CONF-9003159--3

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DE91 004539

Radiation Damage Effects on Calorimeter Compensation

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Full text ~~Abstract~~ of paper
to be presented at
Florida State University's
Radiation Damage Seminar
March 19, 1990
Tallahassee, Florida

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

† Operated by Martin Marietta Energy Systems, Inc. under Contract No. DE-AC05-84OR21400 for the U.S. Department of Energy.

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Abstract

An important consideration in the design of a detector that is to be used at the Superconducting Super Collider (SSC) is the response of the calorimeter to electromagnetic and hadronic particles and the equality of those responses for different types of particles at equal incident energies, i.e. compensation. However, as the simulations that are reported show, the compensation characteristics of a calorimeter can be seriously compromised over a relatively short period of time due to the large radiation levels that are expected in the SSC environment.

1. Introduction

As has been suggested in previous reports and at past conferences, a calorimeter to be used at the Superconducting Super Collider should have an equal response to electromagnetic and hadronic particles, if they are of the same energy. If this is the case the calorimeter is said to be compensating and the calorimeter considered in this study is of the compensating type. In order to achieve compensation, various combinations of passive and active media have been used. Plastic scintillator in combination with uranium or lead can achieve this desired result.

The detectors at the SSC will have to operate in a hostile radiation environment that has so far not been explored at previous or current accelerators. Therefore, the long term effects of exposure to radiation are unknown. However, as has been shown at this conference, plastic scintillator does experience a degradation of its output signal when exposed to the radiation doses that are equivalent to what is expected at the SSC[1]. It has also been shown that the signal output of the scintillator does not fully recover with

