UCID- 18634

COMPARISON BETWEEN CALCULATION AND MEASUREMENT OF ENERGY DEPOSITED BY 800 Mev PROTONS

by

William E. Loewe

April 3, 1980

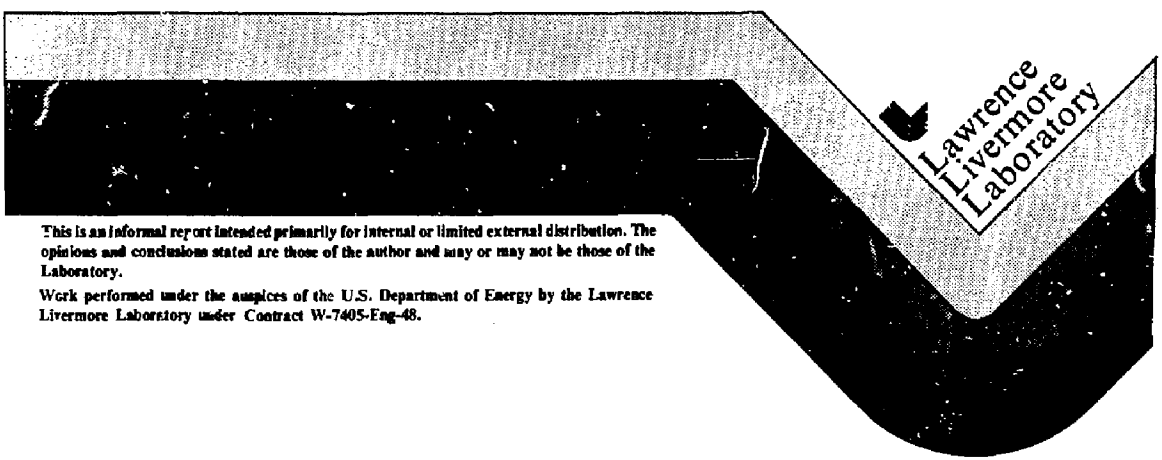


Table of Contents

Introduction

The High Energy Transport Code, HETC,[1] was obtained from the Radiation Shielding Information Center (RSIC) at Oak Ridge National Laboratory and altered as necessary to run on a CDC 7600 using the LTSS software in use at LLNL. HETC was then used to obtain calculated estimates of energy deposited, for comparison with a series of benchmark experiments done by LLNL. These experiments used proton beams of various energies incident on well-defined composite targets in good geometry.[2] The results of these comparisons are the subject of another report.[3]

In this report we are concerned with two aspects of the comparison between calculated and experimental energy depositions from an 800 Mev proton beam. Both aspects involve the fact that workers at SAI had previously used their version of HETC to calculate this experiment and reported their comparison with the measured data.[4] The first aspect to be addressed is that their calculated data and ours do not agree, suggesting an error in the conversion process from the RSIC code.

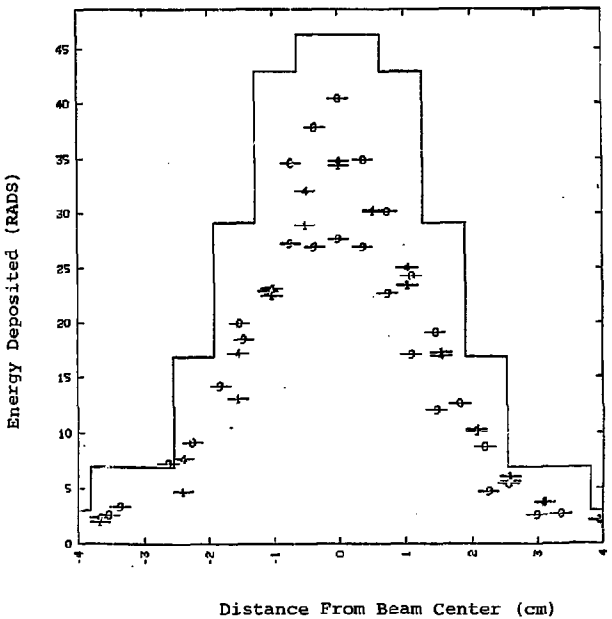
The second aspect is not independent of the first, but is of sufficient importance to merit separate emphasis. It is that the SAI calculations agree well with experiments at the detector plate located some distance from the shower plate, whereas the LLNL calculations show a clearcut discrepancy there in comparison with the experiment. It is shown in Figure 1. This discrepancy has prevented us from concurring

Figure 1

Calculation vs Experiment for 800 Mev Proton Beam

Histogram = Calculation
Symbols = Experimental Data, coded to distinguish diameters at four angles (0^{o}, 45^{o}, 90^{o}, 135^{o}).

