet wide by 21.3 feet deep by 20 feet high. It weighs 2500 tons, and is made up of 54 blocks weighing approximately 46 tons each. The height of the beam above the floor level is 4.1 feet and the magnet gap varies between 45 and 35 cm. The coils, which are water cooled, and made of aluminum, are about 25 feet in diameter, weigh about 60 tons, and produce 0.75 megawatt of heat at 1,750 amperes. The maximum radius R of proton path ($n = 0.2$) = 2.27 meters. The magnetic induction at $R = 2.27$ meters is 1.79 webers/meters^2; and at $R = 0$, the magnetic

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[9] Bengt Hedin, Design of CERN Synchro-Cyclotron Magnet, CERN 55-5, Synchro-Cyclotron Division, January 14, 1955.

induction is 1.88 webers/meter^2. The vacuum chamber and connections are made of welded stainless steel and have a volume of 23 cubic meters. This is pumped down to about 10^{-6} torr using two oil diffusion and three roughing pumps.[10]

The radio frequency system uses a water-cooled tuning fork modulator which modulates the r-f frequency between 29 and 16.5 megacycles at 55 cps.[10]

The target systems shown in figure 6, although designed basically for high-energy physics research, lend themselves readily to engineering. There are eight internal flip targets to produce neutrons at radii corresponding to energies from 110 to 600 Mev. Negative mesons are obtained by use of a suitable target on a Fermi trolley. The external proton beam is obtained by means of a magnetic channel with suitable extraction devices and is brought to focus in a beam area of 15 cm^2. The external current is about 0.3 microamp ($\approx 10^{11}$-10^{12} protons/cm^2/sec).

For the SREL, the CERN accelerator and external beam will be modified to produce variable energy and beam area. As proposed, the proton energy variation will be from 600 Mev down to as low as 100 Mev and capabilities will exist for spreading the beam from 15 cm^2 to 900 cm^2 at the target area. With the existing external beam, a year in the belt could be simulated in minutes to weeks over these target areas.

Electron Linac

Capability will also exist for accelerating electrons from 1 Mev to 30 Mev with beam current in the range of 150 microamp. These parameters will simulate the electron space environment as well as being useful for basic physics research. The beam area and energy will be variable and the linear accelerator design will be used to attain the requisite energy. Figure 7 is the accelerator section of a 10-Mev electron linac. The 30-Mev linac requires one or two additional accelerator sections.

The layout shown in figure 8 has been proposed for the SREL electron linac. The beam could be used in the linac cave or with the beam handling equipment shown, piped into the adjacent test area.

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[10] W. Genter, M. E. Schmitter, S. Kortleven, F. Bollée, and F. Krienen, The CERN 600 Mev Synchrocyclotron at Geneva, Phillips Technical Review, Vol. 22, 1960/61, No. 5, March 1961.

Plan of the Space Radiation Effects Laboratory

The floor plan of the proposed Space Radiation Effects Laboratory is divided into three major areas as shown in figure 9. These are the test and beam handling area, the test setup area, and the support building. The test and beam handling area consists of two independent target areas, the electron accelerator cave, the proton accelerator cave, and the magnet hall which will contain the beam transport and handling for the proton accelerator. The two target areas are about 30 by 30 feet and these dimensions may be changed by moving the walls. One target area is arranged for receiving a combined electron and proton beam. Sufficient area has been allowed around both accelerators which permits ready access and normal maintenance without the inconvenience of moving shielding. Very large targets may be irradiated by piping the beam directly down the magnet hall. The shielding walls are about 18 feet thick. Overhead shielding is provided to reduce skyshine. In addition the proposed arrangement of the physics test areas will isolate them in a manner to give low radiation background, thus permitting the performance of very refined experiments. The setup area allows test setups and measurements to be made without disturbance prior to installation into the target areas. Large vertical lift doors separate the target area from the setup area. The combined test and setup areas occupy approximately 37,000 square feet.

The support building is conveniently located next to the setup areas. It consists of two floors and a basement which will contain the control room and monitoring system for the accelerators, laboratory space, shop facilities, office space, counting areas, etc. The two floors have an area of about 17,000 square feet.

The section view, figure 10, is taken through the synchrocylotron cave, and shows the relationship of the test setup area with the support building and test areas. Also shown are the head room for the overhead crane and the support and pilings needed around the accelerator.

Research Program

In accord with the objectives of minimizing or eliminating the effects of space radiation on all items which comprise space missions we have outlined a research program part of which is already underway in the following areas: materials, these will include seals, cements, plastics, lubricants, solder, damping materials, phosphors, insulators, etc.; external surfaces such as coatings, transparent materials, and optical components; devices such as magnetic, electronic, and solid state; shielding will cover magnetic as well as various bulk configurations; detection encompasses design, development, testing and calibration of new detecting devices; dosimetry will include experimental studies of radiation levels and doses delivered to different areas and constituents of space vehicles; environmental contamination will deal with the ability of radiation to produce corrosive, noxious, atmospheres, for example, ozone and nitrous oxides in closed ecological systems; sputtering phenomena; activation resulting from radiation; chemistry of elastomers and polymers; spectroscopy for the study of radiation induced changes will include nuclear magnetic resonance, electron paramagnetic resonance, infra-red and visible light, electron microscopy, X-ray techniques, and mass spectroscopy; thin films; experimental validation of theoretical studies; biological research including synergistic effects; health physics; and basic physics research.

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 the Virginia Associates Research Center (VARC), to supply the operational personnel for SREL. The participating universities of VARC will also establish a basic physics research program sponsored by government grant, industry grants, or self-initiated. Other institutions requiring a facility with high-energy capability for basic research can cooperate with VARC. Programs for accelerator improvement and development may also be undertaken by 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 operate through the Langley Research Center.

