Radiation Resistivity of Pure Silica Core Image Guides for Industrial Fiberscopes

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Industrial fiberscopes incorporating pure silica core image guides have been extensively used for remote visual inspection in radiation fields including nuclear power plants, owing to their superior radiation resistivity. The authors have been intensively conducting R&D on improving radiation resistivity of pure silica core image guides. This paper reports the results of experiments to compare the effects of core materials on radiation resistivity and to investigate the dependence of radiation resistivity on total dose, does rate, and support pipe material. The results confirmed the superior radiation resistivity of the core material containing fluorine at any irradiation condition and indicated the existence of a critical dose rate at which radiation-induced deterioration was stabilized. No difference in radiation resistivity attributable to support layer material was observed.

1. Introduction

Industrial fiberscopes incorporating a pure silica core image guide, which is a coherent multiple optical glass fiber bundle with high purity silica glass core, have been widely used for remote visual inspection in various fields. Above all, superior radiation resistivity and color fidelity of high purity silica glass have extended the use of fiberscopes as "the eyes seeing the invisible" in nuclear environments, where the inspection using the conventional image guides made of multi-component glass is impossible. With the extensive use for remote monitoring of nuclear installations, the demands for the image guides for use in severer nuclear environments have been increasing.

As a result of our R&D on the improvement in radiation resistivity of image guides[1], we have already revealed that the image guides with three-layer structure of core, cladding and support layer, and OH-free, CI-free and F-containing silica core have the best radiation resistivity.[2),3)] In this paper, we report the effects of core material and the dependence on total dose, dose rate, and support layer material of image guides under gamma-ray irradiation.

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2. Experiments

2. 1 Comparison of core materials

Irradiation using ^{60}Co as the irradiation source was carried out continuously. Table 1 lists the image guide core copmositions subjected to the irradiation tests.

The image guides were composesd of multiple fibers in which each pixel with high purity silica glass core is coherently aligned and fused. Our previous work has already found that F is superior to OH in suppressing gamma-ray-induced degradation in high purity silica in visible wavelength region.[2-4] In this experiment, we compared radiation resistivity of various core materials in detail, under different total doses and dose rates based on the previous experimental results. We also investigated the effects of compositions of support layer on radiation resistivity.

Table 1. Image guide samples for irradiation tests

Preform material							Preform structure	Number of picture elements
Core material				Support pipe material				
Symbols	Cl content (ppm)	OH content (ppm)	F content (ppm)	Symbols	Cl content (ppm)	OH content (ppm)		
A	Free	Free	3.500	X Y	4.000 190	Free 540	Three -layer	3.000
B	Free	Free	4.500	X	4.000	Free		
C	Free	750	Free	X Y	4.000 190	Free 540		
D	1.700	30	Free	X	4.000	Free		
E	Free	100	1.500	X	4.000	Free		

3. Results

3. 1 Comparison of core materials

Figures 1 to 4 plot the spectral loss characteristics of image guides with different core materials under gamma-ray irradiation at 2×10^4, 2×10^5, 5×10^5, and 1×10^6 R/h (irradiation time was 50, 50, 20,and 25 hours, respectively). Core materials A and B show superior resistivity particularly in visible wavelengths. Core material E, which has lower resistivity than core materials A and B, shows the behavior peculiar to both F and OH. As its OH content is as low as 100 ppm, its characteristics are rather similar to those of core materials A and B than those of core material C, which contains OH only. The difference in resistivity between core materials C and D shows a turning point at around 570 nm; below this point, core material C has better resistivity, and above this point alternatively, core material D is better. This turning point shifts to longer region gradually as the dose rate becomes higher. While core material D shows far higher radiation-induced loss in the region from 400 to 500 nm, core material C is better than core material D in whole visible region. The influence of OH in the core materials is clearly observed in the loss characteristics at around 480 and 600 nm. Core material C, containing 750 ppm of OH, shows two absorption peaks there. Core material E containing 100 ppm of OH, has a peak at 480 nm,but its peak at 600 nm is obscure. Though it has been already reported that the absorption at 600 nm depends on OH content,[5] the absoption peak at 480 nm has not been reported yet, even in our test results of OH containing single optical fibers. We assume therefor that this peak is peculiar to image guides and is caused by the combination of the presence of OH and the manufacturing process of image guides.

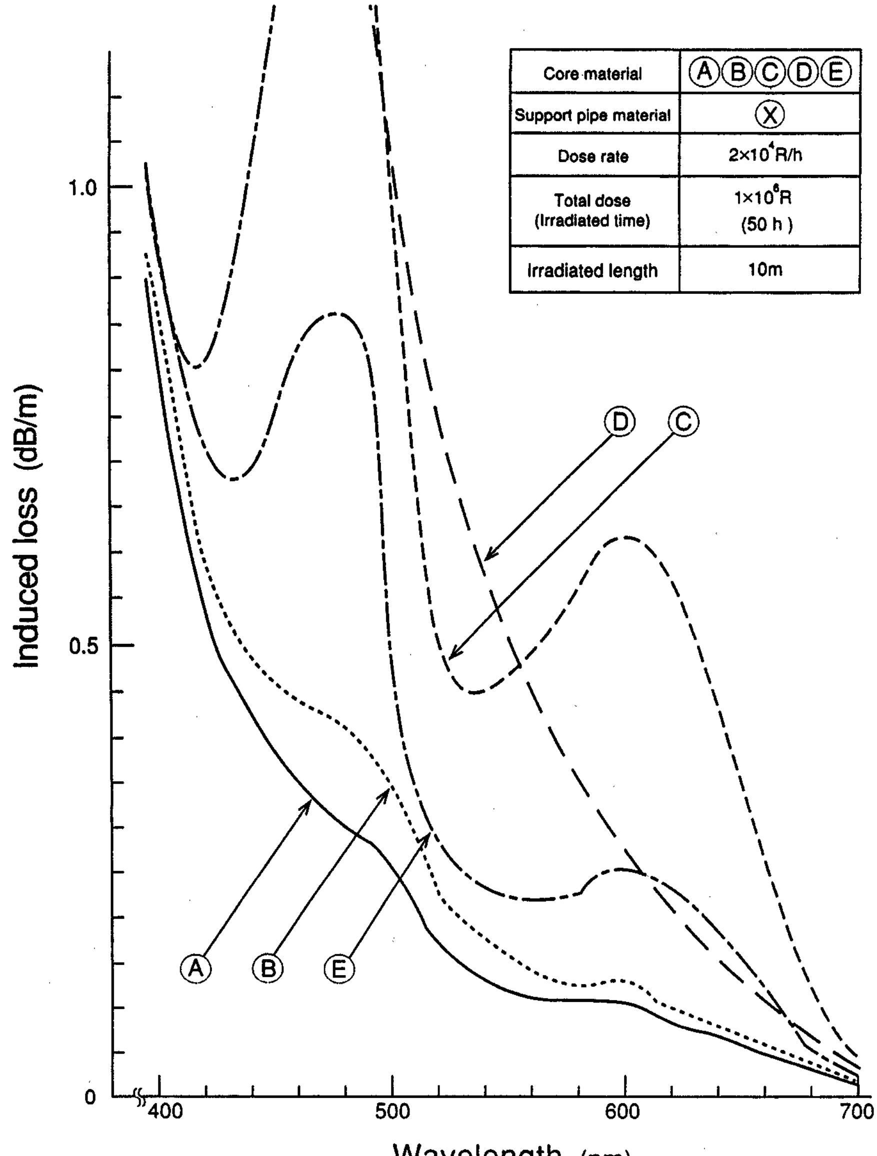


Fig. 1 Core material dependence of in-situ radiation-induced losses (at 2×10^4 R/h and 50-hour irradiations).