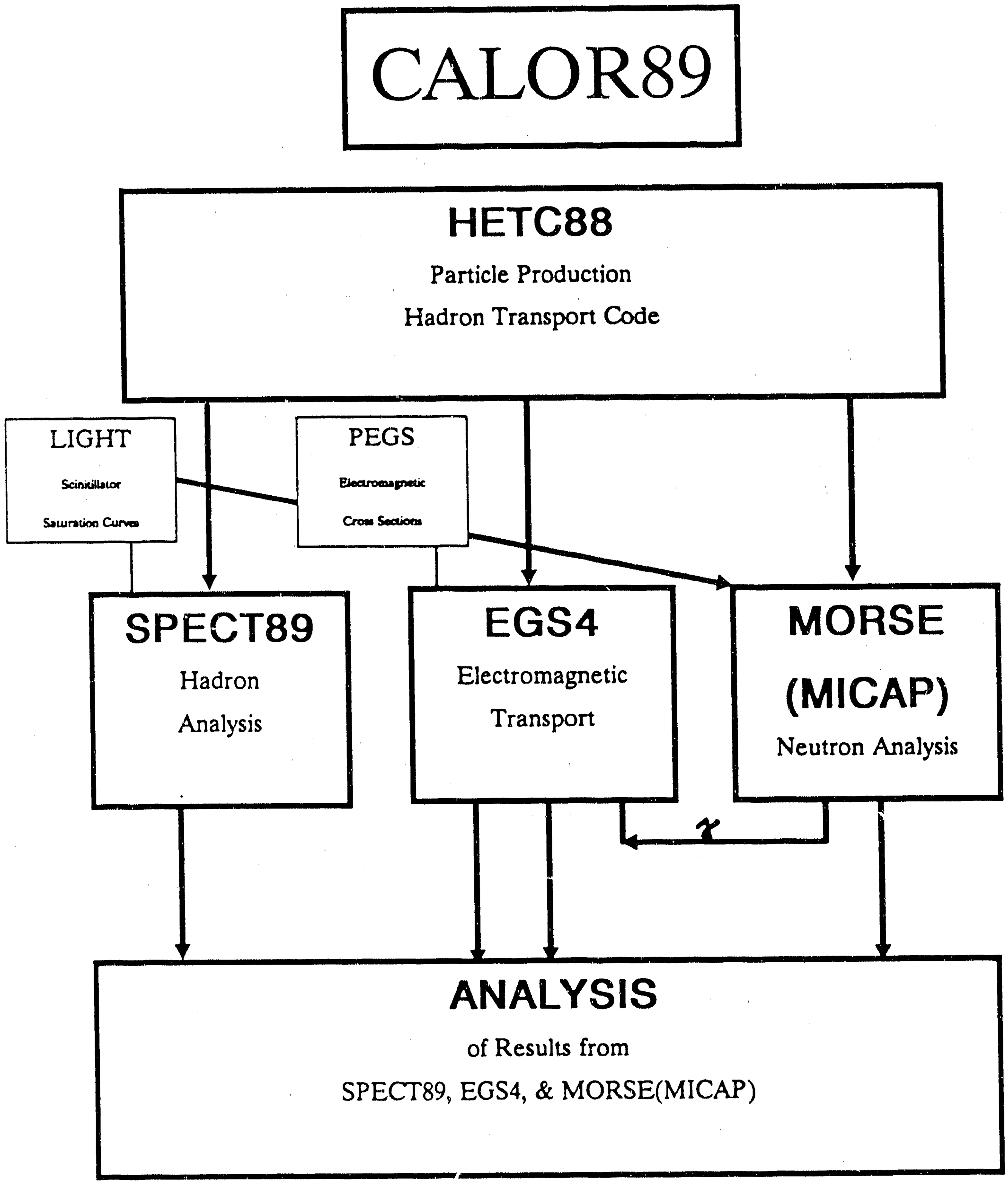


Fig. 1. The CALOR89 Code System

annealing. This implies that the response of the calorimeter will change as a function of time. To determine how the detector response will change is the object of this study.

2. Method

To determine how the response of a calorimeter changes when exposed to radiation doses expected at the SSC, a simple generic slab calorimeter has been simulated using the CALOR89 system of programs. CALOR89[2] consists (Fig. 1) of four primary programs (HETC88[3], SPECT89, EGS4[4], and MORSE[5] or MICAP[6]) plus their ancillary routines and a final analysis program. HETC88 is used to generate and transport the hadronic particles through the calorimeter, while SPECT89 does the energy deposition of the hadrons in the calorimeter. EGS4 is used for the transport and energy deposition of the electromagnetic particles in the calorimeter. MORSE or MICAP is used to transport neutrons that are below 20 MeV. The output of each of these programs (SPECT89, EGS4, MORSE or MICAP) is then used in the final analysis program.

The unit cell of the calorimeter under investigation consists of a 4mm thick lead sheet, followed by a 1mm thick sheet of plastic scintillator. The lead and plastic scintillator sheets were 2m by 2m. This unit cell is then repeated 300 times for a total calorimeter depth of 150cm. This particular configuration of active and passive media turns out to be mildly compensating with an e/h value of 1.05 in the energy range 2 - 20 GeV. To simulate the hadronic and electromagnetic particles entering the SSC calorimeter from 20 TeV p-p collisions, incident 10 GeV negative pions and electrons properly normalized are used.