Plate 4 (Detection Plate)



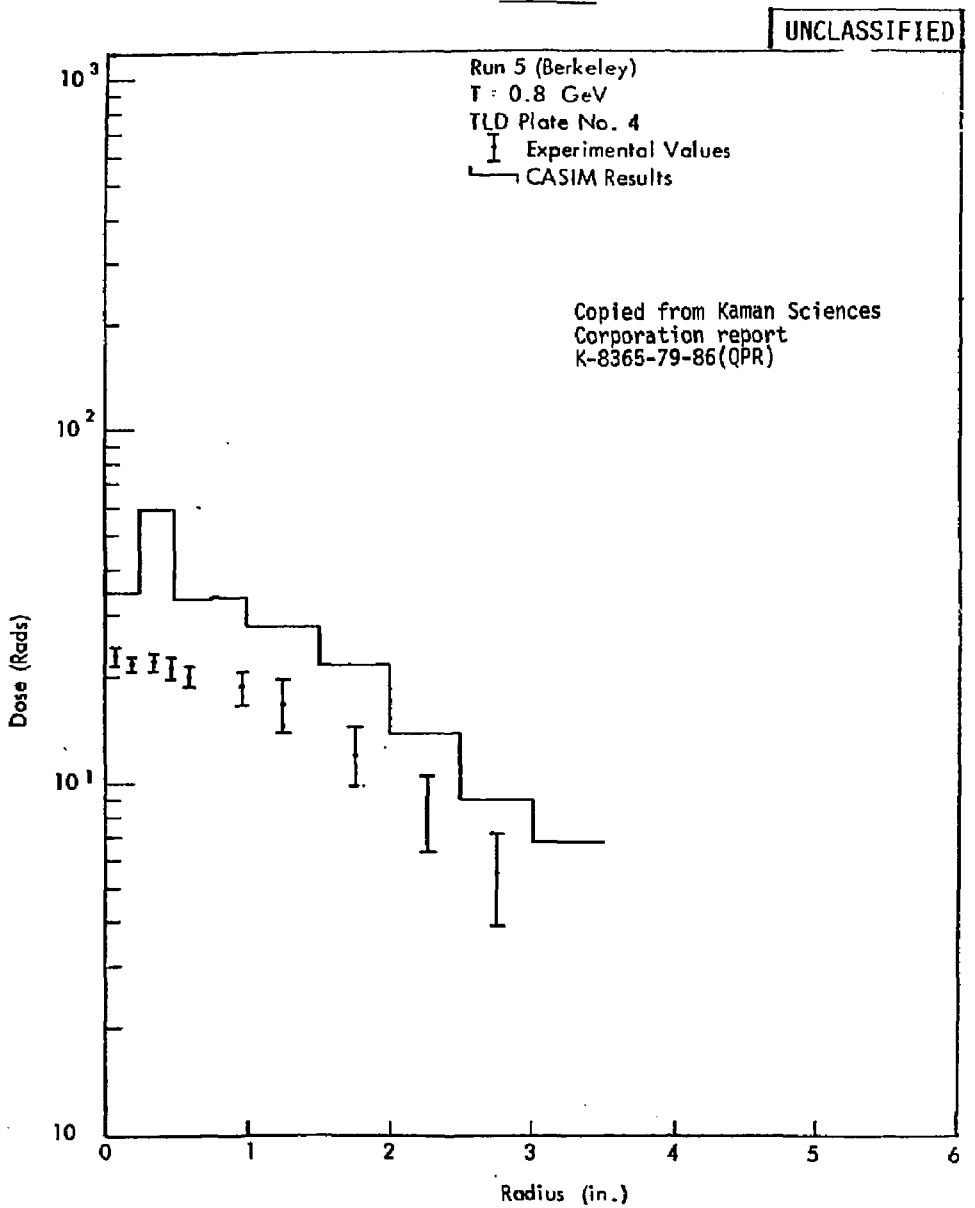
with SAI's conclusion that "....no systematic discrepancies between the measurements and calculations are observed to suggest that any modifications are necessary to the theoretical models." (op. cit.) The same discrepancy as we have observed has since been reported for entirely independent calculations with the modified CASIM code done by workers at Kaman Science Corporation.[5] (see Figure 2 reproduced from their report). This discrepancy is particularly interesting because SAI (op. cit.), LLNL (op. cit.), and KSC[6] all show a similar kind of disagreement with the experiment at 2.1 GEV, shown in Figures 3, 4 and 5, and in fact our work suggests an inverse dependency of the magnitude of the discrepancy on energy.

A contract was let in January, 1980 by LLNL with SAI in order to obtain full details on the two cited aspects of the comparison between calculated and experimental energy depositions from an 800 Mev proton beam. The ensuing discussion is based on the final report of that contracted work.[7]

Discussion

New calculations performed by SAI (op. cit.) agree very well with the LLNL calculations, as shown in Figures 6-10, which have been reproduced from their final report. These calculations have identical problem descriptions, including specifically, source distribution and magnitude as well as material compositions and thicknesses and Monte Carlo spatial binning. The LLNL calculations were run with ten times as

