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Summary of the Meeting on the Radiation Survivability of Scintillation Calorimetry

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A meeting on the Radiation Survivability of Scintillation Calorimetry, sponsored by the SSC Laboratory, was held on June 15 and 16, 1989 at Lawrence Berkeley Laboratory. Attendees are listed at the end of this summary. The objective of the meeting was to ascertain the status of the radiation survivability of plastic scintillators and to investigate the effect of radiation damage to scintillators on scintillation calorimetry.

Don Groom began the meeting by reminding us of radiation doses as a function of pseudorapidity (η) and distance from the interaction point for an integrated luminosity of 10^{40} cm^{-2} (an SSC year of 10^7s at 10^{33} cm^{-2} s^{-1}). See attached transparency copy 1. The region of concern for a scintillation calorimeter using present scintillators is at ηs greater than 2.5. At an η of 3 (the maximum considered for a central calorimeter) the dose at electromagnetic shower maximum at 4 m from the intersection point is 2.5 MRad for 10^{40} cm^{-2}. The dose for hadronic shower maximum is approximately a factor of 10 less. For a survival of ten years, scintillation calorimetry would have to withstand ten times the above doses. The approximate profile of radiation dose as a function of depth is shown at the bottom of transparency copy 1. The peak of electromagnetic dose spans a depth of 5 to 10 radiation lengths several radiation lengths in from the front of the calorimeter.

Transparency copy 2, from Stan Majewski's talk, shows the two types of damage induced by radiation to plastic scintillator. Case 1 shows reduction in light production at the site of particle traversal (local scintillation yield). Case 2 shows reduction of transmission of light along the scintillator (attenuation length effects). Case 3 shows a combination of the two effects.

Transparency copy 3 shows the effect of radiation on the transmittance of polystyrene samples. The upper figure shows that the radiation damage occurs chiefly at wavelengths below 700 mm. Hence, if transmission of scintillation light can be accomplished at wavelengths greater than 700 mm, the effects of radiation will be greater lessened. The lower figure shows that the polystyrene recovers transmittance (anneals) after removing the samples from the radiation. In this case the annealing was done in oxygen. There is debate as to the role of oxygen and other gases in the damaging and annealing processes.

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* Operated by the Universities Research Association, Inc., for the U. S. Department of Energy.

Anna Pla of Alan Bross's group at Fermilab presented the data in transparency copy 4. This shows the affects of 10 MRad on the transmission of light in a specific radiation hardened fiber from Kyowa. The radiation hardening was accomplished by shifting light transmittance to longer wavelengths with the 3HF/p-Terphenyl dopants. The three displayed curves were most likely normalized to each other at the ~10 cm distance, hence lessening of local scintillation yield is not shown. What is shown are the attenuation lengths for the non-irradiated, 10 MRad irradiated, and annealed fiber. Attenuation lengths of 1.0–1.6 m for the annealed fiber are shown.

Transparency copy 5, from the presentation of Kurtis Johnson, shows normalized light output as a function of distance from a photomultiplier tube for seven fibers after 10 MRad irradiation and eight days of recovery. The 3HF fiber, the one in the previous transparency copy, is seen to be the most radiation hard. The lower half of the next transparency copy (6) shows recovery times for the various scintillators. Most of the recovery for the 3HF doped scintillators takes place in five days with some additional recovery out to ten days. Siloxane based scintillators show little, if any, recovery.

Transparency copy 7 shows the effect of amount of 3HF dopant on primary (local) light production after irradiation to 100 MRad and recovery. The Bicron F sample has twice the amount of dopant as the Bicron E sample. The absolute amounts are unknown. The light output of the non-irradiated portions of the samples are shown as plateaus in the middle of the plot; the irradiated portions are the tails near normalized output equal 1. Bicron F shows a primary light reduction of approximately 40%. Primary light loss after 10 MRad and recovery was reported as approximately 20% for 3HF doped fibers by Stan Majewski during the meeting, although it was not clear what level of doping was being referred to.

The next transparency copy (8) from the presentation of Roger Clough of Sandia Labs points out a problem with the way radiation damage studies are currently conducted. The upper plot shows the way damage studies are performed. The radiation is initiated at time zero at a high rate to achieve a given dose and then turned off and recovery allowed to take effect. During the radiation, absorbance of the light increases rapidly then recovers afterwards. The operating case for a calorimeter is presented in the lower plot. The radiation dose increases at some lower rate and recovery occurs while the sample is accumulating dose. If no permanent damage accumulates, the absorbance will reach steady state as indicated by the solid line which is asymptotically flat. If permanent damage accrues, then the absorbance will rise with time as indicated by the dotted line. How well an accelerated-radiation-dose test represents the slowly-accumulating-dose operational case is one of the most important items that needs to be studied in the immediate future. This will be done by Roger Clough and his group at Sandia Labs in Albuquerque.

Data on the radiation hardness of polysiloxane plastic scintillators was presented by James Walker. He claimed little or no radiation damage to doses of 10 MRad. James Walker did not want to have his transparencies copied so there are no copies to present.

The summary of Stan Majewski's talk is shown in transparency copy 9. The main conclusions are: 1) the major contribution to radiation damage is due to radiation-induced absorption in the plastic matrix (i.e., reduced attenuation length), 2) recovery is an experimental fact, 3) damage to intrinsic (local) scintillation yield is relatively unimportant (Stan Majewski expressed reservations on this point during his talk), and 4) a remedy for damage is to shift the transmission of light to longer wavelengths and thus away from the damage to transmission that occurs at wavelengths below approximately 700 mm.

Transparency copy 10 presents the objectives of Roger Clough's program to study the effects of radiation on the optical properties of polymers (i.e. plastic scintillators). As can be seen there are a number of variables whose effect can be investigated. Much remains to be done giving rise to the hope that plastic scintillators that can survive doses to 100 MRad can be fabricated.

The second half of the meeting investigated the effects of radiation damage on scintillation calorimetry performance. Transparency copy 11 presents a cartoon of radiation damage in a fiber and a plate scintillation calorimeter. As the top plot shows, the damage is mainly localized to the region of electromagnetic shower maximum which is 5 to 10 radiation lengths thick near the calorimeter front face. The middle drawing shows a fiber calorimeter with damage at electromagnetic shower maximum. In this region scintillation light yield will be reduced by approximately 10–20% and the attenuation lengths will be reduced to order of one meter. These values are for the 3HF scintillators, which are presently the most radiation hard, irradiated to 10 MRad and allowed to recover. For scintillating fibers the role of light production and transmission are both performed by the fiber. For plate scintillation calorimetry, the roles of primary (local) light production and light transmission are separated as shown in the bottom sketch. The upright plates, on order of 10 cm in width, do not impose severe constraints on attenuation length; however, their primary light production should remain high. The horizontally drawn light guide and wavelength shifter needs to retain long attenuation lengths under irradiation.

Transparency copy 12, from Dave Underwood's talk, depicts the average shower profile for a 10-GeV photon shower in the upper plot and the depletion of light resulting from this profile in the lower plot. This depletion integrates to approximately 30% for a 1 MRad dose and no recovery on SCSN38 scintillator. SCSN38 is much less radiation hard (a factor of 5 or 10?) than the newer 3HF scintillators. Also, recovery would probably reduce the 30% light loss to approximately 5%. Considering all the above factors, a 3HF scintillator irradiated to 10 MRad and allowed to recover would have light loss at the photomultiplier tube on order of 10%. The next transparency copy (13) shows an estimate of the effect on resolution from radiation damage having profiles of 0.5 GeV (upper plot) and 10 GeV (lower plot) photons. The resolution effect is estimated for a 10 GeV photon by considering the exponential distribution of shower initiation in conjunction with the damaged zone giving rise to variation in light reaching the photomultiplier tube. The gist of the estimates is that the effect on resolution is on order 1%.

Transparency copy 14 presents a summary of calculations by Hans Paar on light yield and on resolution effects versus the degraded attenuation length in the damaged region of a scintillation fiber. For a degraded attenuation length (λ_{min}) of

50 cm, roughly comparable to a 3HF fiber irradiated to 10 MRad and annealed, the light yield decreases by 7% and resolution increases by 0.2%. These estimates essentially agree with the magnitude of the previous estimates. The effect of primary scintillation light loss are not considered in this calculation.

A concern for plate-wavelength shifter scintillation calorimetry is illustrated in transparency copy 15 from the talk of Allen Caldwell of the ZEUS collaboration. Wavelength shifters are carefully tuned to provide uniform response for light originating at any location. This tuning is dependent on the attenuation length which may change under irradiation. This effect has yet to be investigated.

Calibration and monitoring of scintillation calorimetry will be essential to detecting and tracking of radiation damage. Transparency copies 16, 17 and 18 present a summary of the in-place calibration and monitoring system for the ZEUS detector. Transparency copy 16 shows an example of longitudinal (depth) monitoring with the movable Co^{60} source. Longitudinal monitoring will be essential to detect and measure radiation damage at the SSC. Transparency copy 18 presents the levels of calibration and stability for the ZEUS calorimetry. The Uranium noise (UNO) calibration of the EMC appears larger than desired, but other quantities are reasonable for an SSC experiment.

Transparency copy 19 presents conclusions about radiation damage in a scintillation calorimeter if the 3HF scintillators presently available are used. The zone of concern for the central detector is for pseudorapidity (η) between 2.5 and 3 (assuming the central detector coverage stops at $\eta = 3$). The depth of concern is approximately the first 10 cm of the calorimeter. Attenuation lengths in this zone will decrease to approximately 1 m after annealing of a dose of 10 MRad. This decrease will cause light at the photomultiplier to decrease by about 10% and resolution to increase by about 1%. There will be an effect to the readout balance of the wavelength shifters. Also in the zone of concern, primary light production will decrease approximately 20% for the same dose after annealing. This will decrease light at the photomultiplier by 20% for electromagnetic particles. This will also affect the electromagnetic-hadronic balance of the calorimeter (e/h). Resolution will also increase by about 1% in the electromagnetic section. The above predictions are assuming the accelerated-radiation-dose measurement represents the damage incurred at low dose rates. This assumption will be checked. Damage to other components of calorimetry has not been considered (glues, papers, tapes, etc.). Tests of real calorimeters at high radiation doses are needed.