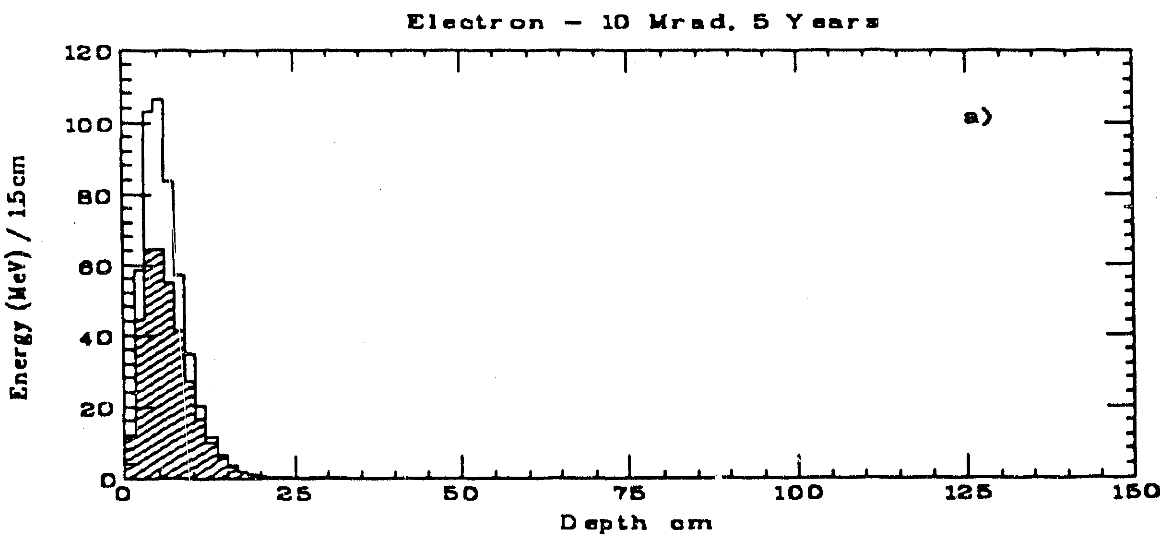
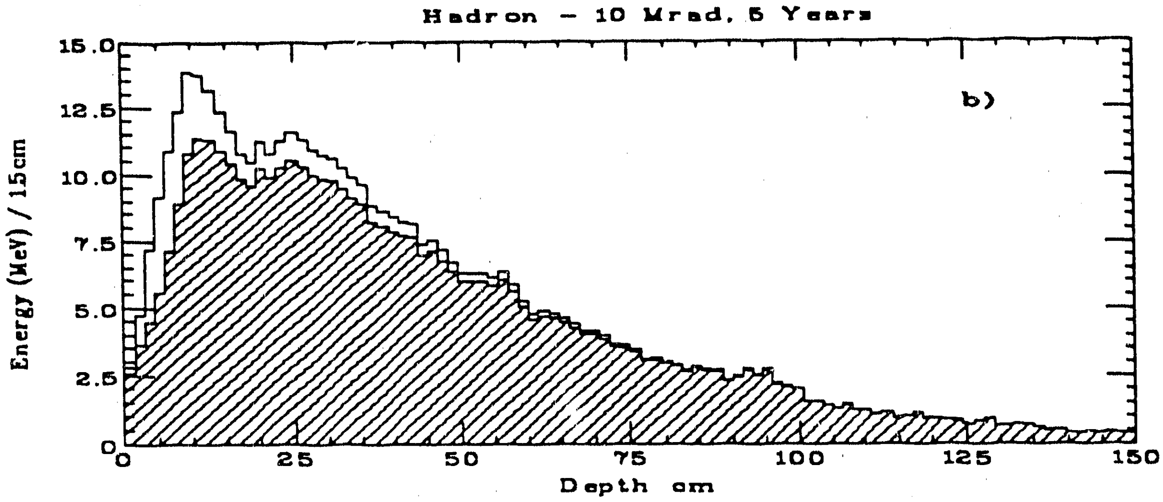


Fig 2a. Electron shower depth profile. The unshaded histogram is the original profile, while the shaded histogram is the resultant profile after 5 years at 10 Megarads/year at 1% signal loss/Megarad/year done geometrically(see text).



