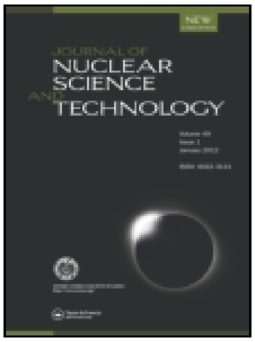

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ORIGINAL PAPER

Calculation of Gamma-Ray Buildup Factors up to Depths of 100 mfp by the Method of Invariant Embedding, (III)

Generation of an Improved Data Set

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An improved data set of gamma-ray buildup factors for point isotropic sources in infinite homogeneous media has been generated by the method of invariant embedding. The points of improvement compared with the standard data set ANSI/ANS-6.4.3 include (1) extension of the buildup factors up to depths of 100 mean free paths, (2) improved treatment of bremsstrahlung, (3) addition of the effective dose buildup factors, (4) consistent use of the cross-section PHOTX to all materials and (5) a quantitative evaluation about the accuracy in transport calculation. The data set obtained are compared precisely with the standard data set ANSI/ANS-6.4.3.

KEYWORDS: buildup factor, radiation transport, radiation shielding, gamma ray, point isotropic source, invariant embedding method, multiple scattering

I. Introduction

The present work has been made to generate an improved data set of gamma-ray buildup factors for point isotropic sources in infinite homogeneous media based on the method of invariant embedding (IE method). The points of improvement compared with the standard data set ANSI/ANS-6.4.3 compiled by American Nuclear Society in 1991[1)] (ANS data) are as follows.

(1) Extension of the buildup factors from depths of 40 mean free paths (mfp) in the ANS data to depths of 100 mfp.

Some shielding calculations for a postulated severe accident on a nuclear reactor require the gamma-ray buildup factor beyond depths of 40 mfp. An extension of the buildup factor of an ordinary concrete at a source energy of 0.5 MeV, a typical source energy of gamma-rays at a postulated severe accident, from depths of 40 mfp to 100 mfp corresponds to the extension from depths of 2 m to 5 m. It was shown in the previous paper[2)] that the IE method can provide the gamma-ray buildup factors efficiently and accurately up to depths of 100 mfp or more.

(2) Treatment of bremsstrahlung in the calculation of buildup factors is improved.

The buildup factors for low-Z materials were calculated by the moments method without the effect of bremsstrahlung in the ANS data. Those for high-Z elements in the ANS data were calculated by the discrete ordinate integral transport code PALLAS[3)] with the effect of bremsstrahlung based on a simple model assuming that all the secondary photons are emitted in the same direction as the primary photon. It was described in the previous paper[4)] that the new method to treat the effect of bremsstrahlung upon the buildup factors was developed. The method is based on a more realistic energy-angle distribution of the secondary photons first calculated by Hirayama[5)] by using the EGS4 code that simulates generation and transport of electron and positron. The new method is used to calculate the buildup factors for low-Z materials as well as high-Z elements.

(3) The gamma-ray cross-section PHOTX is used consistently for all materials.

The buildup factors for low-Z materials were calculated with the gamma-ray cross-section NBS29,[6)] whereas those for high-Z elements were calculated with the cross-section PHOTX[7)] in the ANS data. The buildup factors for all materials are generated based on the cross-section PHOTX in the present data.

(4) The buildup factors are generated for the effective dose as well as the exposure and the energy absorption.

(5) The accuracy of the transport calculation is evaluated quantitatively.

The accuracy of the transport calculation, that is not given in the ANS data, is evaluated quantitatively for typical cases based on the method of error analysis developed in the previous paper.[2)]

In addition to the standard data generated with bremsstrahlung based on the cross-section PHOTX, the following data of buildup factors were calculated to be compared precisely with ANS data.

(1) The exposure buildup factors of 18 low-Z materials were calculated without bremsstrahlung based on the cross-section NBS29 same as the ANS data to compare the method of transport calculation.

(2) The exposure buildup factors of 18 low-Z materials were calculated without bremsstrahlung based on the cross-section PHOTX to check the influence of the cross-section upon the buildup factor.
The data obtained are also used to check the effect of bremsstrahlung upon the buildup factor by comparison with the present standard data.

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(3) The exposure buildup factors of 8 high-Z elements were calculated without bremsstrahlung based on the cross-section PHOTX. The data obtained are used to check the effect of bremsstrahlung upon the buildup factor by comparison with the present standard data.

II. Generation of Standard Data Set

1. Scope of Data Set

The buildup factors are generated for 15 low-Z elements including Be, B, C, N, O, Na, Mg, Al, Si, P, S, Ar, K, Fe, Cu, and 3 compounds including water, concrete, and air and 8 high-Z elements including Rb, Mo, Sn, La, Gd, W, Pb, and U. These materials are same as those in the ANS data except for Ca ($Z=20$) that is omitted since its atomic number is close to K ($Z=19$), and for Rb ($Z=37$), that is added to cover the gap in the atomic number Z between Cu ($Z=29$) and Mo ($Z=42$). The elemental compositions of concrete (NBS concrete) and air are same as those in the ANS data based on the data by Hubbel.[6)]

The data cover the energy range 0.015–15 MeV for the materials except for Pb and U and the energy range 0.03–15 MeV for Pb and U, same as the ANS data.

The evaluated data cover up to depths of 100 mfp, although the calculations were performed up to depths of 300 mfp.

The type of buildup factor includes the exposure buildup factor, the energy absorption buildup factors, and the effective dose buildup factor. Other type of buildup factor can be generated easily since the energy spectra of buildup factors obtained in the calculation of the exposure buildup factors are stored in a data base.

The buildup factors are calculated based on the cross-section PHOTX. The total cross-section without coherent scattering is generated as the sum of Compton scattering, photoelectric effect, and pair production. The coherent scattering and the electron binding effect in incoherent scattering are not taken into account in the present calculations.

The buildup factors for all materials are calculated with the effect of bremsstrhalung of electron and positron and annihilation of positron.

The buildup factors for the high-Z elements are calculated with fluorescence in the vicinity of K edge. The data for K X rays used are the same as the data used by Harima *et al.*[8)] based on the Table of Isotopes.[9)]

2. Method of Calculation

The buildup factors are calculated by the IE method. The detailed description of the IE method is found elsewhere.[2,10)] The method of direct numerical integration is used. The solution for the modified transmission at the initial space mesh is obtained by solving its equation by the Runge–Kutta method. The solutions for extended thickness are obtained by using the functional relation for the modified transmission function. The initial space mesh Δ is chosen as $1/512$ mfp for most low-Z materials and as $1/32{,}768$ mfp for high-Z elements with bremsstrahlung. It was confirmed that the error in the buildup factor due to the space mesh is negligible (less than 0.02%) up to depths of 100 mfp. Even starting from a very fine initial mesh, calculations can efficiently be extended to large depths, since the solution for a double thickness can successively be obtained by using the functional relation. This is an excellent feature of the IE method.

Calculations of buildup factor were performed with 95 energy groups and 15 angular divisions in the forward direction (equivalent to S_{30}).

The effect of bremssstrahlung upon buildup factor is treated by the new method developed previously.[4)] The energy-angle distribution of the yield of the secondary photons emitted through bremsstrahlung of electron and positron generated by a pair production and that of electron recoiled by a Compton scattering are calculated by using the EGS4 code. These yields obtained are used to transport calculations by the IE method based on the approximation that the secondary photons are emitted at the point where the pair production or the Compton scattering takes places. This approximation was examined in the previous paprer.[4)] It was found that the ranges of electron and positron generating the secondary photons are small enough to be neglected in the calculation of buildup factor.

3. Method of Error Analysis

We denote an exposure buildup factor computed with a number of angular divisions G and a number of energy groups N at a depth of X by $B(G,N;X)$. Based on the previous systematic analysis[2)] about the dependence of $B(G,N;X)$ on N and G, it was found that the upper limit and the lower limit for $B(\infty,\infty;X)/B(G,N;X)$ are obtainable in the energy range 15 keV–15 MeV except for the vicinity of the K edge, although the exact value of the buildup factor $B(\infty,\infty;X)$ is unknown. The upper limit depends only on G and X, and the lower limit depends only on N and X, when $G\geq 7$ and $N\geq 40$. The present method of error analysis, however, is not applicable to a exposure buildup factor at source energy in the vicinity of K edge, since the exposure buildup factor is controlled by K X rays and behaves differently there.

The exposure buildup factors in the present work are calculated with $G=15$ and $N=95$. The upper limit is computed from $B(15,95;X)$ and $B(13,95;X)$ and the lower limit is computed from $B(15,95;X)$ and $B(15,86;X)$ for some typical cases.

4. Exposure Buildup Factors

The exposure buildup factors for water, concrete, iron, and lead are given in **Tables 1** to **4**. The exposure buildup factor of the other materials are given in the internal report.[11)]

5. Other Types of Buildup Factors

The other types of buildup factors including the energy absorption and the effective dose are in production by using the data base for the energy spectra of buildup factors calculated and stored in the calculations of the exposure buildup factors. They shall be reported in the near future.