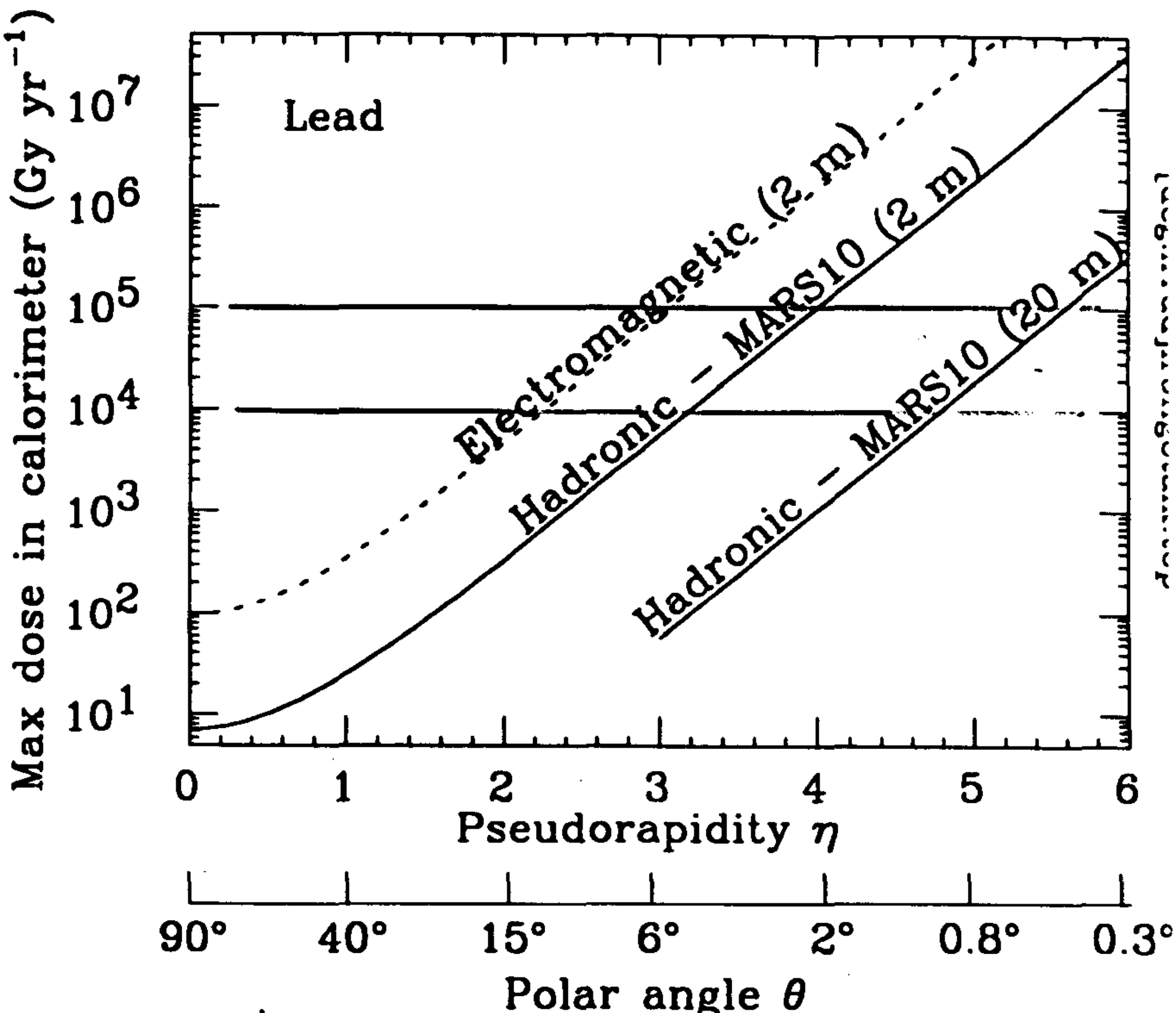
In overall conclusion, radiation survivability of scintillators is an area where progress has been made and progress will continue to be made. Even today while the magnitude of the effects of 10 MRad of radiation are uncomfortable they are not unmanageable. Optimism to make scintillators ten times more radiation hard than present samples was expressed by most researchers.

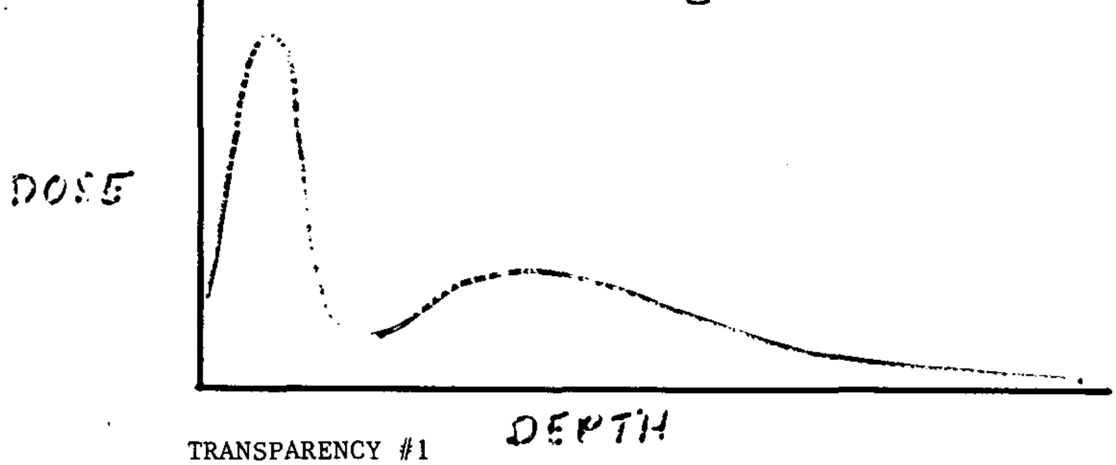
Attendees

Gerry Abrams	Lawrence Berkeley Laboratory
Jim Bensinger	Brandeis University
David Bintinger	SSC Central Design Group/SSC–CDG
Allen Caldwell	Nevis Laboratory
William Carithers	Lawrence Berkeley Laboratory
Roger Clough	Sandia National Laboratories
M. G. D. Gilchriese	SSC Laboratory
Donald Groom	SSC Central Design Group
Charles Hurlbut	Bicron Corporation
Kurtis Johnson	Florida State University
Stan Majewski	University of Florida
Michael Marx	SUNY, Stony Brook
David Nygren	Lawrence Berkeley Laboratory
Hans Paar	University of California, San Diego
Adam Para	Fermi National Accelerator Laboratory
Anna Pla	Fermi National Accelerator Laboratory
Cliff Renschler	Sandia National Laboratories
Rudi Thun	University of Michigan
George Trilling	Lawrence Berkeley Laboratory
David Underwood	Argonne National Laboratory
James Walker	University of Florida
Ed Wang	Lawrence Berkeley Laboratory
James White	Texas A&M University