Concluding Remarks

An architect's rendering of the Space Radiations Effects Laboratory is shown in figure 11. This will be located in the city of Newport News, Virginia within 15 miles of the Langley Research Center, and will lie in a site occupying approximately 100 acres. The principal intent of the Space Radiation Effects Laboratory was to provide a facility in which investigations simulating the space environment could be performed and the results used to increase the reliability and safety of spacecraft and space missions. 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.

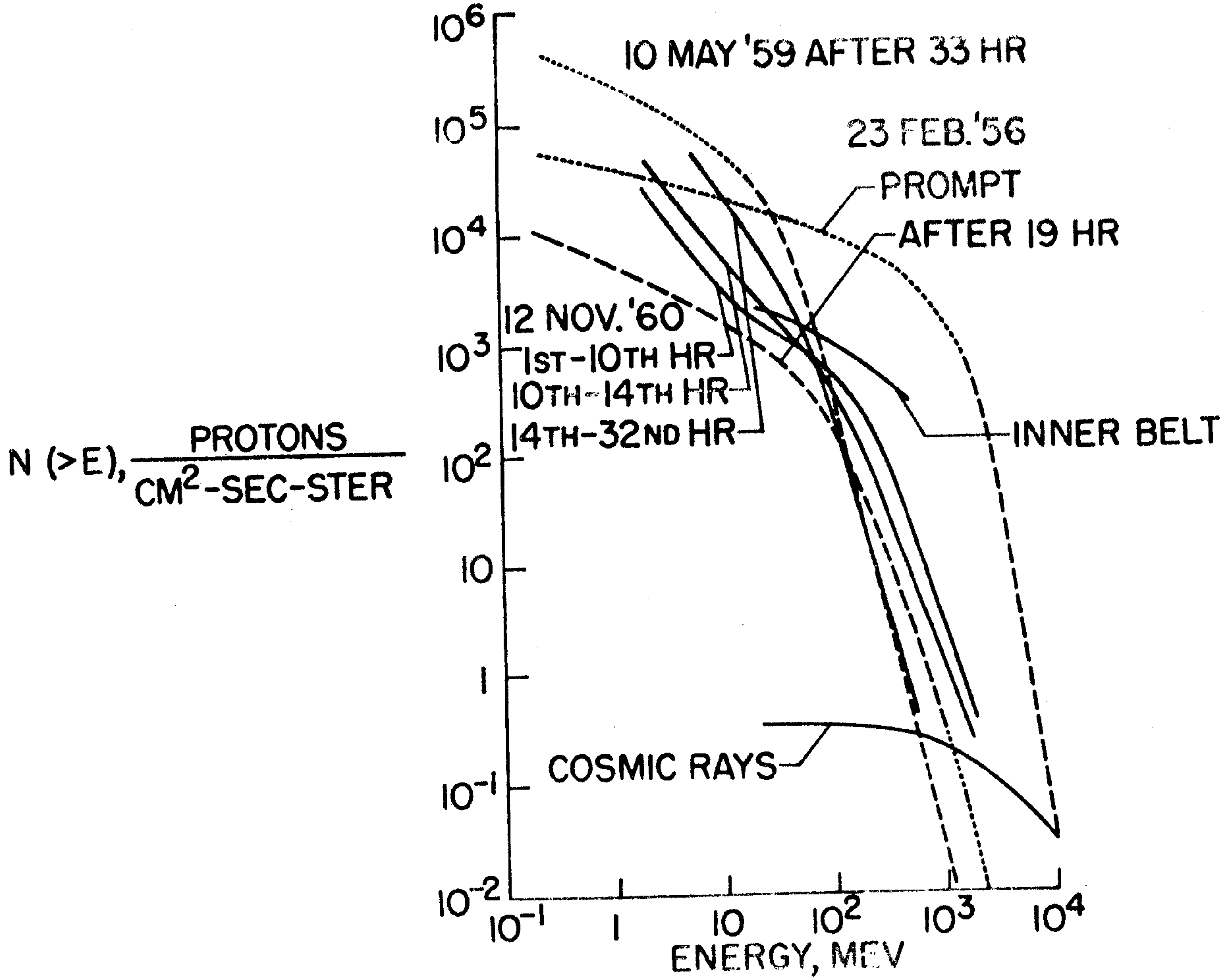

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Figure 1.- The instantaneous integral energy spectra of cosmic rays, solar flare protons, and protons in the inner Van Allen belt. Dotted curves indicate extrapolations of measured data. (From ref. 1.)