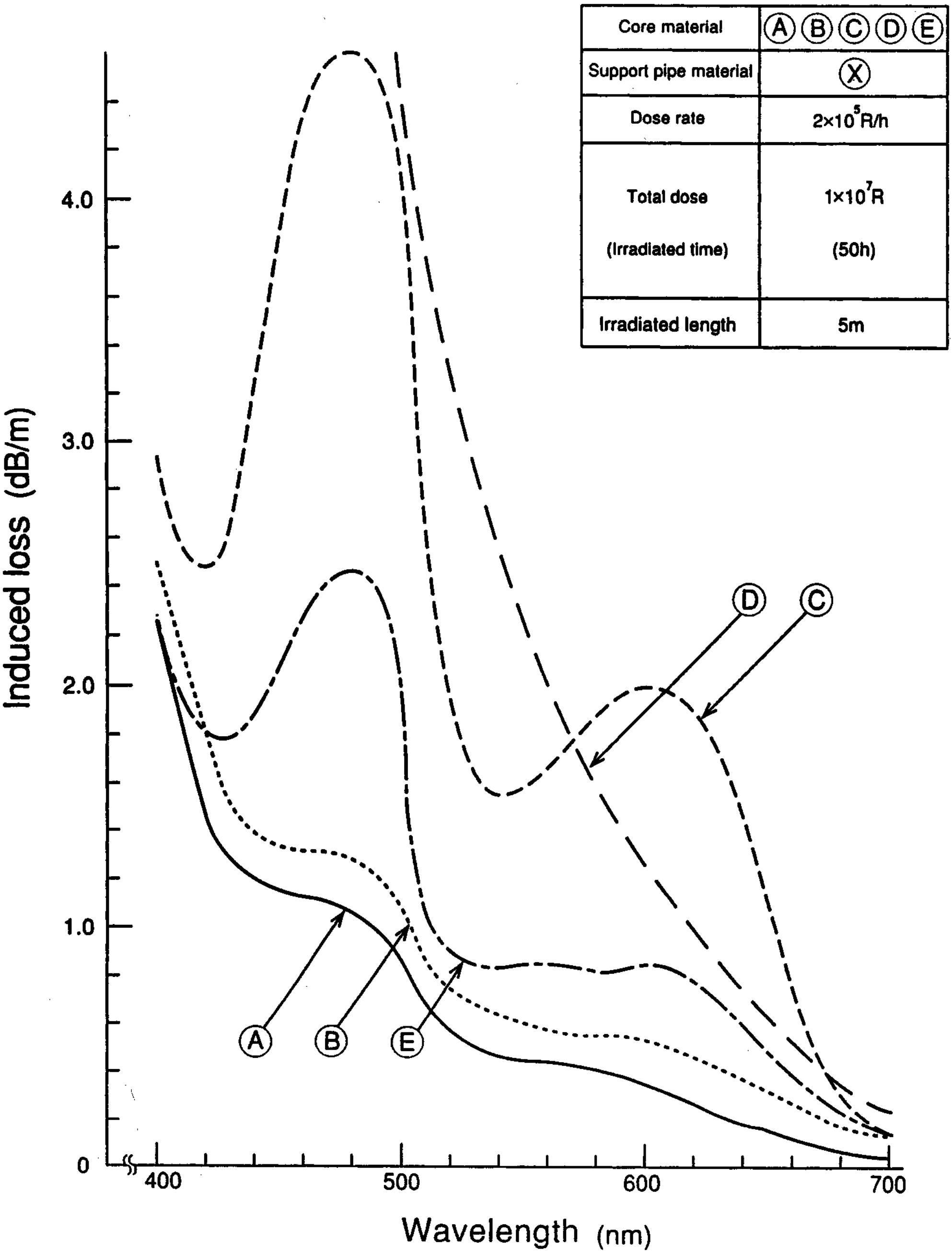


Fig. 2 Core material dependence of in-situ radiation-induced losses (at 2×10^5 R/h and 50-hour irradiations).

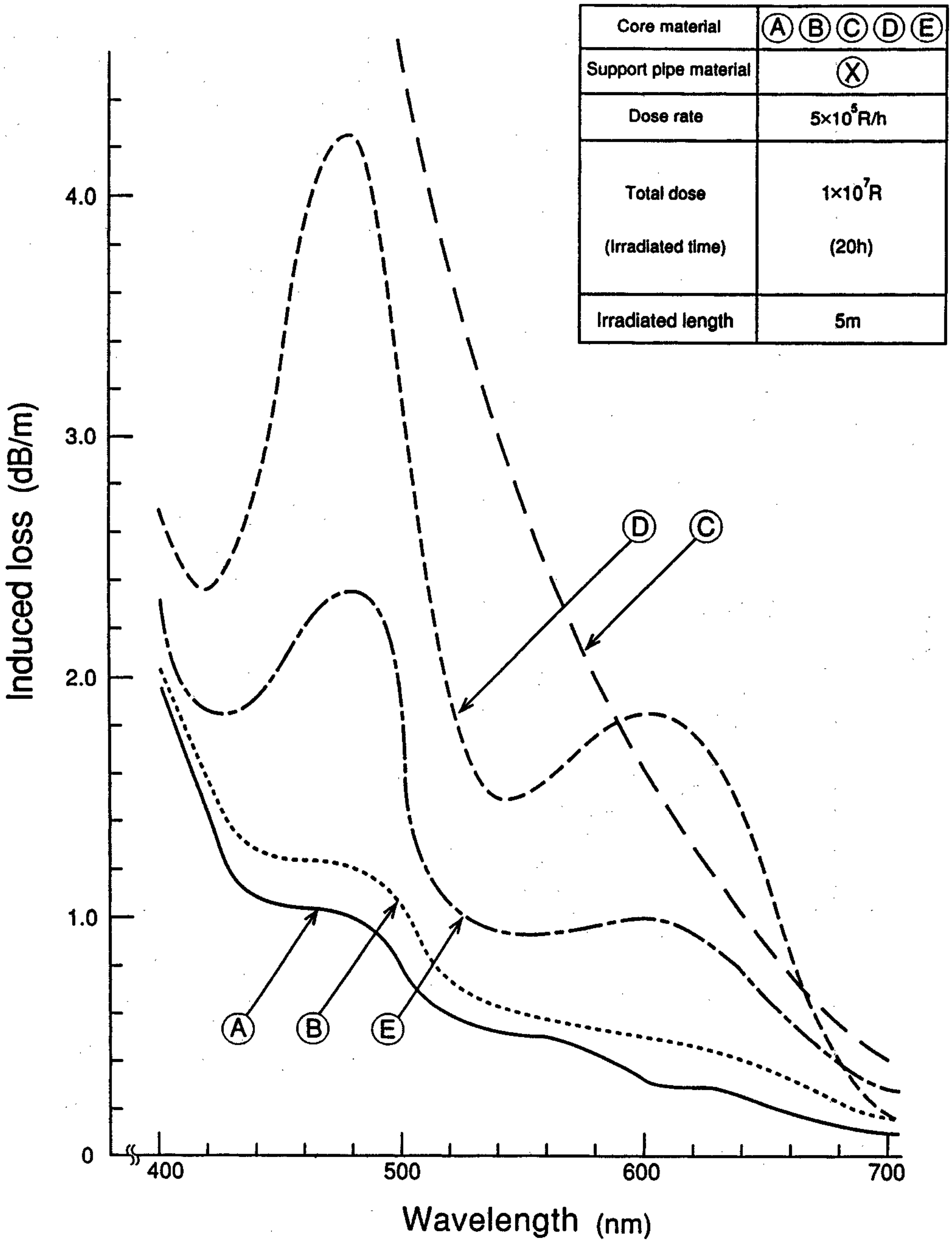


Fig. 3 Core material dependence of in-situ radiation-induced losses (at 5×10^5 R/h and 20-hour irradiations).