ИФВЭ.
Tuscaloosa 13 March 1989
D. E. Groom Alabama-18

(c) Dose at electromagnetic and hadronic cascade maximum





TRANSPARENCY #1

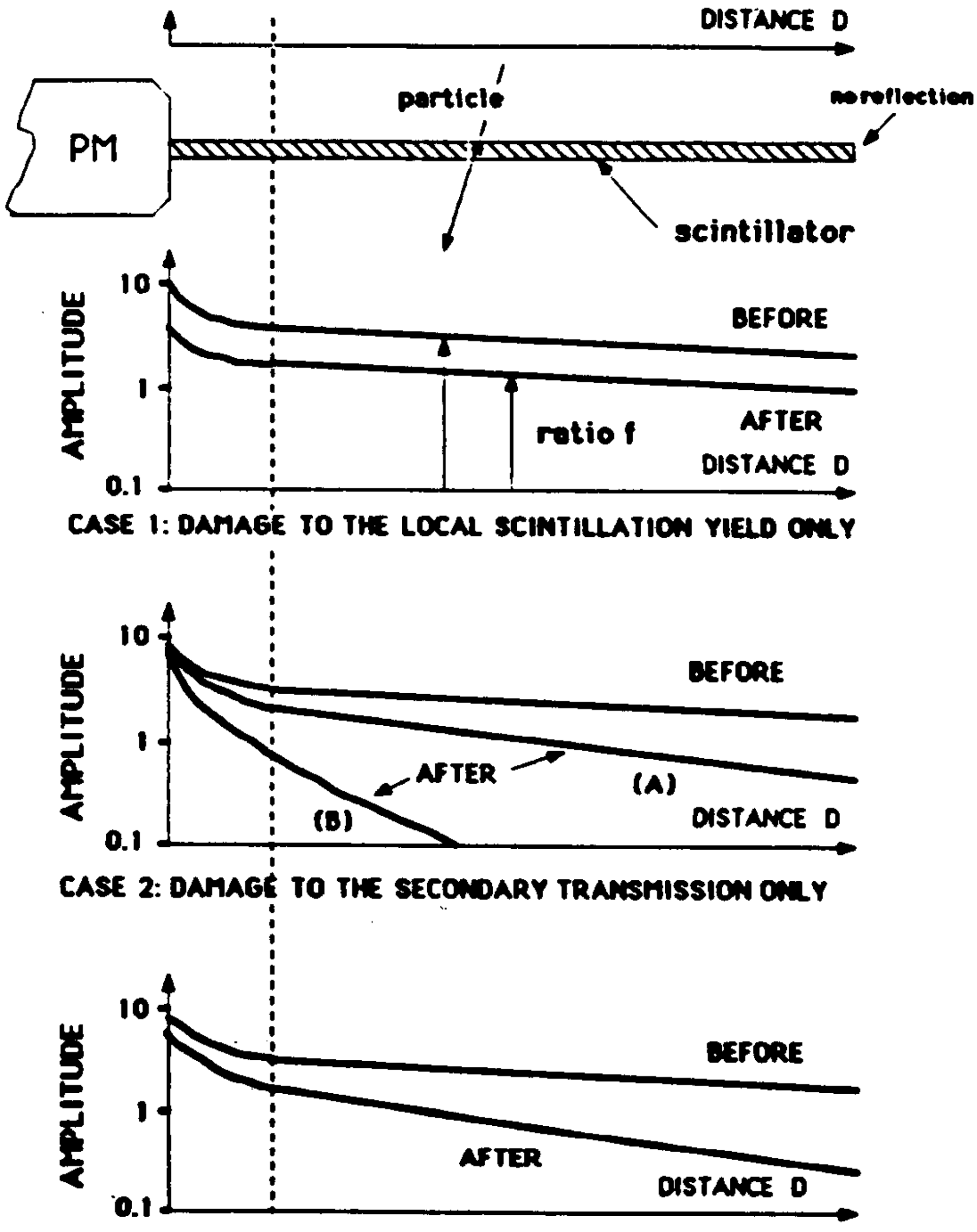


Fig. 2. Radiation damage effects on a scintillation output from a long scintillator, under the assumption of damage to the local scintillation yield only (case 1), damage only to the secondary transmission for two different levels of damage (A) and (B) (case 2), and finally due to a mixture of the two effects (case 3).

Alain Gross

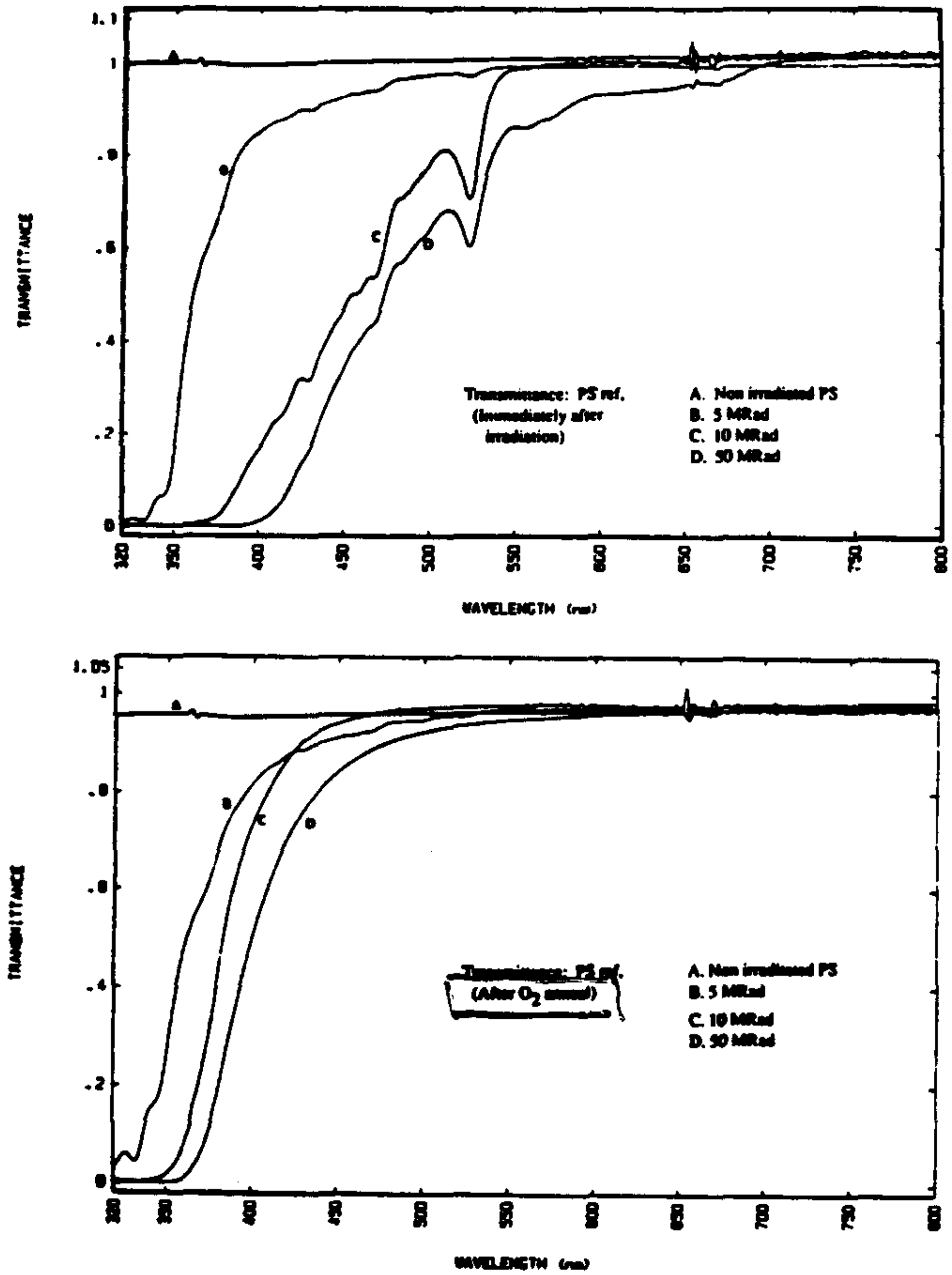
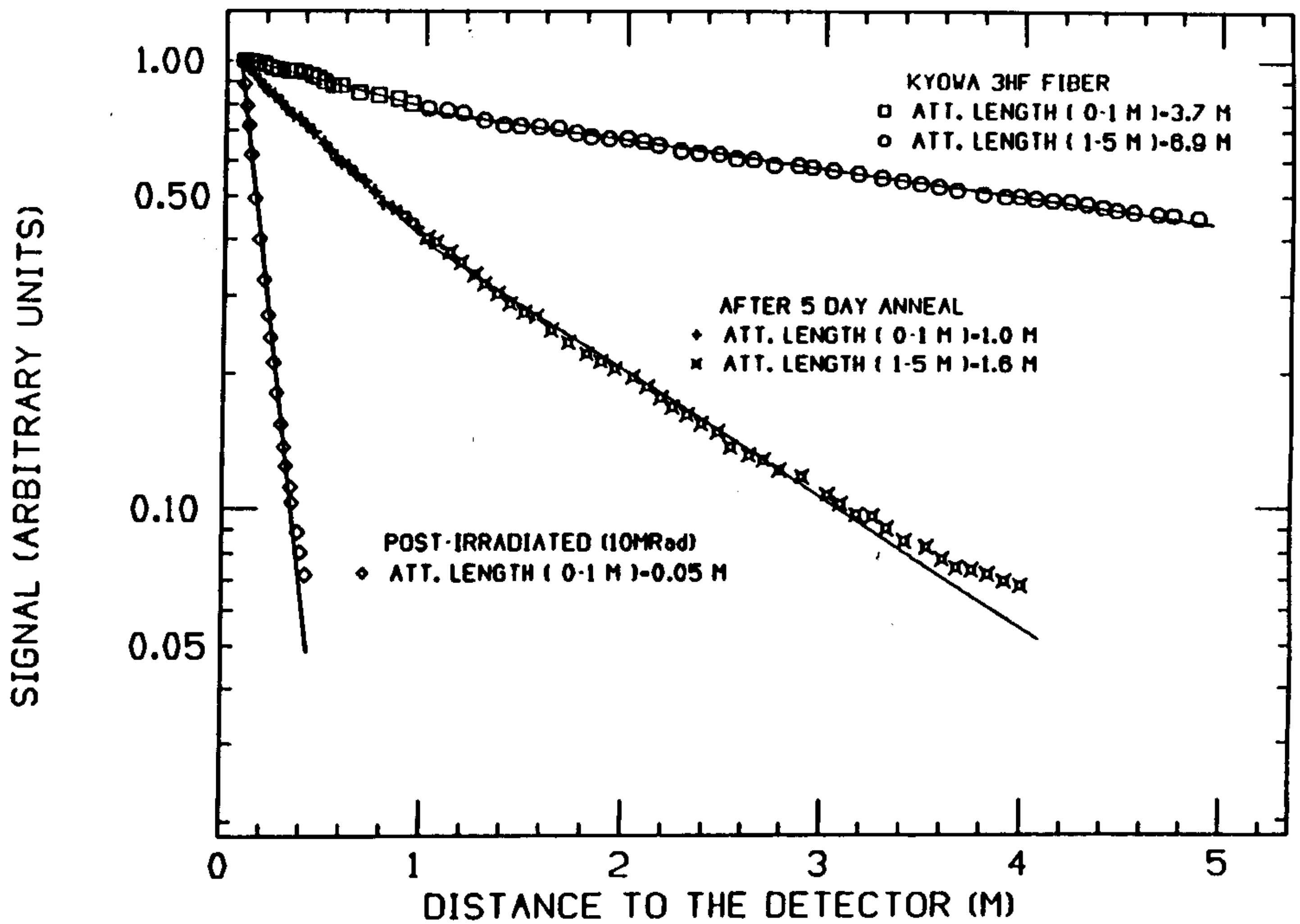
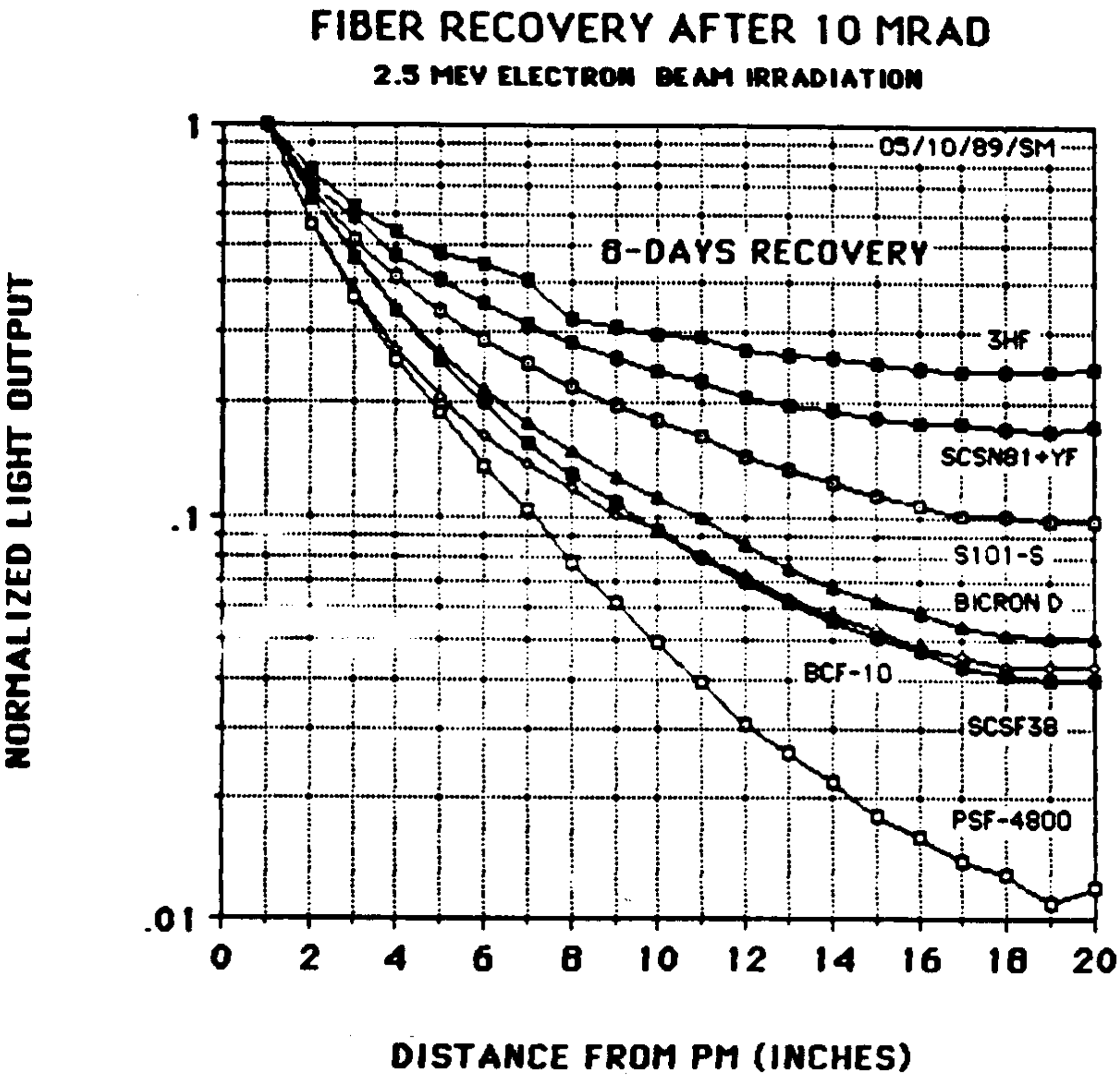