Figure 2



COMPARISON BETWEEN CASIM AND LLL EXPERIMENTS

Figure 3

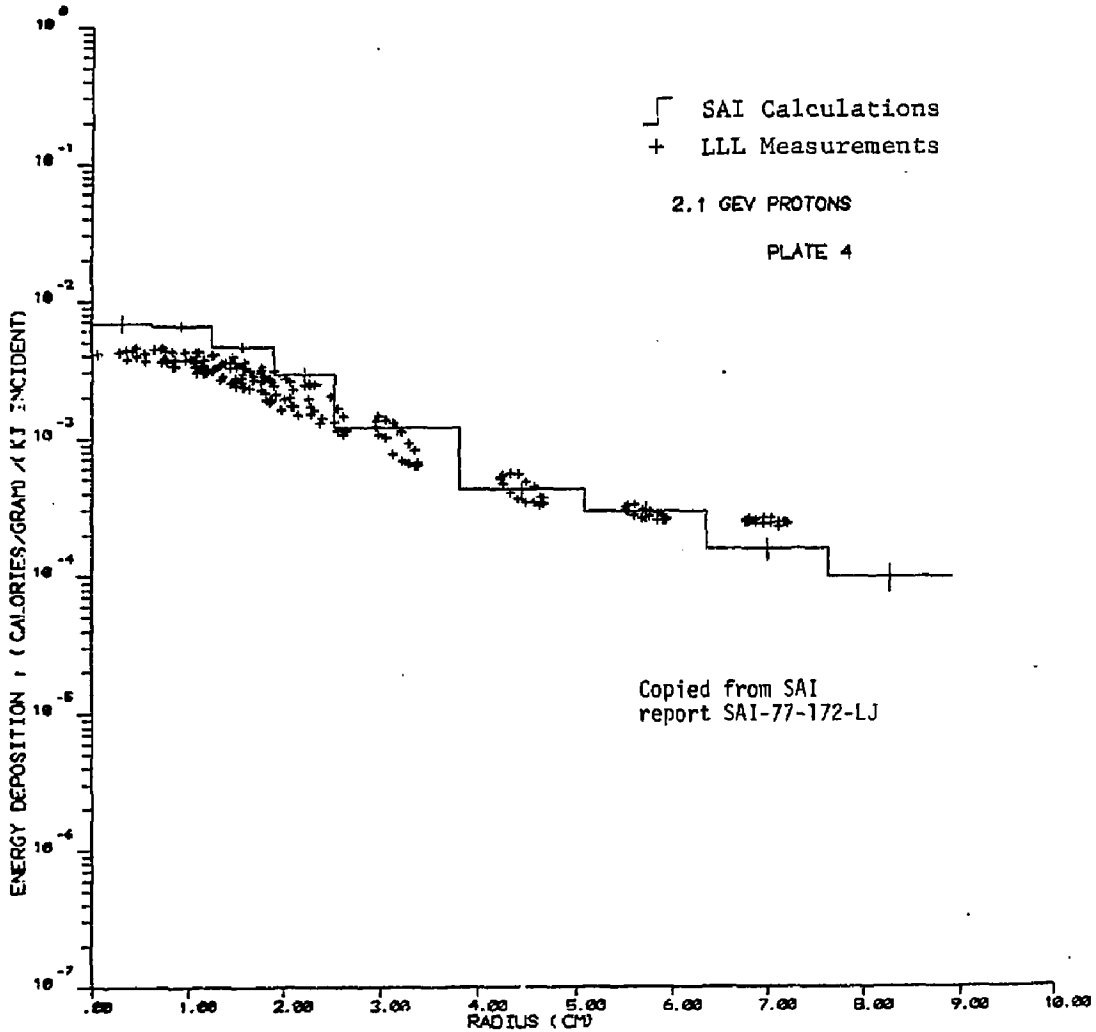


Figure 6(d) (U). Comparison of Calculated and Measured Energy Depositions for E_o = 2.1 GeV Proton Beam at TLD Plate Position #4 (U).