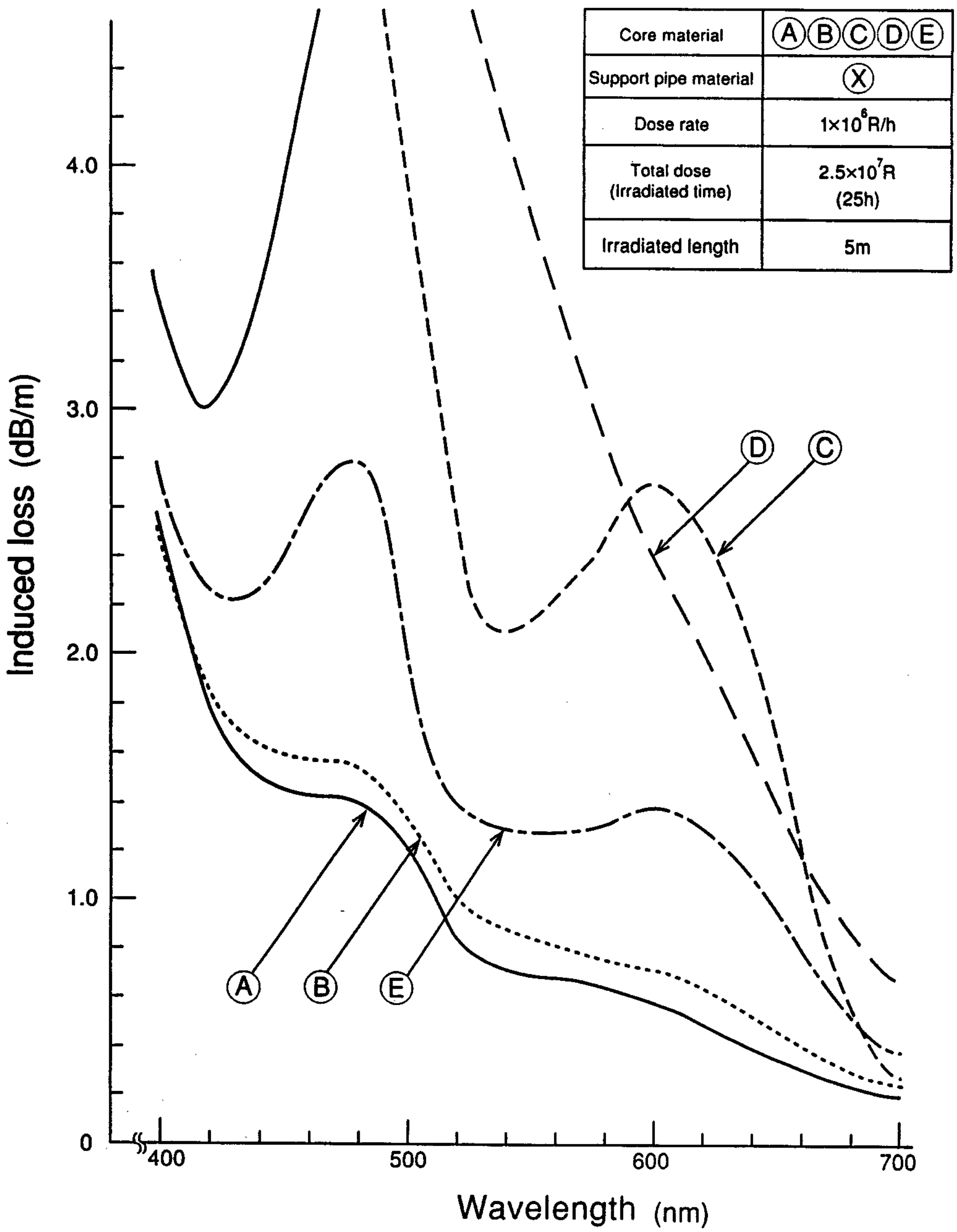
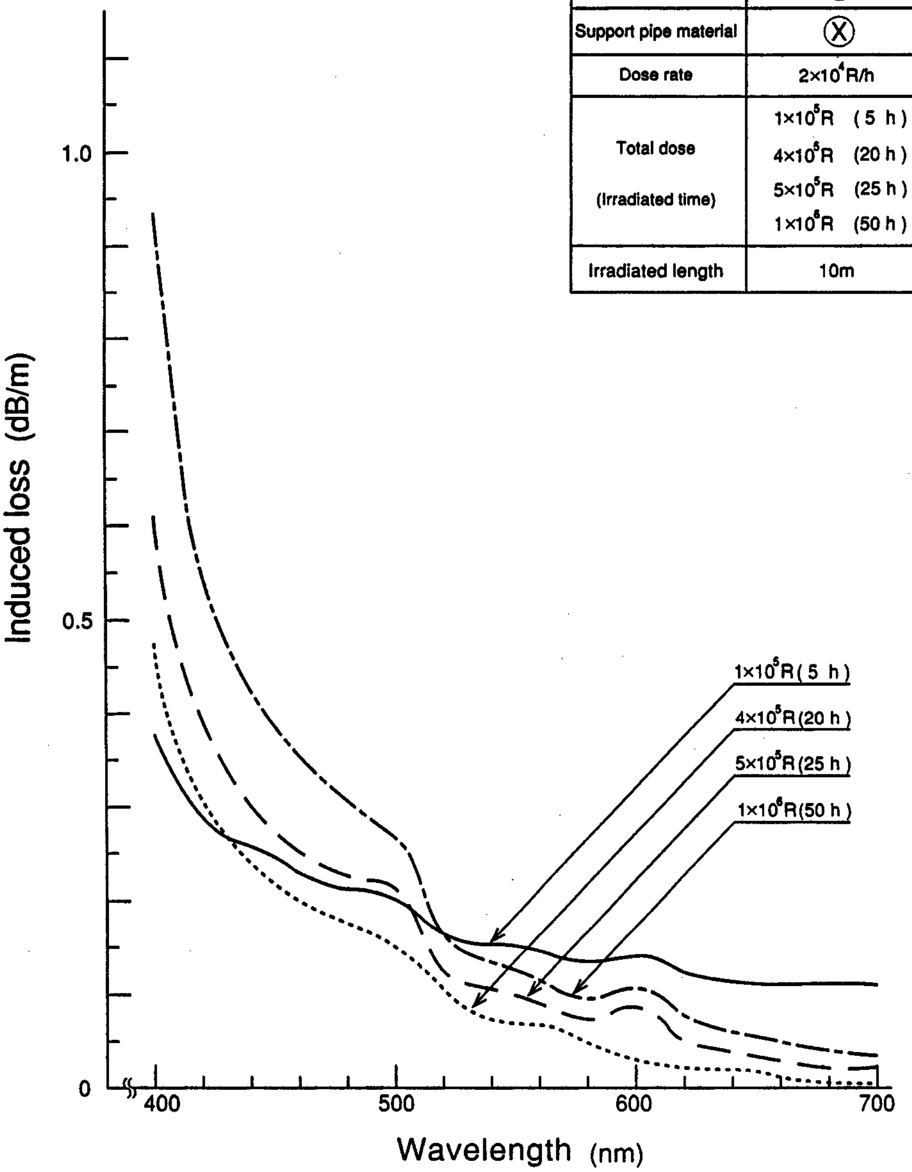


Fig. 4 Core material dependence of in-situ radiation-induced losses (at 1×10^6 R/h and 25-hour irradiations).

3. 2 Dependence on total dose

Figures 5 to 9 show the spectral loss characteristics of image guides under different total doses of gamma-ray irradiation. The dose rate was 2×10^4 R/h. Irradiation time was 5, 20, 25, and 50 hours respectively. While the losses of F-free core materials C and D increase in proportion to total dose, F-containing core materials show lower losses in 20-, 25-, and 50-hour irradiation tests than in 5-hour irradiation. Especially, the loss increase curves are flattened at the wavelengths longer than 500 nm. This behaviour is more obvious in OH-free core material A than OH-containing core material E.



Core material	Ⓐ
Support pipe material	Ⓧ
Dose rate	2×10^4 R/h
Total dose (Irradiated time)	1×10^5R (5 h) 4×10^5R (20 h) 5×10^5R (25 h) 1×10^6R (50 h)
Irradiated length	10m

Fig. 5 Total dose dependence of in-situ radiation-induced losses (for core material A).