III. Comparison with ANS Data

1. Comparison of IE Method with Moments Method

The exposure buildup factors of 18 low-Z materials were

Table 1 Exposure buildup factors (Water)

with bremsstrahlung, PHOTX

	Energy (MeV)												
R(mfp)	15	10	8	6	5	4	3	2	1.5	1	0.8	0.6	0.5
0.5	1.21E+00	1.24E+00	1.26E+00	1.29E+00	1.30E+00	1.32E+00	1.35E+00	1.39E+00	1.42E+00	1.47E+00	1.51E+00	1.57E+00	1.61E+00
1.0	1.37E+00	1.44E+00	1.49E+00	1.56E+00	1.60E+00	1.65E+00	1.73E+00	1.84E+00	1.93E+00	2.08E+00	2.19E+00	2.34E+00	2.45E+00
2.0	1.64E+00	1.78E+00	1.88E+00	2.04E+00	2.14E+00	2.29E+00	2.50E+00	2.84E+00	3.13E+00	3.63E+00	3.98E+00	4.50E+00	4.88E+00
3.0	1.89E+00	2.10E+00	2.26E+00	2.50E+00	2.67E+00	2.90E+00	3.27E+00	3.90E+00	4.48E+00	5.53E+00	6.28E+00	7.45E+00	8.33E+00
4.0	2.13E+00	2.41E+00	2.62E+00	2.95E+00	3.18E+00	3.52E+00	4.06E+00	5.02E+00	5.96E+00	7.72E+00	9.03E+00	1.12E+01	1.28E+01
5.0	2.36E+00	2.71E+00	2.98E+00	3.39E+00	3.70E+00	4.14E+00	4.86E+00	6.20E+00	7.54E+00	1.02E+01	1.22E+01	1.56E+01	1.83E+01
6.0	2.59E+00	3.01E+00	3.33E+00	3.83E+00	4.21E+00	4.76E+00	5.68E+00	7.43E+00	9.22E+00	1.29E+01	1.58E+01	2.08E+01	2.48E+01
7.0	2.81E+00	3.30E+00	3.67E+00	4.27E+00	4.71E+00	5.38E+00	6.51E+00	8.70E+00	1.10E+01	1.59E+01	1.98E+01	2.67E+01	3.25E+01
8.0	3.03E+00	3.59E+00	4.01E+00	4.70E+00	5.22E+00	6.01E+00	7.34E+00	1.00E+01	1.29E+01	1.91E+01	2.42E+01	3.34E+01	4.12E+01
10.0	3.47E+00	4.15E+00	4.68E+00	5.56E+00	6.22E+00	7.25E+00	9.04E+00	1.27E+01	1.68E+01	2.62E+01	3.43E+01	4.92E+01	6.23E+01
15.0	4.52E+00	5.51E+00	6.31E+00	7.65E+00	8.69E+00	1.04E+01	1.34E+01	2.00E+01	2.79E+01	4.76E+01	6.62E+01	1.03E+02	1.38E+02
20.0	5.55E+00	6.83E+00	7.88E+00	9.68E+00	1.11E+01	1.35E+01	1.78E+01	2.78E+01	4.02E+01	7.36E+01	1.07E+02	1.78E+02	2.48E+02
25.0	6.56E+00	8.12E+00	9.42E+00	1.17E+01	1.35E+01	1.66E+01	2.23E+01	3.60E+01	5.35E+01	1.03E+02	1.56E+02	2.73E+02	3.96E+02
30.0	7.55E+00	9.37E+00	1.09E+01	1.36E+01	1.59E+01	1.96E+01	2.69E+01	4.45E+01	6.77E+01	1.37E+02	2.13E+02	3.89E+02	5.82E+02
35.0	8.53E+00	1.06E+01	1.24E+01	1.56E+01	1.82E+01	2.27E+01	3.15E+01	5.32E+01	8.27E+01	1.74E+02	2.78E+02	5.26E+02	8.08E+02
40.0	9.50E+00	1.18E+01	1.39E+01	1.75E+01	2.05E+01	2.58E+01	3.62E+01	6.22E+01	9.83E+01	2.13E+02	3.49E+02	6.83E+02	1.08E+03
45.0	1.05E+01	1.30E+01	1.53E+01	1.94E+01	2.29E+01	2.88E+01	4.09E+01	7.14E+01	1.15E+02	2.56E+02	4.28E+02	8.60E+02	1.38E+03
50.0	1.14E+01	1.42E+01	1.68E+01	2.13E+01	2.52E+01	3.19E+01	4.56E+01	8.08E+01	1.31E+02	3.01E+02	5.13E+02	1.06E+03	1.74E+03
55.0	1.24E+01	1.54E+01	1.82E+01	2.32E+01	2.75E+01	3.50E+01	5.04E+01	9.04E+01	1.49E+02	3.49E+02	6.05E+02	1.28E+03	2.13E+03
60.0	1.33E+01	1.66E+01	1.96E+01	2.51E+01	2.98E+01	3.81E+01	5.52E+01	1.00E+02	1.67E+02	4.00E+02	7.03E+02	1.51E+03	2.57E+03
65.0	1.43E+01	1.78E+01	2.11E+01	2.70E+01	3.21E+01	4.12E+01	6.01E+01	1.10E+02	1.86E+02	4.53E+02	8.08E+02	1.77E+03	3.05E+03
70.0	1.53E+01	1.90E+01	2.25E+01	2.89E+01	3.45E+01	4.44E+01	6.50E+01	1.20E+02	2.05E+02	5.09E+02	9.20E+02	2.06E+03	3.59E+03
75.0	1.62E+01	2.03E+01	2.40E+01	3.09E+01	3.69E+01	4.75E+01	7.00E+01	1.30E+02	2.24E+02	5.68E+02	1.04E+03	2.36E+03	4.16E+03
80.0	1.72E+01	2.15E+01	2.54E+01	3.28E+01	3.93E+01	5.08E+01	7.51E+01	1.41E+02	2.45E+02	6.29E+02	1.16E+03	2.68E+03	4.79E+03
85.0	1.82E+01	2.27E+01	2.69E+01	3.48E+01	4.17E+01	5.40E+01	8.02E+01	1.51E+02	2.66E+02	6.93E+02	1.29E+03	3.03E+03	5.47E+03
90.0	1.92E+01	2.39E+01	2.84E+01	3.68E+01	4.42E+01	5.74E+01	8.55E+01	1.62E+02	2.87E+02	7.59E+02	1.43E+03	3.39E+03	6.20E+03
95.0	2.02E+01	2.52E+01	2.99E+01	3.88E+01	4.67E+01	6.08E+01	9.08E+01	1.73E+02	3.09E+02	8.28E+02	1.58E+03	3.79E+03	6.98E+03
100.0	2.12E+01	2.64E+01	3.15E+01	4.09E+01	4.93E+01	6.42E+01	9.62E+01	1.84E+02	3.32E+02	8.99E+02	1.73E+03	4.20E+03	7.82E+03