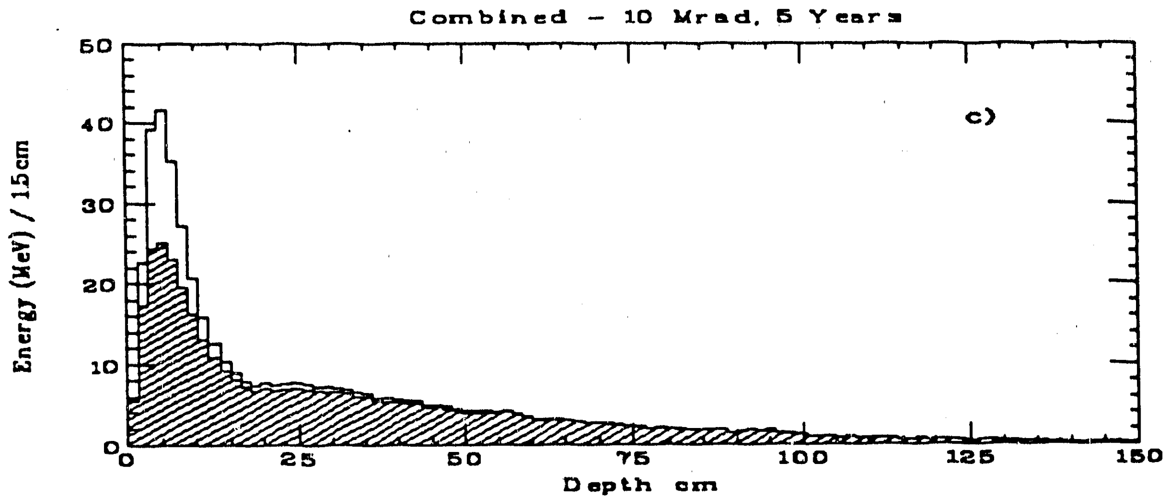


Fig. 2b) The unshaded histogram is the original hadronic signal, while the shaded represents the resultant signal after 5 years at 10 Megarads/year at 1% signal loss/Megarad/year. Fig 2c) Similar histograms for the combined signal. The shaded histograms in b) and c) have been done geometrically.

In the analysis programs, an average energy depth profile was calculated for the pions and the electrons. As can be clearly seen in the unshaded histogram in Fig. 2a, the electrons deposit almost all of their energy in the first 25cm of the calorimeter, whereas the pions(Fig. 2b) more uniformly deposit their energy throughout the calorimeter. From these respective profiles, a combined profile was obtained by adding one-third of the electron signal at a given depth to two-thirds the given pion signal at the same depth. It is assumed that two-thirds of the energy entering the calorimeter at the SSC will be hadronic, while one-third will be electronic. The combined profile is shown in Fig. 2c.

As has been reported by others[1], the radiation dosage is not uniform in pseudo-rapidity. To take this into account, the plastic scintillator has been degraded by three different dosage rates, 5 Megarads per year, 10 Megarads per year, and 15 Megarads

