Improved radiation shielding

K.D. Finkelstein (CHESS) and
S.W. Gray (Cornell Laboratory for Nuclear Studies)

The photo shows a cut away section from an early test sample of heavy concrete. The mix was designed and tested at Cornell. The fine ore and coarse pellets are highly enriched with iron and replace sand and gravel to improve neutron shielding. The pellets are an inexpensive substitute (made for the production of steel) for high-grade, natural iron ore that is commonly used to produce this type of concrete.

The radiation shielding walls which separate the CESR tunnel and CHESS west user area were designed and installed when CHESS was first built. Since that time, particle beam currents and injection rates have steadily increased. Data collected during routine radiation monitoring and from surveys conducted in machine studies designed to anticipate radiation levels after the CESR upgrade, suggests the need for improvements in the shielding of the tunnel walls.

In a cooperative effort CHESS and LNS (Laboratory for Nuclear Science) have studied sources in CESR that produce radiation in the user areas. The group has been responsible for the development and realization of new shielding designs. The result of this work, the new tunnel walls you will see on your next visit to CHESS, will provide a level of radiation protection from 20 to >100 times what was previously available.

An interesting fact of life at our high energy accelerator is that a major contribution to the environmental radiation is not from photons, but instead results from neutrons that are generated by particle beam loss in the ring. Most high energy electrons and positrons that are lost during injection, normal HEP (high energy physics), or from beam dumps collide with the walls of the CESR vacuum chamber producing a so-called electromagnetic shower of particles and Bremstrallung photons [1]. These photons are the most penetrating part of the shower, but they eventually degrade in energy or are lost in processes that create additional particles. The most insidious of these decay products, because of their penetrating power (and ultimately because of ionizing effects in tissue), are neutrons with energies from 1 to greater than 100 MeV. Neutrons are stopped by inelastic scattering and absorption in thick materials such as heavy concrete (cement, water, and typically iron ore substituting for sand and gravel).

The original CHESS-tunnel walls were built of 1 foot thick normal concrete with lead replacing concrete in a 1 foot tall section at beam height. We are presently replacing this with up to 2 feet of heavy concrete combined with a tunnel side facing of lead. This new wall is designed to keep radiation in the CHESS experimental areas near background levels for the foreseeable future. The design for the upgraded walls, the recipe for our heavy concrete and all the concrete casting was done by CHESS and LNS staff. Our estimates on shielding improvements come from evaluating neutron attenuation using the concept of removal cross-sections [2]. By the end of summer, upgrades of the B, C, D, and F3-tunnel walls will have been completed.

In the electromagnetic shower, several mechanisms dominate the production of photo-neutrons, so named because they result form a direct interaction between Bremstrallung photons and the nucleus. These photo-neutrons are released more-or-less isotropically, with an energy spectrum peaked between 1-10 MeV. This energy distribution results from an interplay between the Bremstrallung energy distribution and photonuclear cross-sections. The components of heavy concrete that are most effective in neutron shielding are heavy weight iron ore (typically "nonmagnetic", coarse and fine hematite (Fe_2O_3) aggregate with an iron content of >60% by weight), and water (which is stabilized into the mix as the cement is hydrated). Iron nuclei lower the neutron energy spectrum by inelastic scattering at energies above 1 Mev, while the hydrogen nuclei (in water) further degrade the energy and ultimately absorb neutrons with a cross-section that increases inversely with the square root of energy below several eV.

Our heavy concrete mix incorporates a new material for this application, one that has yielded a significant cost saving in the production of over 200 tons of new wall sections. The material, an artificially enriched iron oxide pellet manufactured [3] in vast quantities from hematite ore (with an iron content of 30-35%, typical of North American ores) for the steel making industry, costs about a third of the traditional material. Its material and chemical properties such as iron and impurity content, strength, size and uniformity make it an excellent substitute for the high grade Brazilian iron ore that has been commonly used as heavy aggregate in radiation shielding. Guided by ACI [4] and ASTM standards [5], we have developed a concrete mix design using facilities at Cornell's George Winter Laboratory in the School of Civil and Environmental Engineering. The concrete has excellent workability, a 28 day compressive strength exceeding 6000psi and a density of 220lbs/cu.ft (3.5gr/cc). In comparison with commercial heavy concrete, the strength is higher, and the den-

CONTINUED ON THE BOTTOM OF PAGE 60

CONTINUED FROM PAGE 59

sity about 10% lower then the heaviest mixes.

The lower density results from an interesting property of the pellets. They are made to be porous, with about 28% of the volume consisting of connected pores of typical size from 1-10 microns. As we understand it, the porosity aides in efficient reduction in the steel making process, but it may have some useful implications for the radiation shielding problem. Most obvious is that the course aggregate can hold a lot of water. Cured, normal concrete contains up to about 5% water by weight and as discussed, the water plays an essential role in neutron attenuation. We have found that water trapped in our coarse aggregate does little to influence the setting of concrete. The pellets makes up 75% of the mixtures volume and if this "excess" water could be made fast in the concrete then the water content could be doubled. A second idea is to impregnate the pellets with a good neutron absorber such as boron, this could further improve the attenuation properties of the mixture. We have made such boron rich samples and are awaiting beamtime at the Cornell Nuclear Reactor (Ward Lab) to test this notion.

We gratefully acknowledge the following individuals for there expert advise, cooperation and hard work on this project. Tim Bond, supervisor of Winter Lab helped in every aspect of concrete mix testing and generously provided space for the concrete block fabrication. Clay Ball and his crew at LNS have expertly designed frames, manufactured shielding blocks, and are responsible for installation of the tunnel walls. Enzo Gardin, of Quebec Cartier Mining offered his resources and advise on a number of technical points. Finally, Professor Douglas Winslow, a CHESS user from Purdue University, was an invaluable source of wisdom and technical help in evaluating the new material and in explaining the fundamentals of concrete engineering.

1. For an excellent review of this subject see Radiological Safety Aspects of the Operation of Electron Linear Accelerator, W.P. Swanson, *Technical Reports Series No.188*, International Atomic Energy Agency, Vienna (1979).
2. An extensive discussion and summary of data on radiation attenuation properties for concrete is found in *Concrete Radiation Shielding*, M.F. Kaplan, Longman Scientific and Technical U.K. and co-published in the U.S.A. by John Wiley & Sons, N.Y. (1989).
3. The ores are mined, enriched, and pelletized by Quebec Cartier Mining Company, 1801 McGill College Ste 1400, Montreal, Quebec Canada H3A 2N4.
4. American Concrete Institute, 1985 Standard ACI 211.1-81.
5. ASTM Designation: C637-90, and C638-92 are found in *Annual Book of ASTM Standards*, Vol 04-02.