	Energy (MeV)											
R(mfp)	0.4	0.3	0.2	0.15	0.1	0.08	0.06	0.05	0.04	0.03	0.02	0.015
0.5	1.66E+00	1.75E+00	1.91E+00	2.07E+00	2.38E+00	2.57E+00	2.65E+00	2.51E+00	2.18E+00	1.69E+00	1.25E+00	1.11E+00
1.0	2.61E+00	2.85E+00	3.31E+00	3.76E+00	4.57E+00	4.98E+00	4.93E+00	4.40E+00	3.41E+00	2.25E+00	1.41E+00	1.17E+00
2.0	5.43E+00	6.29E+00	7.89E+00	9.41E+00	1.18E+01	1.26E+01	1.14E+01	9.12E+00	6.02E+00	3.20E+00	1.64E+00	1.26E+00
3.0	9.61E+00	1.16E+01	1.54E+01	1.89E+01	2.36E+01	2.44E+01	2.02E+01	1.50E+01	8.81E+00	4.04E+00	1.81E+00	1.32E+00
4.0	1.52E+01	1.92E+01	2.66E+01	3.30E+01	4.08E+01	4.08E+01	3.15E+01	2.19E+01	1.17E+01	4.80E+00	1.95E+00	1.36E+00
5.0	2.24E+01	2.92E+01	4.19E+01	5.28E+01	6.43E+01	6.25E+01	4.53E+01	2.98E+01	1.48E+01	5.52E+00	2.07E+00	1.40E+00
6.0	3.11E+01	4.18E+01	6.20E+01	7.91E+01	9.51E+01	9.00E+01	6.17E+01	3.87E+01	1.80E+01	6.21E+00	2.18E+00	1.44E+00
7.0	4.16E+01	5.74E+01	8.77E+01	1.13E+02	1.34E+02	1.24E+02	8.09E+01	4.86E+01	2.13E+01	6.88E+00	2.27E+00	1.47E+00
8.0	5.38E+01	7.61E+01	1.20E+02	1.56E+02	1.83E+02	1.65E+02	1.03E+02	5.95E+01	2.48E+01	7.53E+00	2.36E+00	1.49E+00
10.0	8.42E+01	1.24E+02	2.06E+02	2.72E+02	3.14E+02	2.73E+02	1.57E+02	8.48E+01	3.21E+01	8.79E+00	2.52E+00	1.54E+00
15.0	1.99E+02	3.23E+02	5.92E+02	8.18E+02	9.13E+02	7.35E+02	3.61E+02	1.69E+02	5.30E+01	1.19E+01	2.86E+00	1.63E+00
20.0	3.81E+02	6.65E+02	1.34E+03	1.92E+03	2.10E+03	1.59E+03	6.91E+02	2.89E+02	7.78E+01	1.48E+01	3.13E+00	1.70E+00
25.0	6.37E+02	1.19E+03	2.61E+03	3.90E+03	4.22E+03	3.04E+03	1.19E+03	4.50E+02	1.06E+02	1.78E+01	3.36E+00	1.76E+00
30.0	9.78E+02	1.95E+03	4.60E+03	7.16E+03	7.71E+03	5.32E+03	1.90E+03	6.57E+02	1.39E+02	2.07E+01	3.57E+00	1.81E+00
35.0	1.41E+03	2.97E+03	7.55E+03	1.22E+04	1.32E+04	8.74E+03	2.87E+03	9.17E+02	1.75E+02	2.36E+01	3.76E+00	1.85E+00
40.0	1.94E+03	4.30E+03	1.17E+04	1.97E+04	2.13E+04	1.37E+04	4.16E+03	1.24E+03	2.15E+02	2.66E+01	3.93E+00	1.88E+00
45.0	2.57E+03	5.98E+03	1.73E+04	3.02E+04	3.30E+04	2.05E+04	5.83E+03	1.62E+03	2.58E+02	2.95E+01	4.09E+00	1.92E+00
50.0	3.31E+03	8.04E+03	2.47E+04	4.48E+04	4.93E+04	2.98E+04	7.95E+03	2.07E+03	3.05E+02	3.24E+01	4.24E+00	1.95E+00
55.0	4.17E+03	1.05E+04	3.42E+04	6.42E+04	7.16E+04	4.21E+04	1.06E+04	2.60E+03	3.56E+02	3.54E+01	4.38E+00	1.97E+00
60.0	5.15E+03	1.35E+04	4.62E+04	8.97E+04	1.01E+05	5.81E+04	1.38E+04	3.20E+03	4.11E+02	3.84E+01	4.52E+00	2.00E+00
65.0	6.25E+03	1.69E+04	6.09E+04	1.22E+05	1.40E+05	7.86E+04	1.77E+04	3.90E+03	4.70E+02	4.14E+01	4.65E+00	2.02E+00
70.0	7.48E+03	2.09E+04	7.89E+04	1.64E+05	1.90E+05	1.04E+05	2.24E+04	4.69E+03	5.33E+02	4.45E+01	4.78E+00	2.04E+00
75.0	8.84E+03	2.54E+04	1.00E+05	2.15E+05	2.53E+05	1.37E+05	2.80E+04	5.58E+03	5.99E+02	4.76E+01	4.90E+00	2.06E+00
80.0	1.03E+04	3.06E+04	1.26E+05	2.78E+05	3.32E+05	1.76E+05	3.46E+04	6.58E+03	6.71E+02	5.08E+01	5.02E+00	2.08E+00
85.0	1.20E+04	3.64E+04	1.56E+05	3.55E+05	4.30E+05	2.24E+05	4.22E+04	7.69E+03	7.46E+02	5.41E+01	5.13E+00	2.10E+00
90.0	1.38E+04	4.30E+04	1.91E+05	4.46E+05	5.51E+05	2.82E+05	5.10E+04	8.93E+03	8.26E+02	5.74E+01	5.25E+00	2.12E+00
95.0	1.58E+04	5.02E+04	2.32E+05	5.56E+05	6.97E+05	3.51E+05	6.12E+04	1.03E+04	9.11E+02	6.08E+01	5.36E+00	2.14E+00
100.0	1.79E+04	5.83E+04	2.78E+05	6.85E+05	8.72E+05	4.33E+05	7.29E+04	1.18E+04	1.00E+03	6.43E+01	5.47E+00	2.16E+00

calculated without bremsstrahlung based on the cross-section NBS29 same as the ANS data. These calculations are performed to compare both methods of transport calculation, the IE method in the present data and the moments method in the ANS data.

The result of comparison is summarized in **Table 5**. It is shown that 81% of the present data (366 cases) out of 450 cases (18 materials×25 source energies) agrees with the ANS data within a discrepancy of 5% and 95% of the present data (366+62 cases) agrees with the ANS data within a discrepancy of 10% up to depths of 40 mfp. Since the attenuation factor at depths of 40 mfp is the order of $\exp(-40)\approx10^{-18}$, this agreement is excellent. It is confirmed that both the moments method and the IE method are de-

Table 2 Exposure buildup factors (Concrete)

with bremsstrahlung, PHOTX

	Energy (MeV)												
X(mfp)	15	10	8	6	5	4	3	2	1.5	1	0.8	0.6	0.5
0.5	1.22E+00	1.25E+00	1.26E+00	1.29E+00	1.30E+00	1.32E+00	1.34E+00	1.38E+00	1.40E+00	1.45E+00	1.48E+00	1.53E+00	1.57E+00
1.0	1.39E+00	1.44E+00	1.49E+00	1.55E+00	1.58E+00	1.63E+00	1.70E+00	1.79E+00	1.86E+00	1.99E+00	2.07E+00	2.19E+00	2.27E+00
2.0	1.69E+00	1.79E+00	1.88E+00	2.02E+00	2.11E+00	2.23E+00	2.41E+00	2.68E+00	2.89E+00	3.25E+00	3.48E+00	3.81E+00	4.02E+00
3.0	1.97E+00	2.13E+00	2.26E+00	2.48E+00	2.63E+00	2.83E+00	3.14E+00	3.64E+00	4.04E+00	4.74E+00	5.19E+00	5.84E+00	6.25E+00
4.0	2.24E+00	2.46E+00	2.65E+00	2.94E+00	3.15E+00	3.44E+00	3.90E+00	4.66E+00	5.31E+00	6.44E+00	7.20E+00	8.27E+00	8.96E+00
5.0	2.52E+00	2.79E+00	3.03E+00	3.40E+00	3.67E+00	4.06E+00	4.68E+00	5.74E+00	6.67E+00	8.36E+00	9.49E+00	1.11E+01	1.22E+01
6.0	2.80E+00	3.12E+00	3.41E+00	3.87E+00	4.20E+00	4.69E+00	5.47E+00	6.86E+00	8.12E+00	1.05E+01	1.21E+01	1.44E+01	1.59E+01
7.0	3.07E+00	3.46E+00	3.79E+00	4.34E+00	4.74E+00	5.33E+00	6.29E+00	8.03E+00	9.65E+00	1.28E+01	1.49E+01	1.81E+01	2.02E+01
8.0	3.36E+00	3.79E+00	4.18E+00	4.81E+00	5.27E+00	5.97E+00	7.12E+00	9.24E+00	1.13E+01	1.52E+01	1.81E+01	2.22E+01	2.50E+01
10.0	3.93E+00	4.47E+00	4.96E+00	5.76E+00	6.35E+00	7.27E+00	8.81E+00	1.18E+01	1.47E+01	2.07E+01	2.52E+01	3.18E+01	3.64E+01
15.0	5.43E+00	6.21E+00	6.93E+00	8.15E+00	9.09E+00	1.06E+01	1.32E+01	1.85E+01	2.42E+01	3.71E+01	4.73E+01	6.36E+01	7.53E+01
20.0	7.04E+00	8.00E+00	8.95E+00	1.06E+01	1.19E+01	1.40E+01	1.78E+01	2.58E+01	3.48E+01	5.68E+01	7.53E+01	1.07E+02	1.30E+02
25.0	8.74E+00	9.83E+00	1.10E+01	1.30E+01	1.47E+01	1.74E+01	2.24E+01	3.35E+01	4.63E+01	7.93E+01	1.09E+02	1.60E+02	2.01E+02
30.0	1.05E+01	1.17E+01	1.31E+01	1.55E+01	1.75E+01	2.08E+01	2.72E+01	4.15E+01	5.85E+01	1.05E+02	1.47E+02	2.25E+02	2.89E+02
35.0	1.24E+01	1.36E+01	1.52E+01	1.80E+01	2.03E+01	2.43E+01	3.20E+01	4.98E+01	7.13E+01	1.32E+02	1.90E+02	3.00E+02	3.94E+02
40.0	1.44E+01	1.56E+01	1.73E+01	2.04E+01	2.31E+01	2.78E+01	3.69E+01	5.84E+01	8.47E+01	1.62E+02	2.38E+02	3.87E+02	5.17E+02
45.0	1.64E+01	1.75E+01	1.94E+01	2.29E+01	2.60E+01	3.13E+01	4.19E+01	6.71E+01	9.85E+01	1.94E+02	2.90E+02	4.83E+02	6.58E+02
50.0	1.86E+01	1.95E+01	2.15E+01	2.54E+01	2.88E+01	3.48E+01	4.69E+01	7.60E+01	1.13E+02	2.28E+02	3.47E+02	5.90E+02	8.16E+02
55.0	2.08E+01	2.16E+01	2.37E+01	2.80E+01	3.17E+01	3.84E+01	5.20E+01	8.51E+01	1.27E+02	2.64E+02	4.08E+02	7.08E+02	9.93E+02
60.0	2.31E+01	2.36E+01	2.59E+01	3.05E+01	3.45E+01	4.19E+01	5.71E+01	9.44E+01	1.43E+02	3.01E+02	4.72E+02	8.36E+02	1.19E+03
65.0	2.54E+01	2.57E+01	2.81E+01	3.30E+01	3.74E+01	4.55E+01	6.22E+01	1.04E+02	1.58E+02	3.41E+02	5.41E+02	9.75E+02	1.40E+03
70.0	2.79E+01	2.78E+01	3.03E+01	3.56E+01	4.03E+01	4.91E+01	6.74E+01	1.13E+02	1.74E+02	3.83E+02	6.15E+02	1.12E+03	1.64E+03
75.0	3.04E+01	3.00E+01	3.26E+01	3.82E+01	4.33E+01	5.28E+01	7.27E+01	1.23E+02	1.90E+02	4.26E+02	6.92E+02	1.29E+03	1.89E+03
80.0	3.29E+01	3.21E+01	3.49E+01	4.08E+01	4.62E+01	5.65E+01	7.80E+01	1.33E+02	2.06E+02	4.71E+02	7.73E+02	1.46E+03	2.17E+03
85.0	3.56E+01	3.43E+01	3.71E+01	4.34E+01	4.92E+01	6.02E+01	8.34E+01	1.43E+02	2.23E+02	5.18E+02	8.58E+02	1.64E+03	2.46E+03
90.0	3.83E+01	3.66E+01	3.95E+01	4.61E+01	5.22E+01	6.39E+01	8.89E+01	1.53E+02	2.40E+02	5.66E+02	9.47E+02	1.83E+03	2.78E+03
95.0	4.12E+01	3.88E+01	4.18E+01	4.88E+01	5.53E+01	6.78E+01	9.44E+01	1.63E+02	2.57E+02	6.17E+02	1.04E+03	2.04E+03	3.11E+03
100.0	4.41E+01	4.11E+01	4.42E+01	5.15E+01	5.84E+01	7.16E+01	1.00E+02	1.74E+02	2.74E+02	6.69E+02	1.14E+03	2.25E+03	3.47E+03