Figure 4

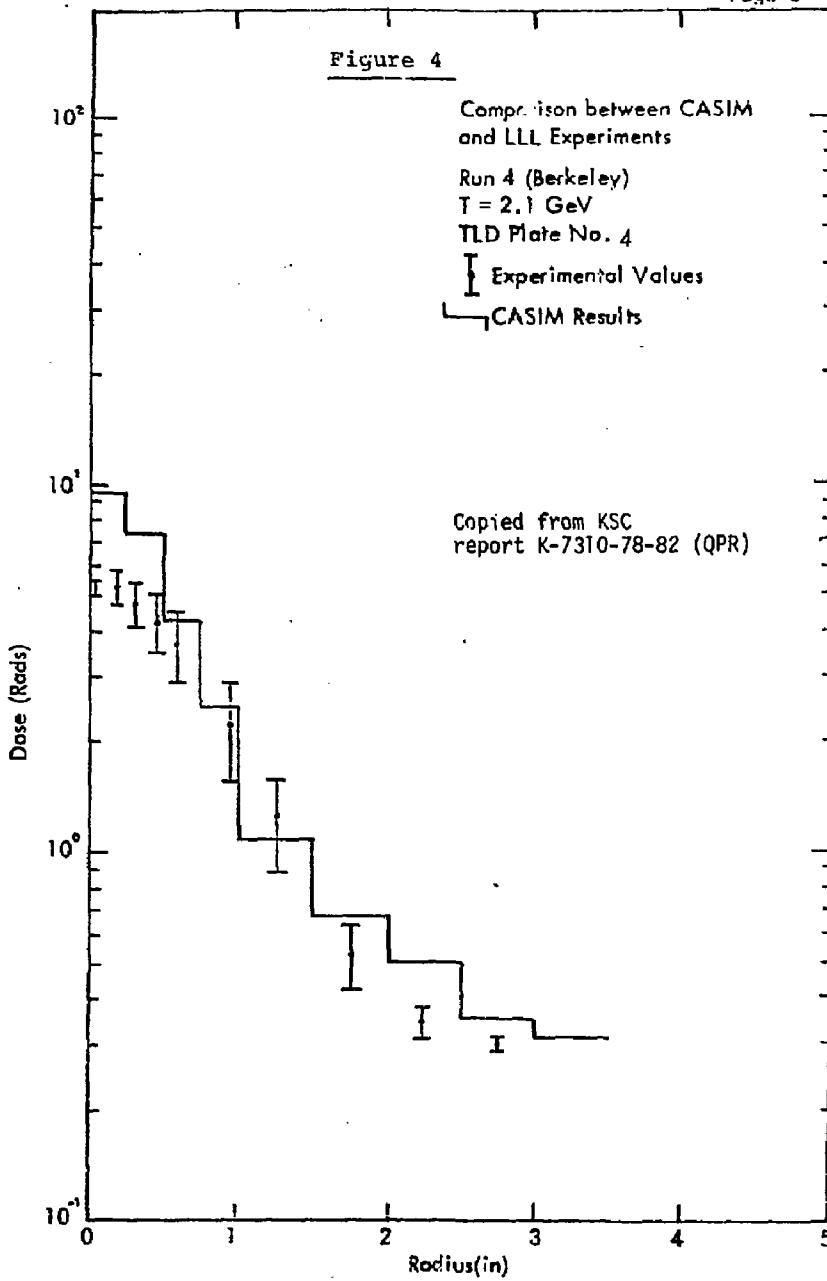
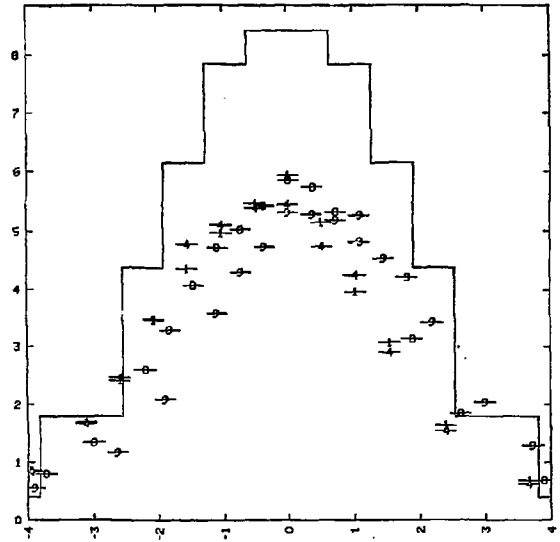

Comparison between CASIM and LLL Experiments
Run 4 (Berkeley)
T = 2.1 GeV
TLD Plate No. 4
Experimental Values
CASIM Results
Copied from KSC report K-7310-78-82 (QPR)
Dose (Rads)
Radius(in)
10^2
10^1
10^0
10^{-1}
0
1
2
3
4
5

