DEC 21 1965

LA-DC-7318 (Full Paper)
CONF-651101-48

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85622

SHIELDING CONSIDERATIONS FOR THE PROPOSED LOS ALAMOS
MESON PHYSICS FACILITY*

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(Sponsored by R. F. Taschek)

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Contract No. W-7405-ENG-36

For presentation at the American Nuclear Society
Meeting in Washington, D. C., November 15-18, 1965.

*Work performed under the auspices of the U. S. Atomic
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Introduction

An 800-MeV, 1 mA average proton linear accelerator has been designed at Los Alamos for the production of intense π meson beams. It is the purpose of this presentation to review briefly some of the design criteria involving the problems of shielding and residual radioactivity as the criteria pertain to the proposed Los Alamos Meson Physics Facility (LAMPF).

General Remarks

In order of increasing energy, the accelerating system for LAMPF is made up of a 750-keV Cockcroft-Walton injector, a 100-MeV Alvarez type linac operating at 202.5 Mc, and a side coupled cavity structure operating at 805 Mc. In Figure 1, which is an artist's rendering of the site structures, the injector building is located at the left. The central structure, approximately 2400 ft in length, contains the main equipment aisle and the accelerator control centers. At the far right is shown the experimental area. In Figure 2, a typical cross-section of the beam channel of the 805-Mc section is shown. As is indicated, the 805-Mc channel is below grade and is covered with compacted earth fill. There are approximately

fifty service shafts like the one on the upper left of Figure 2 to bring rf power, control signals, and utilities to the accelerator structure. The injector, Alvarez structure, and experimental area are essentially on the grade of the local terrain. The shafts will be filled with shielding as is needed to prevent radiation leakage and skyshine. Shown in Figure 3 is a rendering of the experimental area which is serviced by a 165 ft-30 ton bridge crane. Within the experimental area is shown the target area which is constructed entirely of shielding block for maximum experimental flexibility. Permanent hot-cell facilities are shown in the upper left corner of the experimental area and provisions are made to service the target area completely by remote manipulation because of the high levels of residual radioactivity. Figure 4 is a cutaway sketch of the target and hot-cell areas showing the main remote manipulator and its shuttle system for moving between the hot-cell area and the target area.

Shielding Considerations

Some of the principal reasons for choosing a linear accelerator for a meson factory are the minimal beam loss during acceleration, 100% beam extraction, and the confinement of the major radiation problems to the target area. The potential shielding and radiation problems increase along the length of the accelerator and culminate with the distribution, use, and disposal of a proton beam possessing 0.8 megawatt of power.

One approach to the determination of shielding thicknesses is the guaranteeing of the safety of personnel under circumstances

of the "worst possible accident". For LAMPF the most serious accident would be caused by the loss of the full beam (for an indefinite length of time) in the accelerator structure since the target area shielding is designed to reduce the radiation from the stopping of the entire proton beam to accepted tolerance. Unless a time limit is placed on the period of the beam loss, the cost of shielding the 2400-foot length of the accelerator to guarantee complete personnel safety is prohibitive and the accelerator is essentially unserviceable because of residual radiation. Under most circumstances, a beam turn-off time of less than 20 μ sec is expected. Any compromise of complete safety which is reached must be reasonable and becomes a point of operational philosophy. To help decide on a reasonable compromise, one also can approach the shielding problem from the standpoint of personnel safety during maintenance. Restricting consideration to the high-energy portion of the machine, arbitrary maintenance criteria have been chosen which permit personnel access to the accelerator structure for two hours, once a week, two hours after beam turn-off as long as no AEC recommended limit for radiation protection is exceeded. On this basis, the maximum allowable, linearly distributed, average beam spill that can be tolerated for extended periods is 2×10^{-9} amperes/meter. When the shielding is determined for the average beam loss so that the dose rate in the main equipment aisle is 2.5 mrem/hr, the loss of the full beam at full energy produces a dose of 3 rem in one minute in the equipment aisle. At the very worst,

the interlock and safety control system can turn the beam off at the ion source in less than one pulse, 500 μ sec, corresponding to a maximum dose of 25 mrem. There is sufficient redundancy in radiation monitoring both internal and external to the beam channel to make a serious radiation incident extremely improbable in spite of an accelerator failure.