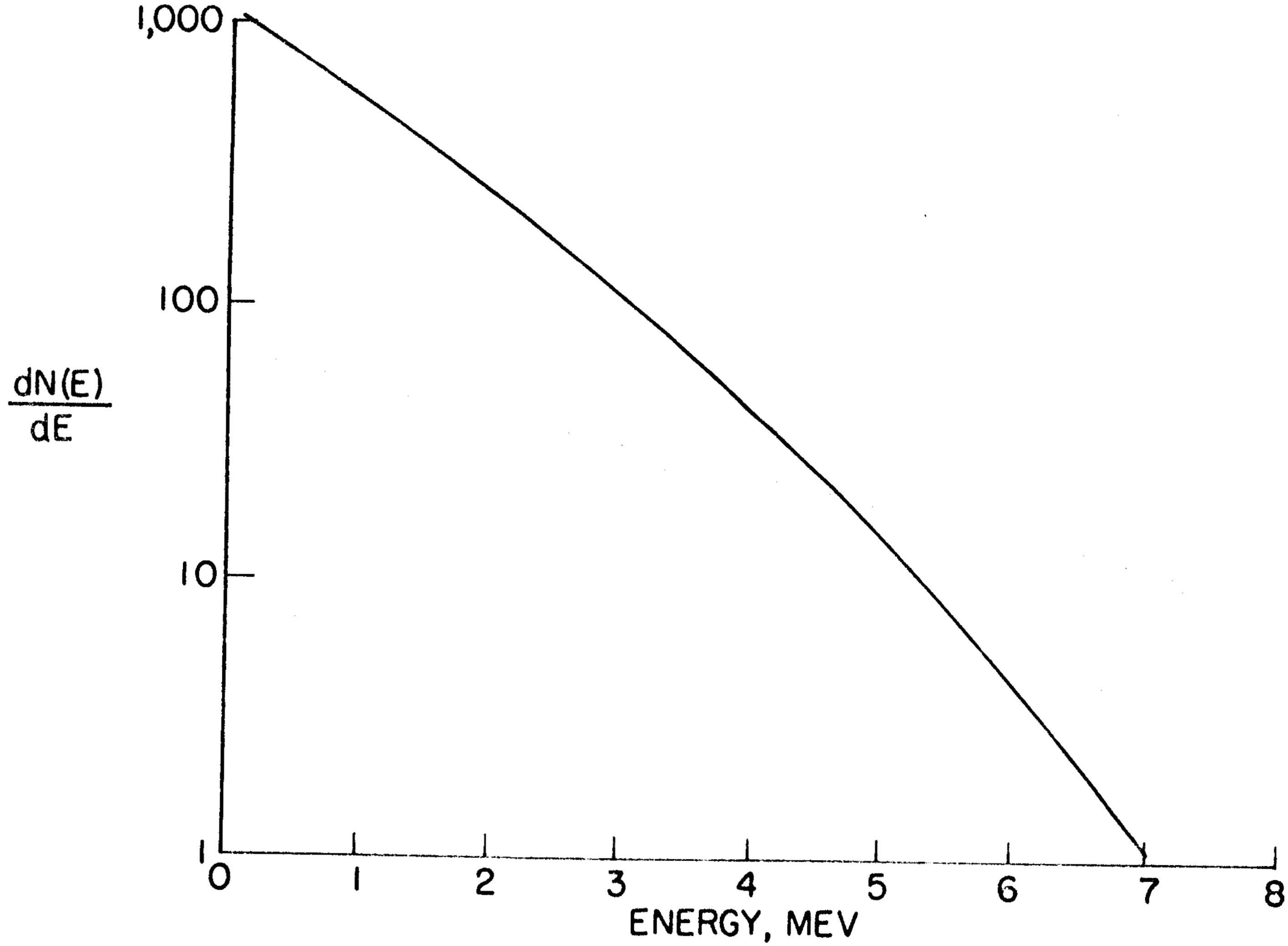

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Figure 2.- Electron fission energy spectrum. (From ref. 4.)

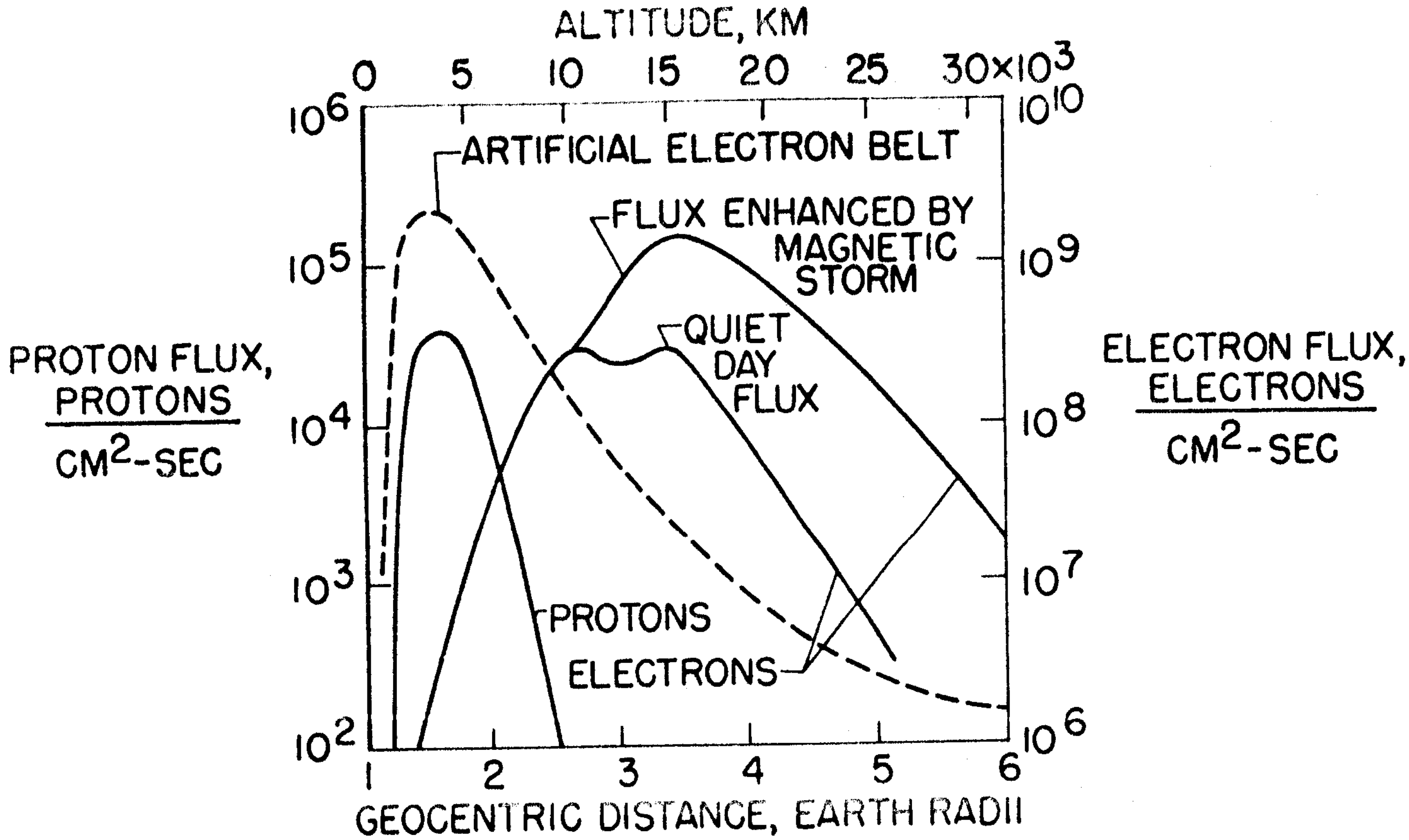

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Figure 3.- Man-made electron belt shown relative to the existing electron and proton distributions. (From ref. 5.) The approximate variation of flux with geocentric distance and altitude in the plane of the geomagnetic equator is depicted.