	Energy (MeV)											
X(mfp)	0.4	0.3	0.2	0.15	0.1	0.08	0.06	0.05	0.04	0.03	0.02	0.015
0.5	1.61E+00	1.68E+00	1.77E+00	1.84E+00	1.87E+00	1.81E+00	1.62E+00	1.46E+00	1.28E+00	1.13E+00	1.04E+00	1.02E+00
1.0	2.37E+00	2.52E+00	2.71E+00	2.81E+00	2.75E+00	2.55E+00	2.09E+00	1.77E+00	1.45E+00	1.21E+00	1.06E+00	1.03E+00
2.0	4.30E+00	4.66E+00	5.04E+00	5.11E+00	4.60E+00	3.94E+00	2.86E+00	2.23E+00	1.68E+00	1.30E+00	1.09E+00	1.04E+00
3.0	6.78E+00	7.42E+00	7.99E+00	7.89E+00	6.59E+00	5.28E+00	3.51E+00	2.59E+00	1.85E+00	1.36E+00	1.11E+00	1.05E+00
4.0	9.83E+00	1.08E+01	1.16E+01	1.11E+01	8.73E+00	6.63E+00	4.11E+00	2.91E+00	1.99E+00	1.41E+00	1.13E+00	1.05E+00
5.0	1.35E+01	1.50E+01	1.59E+01	1.49E+01	1.10E+01	7.99E+00	4.68E+00	3.19E+00	2.11E+00	1.46E+00	1.14E+00	1.06E+00
6.0	1.78E+01	1.99E+01	2.09E+01	1.92E+01	1.35E+01	9.38E+00	5.22E+00	3.45E+00	2.21E+00	1.49E+00	1.15E+00	1.06E+00
7.0	2.27E+01	2.56E+01	2.67E+01	2.41E+01	1.62E+01	1.08E+01	5.76E+00	3.70E+00	2.31E+00	1.53E+00	1.16E+00	1.07E+00
8.0	2.84E+01	3.21E+01	3.34E+01	2.96E+01	1.91E+01	1.23E+01	6.27E+00	3.93E+00	2.40E+00	1.56E+00	1.16E+00	1.07E+00
10.0	4.20E+01	4.81E+01	4.96E+01	4.24E+01	2.54E+01	1.53E+01	7.29E+00	4.37E+00	2.56E+00	1.61E+00	1.18E+00	1.08E+00
15.0	9.04E+01	1.07E+02	1.09E+02	8.67E+01	4.45E+01	2.34E+01	9.71E+00	5.35E+00	2.90E+00	1.71E+00	1.20E+00	1.09E+00
20.0	1.62E+02	1.98E+02	2.01E+02	1.51E+02	6.83E+01	3.23E+01	1.20E+01	6.21E+00	3.18E+00	1.79E+00	1.22E+00	1.09E+00
25.0	2.58E+02	3.25E+02	3.32E+02	2.37E+02	9.68E+01	4.17E+01	1.42E+01	6.98E+00	3.42E+00	1.85E+00	1.23E+00	1.10E+00
30.0	3.81E+02	4.95E+02	5.09E+02	3.48E+02	1.30E+02	5.18E+01	1.64E+01	7.70E+00	3.63E+00	1.91E+00	1.25E+00	1.10E+00
35.0	5.32E+02	7.11E+02	7.37E+02	4.85E+02	1.68E+02	6.23E+01	1.85E+01	8.38E+00	3.82E+00	1.96E+00	1.26E+00	1.11E+00
40.0	7.14E+02	9.79E+02	1.02E+03	6.51E+02	2.10E+02	7.33E+01	2.06E+01	9.02E+00	3.99E+00	2.00E+00	1.27E+00	1.11E+00
45.0	9.28E+02	1.30E+03	1.38E+03	8.47E+02	2.57E+02	8.48E+01	2.26E+01	9.63E+00	4.15E+00	2.04E+00	1.27E+00	1.12E+00
50.0	1.17E+03	1.69E+03	1.80E+03	1.08E+03	3.08E+02	9.67E+01	2.46E+01	1.02E+01	4.31E+00	2.07E+00	1.28E+00	1.12E+00
55.0	1.45E+03	2.13E+03	2.30E+03	1.34E+03	3.64E+02	1.09E+02	2.67E+01	1.08E+01	4.46E+00	2.11E+00	1.29E+00	1.12E+00
60.0	1.77E+03	2.65E+03	2.88E+03	1.64E+03	4.24E+02	1.22E+02	2.87E+01	1.14E+01	4.60E+00	2.14E+00	1.29E+00	1.12E+00
65.0	2.12E+03	3.23E+03	3.55E+03	1.98E+03	4.89E+02	1.35E+02	3.07E+01	1.20E+01	4.74E+00	2.17E+00	1.30E+00	1.13E+00
70.0	2.51E+03	3.90E+03	4.32E+03	2.36E+03	5.59E+02	1.49E+02	3.28E+01	1.25E+01	4.88E+00	2.20E+00	1.30E+00	1.13E+00
75.0	2.94E+03	4.64E+03	5.19E+03	2.78E+03	6.34E+02	1.63E+02	3.48E+01	1.31E+01	5.01E+00	2.23E+00	1.31E+00	1.13E+00
80.0	3.41E+03	5.46E+03	6.17E+03	3.24E+03	7.14E+02	1.78E+02	3.69E+01	1.36E+01	5.14E+00	2.26E+00	1.31E+00	1.13E+00
85.0	3.92E+03	6.38E+03	7.26E+03	3.75E+03	7.99E+02	1.94E+02	3.90E+01	1.42E+01	5.27E+00	2.28E+00	1.32E+00	1.13E+00
90.0	4.47E+03	7.38E+03	8.47E+03	4.31E+03	8.89E+02	2.09E+02	4.12E+01	1.47E+01	5.40E+00	2.31E+00	1.32E+00	1.13E+00
95.0	5.07E+03	8.48E+03	9.82E+03	4.91E+03	9.84E+02	2.26E+02	4.34E+01	1.53E+01	5.52E+00	2.34E+00	1.33E+00	1.13E+00
100.0	5.72E+03	9.69E+03	1.13E+04	5.57E+03	1.08E+03	2.43E+02	4.56E+01	1.59E+01	5.65E+00	2.36E+00	1.33E+00	1.14E+00

pendable in the attenuation calculation of gamma-ray. **Figure 1** gives the ratio of the exposure buildup factor in the ANS data to that calculated by the IE method for iron as a sample of excellent agreement.

It is reported in the ANS[1)] that reconstruction of the flux density from the moments sometimes results in spurious oscillation. **Figure 2** gives the ratio of the exposure buildup factor in the ANS data to that calculated by the IE method for boron at the source energy of 150 keV. An oscillation is observed in the ANS data. The upper limit and the lower limit shown in Fig. 2 indicate that the ratio of the exact value to the value calculated by the IE method lies between them. These limits are obtained according to the method of error analysis described previously. A quantitative evaluation of