Fig. 6. Transmittance of 1 cm thick polystyrene samples after gamma doses of 5-50 MRad as measured immediately after irradiation (upper figure) and after annealing in oxygen (lower figure). Also, transmittance of a non-irradiated sample (curve A) is shown for comparison (from [19]).

KYOWA 3HF/p-Terphenyl 1mm FIBER



TRANSPARENCY #4



FIBER RECOVERY AFTER 10 MRAD
2.5 MEV ELECTRON BEAM IRRADIATION
05/10/89/SM
8-DAYS RECOVERY
3HF
SCSN81+YF
S101-S
BICRON D
BCF-10
SCSF38
PSF-4800
1
.1
.01
0
2
4
6
8
10
12
14
16
18
20
NORMALIZED LIGHT OUTPUT
DISTANCE FROM PM (INCHES)

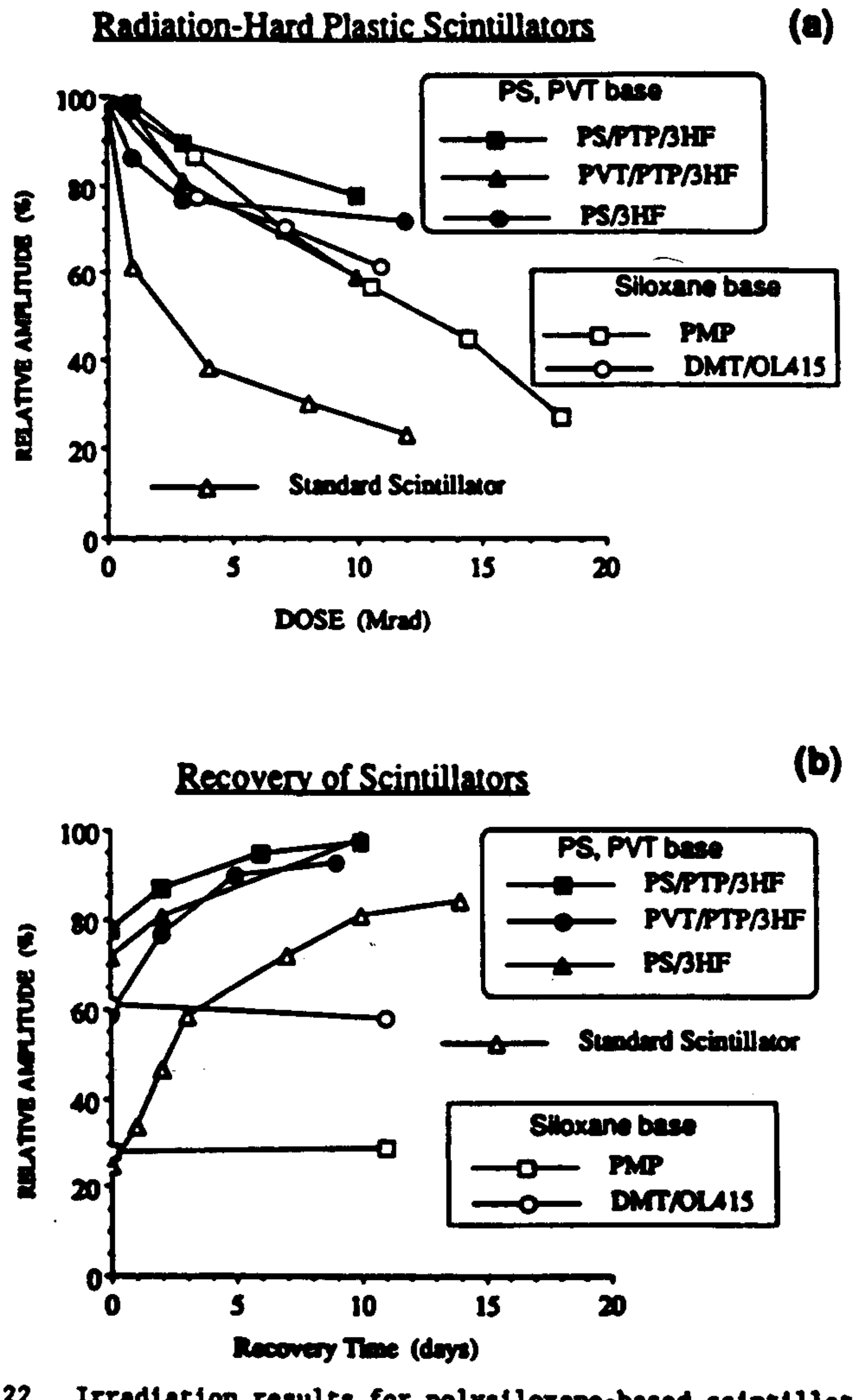
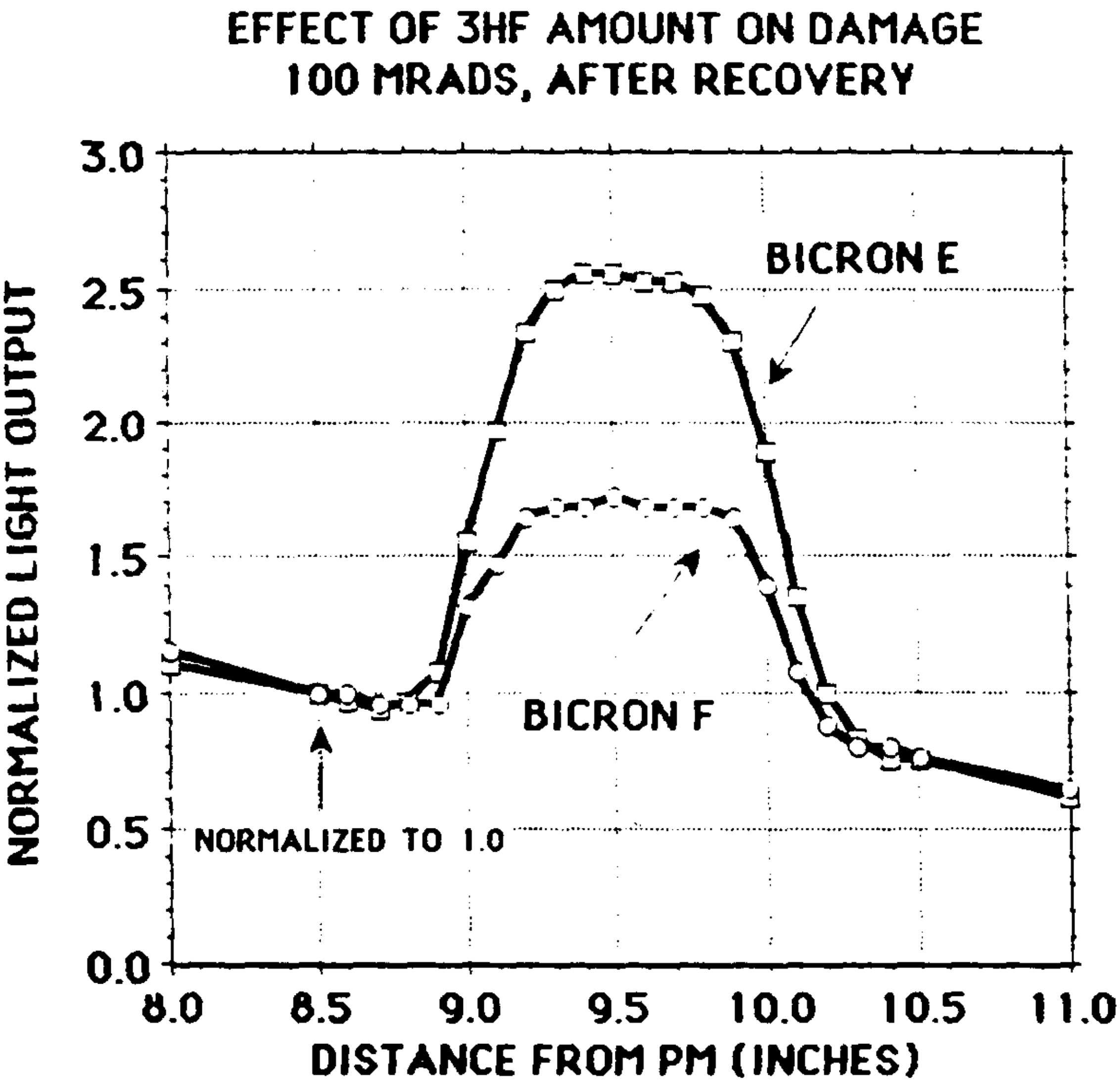