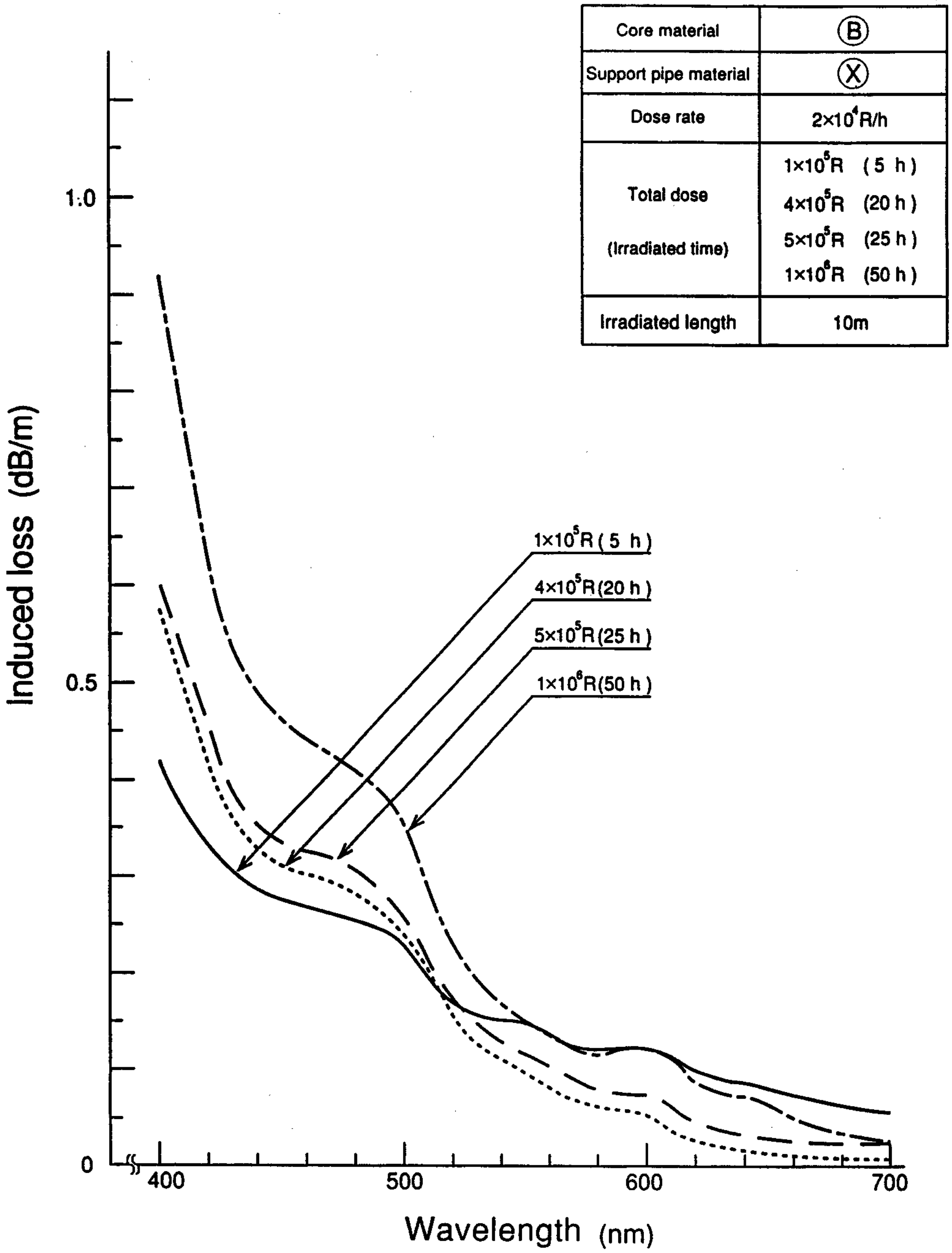


Fig. 6 Total dose dependence of in-situ radiation-induced losses (for core material B).

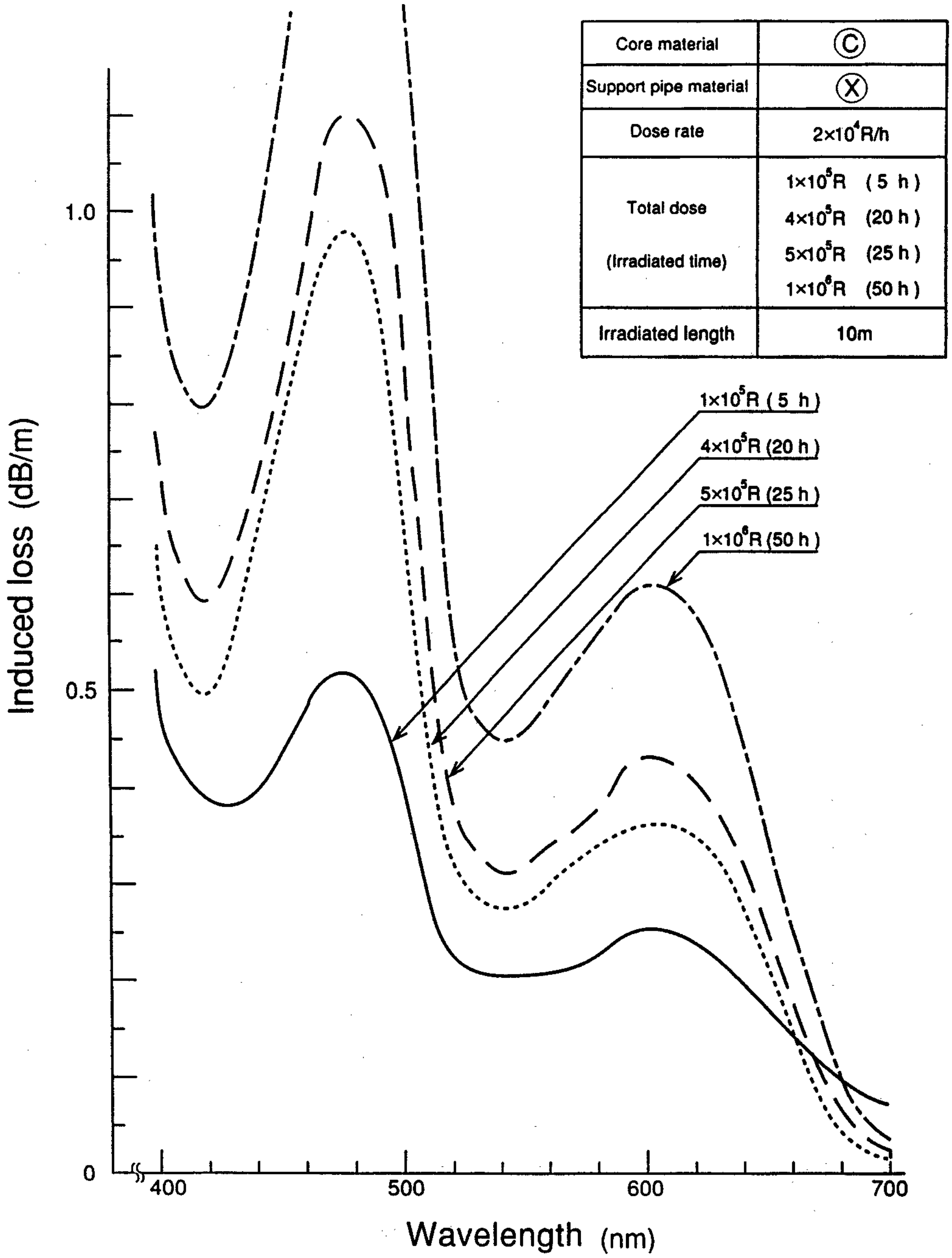


Fig. 7 Total dose dependence of in-situ radiation-induced losses (for core material C).

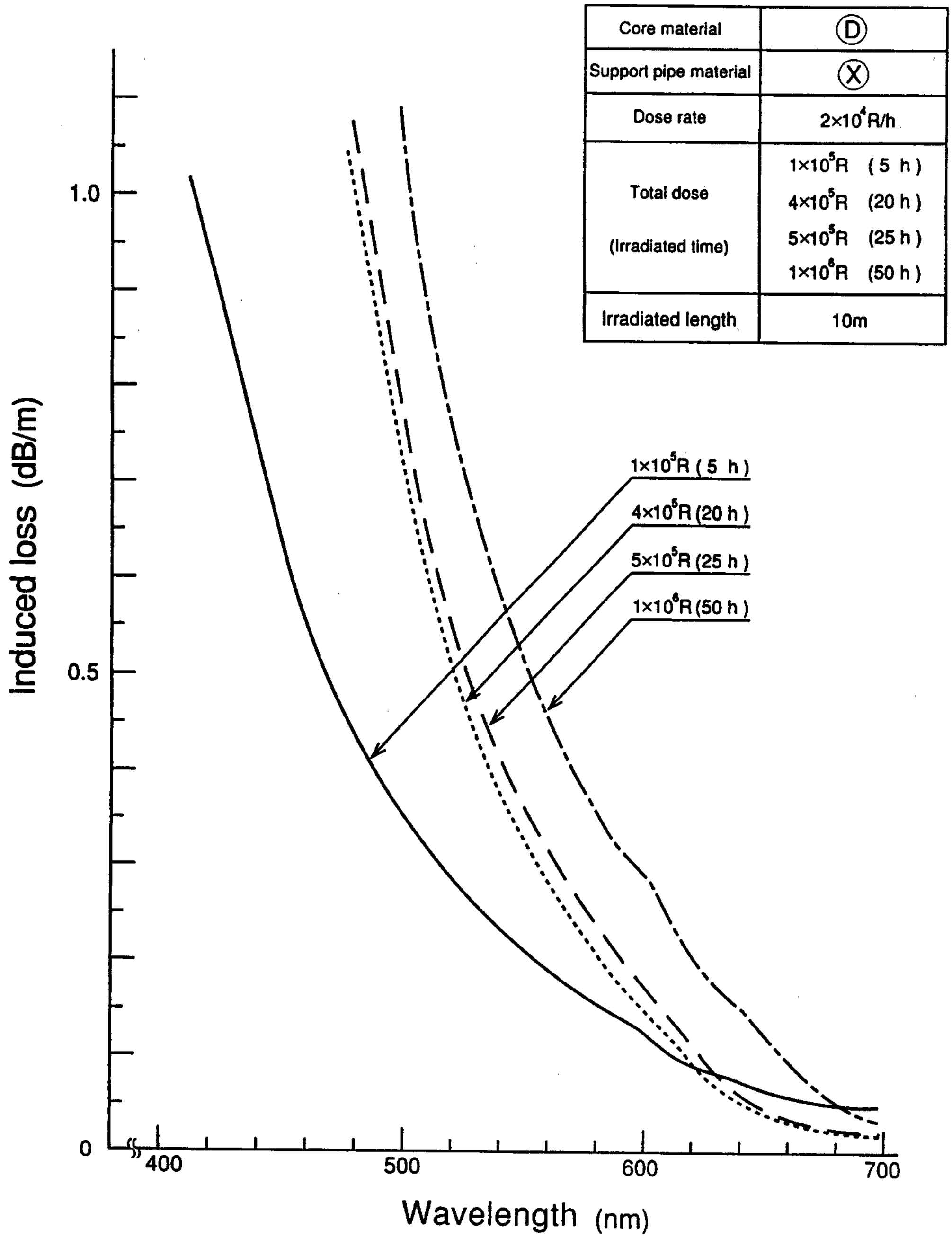


Fig. 8 Total dose dependence of in-situ radiation-induced losses (for core material D).