Figure 5

LLNL Calculations vs. Experiment for 2.1 GEV Protons



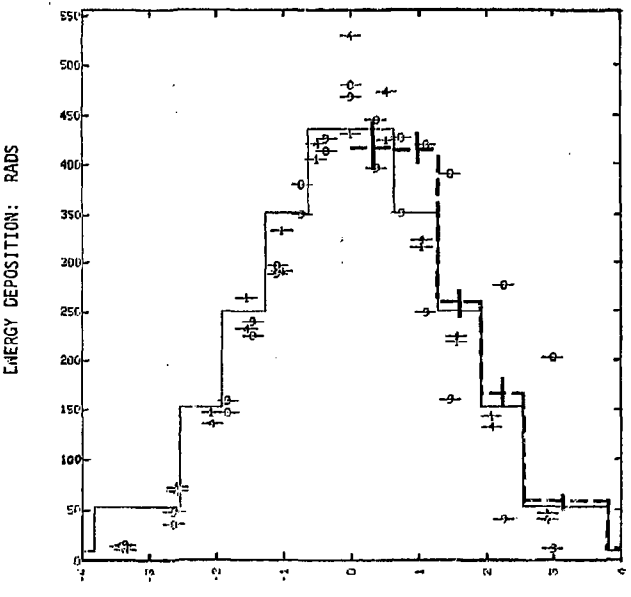


Figure 6

θ experimental data

—— LLL calculations

--- SAI (new) calculations

PLATE 1
800 MeV

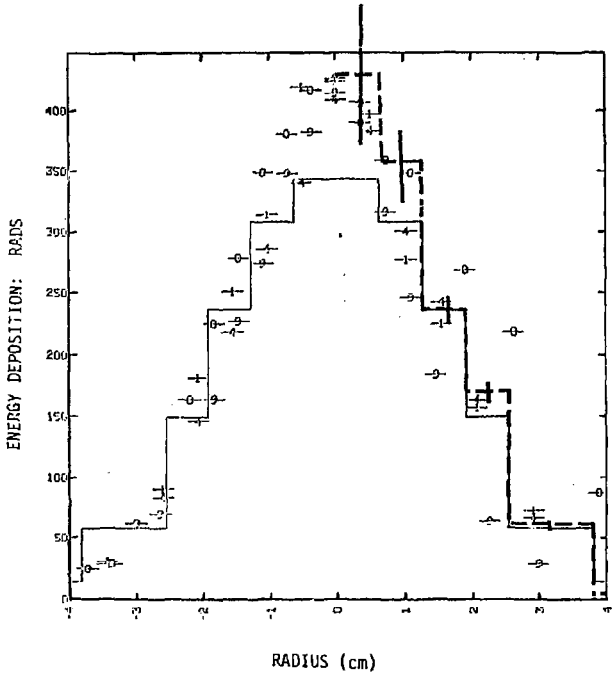


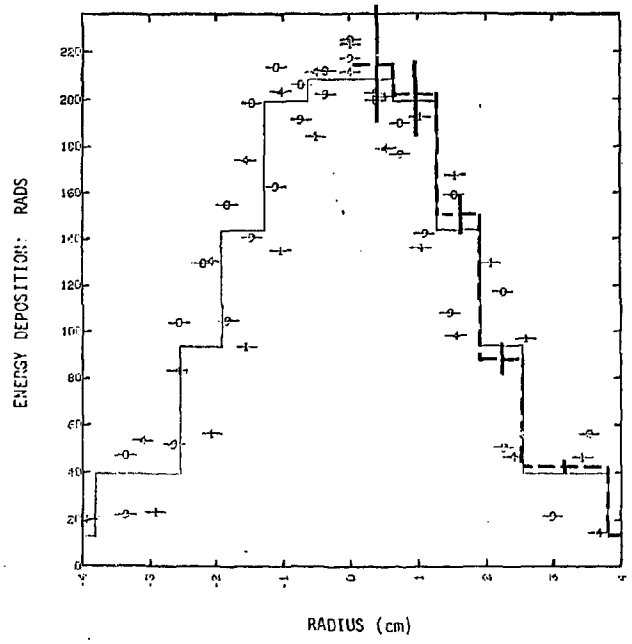
Figure 7

⊖ experimental data

—— LLL calculations

--- SAI (new) calculations

PLATE 2
800 MeV



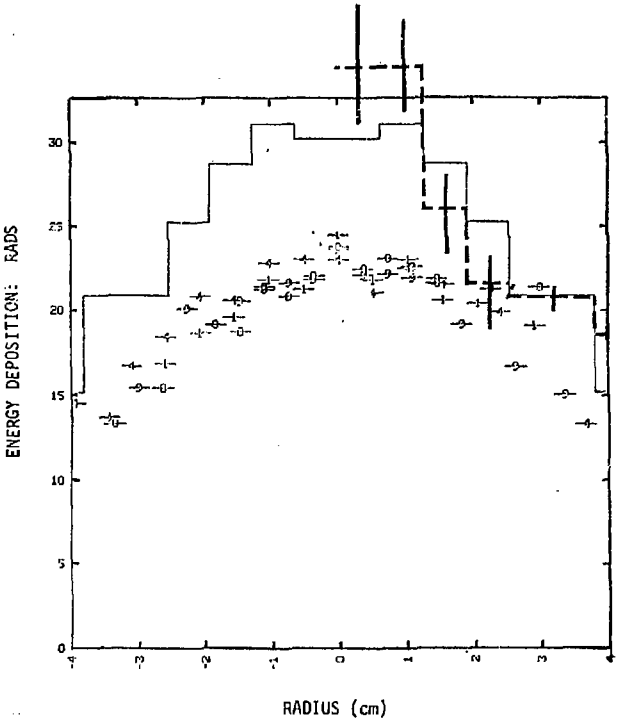
θ experimental data

—— LLL calculations

--- SAI (new) calculations

PLATE 3
800 MeV

Figure 8



e experimental data

—— LLL calculations

---- SAI (new) calculations

PLATE 4

800 MeV

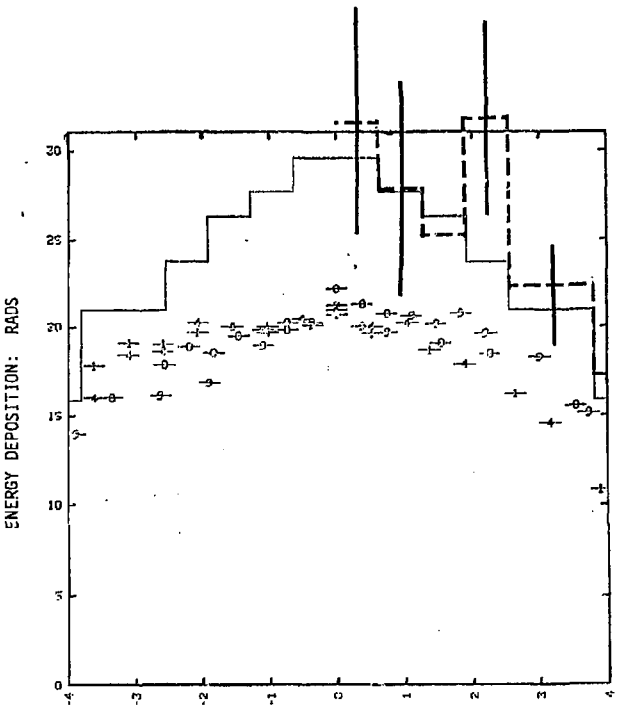


Figure 10

⊕ experimental data

—— LLL calculations

--- SAI (new) calculations

PLATE 5

800 MeV

many source particles as the SAI calculations. Therefore, error bars on the LLNL calculations, omitted for clarity, should be roughly 1/3 the size of those shown for the SAI calculations. Clearly, the calculational results are the same, within statistical error. Because the two versions of HETC were converted from the original ORNL version completely independently, this agreement indicates that both codes were converted correctly in any respect important to energy deposition by cascades from 800 Mev protons.