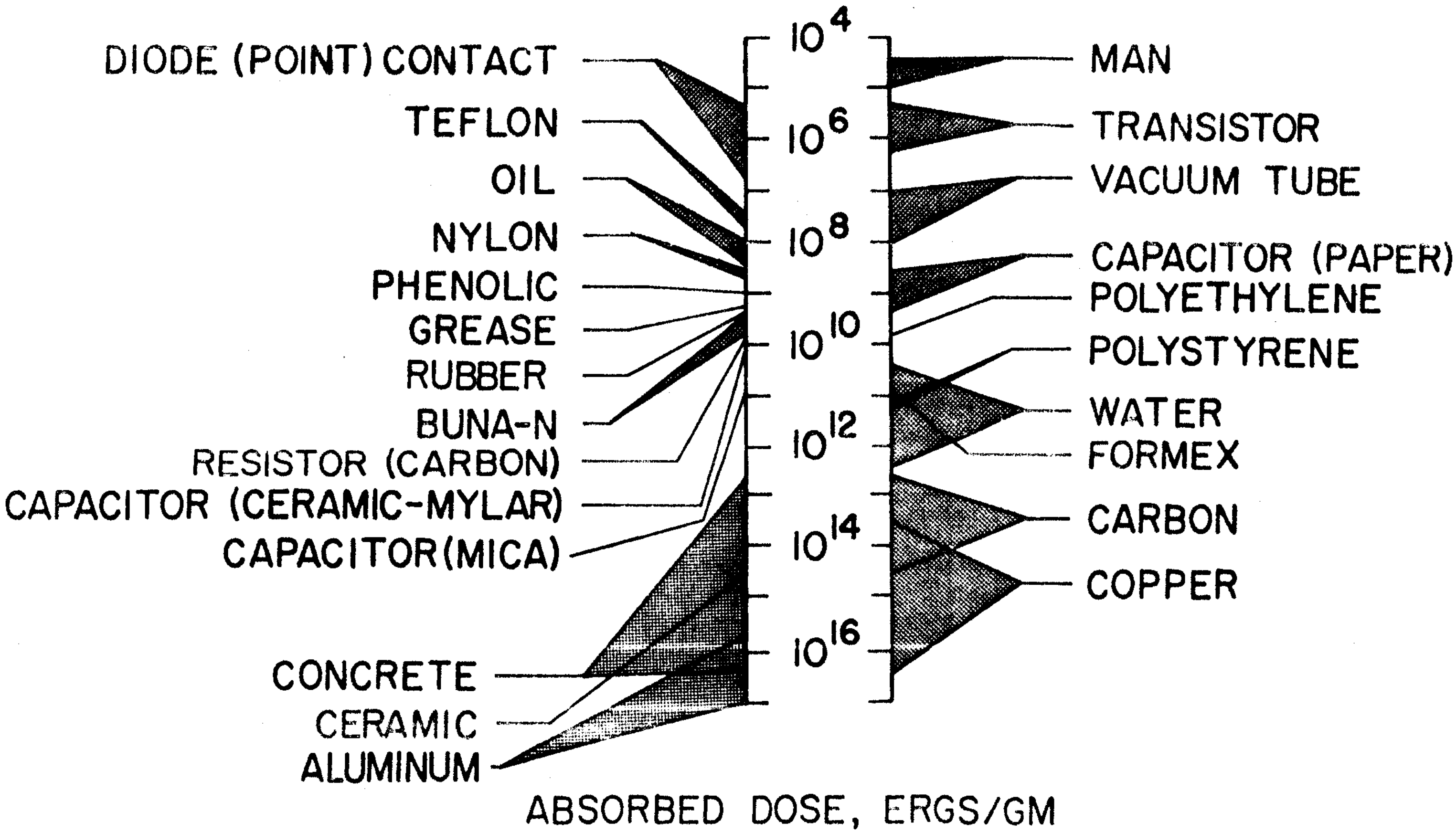

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Figure 4.- Threshold dose for functional radiation damage as given in ref. 8. (Note that the absorbed dose in rads can be obtained by multiplying the dose in ergs/gm by 10^{-2}.)

