Fermilab Library
0 1160 0052524 0

SDC-90-00139

SDC
SOLENOIDAL DETECTOR NOTES

RADIATION DAMAGE TO SCINTILLATOR AND WAVELENGTH SHIFTER AND THE RESULTING EFFECTS ON CALORIMETER PERFORMANCE

J. Proudfoot

November 20, 1990

SDC-90-00139
20 November 1990

Radiation Damage to Scintillator and Wavelength Shifter and the Resulting Effects on Calorimeter Performance

J. Proudfoot
High Energy Physics Division
Argonne National Laboratory

Introduction

Results presented at the recent conference on detector R&D at Fort Worth show that radiation damage to plastic scintillator materials has shown them to be much more promising candidates for the sensitive medium in the SDC calorimeter than was thought even one year ago. Several new classes of polymer have been manufactured and used successfully with many old and new dyes appropriate for use in both scintillator and wavelength shifter applications.

My own perception of the highlights of the contributions on radiation damage to the Fort Worth Conference on Detector R&D for the SSC were contained in the following talks:

R. Clough (Sandia Laboratory):

He presented results from radiation damage studies of scintillator for irradiation and recovery in vacuum or inert atmospheres. The vacuum test was carried out by preparing the scintillator in a sealed tube and observing the damage and recovery. His conclusion is that there are different recovery mechanisms at work - potentially stress relief being the dominant mechanism in vacuum and diffusion in the air/inert atmosphere. There is still much work to

be done to fully understand these data. He is also performing accelerated aging studies.

K. Johnson (Florida State University):

He reported on the unpleasant temperature effects he observed with RH1 (accelerated damage after exposure to elevated temperatures). He has repeated these with other plastics and obtained similar effects. This must be taken as a warning that the full history of the plastic must be explored before we can claim to have definitively proven survivability.

C. Zorn (CEBAF):

He reported on accelerated aging studies. At least in an inert atmosphere total dose was the relevant parameter not dose rate.

J. Harmon (University of Florida):

She gave a convincing, solid state physics style, explanation of the damage and recovery mechanisms in terms of stress sites in the polymer. These give local variations in electron density and hence absorption in the UV. These stress sites anneal more readily (or maybe do not even form) if the glass transition temperature of the plastic lies below room temperature. Again, in my opinion there is still a long way to go to fully understand this interpretation but the sign is right.

J. Walker (University of Florida):

He described the good performance of his rubbery polysiloxane and how you could make rubbery Polystyrene by adding ethyl groups onto the backbone of the polymer chain. He now has a industrial partner involved in large scale production. He also passed round a sample "tile" with a WLS fiber in it, which was a rather impressive demonstration of its potential. My main concerns are the solubility of the fluors, air bubble formation in the plate and fibers, and inhomogeneity due to the mechanical characteristics of the

plastic. He did state however, that by further modifying the polymer to increase cross-linking one could gain mechanical rigidity without raising the glass transition temperature above room temperature.

V. Hagopian (Florida State University):

He presented results on radiation damage testing of many sets of fibers and for the first time scintillator plates based on a radiation resistant plastic produced by BICRON Corporation. These results showed that significant progress has been made and that a 1 MRad exposure could be accumulated with little degradation in the performance on the component plastic.

For more details on this rapidly developing knowledge base and conclusions, which are not biased by my own limited understanding of this topic, one can refer to the Proceedings of the Conferences on Radiation Damage to Plastic Scintillator, held at Florida State University in February 1990 and the Fort Worth Conference on Detector R&D for the SSC, held in October 1991.

In addition, to the above promising results the ZEUS collaboration have completed a detailed study of radiation damage to conventional scintillator and wavelength shifter [Ref. 1]. For SCSN38 in air, they measure an intrinsic light loss of 5.1% (reducing to 4.1% after annealing for 223 days in air) following an accumulated radiation dose of 10000 Gy from 25 MeV protons. In addition, they observe concentration dependent effects in the wavelength shifter Y7. They conclude that the presence of oxygen is important for the recovery of radiation damage and therefore plan to use dry air as the gas in the calorimeter.