SAI's 1978 and 1980 calculations were done with the same code and the same input specifications, with the exception of the source radial profile and magnitude. The 1978 radial profile resulted from their fit to the radial profile of energy deposited in the first plate, while their 1980 radial profile resulted (at the request of LLNL) from using the specification given by the experimentors in their final report on the data. A Gaussian is assumed, with width determined by the beam area at half-maximum. This specification, also based on the radial profile in the first plate, was not available to SAI at the time that their old calculations were run. Figure 11 shows the experimental data in the first plate, the 1980 SAI calculated data (as already shown in Figure 6), and the 1978 SAI first plate calculated data normalized to the same total number of incident protons. Figure 11 shows that there is a difference between these 1978 and 1980 SAI radial profiles in the first plate and therefore in the source distribution. Clearly, the

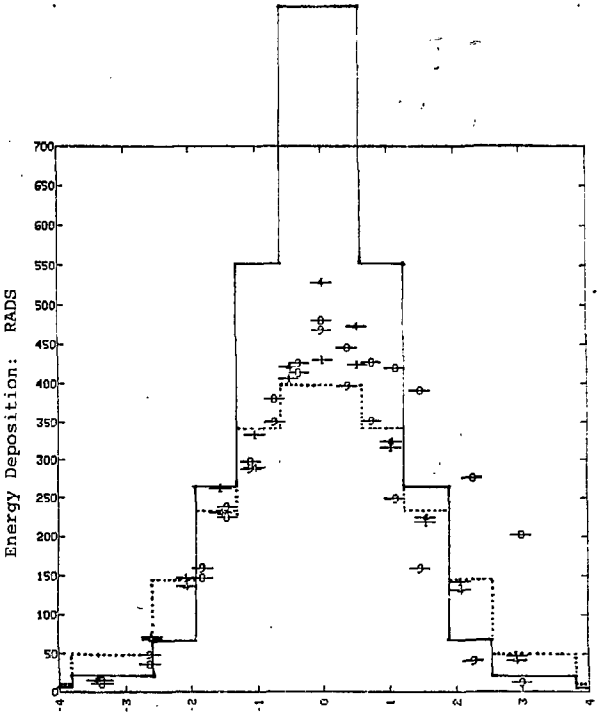

Energy Deposition: RADS
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-4
-3
-2
-1
0
1
2
3
4
Radius (cm)
experimental data
old SAI calculations normalized for 1.4 x 10^11 protons
new SAI calculations normalized for 1.4 x 10" protons
Plate 1
800 Mev

Figure 11

1978 profile is narrower than the 1980 profile. The experimental data are included in Figure 11 only as a reference point for convenience in comparing the two SAI calculational profiles.

The source magnitudes in the 1978 and 1980 SAI calculations were also different. At the time of the 1978 SAI calculations, a final value for source strength was not available. SAI then estimated a source strength of 9.6×10^{10} protons,[8] and divided the experimental data by this strength to obtain (with suitable unit conversions) plots of specific energy deposition expressed as (cal/gm)/(kilojoule incident). Figures 12-16 are duplicates of Figures 6-10, to which have been added the SAI 1978 calculated data based on the SAI estimated source strength of 9.6×10^{10} protons. Color coding, for the various cuts along the beam diameter at four different angles, have been added to these figures to aid in careful comparisons between the calculated and experimental results. The addition of color also serves to emphasize that the apparent spread in experimental data in no way represents the precision of the experiment, but merely reflects asymmetry in the incident proton beam.

The measured incident proton beam intensity of 1.4×10^{11} protons is provided by the experimenters in their final report (op. cit.) All of the calculated data for an 800 Mev beam shown in this report except the "SAI old" (i.e., 1978) data in Figures 12-16 are obtained using this measured source intensity of 1.4×10^{11} protons.

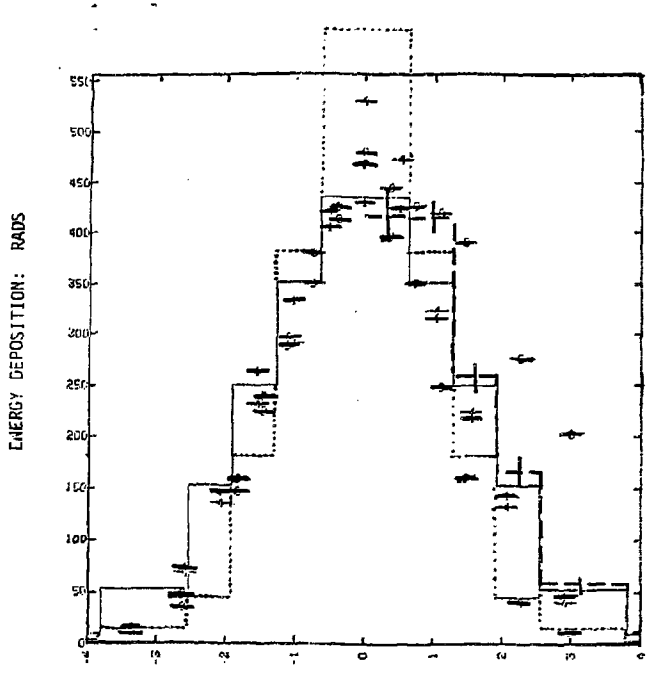

ENERGY DEPOSITION: RADS
RADIUS (cm)
experimental data
LLL calculations
SAI (new) calculation
SAI (old) calculations
PLATE 1
800 MeV