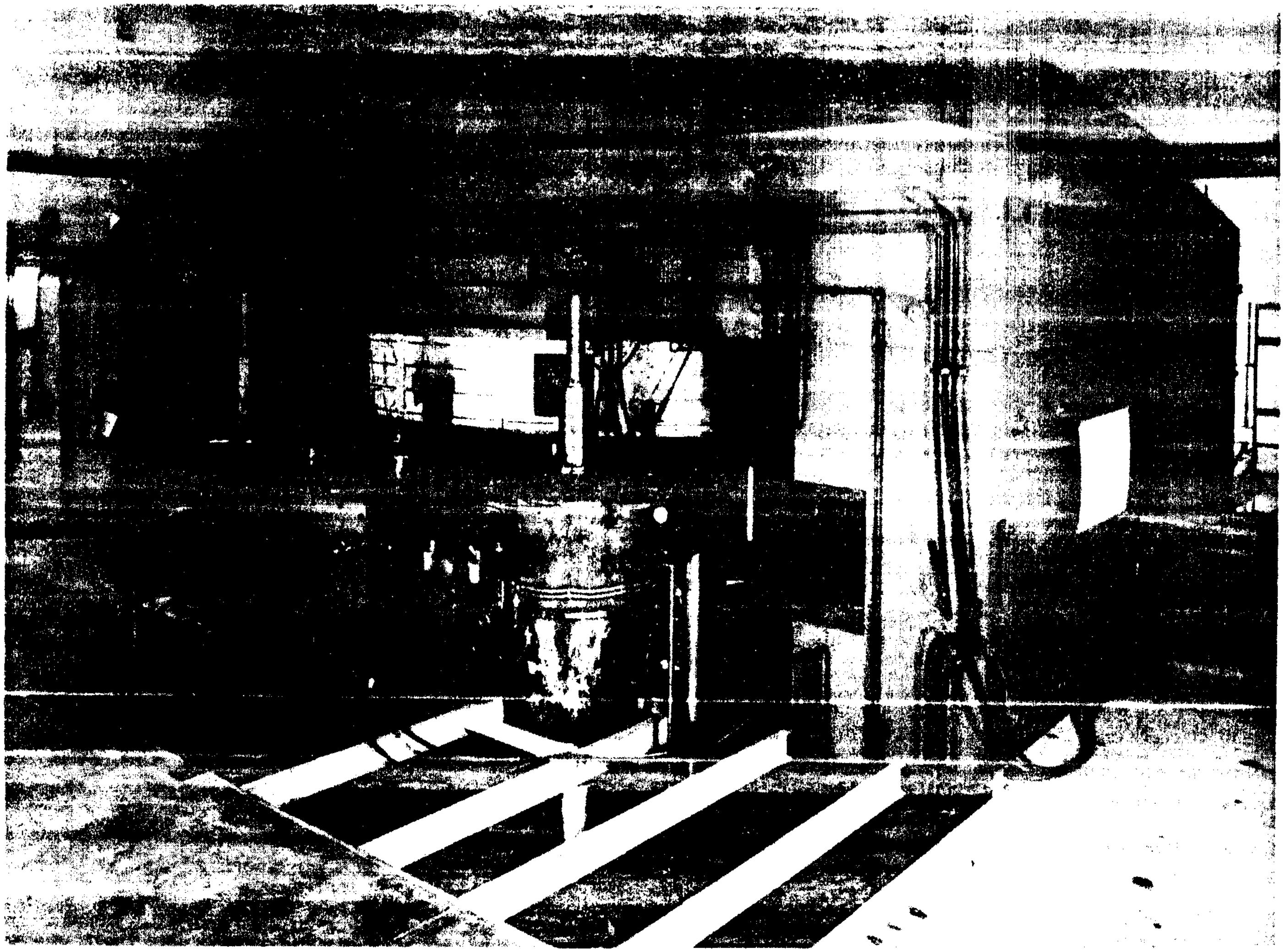

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Figure 5.- CERN 600-MEV Synchrocyclotron.

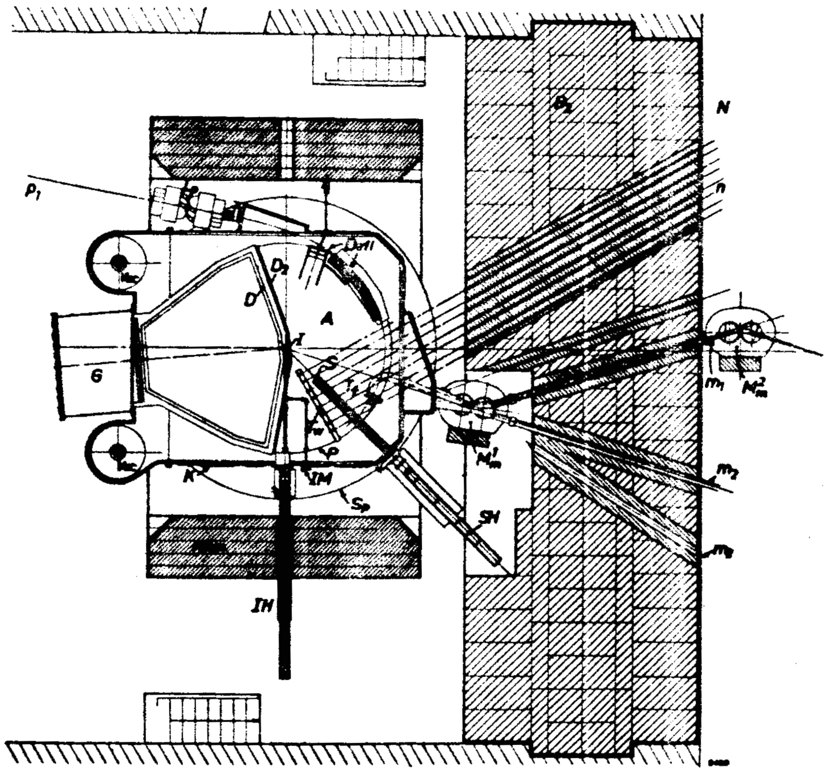

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Figure 6.- Target systems for the CERN 600-MEV synchrocyclotron.