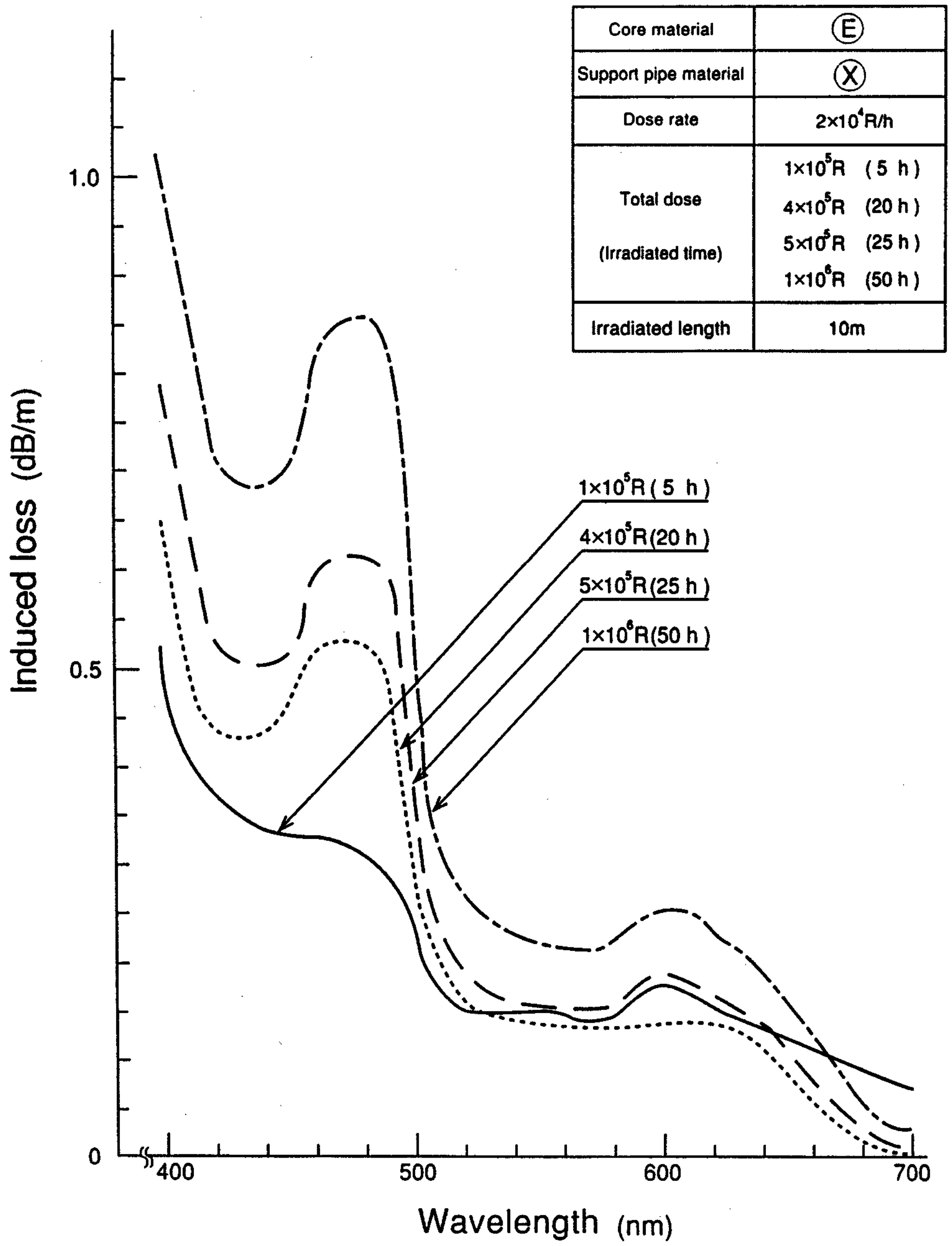


Fig. 9 Total dose dependence of in-situ radiation-induced losses (for core material E).

3. 3 Dependence on dose rate

Figures 10 to 14 show the loss increase characteristics of the image guides irradiated at 2×10^4, 2×10^5, and 1×10^6 R/h, respectively. Only Fig. 10, where the results of core material A are shown, uses the longitudinal scale which doubled the scales of other graphs so that the loss characteristics are more clearly observed. It is apparent in these figures that radiation-induced loss of the image guides core materials C and D increases in proportion to the dose rate even under the same total does of 1×10^6 R/h. In particular, image guide core material D, which contains 1700 ppm of Cl, exhibits this behavior more clearly. Image guides core materials A, B and E, containing F, show smaller loss increase at 2×10^4 R/h, but noticeable difference is not observed at higher dose rates under the same total dose.

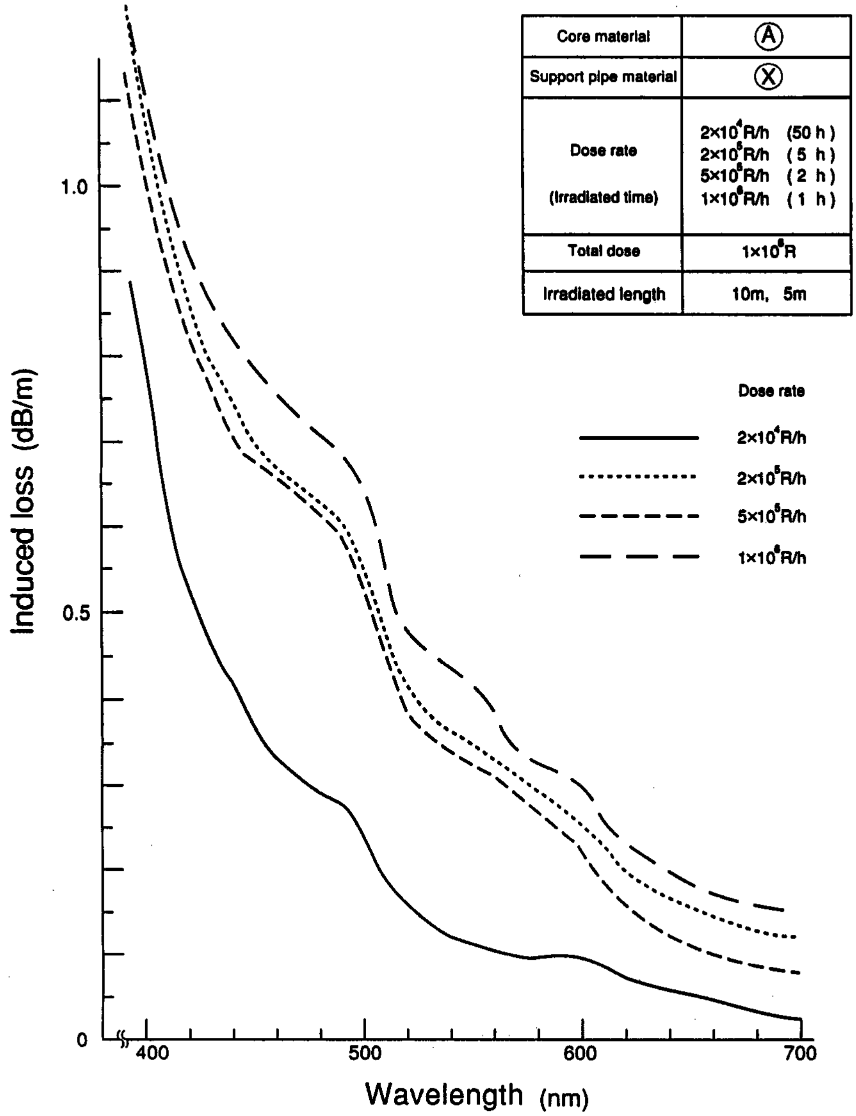


Fig. 10 Dose rate dependence of in-situ radiation-induced losses
(for core material A).