Figure 12

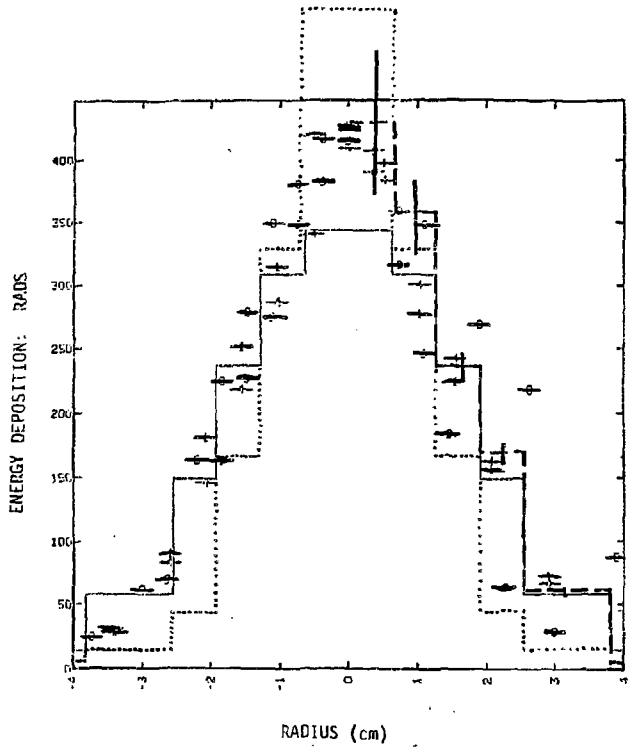


Figure 13

⊕ experimental data

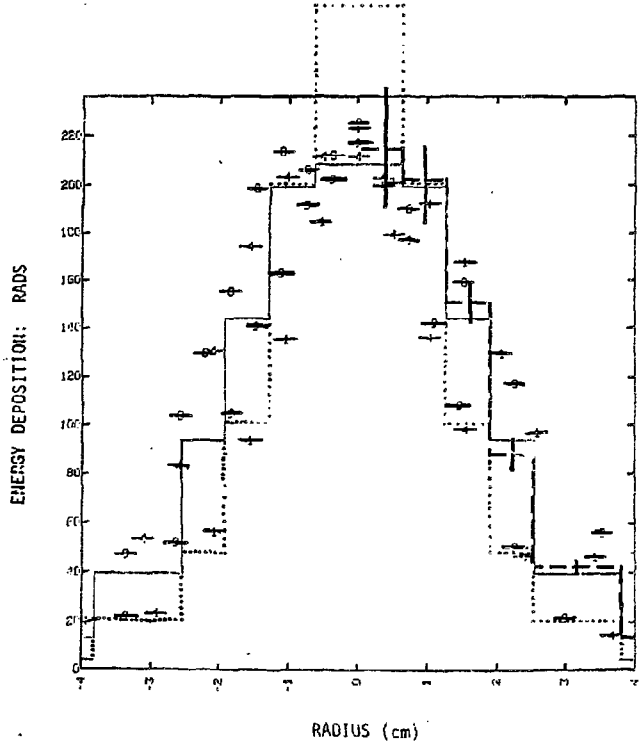
—— LLL calculations

--- SAI (new) calculations

···· SAI (old) calculations

PLATE 2

800 MeV



⊕ experimental data

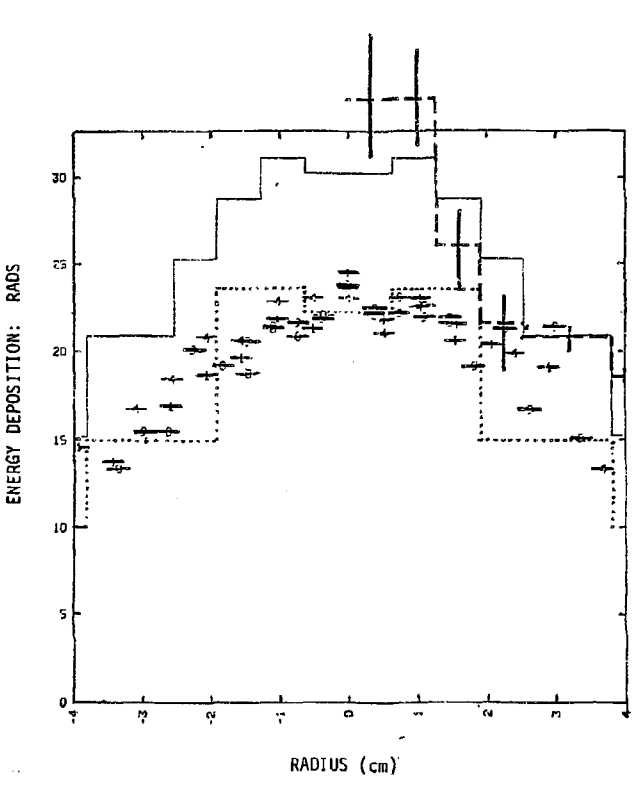
—— LLL calculations

--- SAI (new) calculations

···· SAI (old) calculations

PLATE 3
800 MeV

Figure 14



⊖ experimental data

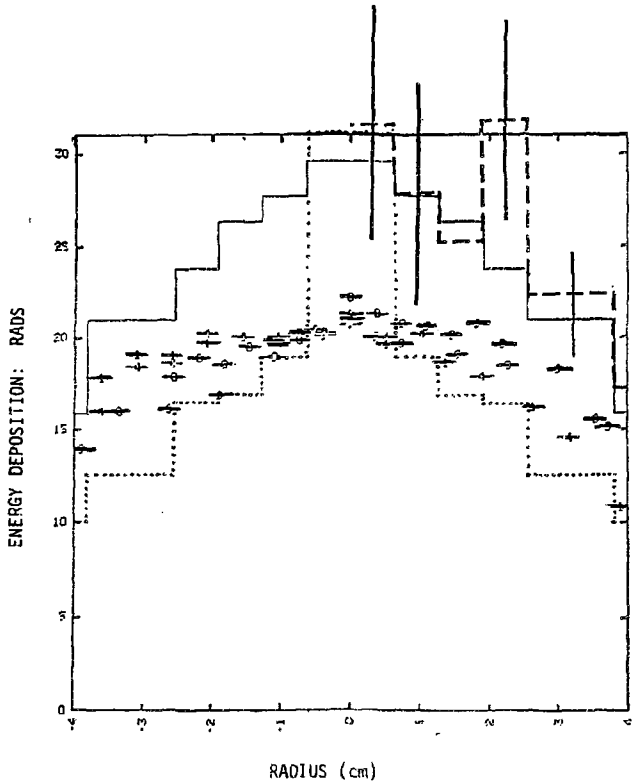
—— LLL calculations

---- SAI (new) calculations

····· SAI (old) calculations

PLATE 4

800 MeV



⊕ experimental data

—— LLL calculations

--- SAI (new) calculations

····· SAI (old) calculations

PLATE 5

800 MeV

It is obvious from Figure 15 that if the 1978 ("old") SAI calculation were multiplied by $\frac{1.4 \times 10^{11}}{9.6 \times 10^{10}} = 1.46$, in order to base them on the measured source intensity, they would agree with the 1980 SAI data to within the statistical error of the Monte Carlo calculations. They therefore would show the same discrepancy in comparison with experiment at the detector plate that all other calculations have shown.

It is worth observing that the reason this 46% difference in source intensity is not glaring in Figure 12 is because the narrower source profile used in the SAI 1978 calculations put roughly enough additional protons in the interior several centimeters to make up the 46% shortfall. (This difference in source profile is washed out at the detector plate-#4). It is also worth noting that this compensation is surprisingly good, so that a discerning eye is required to establish that the SAI 1978 radial profile does indeed not agree as well on the first plate data, on which it was based, as does the radial profile supplied in the experimental final report.

Conclusions

We draw the following conclusions from the preceding discussion.

1) The LLNL version of HETC suffered no errors in the conversion process that affect the 800 Mev beam calculations. (And by extension, there are no code conversion errors affecting any of the calculations necessary to compare with the cited LLNL benchmark experiments).

2) There is an unambiguous discrepancy between the measured and calculated results using either HETC or CASIM.