Finally, to balance the above picture it must be noted that there are still many puzzling affects to be understood. Two of significance are the unexpected damage to the CDF beam-beam counters [Ref. 2] and some of the

observations made in a beam dump damage test of CDF scintillator and wavelength shifter [Ref. 3]. These classes of problem may only be realistically tackled after the basic component properties and calorimeter geometry have been established. Then they must be remembered and dealt with.

Model and Input Data

For this analysis I am going to work from the radiation damage measurements carried out at Florida State University RH1 plate and fibers as this work was carried out within the Calorimeter - Plate Subsystem [Ref. 4,5]. The results on intrinsic light loss obtained in this series of measurements are very comparable to those obtained by the ZEUS collaboration and hence the conclusions up to 500 MRad can be anticipated to be quite reliable. The Tile/Fiber Model I will use is shown schematically in Figure 1. This is the ideal picture of what is wished for in the plate after masking. I use as my ideal optical model:

- Plate dimensions 12 x 12 cm^2.
- Light is collected uniformly along the length of the fiber.
- Maximum distance for radiative transition from scintillator to WLS is 3 cm. (This is the most suspect assumption.)
- Maximum distance propagated in WLS fiber within plate is 12 cm.
- No damage-induced loss of light in the clear fiber going to the photomultiplier tube.

The five pieces of the puzzle I will work from to evaluate the impact of light loss due to irradiation are: photon statistics; light attenuation; in situ calibration rate; scintillator recovery; total dose and dose rate.

a) Photon Statistics

The lead/scintillator EM calorimeter being designed currently has a stochastic resolution of 18%/Rt(E). The effect on this of finite photostatistics is given below.

PE's/GeV	Res. (%) @ 1 GeV	Res (%) @ 10 GeV	Res (%) @ 50 GeV
200	19.3	6.1	2.7
100	20.6	6.5	2.9
50	22.9	7.2	3.2
25	26.9	8.5	3.8

The Freeman/Foster beam test of a fiber tile design measured 250 pe's/GeV (Fig. 2) and is the design goal for this calorimeter. Hence we could accommodate a factor of 10 loss of light without compromising the performance of the detector measurement of electrons from W and Z decay.

b) Effect of Attenuation

It is also useful to have a feel for the light loss from attenuation in the plate over a 3 cm path length as a function of attenuation length.

Attenuation Length (cm)	Light Attenuation (%)
110	2.8
55	5.6
27.5	11.5
13.75	24.4
7.0	53.5

It is evident from these data that unless the assumption about the path length of the radiative transfer is grossly wrong, then light yield is not going to be the issue. Rather the issues will be non-linearity and non-uniformity.

c) In situ Calibration

The W and Z rate at the SSC is enormous. Electrons from their decays can be used to provide a precise calibration on the calorimeter energy scale (as has been demonstrated by the CDF Collaboration). I have carried out this calculation (with some reasonable assumptions about rates and acceptances) for a conceptual SSC calorimeter with granularity (0.05×0.05 η, ϕ). Each calorimeter cell can be calibrated to a precision of 0.4% in a period of 15 days at the design luminosity [Ref. 6]. This is not an unrealistic timescale for calibration (CDF uses about a month for source runs monitoring the response of the calorimeter but actually has run-by-run calibrations for other major parts of the system). Therefore, in evaluating the damage effects I have used 15 days as the timescale to define the calibration precision.

d) Recovery of Light Yield and Attenuation

This is the nastiest piece of the puzzle as the rates and mechanisms are not well understood. The damage measurements on fibers are shown in Table 1 [Ref. 4]. The recovery times are of order a day and the damage exposures were of order hours. The right fiber and the right fluor are clearly essential for this approach to be even considered, as is rapid recovery. Thus the data after recovery will be assumed for the waveshifting fiber. For plates the recovery time scale is of order weeks to months and for these I will compare the ultra-conservative assumption of no recovery with that of full recovery. Finally, as is indicated in Table 1, the damage effects don't scale well with total dose (e.g. RH1 or BICRON G). For this analysis I have used the 3 MRad

data directly for the attenuation length and the scaled light loss (as the conservative assumption).

