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Progress Report
for
The Scintillating Plate Calorimeter
Subsystem

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ABSTRACT

During the past year, Tennessee, Mississippi, and Oak Ridge National Laboratory have been coordinating efforts to benchmark the CALOR89 code system against the ZEUS prototype calorimeter data, and to use the CALOR89 system to generate currently needed data for radiation damage studies, signal collection time, and compensation characteristics of various calorimeter designs. This report describes these results and gives our plans and projected budgets for the following year.

I. Introduction

A strong experimental Superconducting Super Collider (SSC) calorimeter development program must involve a substantial calculational analysis of the proposed detector system. The CALOR89¹ code system offers a solid approach for investigating all facets of calorimeter systems. Due to financial constraints, only a few prototypes can be built and tested. The remainder of the studies must be analytical. Once the calculated results have been shown to agree with the test data, a much wider variation of the design can be investigated. This approach is being followed in our subsystem research.

During the past year, Tennessee, Mississippi, and Oak Ridge National Laboratory have been coordinating efforts to benchmark the CALOR89 code system against the ZEUS² prototype calorimeter data, and to use the CALOR89 system to generate currently needed data for radiation damage studies, signal collection time, and compensation characteristics of various calorimeter designs. Even though the total benchmarking of the ZEUS data has not been completed, the current caliber of the code is such that data generated will certainly be adequate for preliminary design studies. This report describes these results and gives our plans and projected budgets for the following year.

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II. The CALOR89 Code System

A flow diagram of the CALOR89 code system is given in Fig. 1. The transport codes that comprise this system include HETC88³, the high energy hadronic transport code, EGS4⁴, the electron, positron, and gamma ray transport code, MORSE⁵ and MICAP⁶, the low energy ($\leq 20\text{MeV}$) neutron transport codes. Source gamma rays and electrons for EGS4 and neutrons for MORSE are obtained from the data generated in HETC88. The remainder of the codes are for analysis (SPECT and ANALYSIS), cross-section generation (PEGS), and signal reduction due to saturation/recombination effects (LIGHT). The major changes in CALOR and the main reasons for the additional benchmarking are an improved high energy collision model following the methods used in FLUKA87 and a new low energy neutron transport code, MICAP. To prevent too many changes at once, the code will be benchmarked against the new high energy model using the MORSE code and will be followed by additional benchmarking using the MICAP code.

III. Signal Collection Time and Compensation Characteristics of a Pb/Scintillator Calorimeter

The configuration of the calorimeters considered in these calculations are given in Table I. In both cases, the scintillator has been kept at a thickness of 1mm while the lead thickness is varied from 4 to 3mm. The lateral width of both detectors is $2 \times 2\text{m}^2$. The total thickness in the 3mm Pb calorimeter case is slightly larger, but should not grossly affect the comparison between these two systems. There should be slightly less leakage in the 3mm system.

Presented in Fig. 2 are the pulse heights calculated for 10GeV electrons, protons, and pions incident on the 4mm Pb/1mm Plastic calorimeter. The histogram is the actual calculated data and the solid curves represent the fitted Gaussian distributions. All quoted e/π ratios and resolutions are obtained using the fitted data.

The effect of saturation and time cuts on the compensation characteristics of a plastic calorimeter are rather strong. Presented in Fig. 3 are compensation results as a function of time and saturation level for the 4mm Pb/1mm (4,1) Plastic calorimeter for 10 GeV incident protons and pions. As can be determined, the calorimeter would be substantially over compensating if saturation was not present in the plastic scintillation. This important parameter is often neglected when various plastics are considered for the calorimeter. Also as can be seen in this figure, approximately 50-75nsec is required to collect most of the signal and to obtain compensation. Similar data for both calorimeters (3mm (3,1) and 4mm (4,1) Pb) and various particle energies are presented in Fig. 4. Odd fluctuations in the location of the data curves are attributed to back leakage.