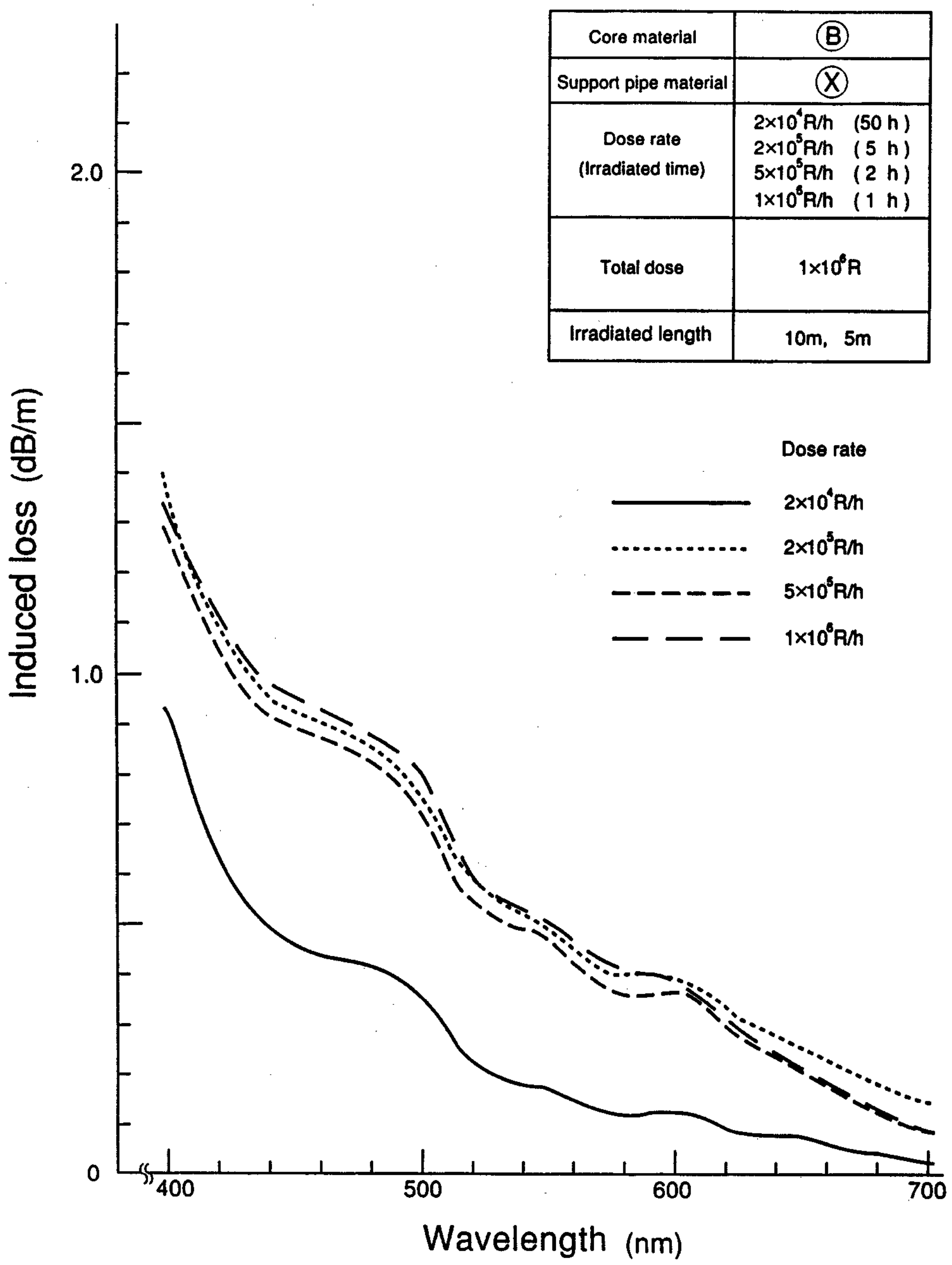


Fig. 11 Dose rate dependence of in-situ radiation-induced losses (for core material B).

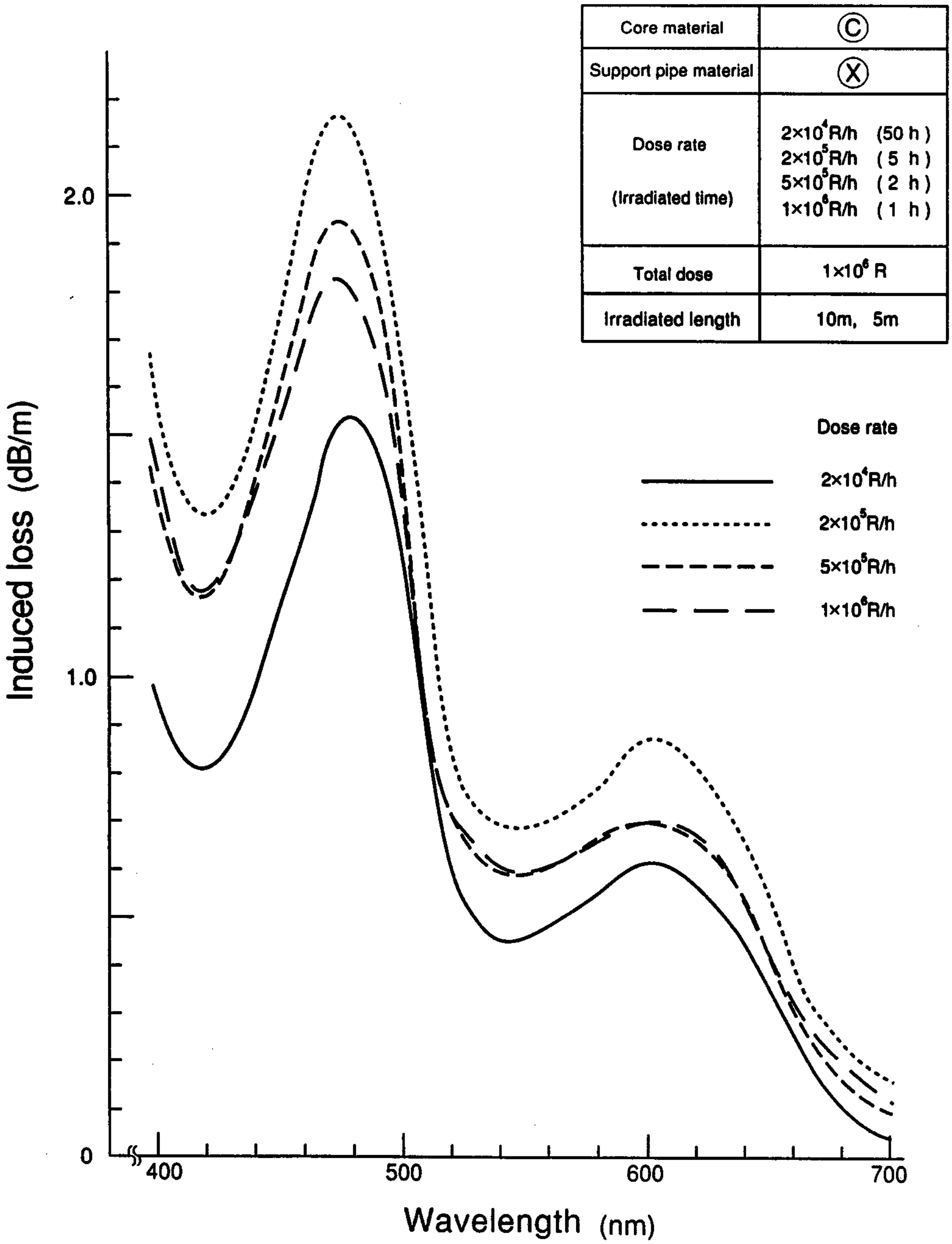


Fig. 12 Dose rate dependence of in-situ radiation-induced losses
(for core material C).