Anticipated types of accelerator failure have been described in various reports^{1,2,3,4} and have been treated in some detail. For example, under conditions described by Visscher and Jakobson¹ a loss of rf power at 200 MeV can cause the loss of most of the beam but the beam will begin to spill at approximately the 400-MeV section of the accelerator. The spill will maximize in the 400 to 500-MeV portion of the accelerator but about one quarter of the beam will reach the end of the accelerator. At energies above about 400 MeV, an rf failure will cause the beam to be lost from the phase stable region for acceleration but the beam will be transported to the end of the accelerator. A more serious type of failure is the loss of a single quadrupole magnet of a doublet system which can lead to the loss of the entire proton beam in the accelerator structure. Even the somewhat less serious loss of a complete doublet focussing magnet can lead to the loss of a large fraction of the beam. Nevertheless, the problem of component failure need not dominate the shielding problems of the accelerator structure, but rather need only be consistent with the problem of average beam spill.

The problem of making a realistic estimate of the average beam spill is difficult and extensive beam dynamics calculations

are continuing at LASL. Jakobson¹ and Visscher,^{1,5} and Gluckstern⁶ have shown the relative adjustment of individual magnetic quadrupole lenses in a given doublet or, to a lesser degree, triplet focussing system to have the most critical mechanical tolerances in the construction of the accelerator. Using the misalignment in lateral position of an individual quadrupole as the dominant error, Visscher⁷ has shown that a change in tolerance from 0.002 inch to 0.001 inch for lateral misalignment can decrease the total beam spill by a factor of at least 10^3 . An average beam spill of 2×10^{-9} amperes/meter for the 805-Mc section of the accelerator is a working allowance of spill for a practical set of electrical and mechanical tolerances including a 0.001-inch tolerance for a lateral misalignment of individual quadrupoles of a doublet magnet.

The shielding requirements for LAMPF are based on experimental data as much as possible and extensive use has been made of such data reported in the literature. The mean free paths for the attenuation of high-energy neutrons in concrete that have been used are presented in the work of Wallace⁸ and in the review article of Lindenbaum.⁹ Most of the existing data on attenuation lengths and build-up factors apply to the forward or beam direction and it has been necessary to devise a means of applying the existing data to shielding in the transverse direction from the proton beam. Alsmiller et al.¹⁰ have calculated the effects as a function of depth of an 800-MeV proton beam incident on a shield and have found that neutrons contribute about 90% of the dose. For the purpose of calculation for LAMPF, no other particles need to be considered. In the

shielding calculation, a revised version¹¹ of the Monte Carlo cascade code of N. Metropolis et al.¹² is used to generate the energy and angular distribution of cascade neutrons from incident nucleons interacting in a given target material. An example of the results of such a computation for 10^5 800-MeV protons incident on thick copper is shown in Figure 5. For ease of display, curves have been drawn to connect the results for the indicated energy and angular intervals. By using the results of the cascade code once to generate the source and a second time for the first interaction of the cascade neutrons in the shield, an energy and angular distribution of high-energy neutrons near the beginning of the shield can be established. It is then possible to use the straight-ahead build-up factors and attenuation lengths to calculate the flux of neutrons external to the shield. The flux of neutrons is normalized to the cosmic-ray energy spectrum of Hess et al.¹³ for the flux to dose conversion. The importance of generating an appropriate input spectrum to the shield can be appreciated by noting the relatively rapid variation in half intensity thickness for the attenuation of neutrons in the 10 MeV to 600 MeV interval in ordinary concrete. As examples, the half-intensity values⁸ for 10 MeV, 100 MeV, and 600 MeV are 3 in., 10 in., and 19 in. respectively. For the beam channel shielding at energies below 400 MeV and for the shielding of the Alvarez structure, the above computational method is being compared with results from the Oak Ridge NTC¹⁴ and O5R¹⁵ codes in the hope of demonstrating significant agreement. The comparison is incomplete at present principally due to the computer time required.