Table 3 Exposure buildup factors (Iron)

with bremsstrahlung, PHOTX

X(mfp)	15	10	8	6	5	4	3	2	1.5	1	0.8	0.6	0.5
	Energy (MeV)												
0.5	1.28E+00	1.28E+00	1.29E+00	1.30E+00	1.31E+00	1.32E+00	1.34E+00	1.36E+00	1.38E+00	1.43E+00	1.43E+00	1.46E+00	1.48E+00
1.0	1.52E+00	1.51E+00	1.53E+00	1.56E+00	1.58E+00	1.62E+00	1.67E+00	1.73E+00	1.78E+00	1.88E+00	1.90E+00	1.96E+00	1.99E+00
2.0	1.97E+00	1.92E+00	1.95E+00	2.03E+00	2.10E+00	2.20E+00	2.33E+00	2.53E+00	2.65E+00	2.89E+00	2.97E+00	3.09E+00	3.13E+00
3.0	2.42E+00	2.33E+00	2.38E+00	2.52E+00	2.63E+00	2.79E+00	3.03E+00	3.39E+00	3.63E+00	4.05E+00	4.22E+00	4.41E+00	4.46E+00
4.0	2.90E+00	2.76E+00	2.84E+00	3.03E+00	3.18E+00	3.42E+00	3.77E+00	4.31E+00	4.71E+00	5.35E+00	5.64E+00	5.94E+00	5.99E+00
5.0	3.44E+00	3.23E+00	3.32E+00	3.57E+00	3.77E+00	4.08E+00	4.55E+00	5.29E+00	5.86E+00	6.80E+00	7.24E+00	7.66E+00	7.71E+00
6.0	4.03E+00	3.74E+00	3.84E+00	4.14E+00	4.39E+00	4.78E+00	5.37E+00	6.33E+00	7.09E+00	8.38E+00	9.01E+00	9.58E+00	9.63E+00
7.0	4.68E+00	4.28E+00	4.40E+00	4.75E+00	5.05E+00	5.50E+00	6.22E+00	7.41E+00	8.38E+00	1.01E+01	1.09E+01	1.17E+01	1.17E+01
8.0	5.40E+00	4.87E+00	4.98E+00	5.38E+00	5.72E+00	6.25E+00	7.10E+00	8.54E+00	9.74E+00	1.19E+01	1.30E+01	1.40E+01	1.40E+01
10.0	7.09E+00	6.17E+00	6.27E+00	6.74E+00	7.16E+00	7.84E+00	8.95E+00	1.09E+01	1.26E+01	1.59E+01	1.76E+01	1.91E+01	1.92E+01
15.0	1.31E+01	1.03E+01	1.02E+01	1.07E+01	1.12E+01	1.22E+01	1.40E+01	1.74E+01	2.07E+01	2.75E+01	3.15E+01	3.50E+01	3.53E+01
20.0	2.28E+01	1.60E+01	1.51E+01	1.53E+01	1.58E+01	1.71E+01	1.95E+01	2.46E+01	2.97E+01	4.11E+01	4.85E+01	5.51E+01	5.57E+01
25.0	3.82E+01	2.35E+01	2.12E+01	2.06E+01	2.10E+01	2.23E+01	2.53E+01	3.24E+01	3.95E+01	5.66E+01	6.82E+01	7.91E+01	8.02E+01
30.0	6.22E+01	3.32E+01	2.85E+01	2.65E+01	2.66E+01	2.80E+01	3.15E+01	4.05E+01	5.00E+01	7.36E+01	9.05E+01	1.07E+02	1.09E+02
35.0	9.88E+01	4.56E+01	3.72E+01	3.31E+01	3.27E+01	3.39E+01	3.79E+01	4.91E+01	6.10E+01	9.21E+01	1.15E+02	1.38E+02	1.41E+02
40.0	1.54E+02	6.10E+01	4.72E+01	4.04E+01	3.92E+01	4.01E+01	4.46E+01	5.80E+01	7.26E+01	1.12E+02	1.42E+02	1.73E+02	1.77E+02
45.0	2.36E+02	8.01E+01	5.88E+01	4.82E+01	4.61E+01	4.66E+01	5.15E+01	6.72E+01	8.46E+01	1.33E+02	1.71E+02	2.11E+02	2.17E+02
50.0	3.56E+02	1.03E+02	7.19E+01	5.66E+01	5.33E+01	5.33E+01	5.85E+01	7.66E+01	9.70E+01	1.55E+02	2.02E+02	2.52E+02	2.61E+02
55.0	5.31E+02	1.31E+02	8.68E+01	6.57E+01	6.09E+01	6.03E+01	6.57E+01	8.63E+01	1.10E+02	1.78E+02	2.35E+02	2.96E+02	3.08E+02
60.0	7.84E+02	1.65E+02	1.03E+02	7.53E+01	6.89E+01	6.74E+01	7.31E+01	9.63E+01	1.23E+02	2.02E+02	2.69E+02	3.43E+02	3.58E+02
65.0	1.15E+03	2.05E+02	1.22E+02	8.54E+01	7.71E+01	7.47E+01	8.06E+01	1.06E+02	1.36E+02	2.27E+02	3.06E+02	3.94E+02	4.12E+02
70.0	1.66E+03	2.52E+02	1.43E+02	9.62E+01	8.57E+01	8.23E+01	8.82E+01	1.17E+02	1.50E+02	2.54E+02	3.44E+02	4.47E+02	4.69E+02
75.0	2.38E+03	3.07E+02	1.65E+02	1.07E+02	9.45E+01	9.00E+01	9.60E+01	1.27E+02	1.64E+02	2.81E+02	3.84E+02	5.03E+02	5.30E+02
80.0	3.40E+03	3.72E+02	1.90E+02	1.19E+02	1.04E+02	9.78E+01	1.04E+02	1.38E+02	1.79E+02	3.08E+02	4.25E+02	5.62E+02	5.94E+02
85.0	4.82E+03	4.47E+02	2.17E+02	1.32E+02	1.13E+02	1.06E+02	1.12E+02	1.49E+02	1.93E+02	3.37E+02	4.69E+02	6.24E+02	6.61E+02
90.0	6.79E+03	5.33E+02	2.47E+02	1.45E+02	1.23E+02	1.14E+02	1.20E+02	1.60E+02	2.08E+02	3.66E+02	5.13E+02	6.89E+02	7.32E+02
95.0	9.51E+03	6.33E+02	2.79E+02	1.58E+02	1.33E+02	1.22E+02	1.29E+02	1.72E+02	2.23E+02	3.97E+02	5.59E+02	7.57E+02	8.06E+02
100.0	1.33E+04	7.46E+02	3.13E+02	1.72E+02	1.43E+02	1.31E+02	1.37E+02	1.83E+02	2.39E+02	4.28E+02	6.07E+02	8.27E+02	8.83E+02

X(mfp)	0.4	0.3	0.2	0.15	0.1	0.08	0.06	0.05	0.04	0.03	0.02	0.015
	Energy (MeV)											
0.5	1.50E+00	1.50E+00	1.46E+00	1.39E+00	1.24E+00	1.17E+00	1.10E+00	1.06E+00	1.04E+00	1.02E+00	1.01E+00	1.00E+00
1.0	2.01E+00	1.99E+00	1.85E+00	1.67E+00	1.39E+00	1.26E+00	1.14E+00	1.09E+00	1.05E+00	1.02E+00	1.01E+00	1.00E+00
2.0	3.13E+00	3.02E+00	2.60E+00	2.16E+00	1.60E+00	1.39E+00	1.20E+00	1.13E+00	1.07E+00	1.03E+00	1.01E+00	1.01E+00
3.0	4.42E+00	4.14E+00	3.34E+00	2.59E+00	1.78E+00	1.48E+00	1.25E+00	1.16E+00	1.09E+00	1.04E+00	1.01E+00	1.01E+00
4.0	5.88E+00	5.38E+00	4.10E+00	3.00E+00	1.93E+00	1.56E+00	1.28E+00	1.18E+00	1.10E+00	1.05E+00	1.02E+00	1.01E+00
5.0	7.52E+00	6.72E+00	4.88E+00	3.38E+00	2.06E+00	1.63E+00	1.31E+00	1.20E+00	1.11E+00	1.05E+00	1.02E+00	1.01E+00
6.0	9.32E+00	8.16E+00	5.67E+00	3.76E+00	2.19E+00	1.69E+00	1.34E+00	1.21E+00	1.12E+00	1.05E+00	1.02E+00	1.01E+00
7.0	1.13E+01	9.69E+00	6.47E+00	4.12E+00	2.30E+00	1.75E+00	1.36E+00	1.22E+00	1.12E+00	1.06E+00	1.02E+00	1.01E+00
8.0	1.34E+01	1.13E+01	7.28E+00	4.46E+00	2.41E+00	1.80E+00	1.38E+00	1.23E+00	1.13E+00	1.06E+00	1.02E+00	1.01E+00
10.0	1.82E+01	1.48E+01	8.94E+00	5.13E+00	2.60E+00	1.89E+00	1.41E+00	1.25E+00	1.14E+00	1.06E+00	1.02E+00	1.01E+00
15.0	3.28E+01	2.50E+01	1.32E+01	6.68E+00	2.99E+00	2.06E+00	1.48E+00	1.29E+00	1.16E+00	1.07E+00	1.02E+00	1.01E+00
20.0	5.12E+01	3.68E+01	1.77E+01	8.10E+00	3.32E+00	2.20E+00	1.53E+00	1.32E+00	1.17E+00	1.08E+00	1.03E+00	1.01E+00
25.0	7.30E+01	5.02E+01	2.22E+01	9.43E+00	3.60E+00	2.32E+00	1.57E+00	1.34E+00	1.18E+00	1.08E+00	1.03E+00	1.01E+00
30.0	9.84E+01	6.50E+01	2.69E+01	1.07E+01	3.85E+00	2.42E+00	1.61E+00	1.36E+00	1.19E+00	1.09E+00	1.03E+00	1.01E+00
35.0	1.27E+02	8.11E+01	3.16E+01	1.19E+01	4.08E+00	2.51E+00	1.64E+00	1.38E+00	1.20E+00	1.09E+00	1.03E+00	1.01E+00
40.0	1.59E+02	9.85E+01	3.64E+01	1.31E+01	4.30E+00	2.59E+00	1.66E+00	1.39E+00	1.21E+00	1.09E+00	1.03E+00	1.01E+00
45.0	1.94E+02	1.17E+02	4.13E+01	1.42E+01	4.50E+00	2.66E+00	1.69E+00	1.40E+00	1.21E+00	1.09E+00	1.03E+00	1.01E+00
50.0	2.32E+02	1.37E+02	4.63E+01	1.54E+01	4.69E+00	2.73E+00	1.71E+00	1.41E+00	1.22E+00	1.10E+00	1.03E+00	1.02E+00
55.0	2.73E+02	1.57E+02	5.14E+01	1.65E+01	4.87E+00	2.80E+00	1.73E+00	1.43E+00	1.22E+00	1.10E+00	1.03E+00	1.02E+00
60.0	3.17E+02	1.79E+02	5.66E+01	1.76E+01	5.05E+00	2.87E+00	1.75E+00	1.44E+00	1.23E+00	1.10E+00	1.03E+00	1.02E+00
65.0	3.64E+02	2.02E+02	6.18E+01	1.87E+01	5.22E+00	2.93E+00	1.77E+00	1.45E+00	1.23E+00	1.10E+00	1.03E+00	1.02E+00
70.0	4.14E+02	2.25E+02	6.72E+01	1.98E+01	5.39E+00	2.99E+00	1.79E+00	1.46E+00	1.24E+00	1.11E+00	1.03E+00	1.02E+00
75.0	4.66E+02	2.50E+02	7.26E+01	2.09E+01	5.56E+00	3.05E+00	1.81E+00	1.47E+00	1.24E+00	1.11E+00	1.04E+00	1.02E+00
80.0	5.22E+02	2.76E+02	7.81E+01	2.20E+01	5.73E+00	3.11E+00	1.83E+00	1.48E+00	1.25E+00	1.11E+00	1.04E+00	1.02E+00
85.0	5.80E+02	3.02E+02	8.37E+01	2.31E+01	5.89E+00	3.17E+00	1.85E+00	1.48E+00	1.25E+00	1.11E+00	1.04E+00	1.02E+00
90.0	6.42E+02	3.30E+02	8.94E+01	2.42E+01	6.06E+00	3.23E+00	1.86E+00	1.49E+00	1.25E+00	1.11E+00	1.04E+00	1.02E+00
95.0	7.06E+02	3.58E+02	9.53E+01	2.53E+01	6.22E+00	3.28E+00	1.88E+00	1.50E+00	1.26E+00	1.11E+00	1.04E+00	1.02E+00
100.0	7.73E+02	3.88E+02	1.01E+02	2.65E+01	6.39E+00	3.34E+00	1.90E+00	1.51E+00	1.26E+00	1.11E+00	1.04E+00	1.02E+00