e) Total Dose and Dose Rate

Finally, there is the question of what total dose and dose rate to assume. The in situ calibration used a luminosity 10^{33} cm-2 s-1 and hence is associated with relatively modest radiation doses in the barrel. However, I will compute the effect of 1 MRad delivered uniformly over 1 year of 350 days.

Analysis

It is now straightforward to calculate the effect of radiation damage in a 15 day period for the 5 pieces of the puzzle given above.

a) Intrinsic Light Loss in Scintillator and WLS Dye

Dye	Before Recovery	After Recovery
RH1	4.3%/MRad	1%/MRad
Bicron G (3HF)	3%/MRad	2.7%/Mrad

Hence light loss per 15 day period is 0.31% before recovery and 0.16% after recovery.

b) Attenuation Light Loss in WLS Fiber

I will make the assertion that whatever dye is used, it's emission peak will be greater than 520nm and hence the effect of attenuation can be estimated using the 3HF data.

The maximum transit distance in green fiber is 12 cm. The undamaged attenuation length is 190 cm and gives a light loss of 6.5%. The attenuation

length after 3 MRad is 167 cm and gives a light loss of 7.5%. The difference is what is significant. It implies a gain shift on average of about 0.5% (negligible in comparison to the intrinsic light loss) and a corresponding damage induced non-uniformity of 0.5%. Thus it is non-uniformity which is the key issue with regard to damage in the fiber.

This evaluation of the effects of radiation damage assumes a point source mapping correction. However, the true optical collection is actually a line source and hence if one assumes a mapping correction as such then the effective non-uniformity can be greatly reduced. This is probably one of the most serious issues for the design of the optical system.

c) Attenuation in Scintillator

Before recovery, the attenuation length in RH1 plate is 7.8 cm (Fig. 3) after exposed to a total dose of 1MRad. Its rather hard to guess the effects at low dose and dose rate as this is self-evidently a non-linear system. Nonetheless I will provoke argument and assume an exponential dependence with dose constant of 2.65 (for dose in MRad). This might even be the correct model if we are studying radiation induced stress dislocations!

Assuming an initial attenuation length of 110 cm, we get that the change in attenuation length in the first period of 15 days is 11.8 cm. The resulting change in light yield is 0.33%. The change in attenuation in the final 15 day period is from 8.7 cm to 7.8 cm with a resulting change in light yield of 5.7%.

After 1 MRad of exposure, the RH1 plate was observed to fully recovery with 22 days. Hence in the scenario of damage and recovery one can expect dynamic equilibrium to occur within this period and that the damage induces fluctuations in the response to be of order 0.3% (i.e. the change observed in the first 15 day period).

d) Depth Non-Uniformity and e/h Response

This has been studied by Tom Handler and Tony Gabriel using the CALOR code system and a different optical system model. The effective loss of light given above is about 4%/MRad/yr. [Ref 4]. Hence the 5 Mrad line in Figures 4 and 5 is the one of interest. This indicates that if we demand e/h equal to 1 within 10%, then the detector lifetime is 8 years @ 1 MRad/yr. However, I believe that these calculations are somewhat pessimistic as they do not include average gain correction as can be obtained in a real detector. A better model is required in this area to obtain an accurate evaluation of this aspect of the calorimeter performance.

Conclusions

With present day scintillators and waveshifters, assuming recovery assumptions are valid, for a 1 MRad exposure delivered uniformly throughout 1 year the fluctuations and changes in response in a 15 day period can be well tracked by in situ W and Z calibration. This would therefore allow the fundamental constant term to be kept below the 1% level as is our goal. If long term aging effects are not significant this result implies that, with a safety factor of 2, present day scintillator can be used out to $\eta = 2$ for 10 years @ $L = 10^{34}$ cm-2 s-1.