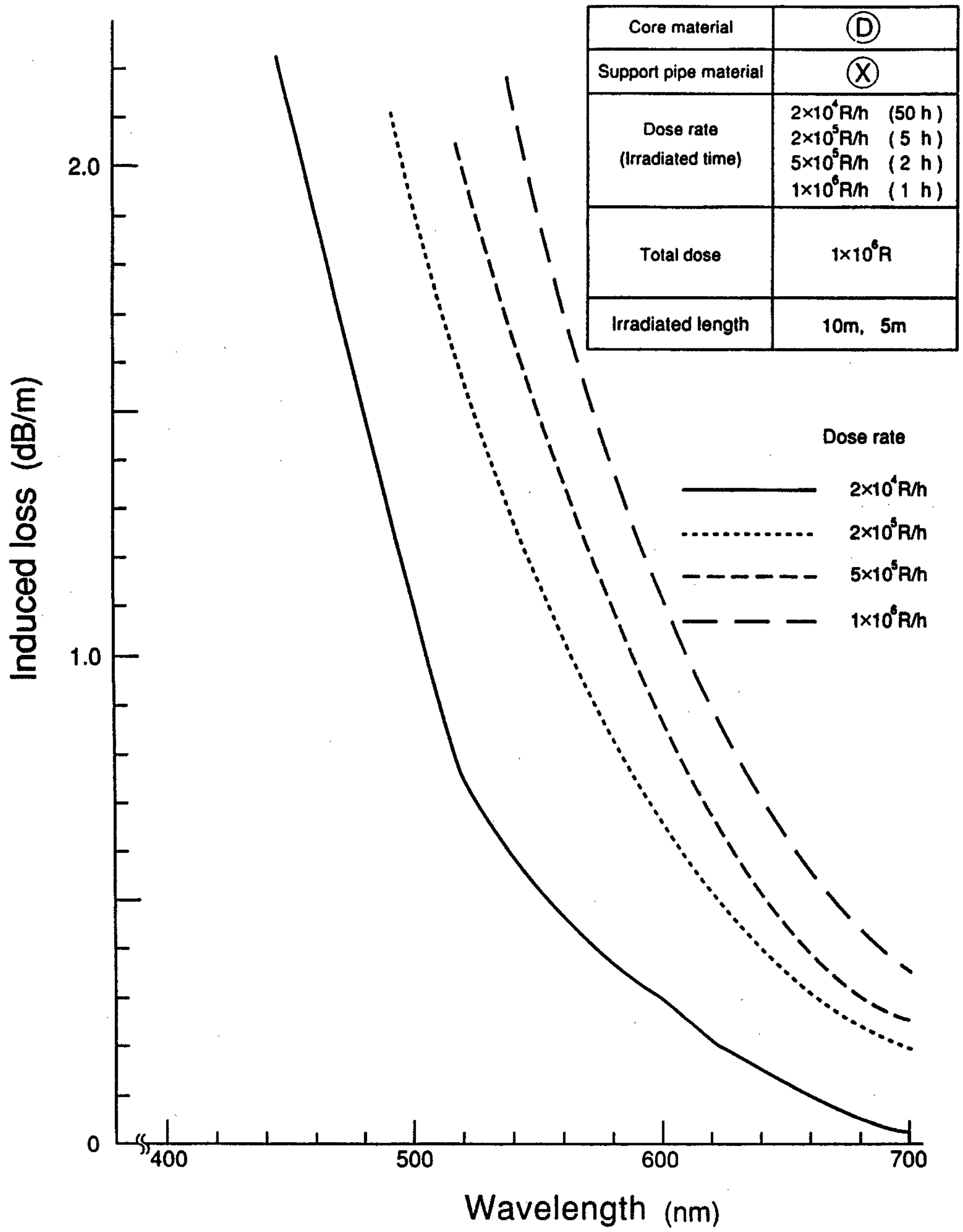


Fig. 13 Dose rate dependence of in-situ radiation-induced losses (for core material D).

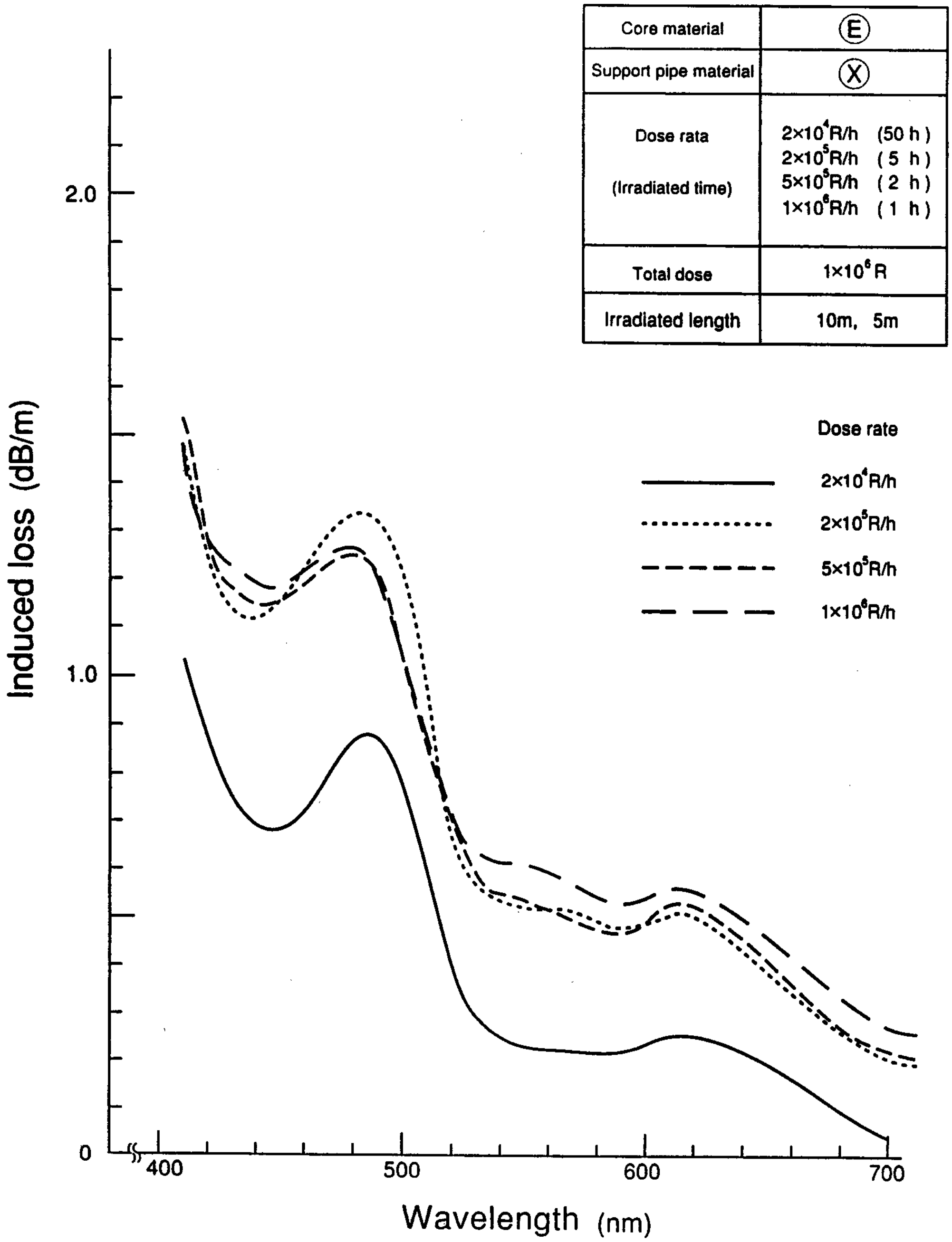


Fig. 14 Dose rate dependence of in-situ radiation-induced losses (for core material E).

3. 4 Dependence on support layer material

Figures 15 to 16 plot the loss increase characteristics of image guides to compare the infuluence of OH content in support layer material. Core materials used for this experiment were A and C. It is observed in Fig. 15 that the results on core material A have little dependence on the support layer material. In Fig. 16, the results on core material C have no substantial difference owing to support layer material, except that the results on the support layer without OH are higher at the wavelengths shorter than 500 nm.