accuracy based on the same method was performed to all of the 22 cases having discrepancy more than 10% (denoted by △ in Table 5). The upper limit obtained is 1.01 or less and the lower limit is 0.95 or above at depths of 40 mfp for all 22 cases. It indicates that the buildup factors calculated by the IE method is accurate enough to be used to correct the spurious oscillation in the moments method calculations.

2. Influence of Cross-section

The exposure buildup factors of 18 low-Z materials were calculated without bremsstrahlung based on the cross-section PHOTX and compared with those calculated based on the cross-section NBS29 to check the influence of the cross-section upon the exposure buildup factor. The energy absorption cross-section for air used in the calculation of

Table 4 Exposure buildup factors (Lead)

with bremsstrahlung, PHOTX

	Energy (MeV)															
X(mfp)	15	10	8	6	5	4	3	2	1.5	1	0.8	0.6	0.5	0.4	0.3	0.2
0.5	1.39E+00	1.32E+00	1.29E+00	1.27E+00	1.25E+00	1.25E+00	1.25E+00	1.25E+00	1.23E+00	1.20E+00	1.18E+00	1.15E+00	1.13E+00	1.10E+00	1.07E+00	1.16E+00
1.0	1.71E+00	1.55E+00	1.49E+00	1.44E+00	1.42E+00	1.42E+00	1.43E+00	1.45E+00	1.43E+00	1.37E+00	1.33E+00	1.27E+00	1.22E+00	1.17E+00	1.11E+00	1.20E+00
2.0	2.42E+00	2.00E+00	1.86E+00	1.77E+00	1.75E+00	1.76E+00	1.80E+00	1.83E+00	1.79E+00	1.67E+00	1.59E+00	1.46E+00	1.38E+00	1.28E+00	1.18E+00	1.23E+00
3.0	3.31E+00	2.51E+00	2.27E+00	2.13E+00	2.10E+00	2.12E+00	2.19E+00	2.22E+00	2.15E+00	1.95E+00	1.81E+00	1.62E+00	1.50E+00	1.36E+00	1.23E+00	1.25E+00
4.0	4.50E+00	3.13E+00	2.75E+00	2.54E+00	2.50E+00	2.52E+00	2.60E+00	2.61E+00	2.49E+00	2.20E+00	2.02E+00	1.77E+00	1.61E+00	1.43E+00	1.27E+00	1.27E+00
5.0	6.09E+00	3.89E+00	3.31E+00	3.00E+00	2.93E+00	2.96E+00	3.03E+00	3.02E+00	2.83E+00	2.44E+00	2.21E+00	1.90E+00	1.70E+00	1.50E+00	1.30E+00	1.28E+00
6.0	8.25E+00	4.82E+00	3.98E+00	3.53E+00	3.42E+00	3.43E+00	3.49E+00	3.42E+00	3.17E+00	2.67E+00	2.38E+00	2.01E+00	1.78E+00	1.55E+00	1.33E+00	1.30E+00
7.0	1.12E+01	5.97E+00	4.76E+00	4.12E+00	3.97E+00	3.95E+00	3.98E+00	3.84E+00	3.50E+00	2.90E+00	2.55E+00	2.12E+00	1.86E+00	1.60E+00	1.36E+00	1.31E+00
8.0	1.52E+01	7.40E+00	5.70E+00	4.80E+00	4.58E+00	4.51E+00	4.49E+00	4.27E+00	3.83E+00	3.11E+00	2.71E+00	2.23E+00	1.94E+00	1.64E+00	1.38E+00	1.32E+00
10.0	2.83E+01	1.14E+01	8.12E+00	6.45E+00	5.99E+00	5.76E+00	5.59E+00	5.13E+00	4.48E+00	3.52E+00	3.01E+00	2.42E+00	2.07E+00	1.72E+00	1.42E+00	1.34E+00
15.0	1.36E+02	3.37E+01	1.95E+01	1.28E+01	1.10E+01	9.78E+00	8.77E+00	7.40E+00	6.09E+00	4.45E+00	3.67E+00	2.83E+00	2.34E+00	1.88E+00	1.50E+00	1.37E+00
20.0	6.58E+02	9.99E+01	4.58E+01	2.43E+01	1.89E+01	1.53E+01	1.26E+01	9.78E+00	7.67E+00	5.29E+00	4.24E+00	3.17E+00	2.56E+00	2.00E+00	1.56E+00	1.40E+00
25.0	3.15E+03	2.94E+02	1.06E+02	4.43E+01	3.07E+01	2.25E+01	1.69E+01	1.23E+01	9.22E+00	6.07E+00	4.76E+00	3.48E+00	2.75E+00	2.11E+00	1.61E+00	1.42E+00
30.0	1.49E+04	8.52E+02	2.40E+02	7.82E+01	4.82E+01	3.17E+01	2.18E+01	1.48E+01	1.07E+01	6.81E+00	5.24E+00	3.77E+00	2.93E+00	2.20E+00	1.66E+00	1.44E+00
35.0	6.96E+04	2.43E+03	5.35E+02	1.34E+02	7.32E+01	4.32E+01	2.72E+01	1.74E+01	1.22E+01	7.51E+00	5.69E+00	4.04E+00	3.09E+00	2.27E+00	1.69E+00	1.46E+00
40.0	3.21E+05	6.87E+03	1.17E+03	2.26E+02	1.09E+02	5.74E+01	3.31E+01	2.00E+01	1.37E+01	8.19E+00	6.12E+00	4.30E+00	3.24E+00	2.34E+00	1.72E+00	1.47E+00
45.0	1.46E+06	1.91E+04	2.54E+03	3.73E+02	1.58E+02	7.46E+01	3.95E+01	2.27E+01	1.52E+01	8.85E+00	6.53E+00	4.56E+00	3.39E+00	2.41E+00	1.75E+00	1.49E+00
50.0	6.61E+06	5.26E+04	5.42E+03	6.06E+02	2.25E+02	9.52E+01	4.64E+01	2.54E+01	1.66E+01	9.50E+00	6.93E+00	4.81E+00	3.53E+00	2.47E+00	1.78E+00	1.50E+00
55.0	2.96E+07	1.43E+05	1.14E+04	9.70E+02	3.16E+02	1.20E+02	5.37E+01	2.81E+01	1.80E+01	1.01E+01	7.32E+00	5.06E+00	3.67E+00	2.52E+00	1.80E+00	1.51E+00
60.0	1.31E+08	3.87E+05	2.39E+04	1.53E+03	4.38E+02	1.49E+02	6.15E+01	3.08E+01	1.94E+01	1.08E+01	7.71E+00	5.31E+00	3.81E+00	2.57E+00	1.83E+00	1.52E+00
65.0	5.78E+08	1.04E+06	4.94E+04	2.40E+03	5.99E+02	1.82E+02	6.97E+01	3.36E+01	2.08E+01	1.14E+01	8.09E+00	5.56E+00	3.95E+00	2.62E+00	1.85E+00	1.53E+00
70.0	2.53E+09	2.76E+06	1.01E+05	3.72E+03	8.13E+02	2.21E+02	7.83E+01	3.64E+01	2.22E+01	1.20E+01	8.47E+00	5.82E+00	4.08E+00	2.67E+00	1.87E+00	1.54E+00
75.0	1.10E+10	7.28E+06	2.06E+05	5.71E+03	1.09E+03	2.66E+02	8.72E+01	3.92E+01	2.36E+01	1.26E+01	8.85E+00	6.08E+00	4.22E+00	2.71E+00	1.89E+00	1.55E+00
80.0	4.76E+10	1.91E+07	4.16E+05	8.69E+03	1.45E+03	3.18E+02	9.66E+01	4.20E+01	2.49E+01	1.32E+01	9.22E+00	6.35E+00	4.36E+00	2.76E+00	1.91E+00	1.57E+00
85.0	2.05E+11	4.98E+07	8.36E+05	1.31E+04	1.92E+03	3.76E+02	1.06E+02	4.48E+01	2.63E+01	1.39E+01	9.60E+00	6.62E+00	4.50E+00	2.80E+00	1.92E+00	1.58E+00
90.0	8.77E+11	1.29E+08	1.67E+06	1.98E+04	2.53E+03	4.43E+02	1.16E+02	4.76E+01	2.76E+01	1.45E+01	9.98E+00	6.90E+00	4.64E+00	2.84E+00	1.94E+00	1.59E+00
95.0	3.74E+12	3.33E+08	3.32E+06	2.95E+04	3.30E+03	5.19E+02	1.27E+02	5.05E+01	2.89E+01	1.51E+01	1.04E+01	7.19E+00	4.78E+00	2.88E+00	1.96E+00	1.59E+00
100.0	1.59E+13	8.56E+08	6.55E+06	4.38E+04	4.28E+03	6.03E+02	1.38E+02	5.33E+01	3.02E+01	1.58E+01	1.08E+01	7.48E+00	4.92E+00	2.91E+00	1.97E+00	1.60E+00