The ultimate limit on total dose can not be wholly determined from the current set of data as there is insufficient information on dose and dose rate dependence. However, it must be bounded by the irrecoverable light loss in the fluor system, which would set a limit of approximately 10 MRads if one can tolerate a 50% loss of light (as is the case for our optical design starting with 250 pe's/GeV). Clearly, the assumption of damage and recovery equilibrium in the scintillator response may break down at some point between

3 and 10 MRads total dose. If one assumes the 10 MRad limit, then use of current day scintillator in the endcap calorimeters is also possible if the mechanical design allows replacement of the damaged EM scintillator every 2-3 years.

Finally, the issue of the plastic base is no longer the major limiting factor in the design of the light collection system (and this is more so the case for the longer the wavelength of the scintillator and waveshifter emission). The limiting factors are presently set by the irrecoverable light loss and our ability to maintain a dynamic calibration with sufficient precision. Hopefully work being carried out in the next year will identify dyes capable of withstanding 100 MRad with no loss of light and thereby further reduce the impact of radiation damage on the optical system, and the heavy dependence on calibration.

References

1) ZEUS Status Report, 1989 (unpublished).

2) Beam-Beam Counter inefficiencies - evidence from bench tests and the data, CDF Note 1214

   Radiation damage to SCSN23 , SCSN81 and Y7 scintillators, N. Giokaris, submitted to the Fort Worth Conference on Detector R&D for the SSC.

3) Report on radiation exposure of a lead scintillator stack, D. G. Underwood, ANL-HEP-TR-90-108.

4) Progress report for the Scintillator Plate Calorimeter Subsystem, 1990, H. Spinka et. al.

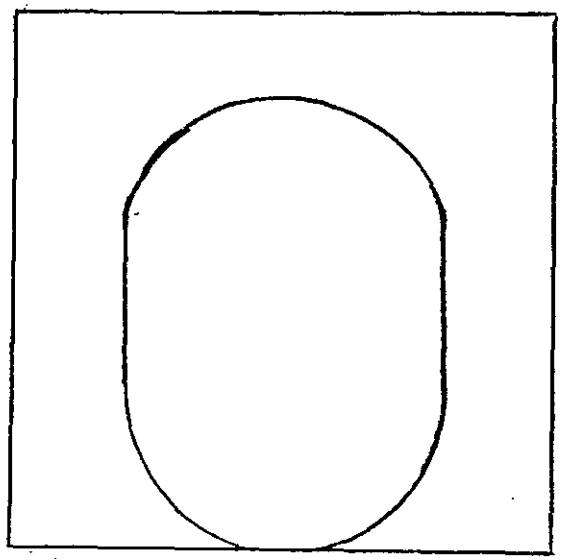
5) Radiation damage tests of new scintillating fibers and plates, V. Hagopian, submitted to the Fort Worth Conference on Detector R&D for the SSC.

6) Radiation tolerance implications for the mechanical design of a scintillator calorimeter for the SSC, J. Proudfoot, ANL-HEP-CP-90-34.

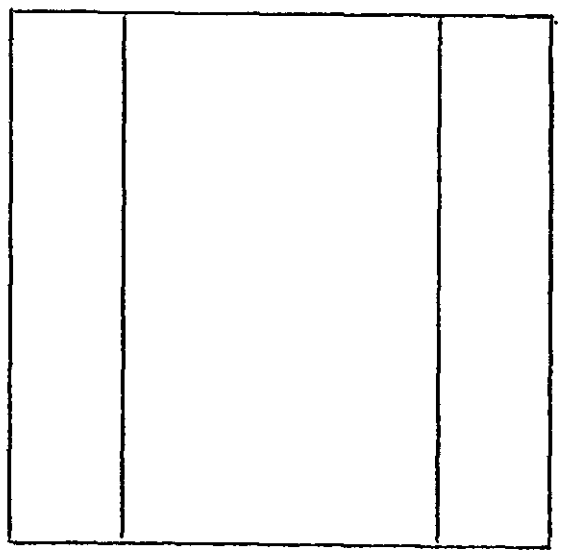
Table 1. (From Ref. 4)

