**The Response of a Uranium-Plastic
Calorimeter to Low GeV (≤ 10 -GeV) Protons**

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Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
Price: Printed Copy \$4.00; Microfiche \$3.00

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Contract No. W-7405-eng-26

Engineering Physics Division

THE RESPONSE OF A URANIUM-PLASTIC CALORIMETER
TO LOW GeV (≤ 10 -GeV) PROTONS*

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JANUARY, 1979

* Submitted for
Journal publication

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ABSTRACT

The calculated response of a uranium-plastic calorimeter for incident 1-10 GeV protons is presented and compared to previously published data for a uranium-liquid argon calorimeter.

INTRODUCTION

In a previous paper¹⁾, the calculated response of a uranium-liquid argon calorimeter to low GeV (≤ 20 GeV) hadrons was investigated and the results obtained compared favorably with available experimental data²⁾. Since those results were published, there has been a growing interest in uranium-plastic calorimeters³⁾ since these devices do not require the cryogenics associated with liquid argon and would be more more adaptable to a variety of experimental setups, for example, large 4π detection systems. Presented in this Note are the calculated results for the response of 1-10 GeV protons incident on a uranium-plastic calorimeter. The device is cylindrical with a radius of 50 cm and has 350 unit cells, each cell containing a uranium sheet of thickness 0.2 cm and a plastic sheet of thickness 1.0 cm.

The same calculational procedures as described in Ref. 1 have been applied here as well as accounting for the additional effect of saturation associated with plastic scintillators⁴⁾. Due to the non-analog Monte Carlo characteristics of the low-energy (≤ 20 MeV) neutron-photon transport code MORSE⁵⁾ which is used in the calculations, an average saturation level was applied to all proton and heavier ion (α 's, C^{12} 's, etc.) recoils in the plastic scintillator resulting from collisions by neutrons with energies ≤ 20 MeV. This average saturation level was approximately calculated by considering the average neutron spectrum in the low energy region, the possible reactions and recoil energies, and the corresponding saturation factors. The value obtained for the saturation level was 0.50, that is for each MeV deposited in recoil energy only 50% of this energy will be detected as light. This

approximate treatment of the saturation effect is only applied to the energy deposited by low-energy neutron collisions, and, as before⁴), a detailed treatment of the saturation effect is applied to the remainder of the charged particle cascade.

RESULTS

Presented in Fig. 1 is the average energy* deposited in the plastic scintillator as a function of proton energy for several conditions, that is, fission, no fission, saturation and no saturation. The curve of most interest is (1,A) which represents the experimentally expected values when the energy deposition is converted to light. Note that in this case the fissioning and capture characteristics of uranium return just enough energy to the system to compensate for the saturation effects corresponding to a system which does not have fission and saturation (2,B). Additional energy ($\sim 20\%$) in the fission cases can be detected if the time window is increased from 50 nsec to 100's of nsecs. However, the rate at which this energy is collected is very small and therefore this makes its usefulness minimal. The $\blacktriangle$'s in the figure represent the energy deposited in the liquid argon for the uranium-liquid argon calorimeter described in Ref. 1 (uranium plates 0.16 cm, argon gaps 0.19 cm).

The expected resolution of the uranium-plastic calorimeter for several conditions, that is, saturation, no saturation, and fission, no fission, are given in Figs. 2 and 3. As before, the $\blacktriangle$'s are data from Ref. 1.

* Throughout this Note energy means effective energy, i.e., energy deposited which can be detected as light. For the no saturation cases, all energy deposited in the plastic scintillator is assumed to be detectable.

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Fig. 1. Average energy deposited in the plastic scintillator as a function of proton energy.

Fig. 2. Resolution of the calorimeter if saturation effects are neglected.

Fig. 3. Resolution of the calorimeter if saturation effects are included.

Some improvement in the resolution can be obtained by considering the energy deposited at times greater than 50 nsec, but this improvement is generally $\lesssim 10\%$.

Since the energy deposition is essentially the same for cases (1,A) and (2,B), one might expect the resolution for these two cases to be the same. However, by comparing the resolution associated with these two cases in Figs. 2 (top curve) and 3 (bottom curve) it can be seen that they are not equal. As stated in Ref. 1, there are two reasons the resolution of uranium-loaded calorimeters improve. The first reason is the shift of the peak of the pulse height distribution to a higher value. The second reason is due to a narrowing of the pulse height distribution because of the correlation between the number of neutrons produced and the number of fissioning and captures occurring, i.e., a large hadronic component of the energy deposition usually implies a smaller pulse height value which due to fissioning and captures will be increased toward the mostly electromagnetic part of the pulse height distribution where there is very little fissioning and capture amplification. Therefore, since the energy deposited is essentially the same in both cases, the improvement in the resolution is due only to the tightening of the pulse height distribution. This tightening effect becomes less with increasing energy as the average particle cascade becomes more and more electromagnetic in character.

The improvement in the resolution of the uranium-plastic calorimeter over the uranium-liquid argon calorimeter as shown in Fig. 2 for the case of no saturation is a direct consequence of the larger amount of energy

detected in the uranium-plastic device. However, as can be seen in Fig. 3, when the saturation effect is applied to the plastic scintillator the results become similar even though the energy detected by the plastic is still larger. This is due to two effects. First of all, larger sampling fluctuations are present in the plastic calorimeter, but this is a rather small effect, $\lesssim 15\%$. Secondly, a large portion of the additional energy ($\sim 40\text{-}50\%$) which fissioning and capture returns to the system to tighten the pulse height distribution is associated with the low-energy fission neutrons. Since this energy appears (due to neutron collisions) in the plastic as hydrogen, carbon ion, etc. recoils and has been reduced due to the saturation effect, a weakening of the correlation results. This dependence of the resolution on all low-energy (≤ 20 MeV) neutrons is shown in Fig. 4 for 2- and 8-GeV incident protons. A "0" level of saturation applied to low-energy neutrons implies that the ion recoils from the neutron collisions are not detectable at all, whereas a value of "1.0" indicates that all of the energy can appear as light. For both cases, a factor of 2 variation in the resolution is possible. It should be remembered that in Figs. 2 and 3, 0.5 was used as an acceptable level of saturation. The same effect can be seen by calculating the ratio of the resolution with saturation to the no saturation resolution with and without fission. The average values obtained for the energy range of 1-10 GeV are 1.18 without fission and 1.38 with fission, that is, an 18% worsening of the resolution due to saturation effects if fission is not present and 38%, if fission is present.

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Fig. 4. Change in the resolution due to various levels of saturation applied to the energy deposited as ion recoil resulting from low-energy collisions (≤ 20 MeV).

ACKNOWLEDGMENTS

The authors wish to thank C. W. Fabjan, CERN, G. T. Gillies, University of Virginia, R. Palmer, Brookhaven National Laboratory, W. Selove, University of Pennsylvania, A. L. Sessom, Howard University, and W. J. Willis, Brookhaven National Laboratory and CERN, for their interest in these calculations.

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