	Energy (MeV)														
X(mfp)	0.16	0.15	0.14	0.13	0.12	0.11	0.10	0.09	0.089	0.088	0.08	0.06	0.05	0.04	0.03
0.5	1.25E+00	1.29E+00	1.33E+00	1.38E+00	1.44E+00	1.51E+00	1.60E+00	1.68E+00	1.69E+00	1.04E+00	1.03E+00	1.02E+00	1.01E+00	1.01E+00	1.00E+00
1.0	1.36E+00	1.44E+00	1.52E+00	1.64E+00	1.77E+00	1.94E+00	2.15E+00	2.36E+00	2.38E+00	1.06E+00	1.05E+00	1.03E+00	1.02E+00	1.01E+00	1.01E+00
2.0	1.46E+00	1.60E+00	1.78E+00	2.04E+00	2.39E+00	2.85E+00	3.47E+00	4.16E+00	4.25E+00	1.08E+00	1.07E+00	1.04E+00	1.03E+00	1.02E+00	1.01E+00
3.0	1.51E+00	1.69E+00	1.97E+00	2.41E+00	3.08E+00	4.06E+00	5.48E+00	7.27E+00	7.51E+00	1.10E+00	1.09E+00	1.05E+00	1.03E+00	1.02E+00	1.01E+00
4.0	1.53E+00	1.75E+00	2.13E+00	2.80E+00	3.93E+00	5.80E+00	8.79E+00	1.30E+01	1.36E+01	1.12E+00	1.10E+00	1.05E+00	1.04E+00	1.02E+00	1.01E+00
5.0	1.54E+00	1.79E+00	2.28E+00	3.24E+00	5.08E+00	8.46E+00	1.45E+01	2.40E+01	2.54E+01	1.13E+00	1.11E+00	1.06E+00	1.04E+00	1.02E+00	1.01E+00
6.0	1.55E+00	1.83E+00	2.44E+00	3.77E+00	6.67E+00	1.26E+01	2.44E+01	4.52E+01	4.83E+01	1.14E+00	1.12E+00	1.06E+00	1.04E+00	1.02E+00	1.01E+00
7.0	1.56E+00	1.87E+00	2.61E+00	4.46E+00	8.96E+00	1.94E+01	4.22E+01	8.65E+01	9.35E+01	1.15E+00	1.12E+00	1.07E+00	1.04E+00	1.03E+00	1.01E+00
8.0	1.57E+00	1.90E+00	2.81E+00	5.35E+00	1.23E+01	3.03E+01	7.40E+01	1.68E+02	1.83E+02	1.16E+00	1.13E+00	1.07E+00	1.05E+00	1.03E+00	1.01E+00
10.0	1.58E+00	1.98E+00	3.34E+00	8.19E+00	2.49E+01	7.87E+01	2.37E+02	6.47E+02	7.20E+02	1.17E+00	1.14E+00	1.07E+00	1.05E+00	1.03E+00	1.01E+00
15.0	1.60E+00	2.20E+00	6.15E+00	3.29E+01	1.95E+02	1.07E+03	5.03E+03	2.07E+04	2.39E+04	1.20E+00	1.16E+00	1.09E+00	1.06E+00	1.03E+00	1.02E+00
20.0	1.61E+00	2.52E+00	1.46E+01	1.74E+02	1.88E+03	1.70E+04	1.22E+05	7.24E+05	8.62E+05	1.22E+00	1.18E+00	1.09E+00	1.06E+00	1.04E+00	1.02E+00
25.0	1.62E+00	3.00E+00	4.12E+01	1.01E+03	1.95E+04	2.93E+05	3.18E+06	2.70E+07	3.30E+07	1.24E+00	1.19E+00	1.10E+00	1.06E+00	1.04E+00	1.02E+00
30.0	1.62E+00	3.75E+00	1.27E+02	6.13E+03	2.09E+05	5.21E+06	8.65E+07	1.05E+09	1.32E+09	1.25E+00	1.20E+00	1.10E+00	1.07E+00	1.04E+00	1.02E+00
35.0	1.63E+00	5.00E+00	4.08E+02	3.79E+04	2.28E+06	9.42E+07	2.41E+09	4.24E+10	5.47E+10	1.26E+00	1.21E+00	1.11E+00	1.07E+00	1.04E+00	1.02E+00
40.0	1.64E+00	7.09E+00	1.35E+03	2.38E+05	2.51E+07	1.72E+09	6.81E+10	1.74E+12	2.31E+12	1.27E+00	1.22E+00	1.11E+00	1.07E+00	1.04E+00	1.02E+00
45.0	1.64E+00	1.07E+01	4.58E+03	1.52E+06	2.80E+08	3.16E+10	1.94E+12	7.20E+13	9.86E+13	1.28E+00	1.22E+00	1.11E+00	1.07E+00	1.04E+00	1.02E+00
50.0	1.65E+00	1.69E+01	1.58E+04	9.82E+06	3.16E+09	5.84E+11	5.54E+13	3.01E+15	4.25E+15	1.28E+00	1.23E+00	1.12E+00	1.07E+00	1.04E+00	1.02E+00
55.0	1.66E+00	2.76E+01	5.47E+04	6.40E+07	3.59E+10	1.09E+13	1.59E+15	1.26E+17	1.84E+17	1.29E+00	1.23E+00	1.12E+00	1.08E+00	1.04E+00	1.02E+00
60.0	1.66E+00	4.65E+01	1.92E+05	4.21E+08	4.11E+11	2.03E+14	4.59E+16	5.33E+18	8.03E+18	1.30E+00	1.24E+00	1.12E+00	1.08E+00	1.05E+00	1.02E+00
65.0	1.67E+00	7.97E+01	6.78E+05	2.79E+09	4.75E+12	3.82E+15	1.33E+18	2.25E+20	3.51E+20	1.30E+00	1.24E+00	1.12E+00	1.08E+00	1.05E+00	1.02E+00
70.0	1.67E+00	1.38E+02	2.41E+06	1.86E+10	5.52E+13	7.22E+16	3.86E+19	9.55E+21	1.54E+22	1.31E+00	1.25E+00	1.12E+00	1.08E+00	1.05E+00	1.02E+00
75.0	1.68E+00	2.41E+02	8.57E+06	1.25E+11	6.44E+14	1.37E+18	1.13E+21	4.06E+23	6.75E+23	1.31E+00	1.25E+00	1.13E+00	1.08E+00	1.05E+00	1.02E+00
80.0	1.68E+00	4.23E+02	3.06E+07	8.39E+11	7.55E+15	2.61E+19	3.29E+22	1.73E+25	2.97E+25	1.32E+00	1.25E+00	1.13E+00	1.08E+00	1.05E+00	1.02E+00
85.0	1.69E+00	7.44E+02	1.10E+08	5.66E+12	8.89E+16	4.99E+20	9.65E+23	7.36E+26	1.31E+27	1.32E+00	1.26E+00	1.13E+00	1.08E+00	1.05E+00	1.02E+00
90.0	1.69E+00	1.31E+03	3.93E+08	3.82E+13	1.05E+18	9.57E+21	2.84E+25	3.15E+28	5.79E+28	1.32E+00	1.26E+00	1.13E+00	1.08E+00	1.05E+00	1.02E+00
95.0	1.70E+00	2.32E+03	1.41E+09	2.59E+14	1.24E+19	1.84E+23	8.36E+26	1.35E+30	2.56E+30	1.33E+00	1.26E+00	1.13E+00	1.08E+00	1.05E+00	1.02E+00
100.0	1.71E+00	4.09E+03	5.06E+09	1.76E+15	1.48E+20	3.56E+24	2.47E+28	5.78E+31	1.14E+32	1.33E+00	1.26E+00	1.13E+00	1.08E+00	1.05E+00	1.02E+00

the exposure buildup factor is also changed from the data in NBS29 to that in the ANS. **Figure 3** gives the ratio of the exposure buildup factor calculated with PHOTX to that with NBS29 for C. A difference more than 20% is observed at depths of 40 mfp for the source energies including 0.10 MeV, 0.08 MeV, 0.06 MeV, 0.05 MeV, 0.04 MeV, 0.03 MeV, and 0.02 MeV in the energy range 0.02 MeV to 0.10 MeV. The photoelectric cross-section for C in PHOTX (0.0208 barns at 0.05 MeV and 4.34 barns at 0.02 MeV) is larger than that in NBS29 (0.0193 barns at 0..05 MeV and 4.01 barns at 0.02 MeV) in the energy range below 0.05 MeV. The difference in the photoelectric cross-section results in the difference of exposure buildup factor. A similar difference is observed for Be and B in the energy range be-