Fig. 22. Irradiation results for polysiloxane-based scintillators and for standard base (PVT, PS) plastic scintillators doped with 3HF. BC408 (standard scintillator) was used as a reference. Scintillation output as measured during irradiation (a), and recovery (b) [46].



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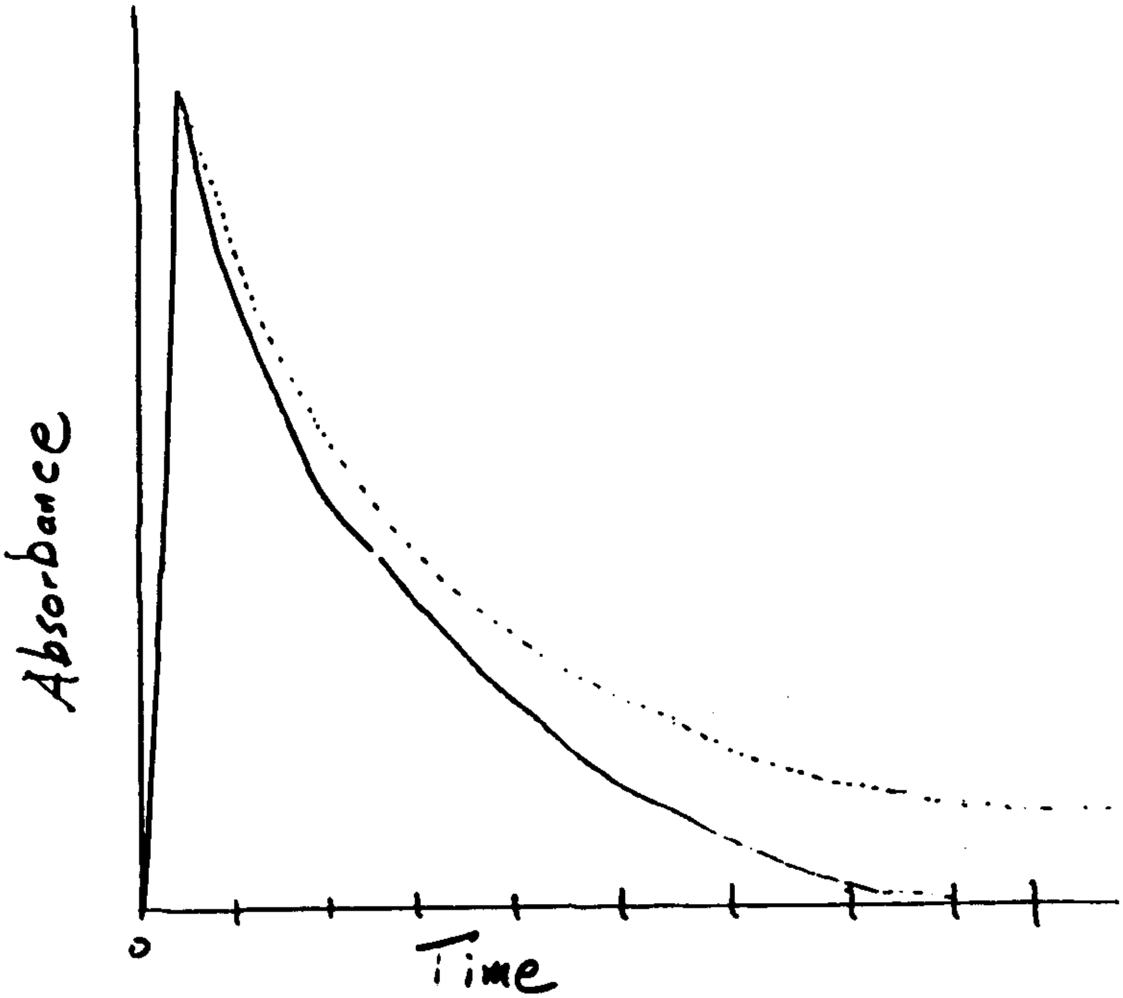
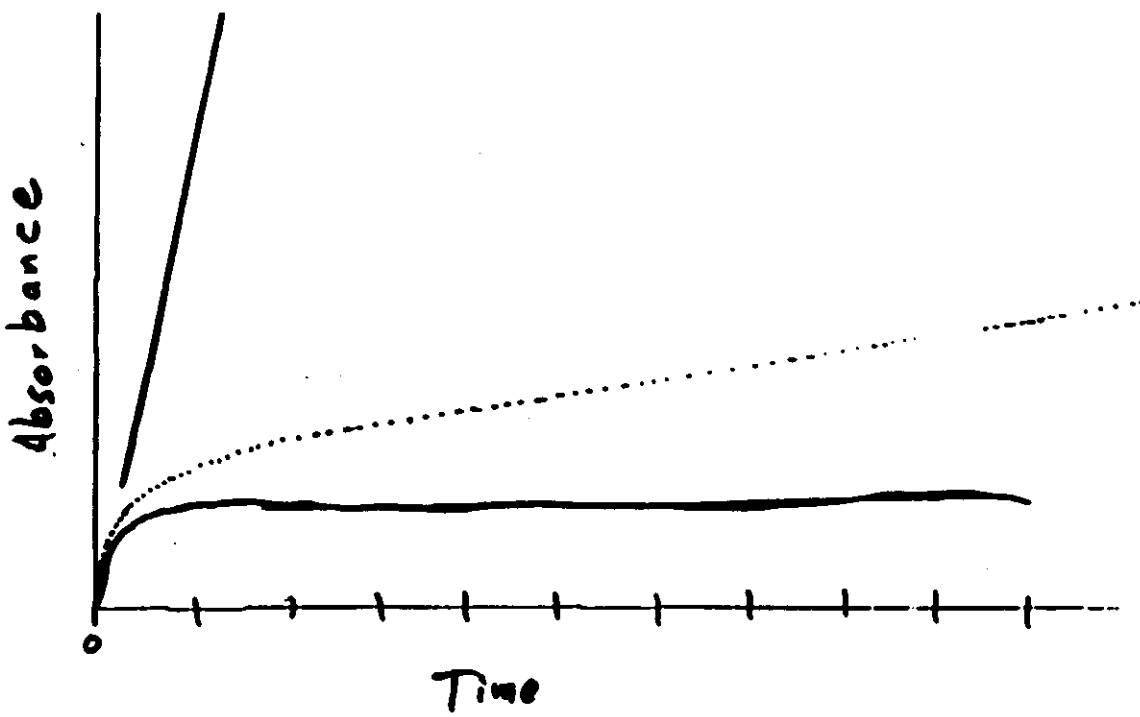




TRANSPARENCY #8

4. SUMMARY OF THE RADIATION DAMAGE RESULTS

(1) The main conclusion from all the presented data is that the major contribution to radiation damage in plastic scintillators comes from the radiation-induced absorption/discoloration in the plastic matrix. In some cases, additional transmissional effects due to fluors were observed.

(2) Recovery of transmission after the accelerated irradiation tests is a very important and well-documented experimental fact that demonstrates the existance of a process of continuous dynamic repair which shall take place in the real experimental conditions. However, at present the exact predictions of the speed and extent of this cure are impossible, especially for air conditions.

JPTb 10MRAD

(3) Damage to the intrinsic scintillation yield of many fluors seems to be relatively unimportant, with some fluor molecules exhibiting in plastic matrices an exceptional radiation resistance approaching our set goal of 100 MRad (example: TPB in polystyrene).

(4) From the above, it stems that the best remedy for the damage problem is to bypass the (permanently) damaged region in the transmission spectrum by long waveshifting of the scintillation light, preferably in a small number of steps by utilizing large Stoke's shift fluors, such as molecules undergoing intra-molecular proton transfer, the examples of which are 3-HF, BPD and HBT.