The results of the shielding computations indicate that 25 feet of compacted earth fill are necessary to separate the beam channel from the main equipment aisle during normal operation to reduce the radiation level in the equipment aisle to 2.5 mrem/hr at the high-energy end of the accelerator. With somewhat less certainty, the same calculational methods when applied to the target area indicate a need for the equivalent of 20 feet of magnetite concrete in the transverse direction to the beam and 35 feet in the forward direction. In addition, two feet to three feet of steel are assumed to be used as shielding in the immediate vicinity of each target or beam stop inside the main target area shielding. In actual plans, one wall of the target area is constructed of 10 feet of steel to shorten the pion beam channels. About two feet of ordinary concrete are used outside of the steel to provide attenuation for neutrons below 1 MeV. The radiation and shielding problems of the target area are 10^3 and 10^4 times as great as the problems in the beam channel and any uncertainty in their proper assessment arises in the extrapolation by calculation of experimentally observed attenuation and activation factors. Supplementary shielding is required for individual experiments in the experimental area. Typically, six feet of ordinary concrete is required to attenuate the neutrons from the stopped π^- beams.

Residual Radioactivity

In addition to the residual radioactivity created by the primary proton beam and the cascade particles, a large fraction

of the total residual activity is created by the neutrons evaporated from the excited nuclei left after the cascade processes. An 800-MeV proton has about 90% probability of undergoing an absorption interaction before it is stopped in a thick copper target. For each proton interacting, two cascade and three evaporation neutrons are produced as an average. Thermal neutrons are produced by the eventual thermalization of the evaporation and cascade neutrons by the hydrogen of water in concrete and earth. The total residual activity is calculated using the data which can be found in such compilations as those of Bruninx,¹⁶ Caretto,¹⁷ Jessen et al.,¹⁸ and the Reactor Handbook.¹⁹ The agreement between calculation and the experimental work of Fulmer et al.²⁰ is generally within 20%.

The calculation of residual activity for the maximum allowable beam spill at the high-energy end of the accelerator presumes the use of boron additives in the concrete walls to remove the thermal neutrons. Briefly summarizing more detailed information presented elsewhere,^{20,21} the addition of boron to concrete will suppress the thermal production of Na²⁴ and Mn⁵⁶ in the walls of the beam channel, Ar⁴¹ in the air, and Cu⁶⁴ in the accelerator structure. Serious consideration is also being given to the lining of the target areas with boron-loaded carbon to suppress the thermal activation of target area components.

Conclusion

The importance of the problems of radiation damage and air contamination have not been ignored even though their consideration has been excluded from this brief presentation. A degree of conservatism has been included in the final shielding designs for LAMPF in an attempt to anticipate problems which may be caused by the existing uncertainties in neutron attenuation factors and in the biological effectiveness of radiations from the accelerator, or by factors as yet unknown.

REFERENCES

1. M. Jakobson and W. M. Visscher, Los Alamos Scientific Laboratory Internal Report, unpublished, April, 1964.
2. Los Alamos Scientific Laboratory, A Proposal for a High-Flux Meson Facility, September, 1964.
3. Yale University Design Study Staff, A Final Report on the Design of a Very High Intensity Proton Linear Accelerator as a Meson Factory of 750 MeV, Y-12, October, 1964.
4. H. B. Knowles, "Radiation Hazards Peculiar to a Linear Accelerator Meson Factory," in The First AEC Symposium on Accelerator Radiation Dosimetry and Experience at the Brookhaven National Laboratory, November 3-5, 1965.
5. W. M. Visscher, Los Alamos Scientific Laboratory, "Optimization of Magnetic Lenses for Waveguide Portion of a Proton Linac," in The First National Particle Accelerator Conference, Washington, D. C., March 10-12, 1965, IEEE Trans. on Nucl. Science, Vol. NS-12, No. 3, pp 617-622, June, 1965.
6. R. L. Gluckstern, Yale University, Y-7, unpublished data, January, 1964.
7. W. M. Visscher, Los Alamos Scientific Laboratory, personal communication, July, 1964.
8. R. W. Wallace, "Shielding and Activation Considerations for a Meson Factory," Nucl. Instr. and Methods 18 19: 405 (1962).
9. S. J. Lindenbaum, "Shielding of High Energy Accelerators," in Ann. Rev. of Nucl. Science, Vol. 11, pp 213-258, Annual Reviews Inc., Palo Alto, California, 1961.
10. R. G. Alsmiller, Jr. and J. E. Murphy, Nucleon-Meson Cascade Calculations: Shielding Against an 800 MeV Proton Beam, USAEC Report ORNL-3406, Oak Ridge National Laboratory, February, 1963.