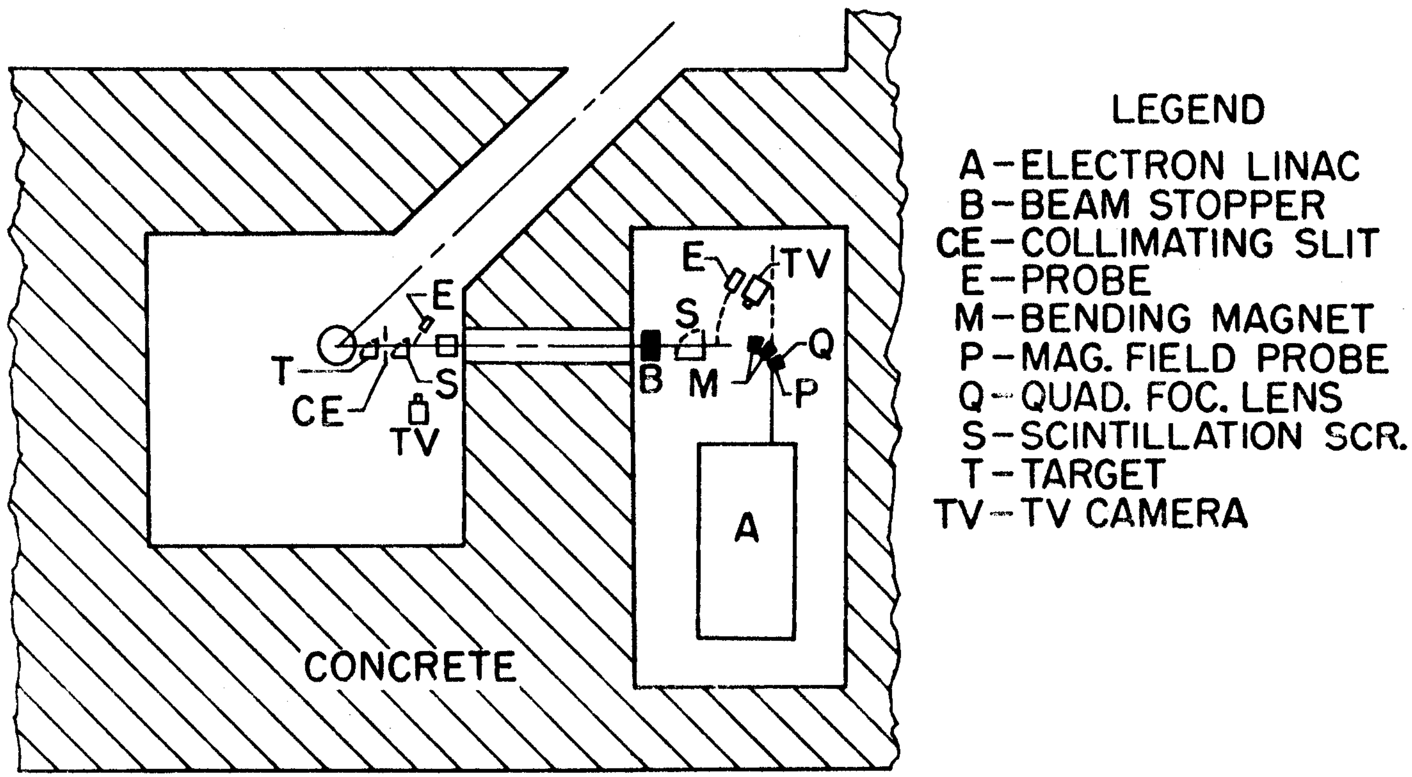

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Figure 8.- Schematic of the electron linac proposed for SREL.