2.

(5) Oxygen plays an important role in the damage and recovery processes, and from the still preliminary data it seems that the negative effects outweigh the stimulating effect it has on accelerating recovery of transmission in plastics.

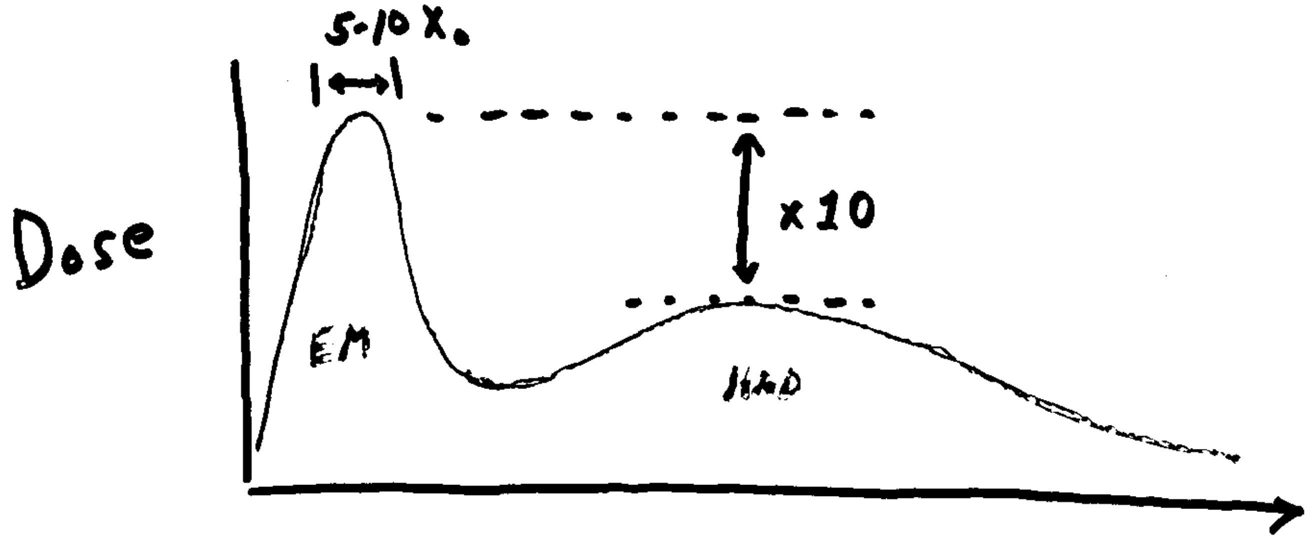
(6) Contrary to the original "common wisdom", polystyrene- and PVT-based scintillators seem to recover (in transmission) in argon and nitrogen, though much more slowly than in air or oxygen.

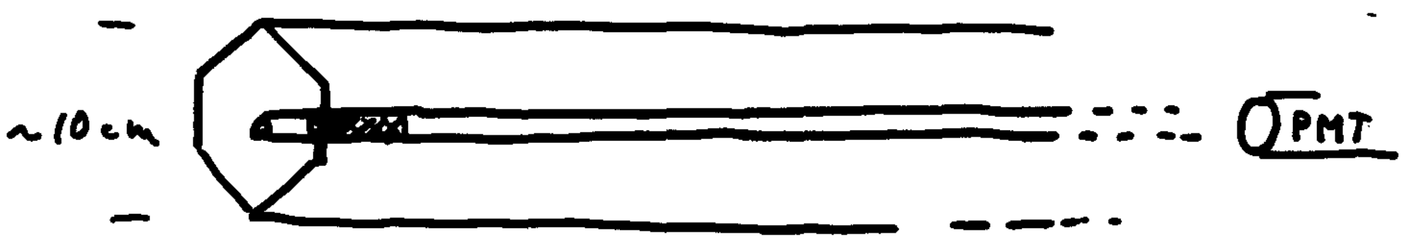
(7) The additional effect of radiation damage to the local primary scintillation yield is probably due to direct transfer of excitation energy in plastic matrices into heat. The experimental data indicate that this is the second non-recovering part of the radiation damage, in addition to residual transmission damage.

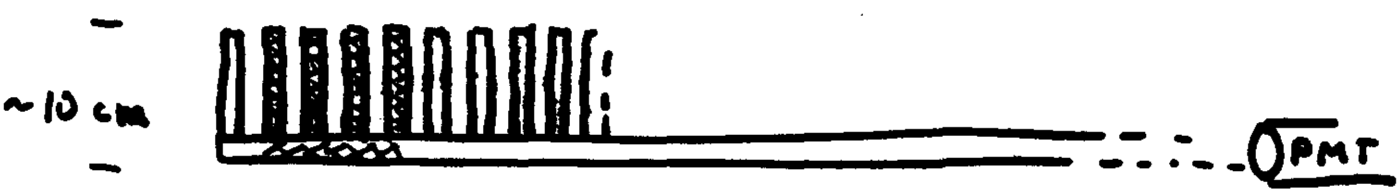
Objectives

- Identify Crucial Factors in the Loss of Scintillation Efficiency:
  - Influence of Polymer Molecular Structure
  - Influence of Dye Molecular Structure
  - Role of Oxygen
  - Role and Nature of Impurities
  - Identify Color Centers
- Evalute Potential Stabilizer Additives
- Develop Predictive (Accelerated) Aging Methodolo[gy]
- Make Lifetime Predictions for Candidate Materials Under Application Environments
- Iterative Development of Improved Radiation-Resistant Materials

(CERN)