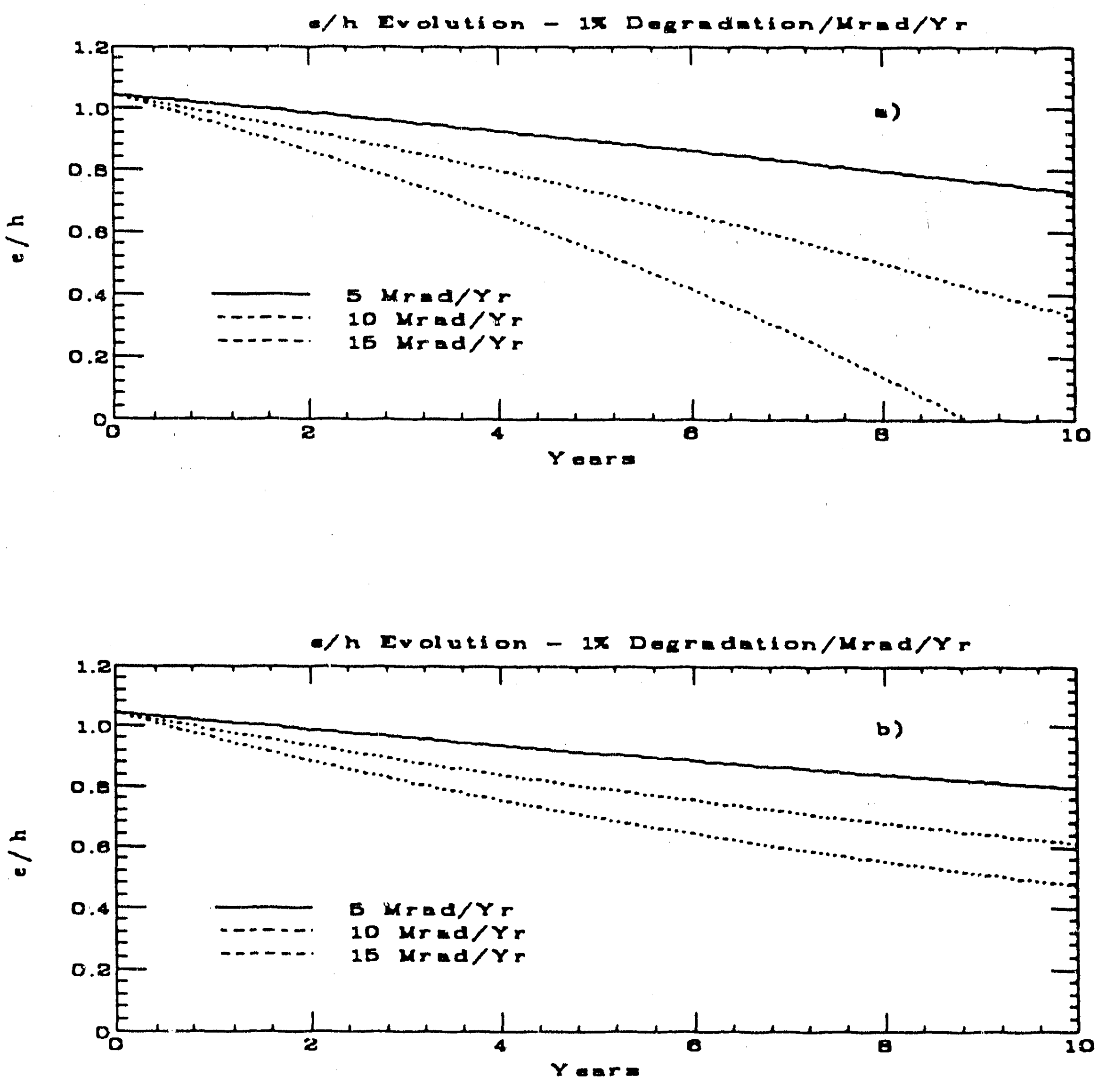


Fig 3. e/h evolution for a) linear degradation, and

b) geometric degradation.

per year. These dosages correspond to pseudo-rapidities that are values of 3 and larger. In addition, as has been reported at this conference, the degradation factor for plastic scintillator varies depending upon the type of scintillator used. Therefore, the plastic scintillator signal has been degraded by three different values, 0.2% net loss of signal per Megarad per year, 0.5% net loss, and 1.0% net loss. The time degradation of the scinitillator was carried out in two different ways. 1) A linear loss of signal: Effectively this means that the degradation builds up linearly with time, eventually reaching 100% for one particular case; and 2) A geometric loss of signal: This means the resultant signal is a percentage of the previous signal. The first method of course is the more severe case.

The peak of the combined distribution signal corresponds to the maximum dosage per year, and the other bins are accordingly scaled in dosage. The shaded histograms in Fig. 2 represent the resultant signals after an exposure of 10 Megarads per year for 5 years at a degradation factor of 1% done geometrically. As is readily seen, the electron signal is appreciably degraded, whereas the pion signal is hardly affected.This leads to a decrease in the value of e/h as a function of time.

In Fig 3a, the e/h evolution is presented as a function of time for a degradation factor of 1% done linearly for the three different dosage rates. As can be seen, e/h rapidly degrades for a dosage rate of 15 Megarads. After a period of two years, e/h has fallen from an initial value of 1.05 to values of 0.98, 0.92, and 0.86 for the dosage rates of 5, 10, and 15 Megarads, respectively. Therefore depending on the exact dose rate, the compensation characteristics have decreased by as much as 17% within two years. In Fig. 3b, the e/h evolution is given for geometric degradation. Here e/h has fallen to 0.99, 0.93, and 0.88 after two years, again for the same dose rates. Though not as bad as the linear assumption, the geometric case still shows a 15% decrease in compensation due to the plastic scintillator degradation.

3. Conclusions

As have been shown by the simulation studies, the compensation characteristics of a calorimeter that is part of a detector to be operated at the SSC will be severly degraded as a function of time due to the radiation doses encountered at the SSC. Our estimate that the plastic scintillator will recover to 99% of its signal output is currently over-optimistic. It therefore would seem that for a calorimeter to be useful, it will have to have design features that will enable the experimenters to quickly and easily replace the forward sections of the calorimeter, unless sufficiently radiation hardened plastic scintillator becomes available.

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