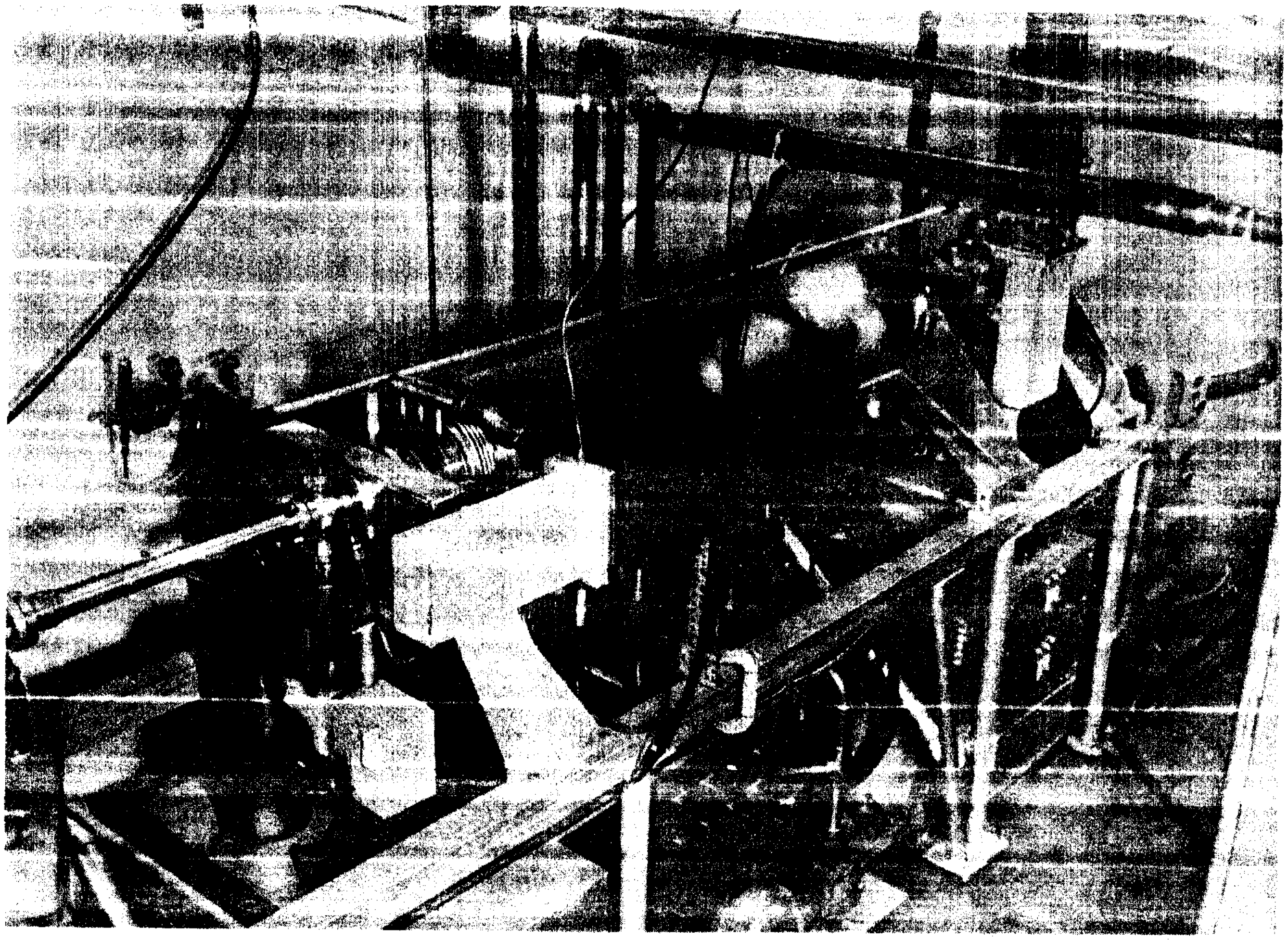

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Figure 7.- Accelerating section of a 10-MEV electron linac.

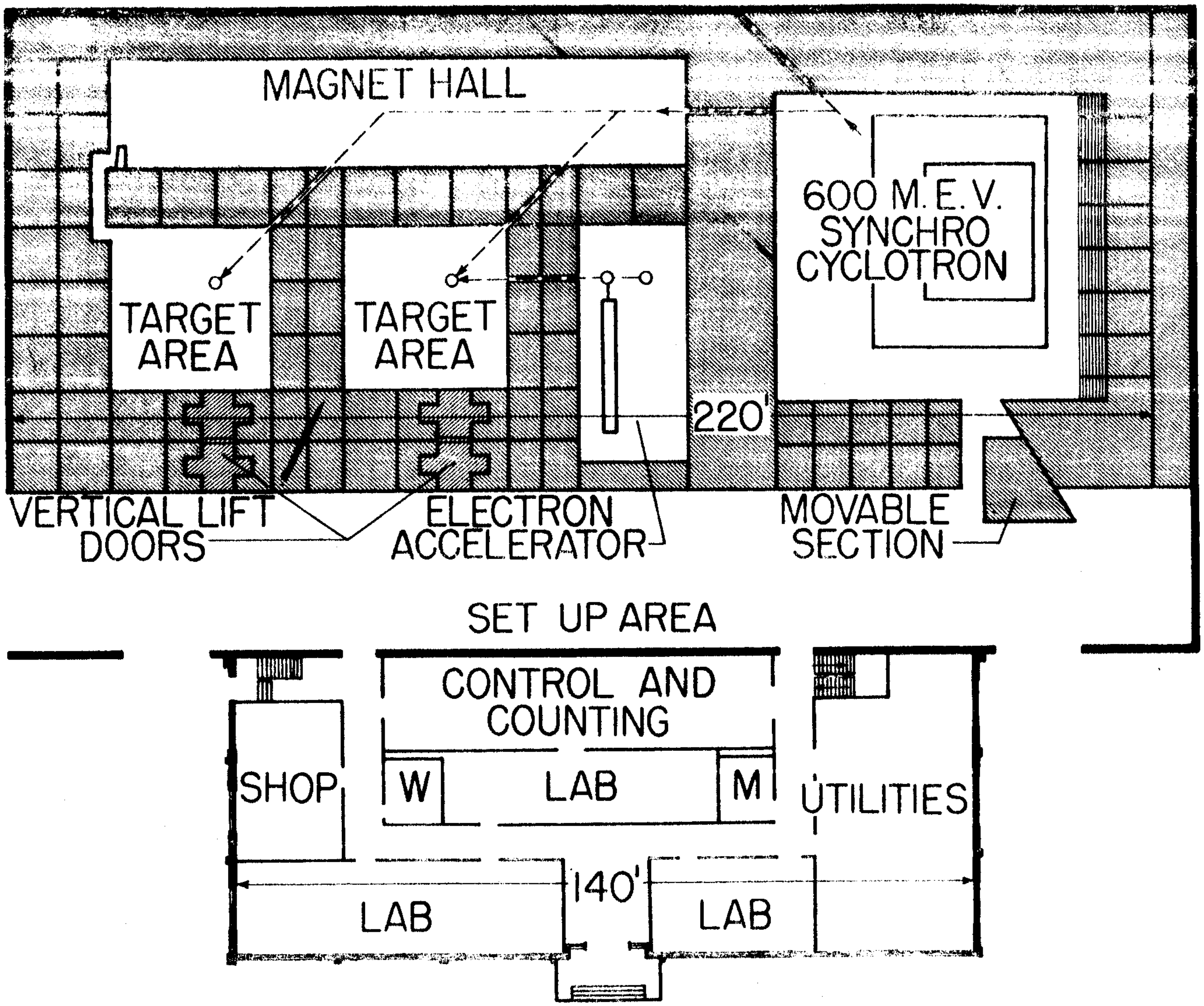

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Figure 9.- Plan view of the Space Radiation Effects Laboratory.