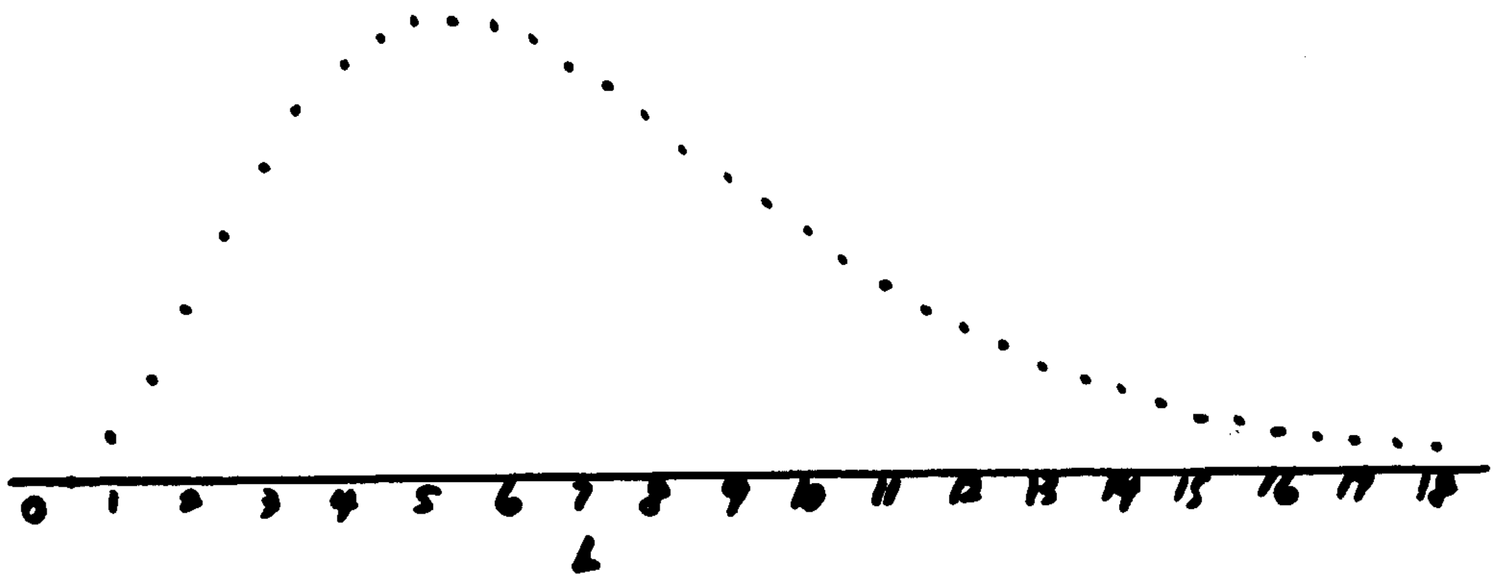


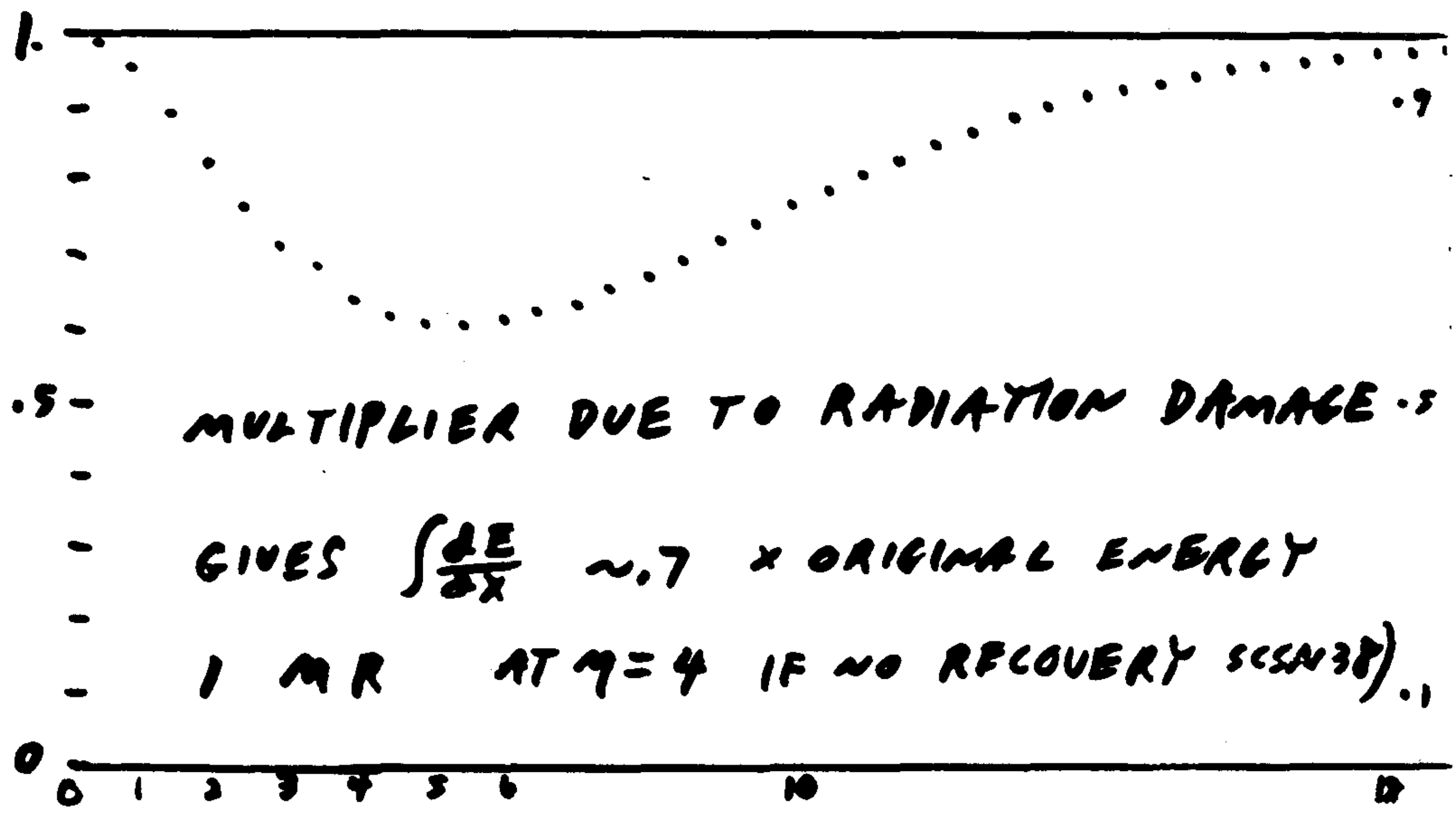


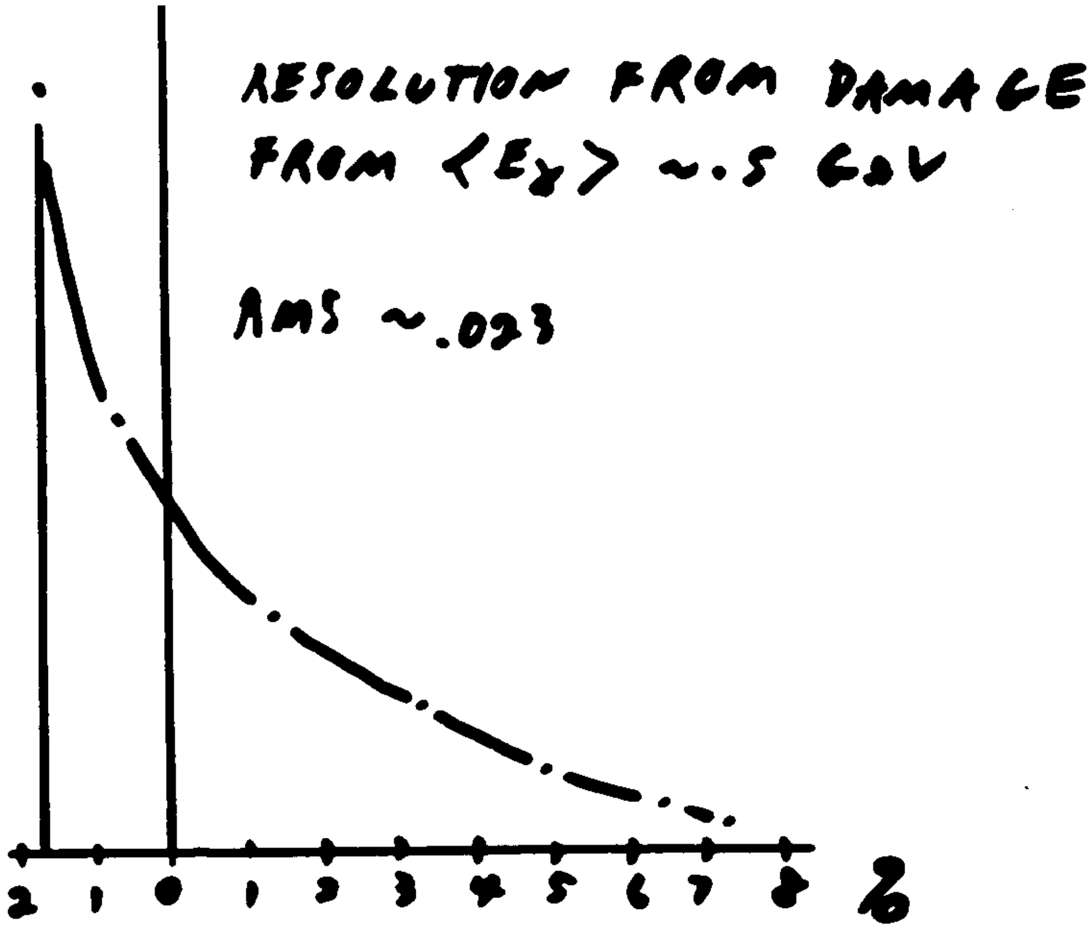
Need Real Calorimeter Test

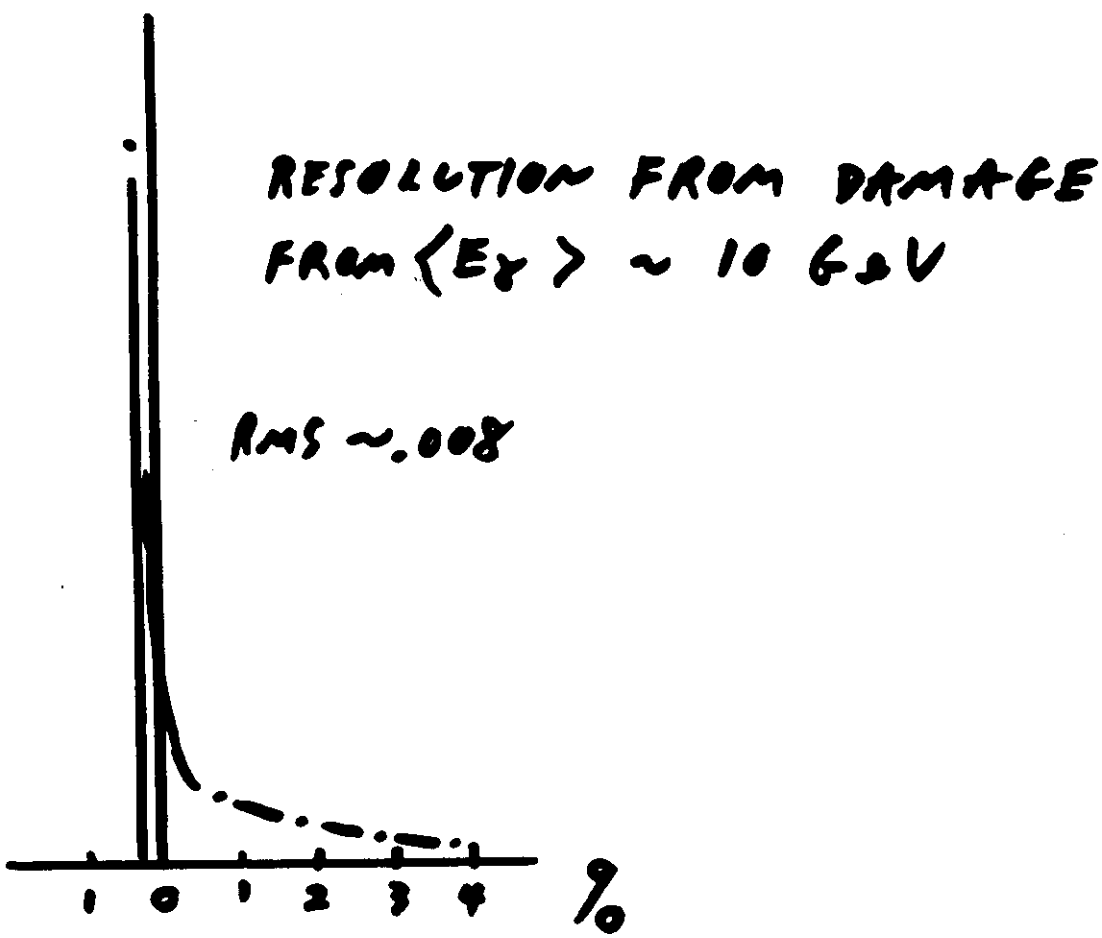
EXTREME EXAMPLE

10 GeV SHOWER ~AVE AT $\eta \simeq 4$







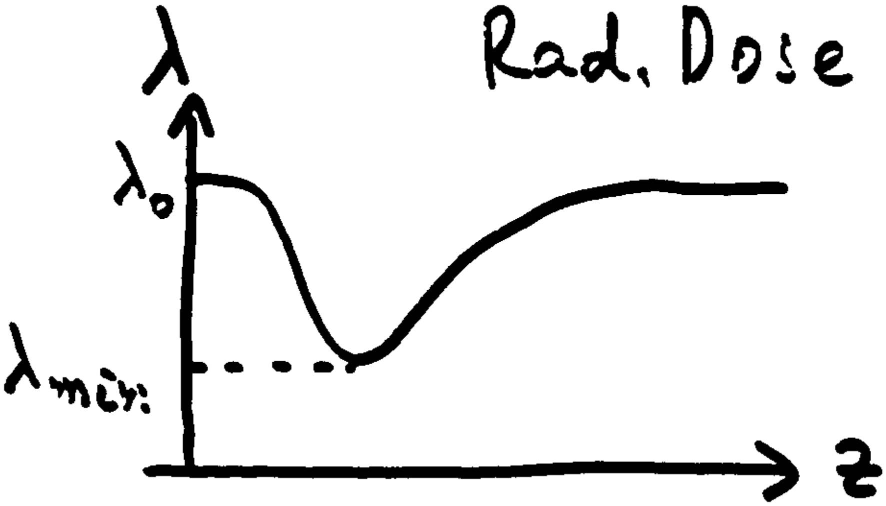


TRANSPARENCY #13

$\lambda(z)$ = attenuation length

set: $\frac{1}{\lambda(z)} - \frac{1}{\lambda_0} \propto$ Rad. Dose

Rad. Dose $\propto \langle \nu(z) \rangle$



use $\lambda_0 = 200$ cm

$R = 0.85$

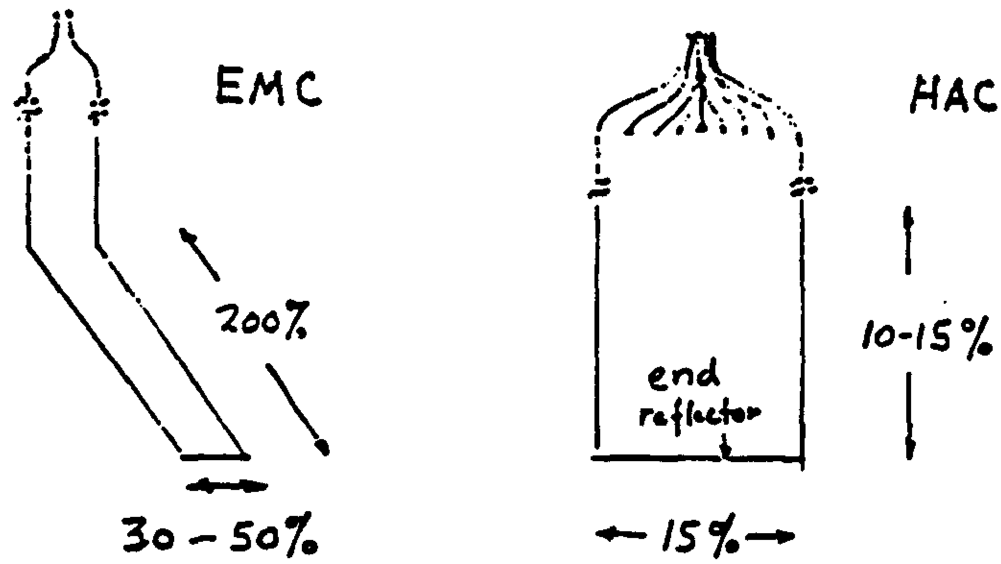
λ_{min}	yield	σ/E
200 cm	498	0.04%
50	465	0.2
20	405	0.6
10	325	1.8

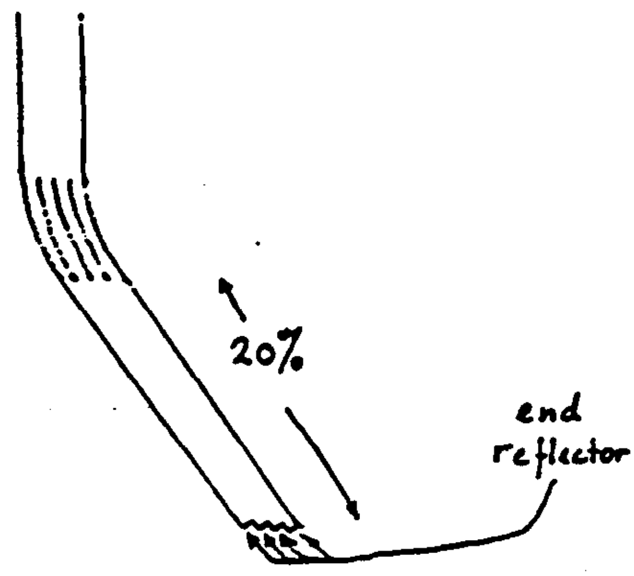
agrees!

EGS and Hadronic MC

next

- WLS NON-UNIFORMITY





- CORRECTION – Reflection Mask

ZEUS Calorimeter Calibration

Tools: DU current
Monitors overall gain of calorimeter + PMT + electronics

Radioactive point source
Monitors longitudinal uniformity of calorimeter

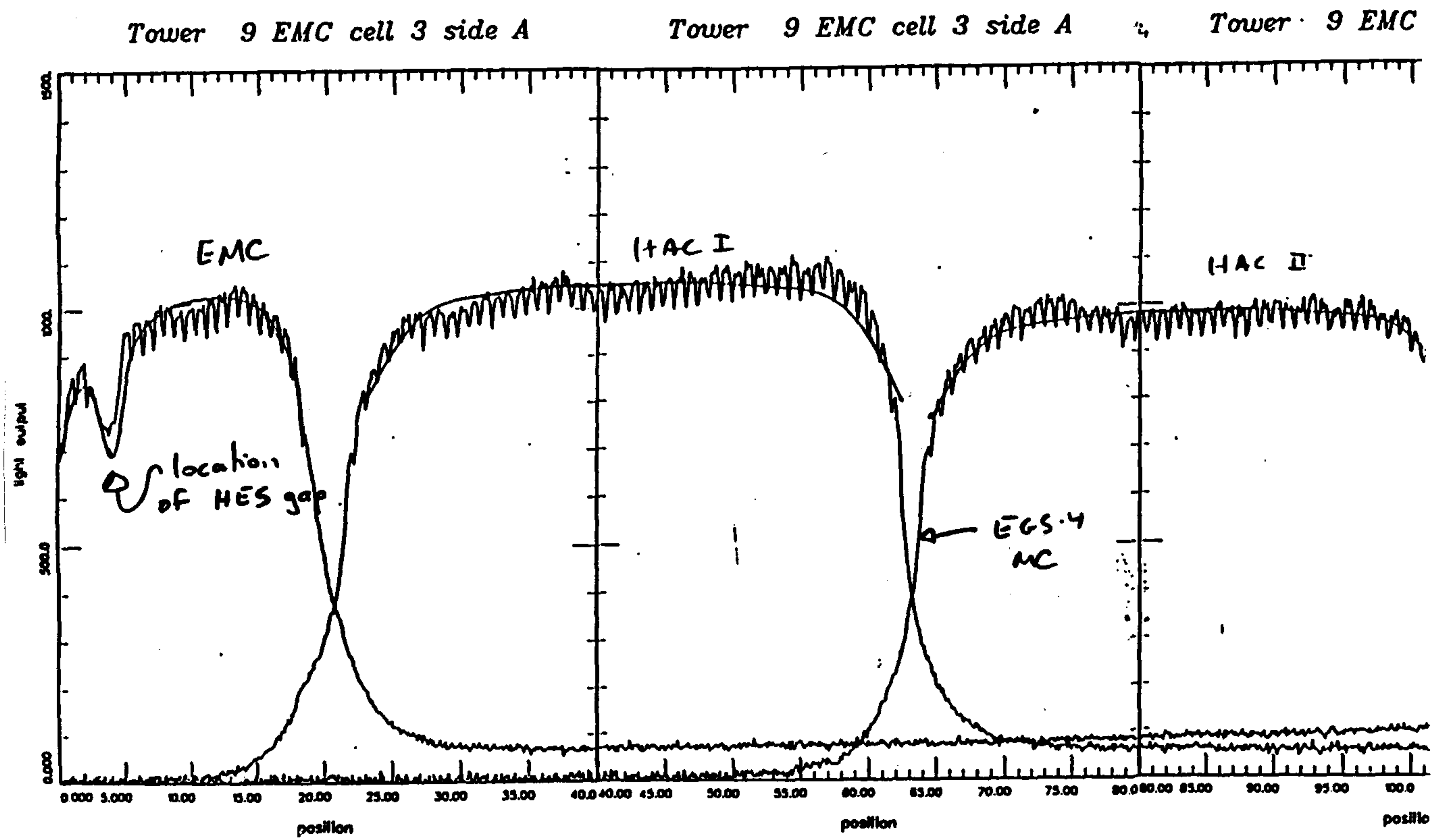
Laser Monitors PMT + electronic