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Fig. 1 The CALOR89 Code System

Table I

Geometry of the Lead-Scintillator Calorimeters

4mm Pb, 1mm Sci

- Total depth - 150cm
- 300 Samplings
- 7.02 Interaction lengths of Lead

3mm Pb, 1mm Sci

- Total depth - 160cm
- 400 Samplings
- 7.02 Interaction lengths of Lead

The resolution as a function of cutoff times, particle energies, and calorimeters is presented in Fig. 5. The data have been fitted to

$$\sigma/E = A/\sqrt{E} ,$$

and the A value plotted. Due to back leakage the resolution becomes slightly larger at 20 GeV. Also due to less compensation for the 3mm/1mm calorimeter case, generally speaking, the resolution will be worse and a constant term should be added to the equation, i.e., $\sigma/E = A/\sqrt{E} + B$, before fitting.

Fig. 2 Pulse height distributions for 10 GeV electrons, protons, and pions incident on a 4mm Pb/Imm Plastic calorimeter (Histogram - calculated data, solid curve-Gaussian fit).

Different Neutron Cutoff Times

Fig. 3 Variation of compensation as a function of time and saturation level.

Fig. 4 Variation of compensation as a function of time, energy, and calorimeter geometry.
 3,1 = 3mm Pb/1mm scintillator
 4,1 = 4mm Pb/1mm scintillator

Different Neutron Cutoff Times

Different Neutron Cutoff Times

Fig. 5 Variation of resolution ($\sigma/E = A/\sqrt{E}$) as a function of time, energy, and calorimeter.
 3,1 = 3mm Pb/1mm scintillator
 4,1 = 4mm Pb/1mm scintillator
 A is the measure of resolution plotted

IV. Radiation Damage Effects on Calorimeter Compensation.

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 SSC⁷. It has also been shown that the signal output of the scintillator does not fully recover with 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 study for this section. The calorimeter configuration used for these studies is the same as the (4.1) used in the previous section, i.e., 4mm Pb/1mm scintillator. This unit cell is repeated 300 times.

This particular configuration of active and passive media turns out to be mildly compensating with 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.

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. 6a, the electrons deposit almost all of their energy in the first 25cm of the calorimeter, whereas the pions (Fig. 6b) 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 electromagnetic. The combined profile is shown in Fig. 6c.

As has been reported by others⁷, 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, 15 Megarads per year. These dosages correspond to pseudo-rapidities that are values of 3 and larger. In addition, as has been reported at the Florida State Conference (March, 1990), 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 scintillator 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 signal: this means the resultant signal is a percentage of the previous signal. The first method, of course, is the more severe case.

*Only the 1.0% data is presented here.

Electron - 10 Mrad, 5 Years

Fig. 6a 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.

Hadron - 10 Mrad, 5 Years

Fig. 6b Hadronic shower depth profile. 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.

Combined - 10 Mrad, 5 Years

Fig. 6c Similar histograms for the combined signal. The shaded histograms in 6a, 6b and 6c have been done geometrically.

Fig. 7a e/h evolution for linear degradation.

Fig. 7b e/h evolution for geometric degradation.

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. 6 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. 7a, the e/h evolution is presented as a function of time for 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. 7b, 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.

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 severely 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.

VI. General Design Calculations for the SSC Plate Calorimeter

During the Subsystem/CALOR meeting held at ORNL on June 19-20, 1990, several sets of general design calculations to be carried out were agreed upon. This set of calculations will serve two purposes. First of all, a benchmark calorimeter calculation will be carried out at the University of Tennessee, the University of Mississippi, and at Argonne National Laboratory under the auspices of ORNL to ensure that the code system is yielding consistent results. In addition, a series of calculations is planned which will aid in the design of the prototype calorimeter. The following provided by J. Proudfoot outlines the calculations.