11. S. L. Whetstone, Status of the LASL Monte Carlo Intranuclear Cascade Calculation (1964), USAEC Report LA-3206-MS, Los Alamos Scientific Laboratory, March, 1965.
12. N. Metropolis, R. Bivins, M. Storm, A. Turkevich, J. M. Miller, and G. Friedlander, "Monte Carlo Calculations on Intranuclear Cascades," Phys. Rev. 110: 185 (1958), Phys. Rev. 110: 204 (1958).
13. W. N. Hess, H. W. Patterson, R. Wallace, and E. L. Chupp, The Cosmic-Ray Neutron Energy Spectrum, USAEC Report UCRL-8628, Lawrence Radiation Laboratory, February, 1959.
14. W. E. Kinney, The Nucleon Transport Code, NTC, USAEC Report ORNL-3610, Oak Ridge National Laboratory, August, 1964.
15. R. R. Coveyou, J. G. Sullivan, and H. P. Carter, O5R: A General Purpose Monte Carlo Neutron Transport Code, USAEC Report ORNL-3622, Oak Ridge National Laboratory, 1965.
16. E. Bruninx, High Energy Nuclear Cross-Sections, Parts I, II, and III, C.E.R.N. Reports CERN 61-1, January, 1961; CERN 62-9, February, 1962; and CERN 64-17, March, 1964.
17. A. A. Caretto, Jr., Literature Survey of Nucleon 2 Nucleon Reaction Cross-Sections at Energies above 100 MeV, Report NYO 10693, July, 1964.
18. P. Jessen, M. Bormann, F. Dreyer, and H. Neuert, Compilation of Experimental Excitation Functions of Some Fast Neutron Reactions up to 20 MeV, Institut fur Experimentalphysik, Hamburg-Germany, January, 1965. NP-15018 is a facimile report reproduced by the USAEC.
19. C. R. Tipton, Jr. (Ed.), Reactor Handbook, Vol. I Materials, 2nd ed., pp 1023-1149, Interscience Publishers, Inc., New York, 1960.
20. C. B. Fulmer, K. S. Toth, M. Barbier, "Residual Radiation Studies for Meson Factories," Nucl. Instr. Methods, 31: 45-54 (1964).

21. 200 BeV Accelerator Design Study, USAEC Report UCRL-16000, Lawrence Radiation Laboratory, June, 1965.
22. D. R. F. Cochran, H. I. Israel, D. W. Mueller, "The Radiation and Shielding Design Factors for the Los Alamos Meson Physics Facility," in The First AEC Symposium on Accelerator Radiation Dosimetry and Experience at the Brookhaven National Laboratory, November 3-5, 1965.

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Figure 1 Artist's Rendering of the Proposed Los Alamos Meson
Physics Facility

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Figure 2 Cross-Section of Beam Channel and Main Equipment Aisle - 805-Mc Section

BEAM CHANNEL & EQUIPMENT AISLE

Figure 3 Rendering of Target and Experimental Areas

LOS ALAMOS MESON PHYSICS FACILITY

Figure 4
Rendering of Target Area and Remote Handling Facility

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LOS ALAMOS MESON PHYSICS FACILITY
CONCEPT TARGET AREA EQUIPMENT
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Figure 5 Calculated Energy and Angular Distribution of Cascade Neutrons from 10^5 800-MeV Protons Incident on Thick Copper