Particles
μ - monitors transverse uniformity + overall gain

e - measures local response (front of EMC section)

h - measures global response of calorimeter

Co^{60} scan   IOU suppressed



TRANSPARENCY #17

SUMMARY

ZEUS U-scinti. calorimeter

$$\frac{\sigma}{E} = \begin{matrix} 18\ \% / \sqrt{E} & \text{for electron} \\ 35\ \% / \sqrt{E} & \text{for hadron} \end{matrix}$$

e/h = 1 (1 - 100 GeV)

calibration and stability

electronics < 0.5 ADC channels
after 24 hours

UNO < 1 % after 8 hours

UNO calibration

EMC 3.5 % (e)

HAC 1.2 % (μ), 1.6 % (h)

Conclusions about Radiation Damage in a Calorimeter

Zone of Concern: η 2.5 → 3
depth 5 to 10 cm at front

Attenuation Length Decrease (to ~1m, 10 MRad, Recov.
Light at PMT decrease ~ 10 %
Resolution increase ~ 1 %
Readout balance (plate-WLS) ?

Scintillation Light Decrease (~ 20%, 10 MRad, Recov.
Light at PMT decrease ~ 20% EM
e/h decreases ?
Resolution increase ~ 1 %

Damage to other components ?

Need Real Calorimeter Test

TRANSPARENCY #19