One consequence that follows from these conclusions is that since the measurements were done carefully and precisely, the discrepancy implies either:

(a) the calculated and experimental circumstances differed in some unknown way,*

(b) there is a deficiency in both HETC and CASIM, most probably in physics models or cross sections embedded in these codes.

These conclusions and consequences require a context for evaluating their significance. On the one hand, the shower plate and detector plate lie fifteen inches apart, so that the experiment represents an exceedingly demanding test for the calculations. Furthermore, applications of interest may not require accuracy to better than 45%.

On the other hand, until the cause of the discrepancy is identified, there can be little realistic confidence that a much larger discrepancy might not occur in another situation - perhaps a similar, but different application for which the right answer is not known. (There is indeed the previously mentioned suggestion from comparisons at other beam energies that the discrepancy becomes larger at lower energies).

---

*There is general agreement, at least by inference, that the known beam asymmetries, which could be modeled in the calculations, would not be important to the results.

REFERENCES:

1. HETC, Monte Carlo High-Energy Nucleon Transport Code, CCC-178 (1970, ORNL. The LLNL version has improved performance made possible by generous aid from T.A. Gabriel at ORNL.

2. "Measurement of Energy Deposited by Charged Particle Beams in Composite Targets," by K. Crase et al., UCRL-52459 (1977).

3. "Energy Deposition by High Energy Protons, Comparison of Theory and Experiment," by W.E. Loewe and C.W. Pollock, UCRL-52944, abstracted in LLL Research Monthly, August (1979).

4. "Code Validation Calculations for a Simplified Target," by T.W. Armstrong and B.L. Colborn, SAI-77-172-LJ (1978).

5. "Evaluation of Fleet Ballistic Missles and Re-entry Systems," Chapter II, by R.G. Ponzini and D.L. Steele, K-7310-78-86 (QPR), (1978).

6. "Evaluation of Fleet Ballistic Missiles and Re-entry Stystems," K-7310-78-82 (QPR), (1978).

7. "Additional HETC Calculations for Flat Plate Target," by B.L. Colborn and T.W. Armstrong, SAI-134-80-226-LJ, (1980).

8. SAI-134-80-226-LJ, (1980), previously cited.