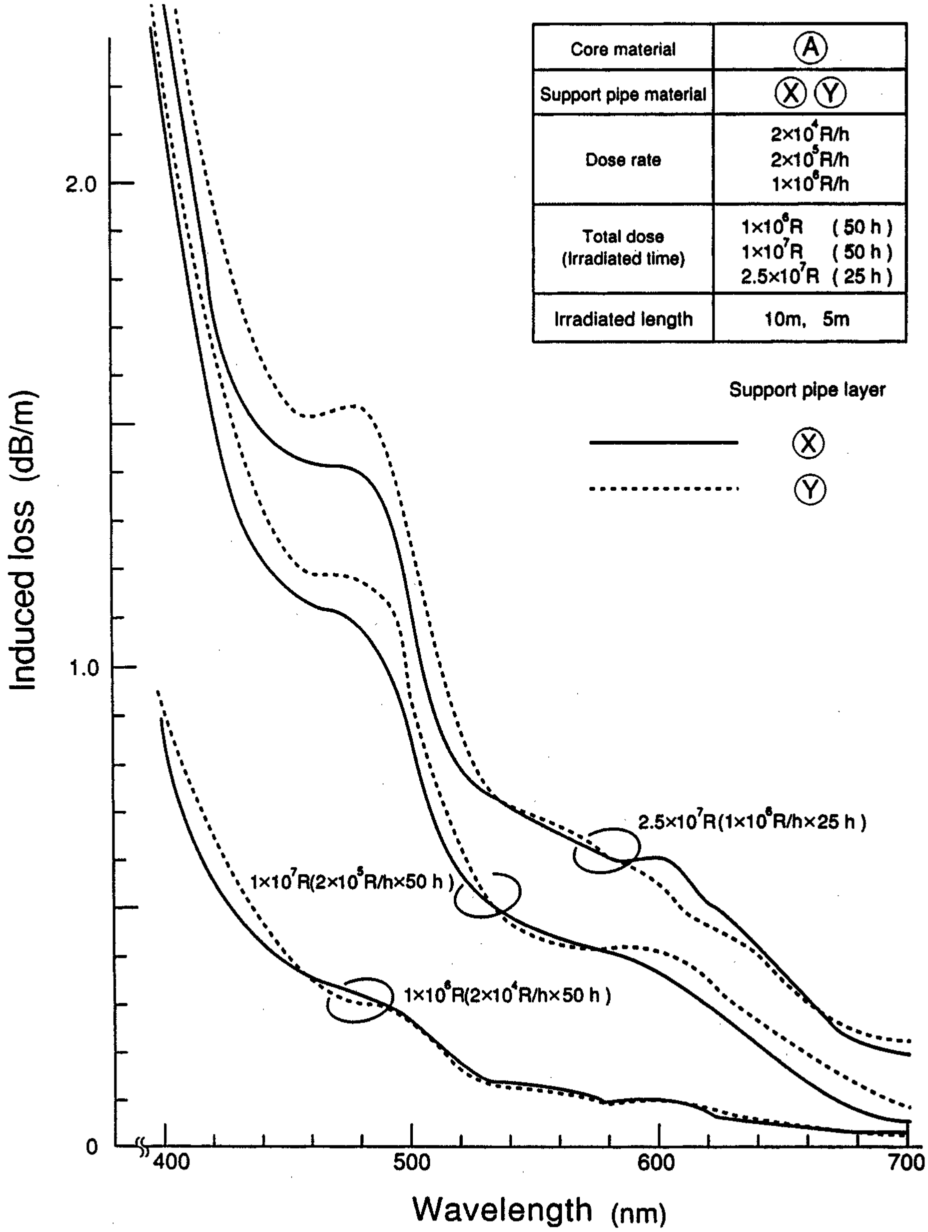


Fig. 15 Support layer dependence of in-situ radiation-induced losses (for core material A).

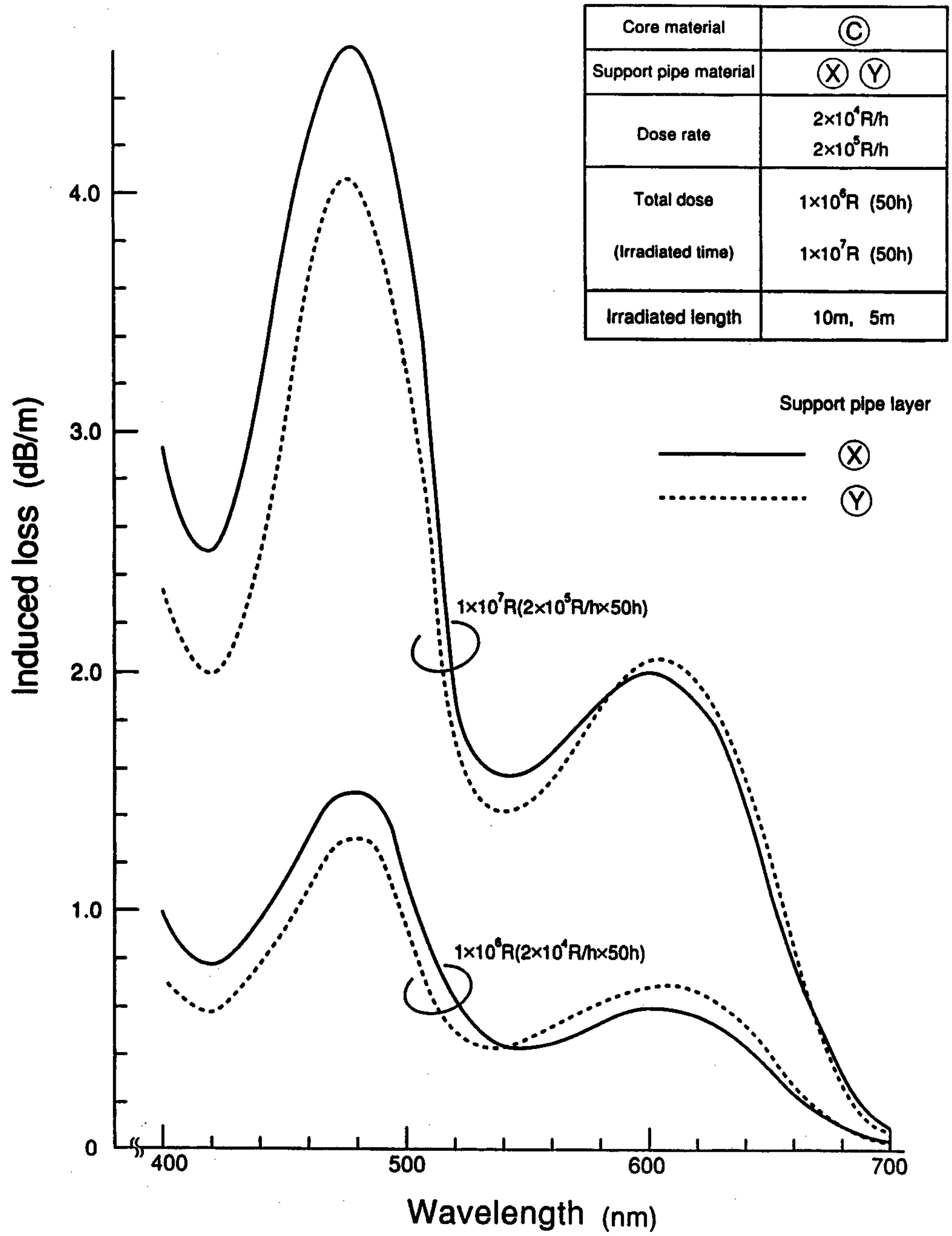


Fig. 16 Support layer dependence of in-situ radiation-induced losses (for core material C).

4. Discussion

4. 1 Irradiation time

The loss increases under 5 hours irradiation and more than twenty hours of irradiation were compared. At a dose rate of 2×10^4 R/h, the loss increase under 5 hours irradiation was higher than the results obtained in longer irradiation time in wavelengths from 500 to 700 nm, as shown in Figs. 5, 6 and 9. At higher dose rates, this behavior was not observed and the losses increased in proportion to the irradiation time.

4. 2 Dose rate

Dependence on dose rate of loss increase the same total dose was considered. The image guides containing F show the smallest loss increase at dose rate of 2×10^4 R/h, as shown in Figs. 10, 11 and 14.

4. 3 Discussion

The results summarized in sections 4. 1 and 4. 2 suggest that the F-containing core has a critical dose rate at which radiation-induced deterioration is stabilized when the number of electrons produced by gamma-ray irradiation exceeds a certain value. The results of these experiments indicate that the critical dose rate exists in the range from 2×10^4 to 2×10^5 R/h. We assume that this is because the electrons liberated by gamma rays and the electrons re-attracted by F atoms in the core material exist simultaneously and because, at a dose rate lower than said critical value, the re-attracted electrons exist in such a relatively large number that they do not promote radiation-induced deterioration.

5. Conclusion

We have investigated the effects of core material on radiation resisitivity of image guides, by comparing four materials : F, OH, C1+OH, and F+OH. The results revealed that radiation resistivity of these materials was in the order of, from the best, F, F+OH, OH, and C1+OH, at any irradiation condition. The superior resistivity of F-containing core image guides was reconfirmed. Influence of four levels of dose rates on radiation-induced spectral loss increase was investigated under a total dose of 1×10^6 R. As the result, loss increase in the image guide with F-containing core was the smallest at the lowest dose of 2×10^4 R/h, and clear difference was not found in the loss increase at the other three dose rates. This result indicates that a critical dose rate at which radiation-induced deterioration in F-containing core is stabilized exists in the range from 2×10^4 R/h to 2×10^5 R/h.

6. References

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