General Discussions

This meeting centered on the material composition issues (scintillator and alloys), EGS parameters, CALOR parameters, and the need for all groups to be using common values, as well as the specific simulation goals. The long-term goal is to study fully a matrix of:

Four scintillator thicknesses (1, 2.5, 5, 10 mm)
 Four absorber thicknesses (0.5, 1, 2, 4 r.l.)
 Three primary absorbers (DU, Pb, Fe)
 Six particle energies (10, 5, 2 GeV)
 Six integration gate lengths (16, 32, 48, 96, 192, 288 nsec)

Simulation Parameters

Geometry:	-1 to 1m in lateral extent 8 λ^{Int} depth (i.e., excluding plastic) EM section 20 r.l. absorber
MORSE:	$t_{max} = 300$ nsec neutron cutoff = 20 MeV ALL OTHERS AT DEFAULT VALUES
EGS:	Use all default values (No ESTEPE)
PEGS:	$e^{\pm}$ cutoff = 1.511 MeV γ cutoff = 0.100 MeV
Remaining Modules:	Use all default values

Materials Parameters

Scintillator:	C:H	= 0.978
	Density	= 1.04 gm/cm ³
	Number density H	= 4.92 x 10 ²² atoms/cm ³
	Number density C	= 4.81 x 10 ²² atoms/cm ³
	Birk's Constant	= 0.0131 gm/cm ² /MeV
Depleted Uranium: (100% U ²³⁸)	Density	= 18.95 gm/cm ³
	λ^{Int}	= 10.50 cm
	1 r.l.	= 0.33 cm
	Number density	= 4.794 x 10 ⁻²
Iron:	Density	= 7.87 gm/cm ³
	λ^{Int}	= 16.76 cm
	1 r.l.	= 1.76 cm
	Number density	= 8.486 x 10 ⁻²
Lead:	Density	= 11.35 gm/cm ³
	λ^{Int}	= 17.09 cm
	1 r.l.	= 0.56 cm
	Number density	= 3.299 x 10 ⁻²

Near-Term Goals and Distribution of Tasks

It was agreed that the time required to complete analysis of the full matrix was substantial, and therefore, achievable near-term goals were established to address the immediate mechanical issues. The analysis is to include the time dependence of shower energy deposition, e/h , resolution, longitudinal profile and lateral profile.

Runs are to be for:

10 GeV incident e^- , π^-
1000 histories for π^-
250 histories for e^-

The three absorbers will be done by separate groups who will each cross check one point for a different absorber. The cross checks, and any additional benchmarks, will be carried out for 2.5mm scintillator and 1 r.l. absorber. The distribution of absorbers is:

<u>Absorber</u>	<u>Group</u>	<u>Cross Check Absorber</u>
Depleted U	University of Tennessee/ORNL	Pb
Pb	Argonne National Laboratory/ORNL	Fe
Fe	University of Mississippi/ORNL	Depleted U

Configurations

- 1 set of points for constant absorber thickness of 1 r.l. at varying scintillator thicknesses of 1mm, 2.5mm, and 10mm.
- 1 set of points for a constant scintillator thickness of 2.5mm at varying absorber thicknesses of 0.5, 1, 2, 4 r.l.

Schedule

- Benchmark configuration run and cross check are to be completed by July 14th.
- Following comparison of results at benchmark configuration, the remaining points are to be run. The target date for completion of this study is September 1, 1990 (optimistic).

VI. ZEUS Benchmark Calculations (as of August 1, 1990)

Due to the need for immediate, preliminary design data and to the late arrival of adequate funding, the ZEUS benchmark calculations are progressing at a slow rate. Currently, the geometry of the prototype calorimeter has been assembled and debugged. Calculations using this geometry with the codes HETC, SPECT (with proper saturation levels), and EGS have been carried out for electrons, protons, and pions at three different energies, 2, 5, and 10 GeV. Only MORSE and the transport of the MORSE produced gamma rays by EGS need to be carried out. Once these final calculations have been done, these data generated by the various codes can be analyzed to determine the calculated responses of the ZEUS prototype calorimeter. Preliminary investigations of the raw data indicate no surprises.

VII. Anticipated Progress for FY91

During FY91, the calculations to aid in the design of the scintillating plate calorimeter will be expanded and refined. Benchmark and design calculations which were started during FY90 will be completed and those which are to be compared with experimental data will be further analyzed. Differences between experimental and calculated results will be determined and the differences resolved. Additional calculations needed for the prototype will be started. Improvements in the CALOR system as it relates to scintillation calorimetry will be continued.

VIII. Budgets for FY91 (See overall budget sheet for breakdown)

University of Mississippi	\$ 98.64K
University of Tennessee	\$ 42.77K
ORNL	\$130K*

IX. References

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