Summary of Radiation Damage of Fibers

Fiber	Attn Length Undamaged	Attn Length No Recovery	Attn Length After Recovery	Light Loss No Recovery	Light Loss After Recovery
BC048 10 Mrad Blue				50%	25%
3HF Bicron 10 Mrad Green	190 cm	< 10 cm	30 cm	35%	25%
Optectron 10 Mrad Blue	200 cm	< 5 cm	12 cm		
CSN81+Y7 Mrad Green	250 cm	< 5 cm	62 cm	25%	9%
SCSN81+Y7 1.2 Mrad Breen	250 cm	< 33 cm	95 cm	7%	2%
Bicron G (3HF) 3 Mrad Green	190 cm	< 10 cm	167 cm	12%	8%
Bicron RH1 10 Mrad Blue	235 cm	< 22 cm	60 cm	17%	8%
Bicron RH1 3 Mrad Blue	235 cm	< 40 cm	75 cm	13%	3%
Bicron RH1 1.2 Mrad Blue	235 cm	< 81 cm	100 cm	8%	1.6%



"Real"
Tile-Fiber Geometry



Schematic
Tile-Fiber Geometry

Figure 1

LIGHT YIELD GOOD -

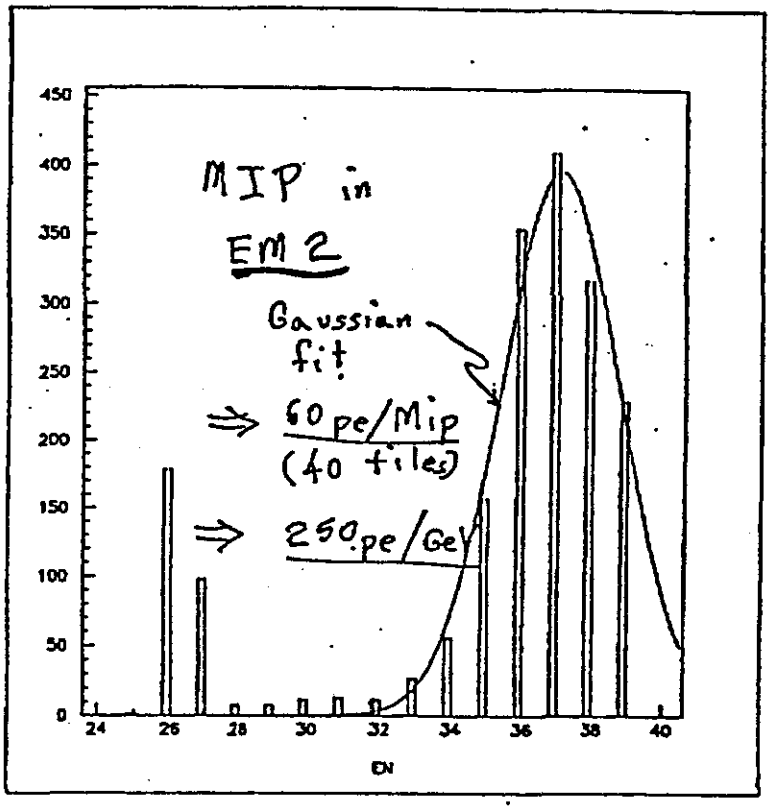


Figure 2

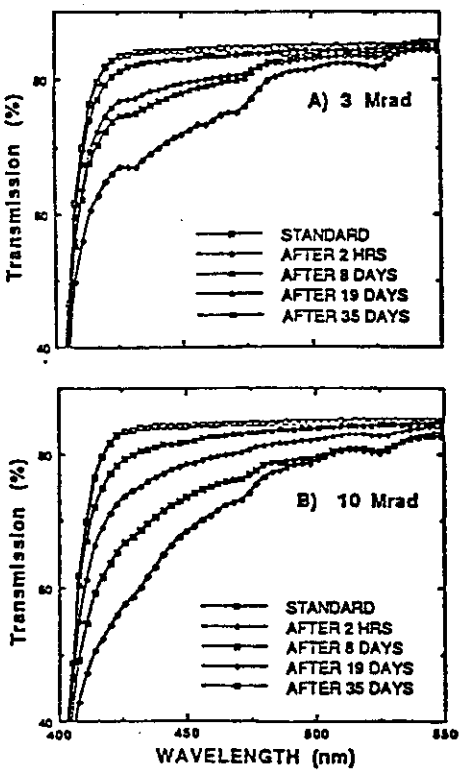


Fig.3. Transmission accross 5 mm RH-1 scintillator plate before and after radiation.

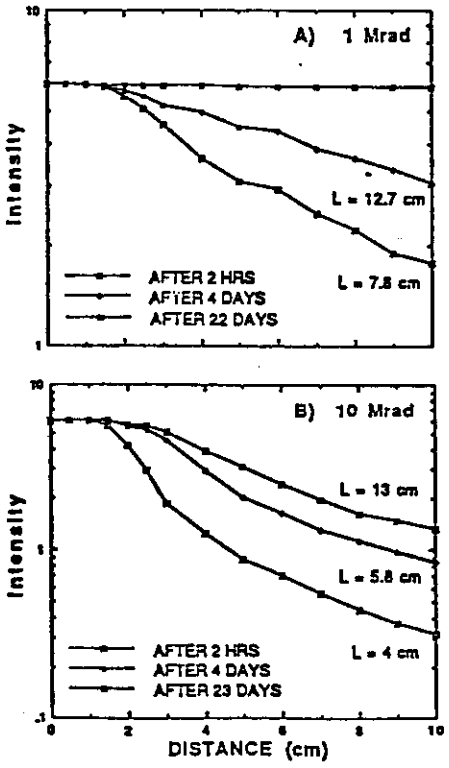


Fig.4. Light yield of 10x2x0.5 cm³ RH-1 plate scintillator. L is attenuation length.