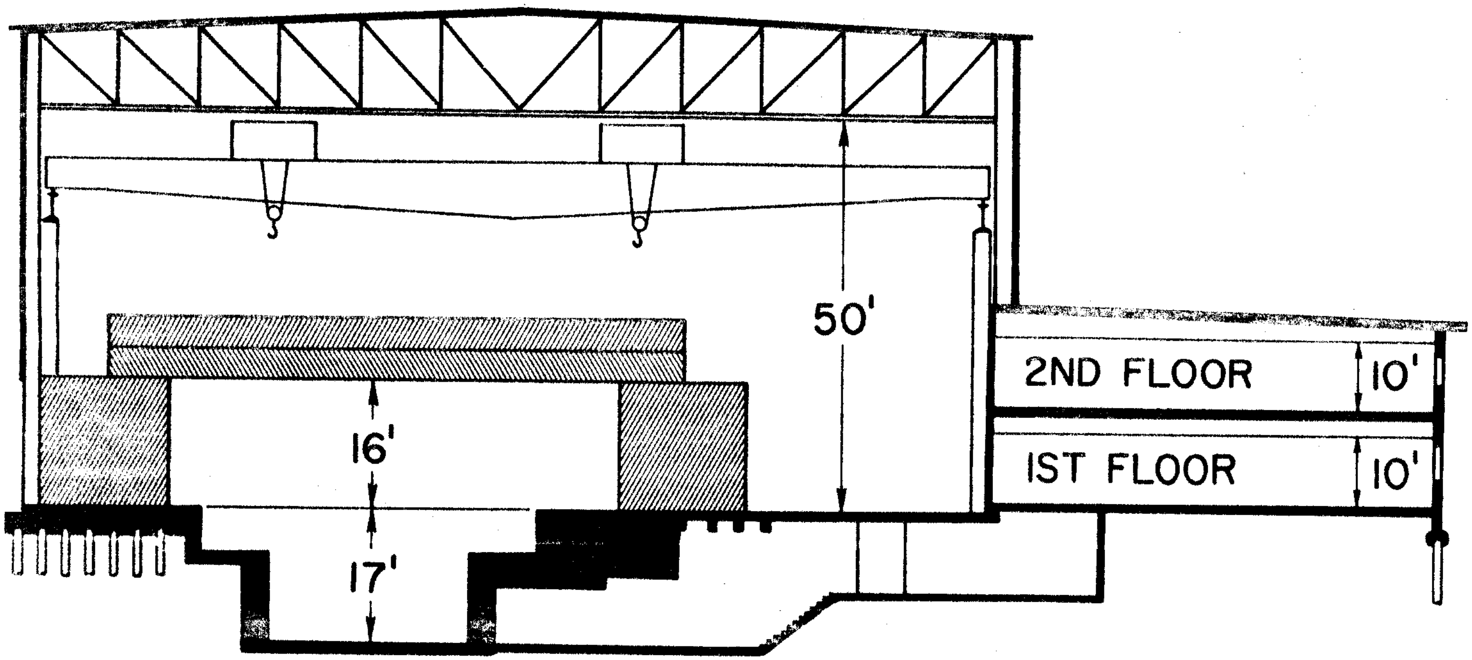

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Figure 10.- Section of the Space Radiation Effects Laboratory taken through the synchrocyclotron cave.

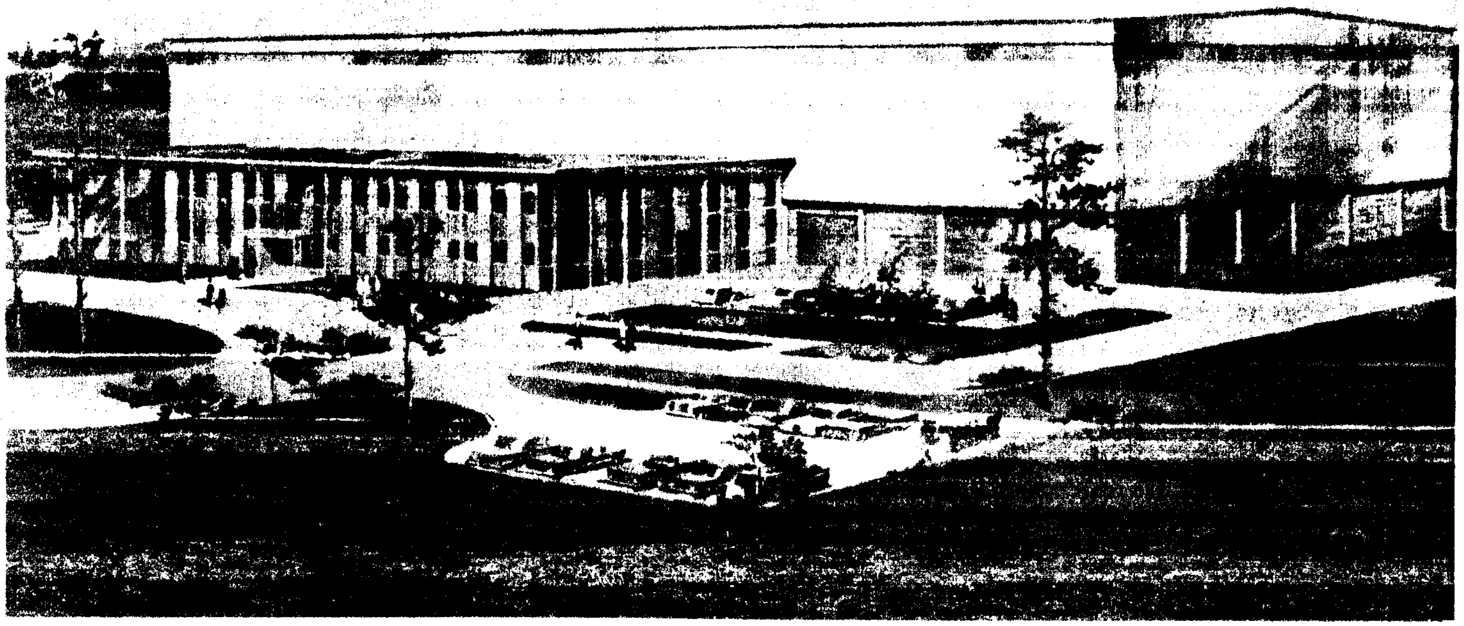

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Figure 11.- Architect's perspective rendering of the Space Radiation Effects Laboratory.