Figure 3

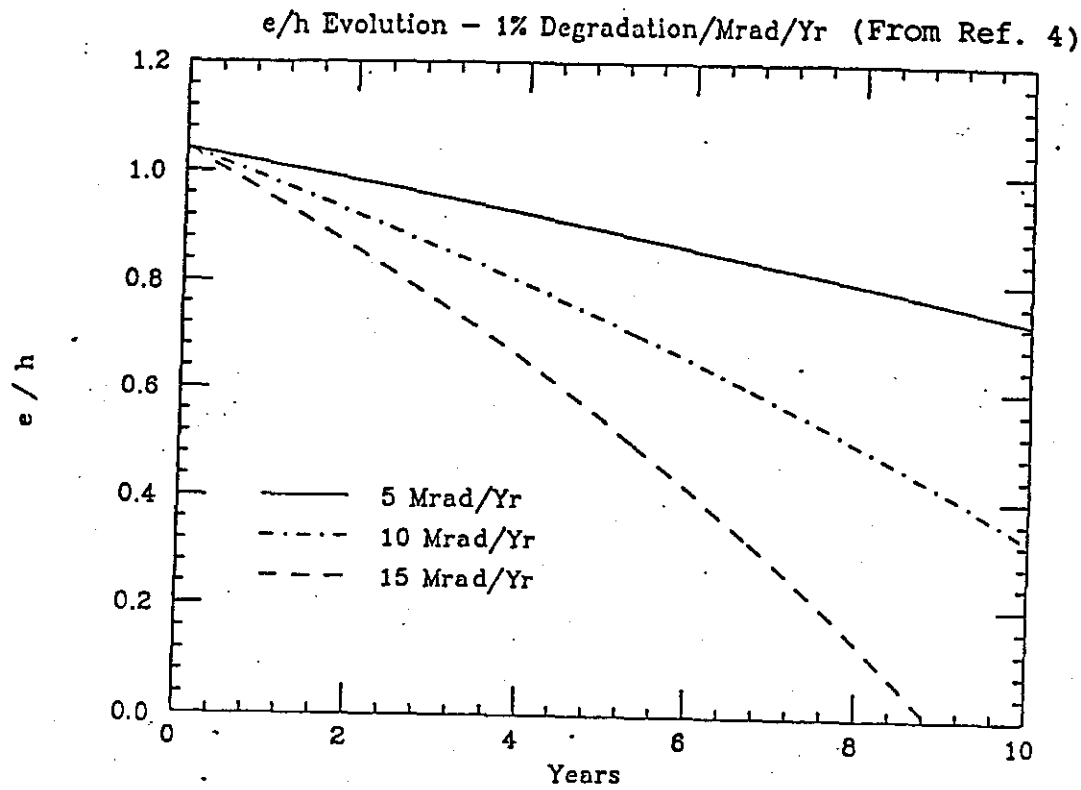


Fig. 7a *e/h* evolution for linear degradation.

Figure 4

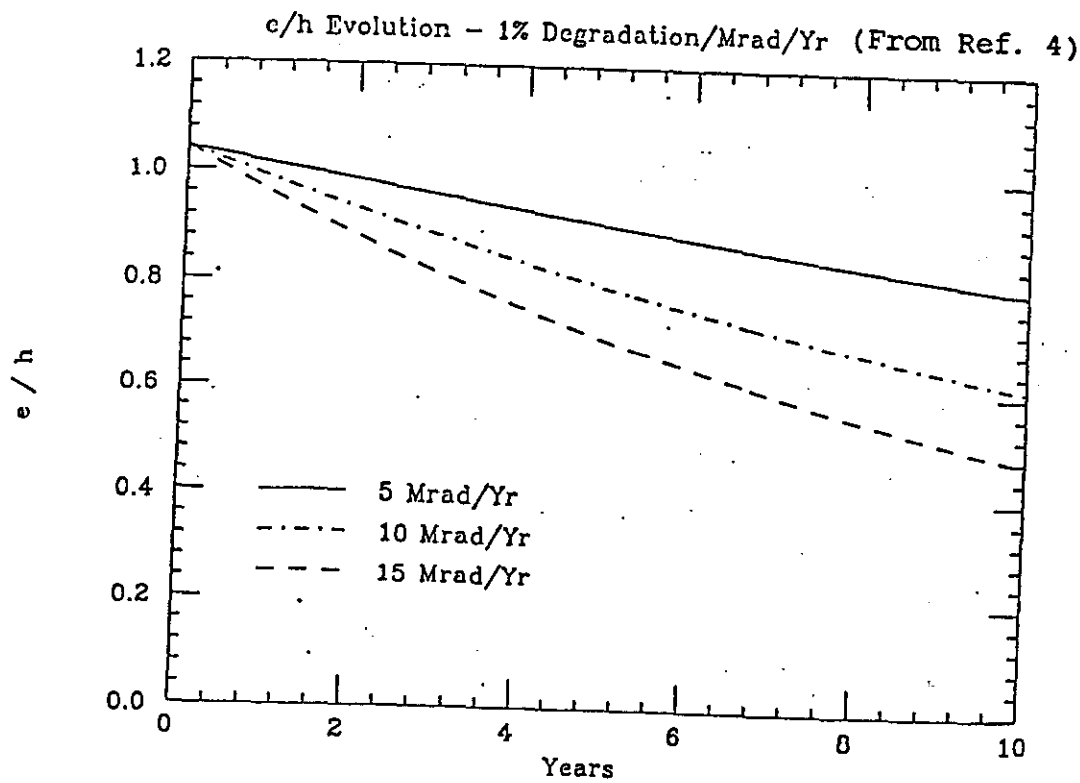


Fig. 7b *e/h* evolution for geometric degradation.

Figure 5