Table 5 Comparison of exposure buildup factor in ANS data to that calculated by IE method without bremsstrahlung based on corss-section NBS29

Source Energy (MeV)	Difference of exposure buildup factor in ANS data[1] from that calculated by IE method up to depths of 40 mfp ◎: no more than 5% ○: 6〜10% △: more than 10%																			
	Be	B	C	N	O	Na	Mg	Al	Si	P	S	Ar	K	Fe	Cu	WAT[1]	CRT[2]	AIR		
15.0	◎	◎	◎	◎	◎	◎	◎	◎	○	○	◎	◎	○	◎	◎	◎	◎	◎		
10.0	◎	○	○	◎	◎	◎	◎	◎	◎	◎	◎	○	◎	○	○	◎	○	○		
8.0	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎		
6.0	◎	◎	◎	◎	◎	○	○	◎	◎	◎	◎	◎	◎	○	◎	◎	◎	◎		
5.0	◎	◎	◎	◎	◎	◎	△	○	△	○	◎	◎	○	◎	○	◎	○	◎		
4.0	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	◎	◎	◎	◎	◎	◎	◎		
3.0	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	◎	◎	◎	◎		
2.0	◎	○	◎	△	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎		
1.5	◎	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎		
1.0	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎		
0.8	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎		
0.6	○	◎	◎	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎		
0.5	◎	△	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎		
0.4	◎	△	◎	◎	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎		
0.3	○	◎	◎	◎	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○		
0.2	○	◎	◎	◎	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	◎	◎		
0.15	○	△	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○	◎	○		
0.10	◎	△	○	○	○	◎	◎	◎	◎	◎	○	◎	◎	◎	◎	○	◎	◎		
0.08	◎	△	○	◎	○	○	○	△	◎	△	○	◎	◎	◎	◎	◎	◎	◎		
0.06	◎	○	○	◎	◎	○	◎	△	◎	◎	◎	◎	◎	◎	◎	◎	△	○		
0.05	○	○	○	○	◎	○	△	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	○		
0.04	○	○	◎	◎	◎	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	○		
0.03	○	△	△	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	△	◎	△		
0.02	△	△	○	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎		
0.015	△	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	◎	Total	Fraction (%)
◎	16	12	18	19	19	20	21	21	23	22	22	24	23	22	23	21	22	18	366	81
○	7	6	6	5	6	5	2	2	1	2	2	1	2	3	2	2	2	6	62	14
△	2	7	1	1	0	0	2	2	1	1	1	0	0	0	0	2	1	1	22	5

1 Water 2 Concrete

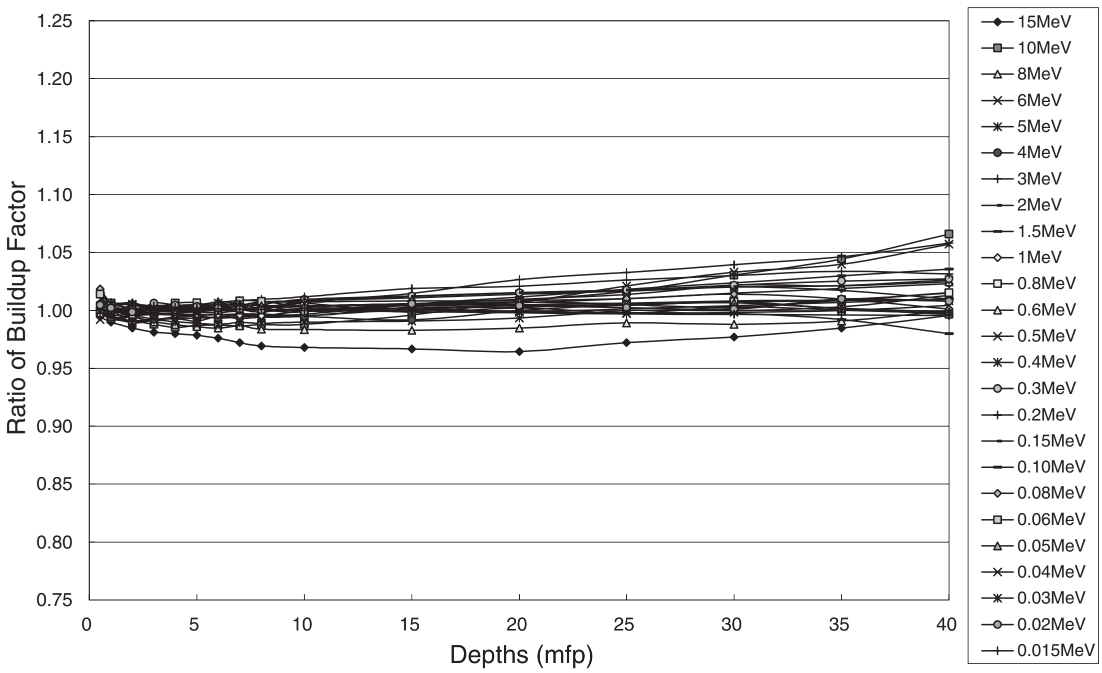

Fig. 1 Ratio of exposure buildup factor in the ANS data[1] to that calculated by the IE method for iron Both data are calculated without bremsstrahlung based on the cross-section NBS29.

low 0.04 MeV with a magnitude about 20% to 30%. The difference in the exposure buildup factors for other materials due to the difference in the cross-section is found less than about 20%.

3. Effect of Bremsstrahlung

The exposure buildup factors for all 26 materials are calculated both with and without bremsstrahlung based on the cross-section PHOTX to check the effect of bremsstralung.

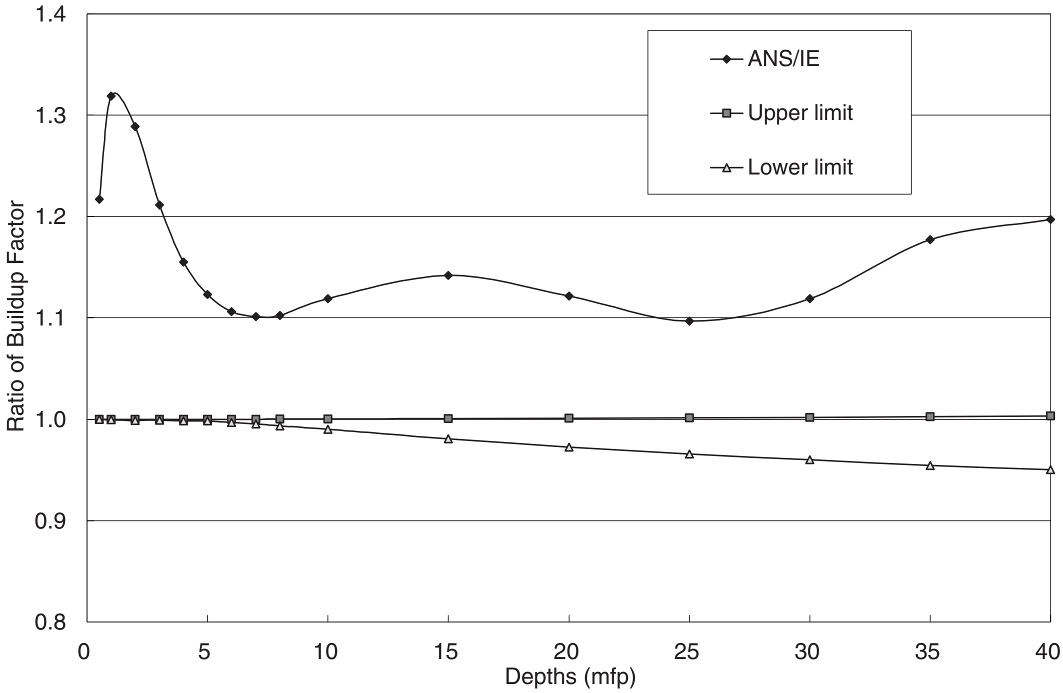

Fig. 2 Ratio of exposure buildup factor in the ANS data[1] to that calculated by the IE method for boron at source energy of 150 keV
Both data are calculated without bremsstrahlung based on the cross-section NBS29.
Upper limit: Ratio of the exact value to the present calculated value lies below this line
Lower limit: Ratio of the exact value to the present calculated value lies above this line

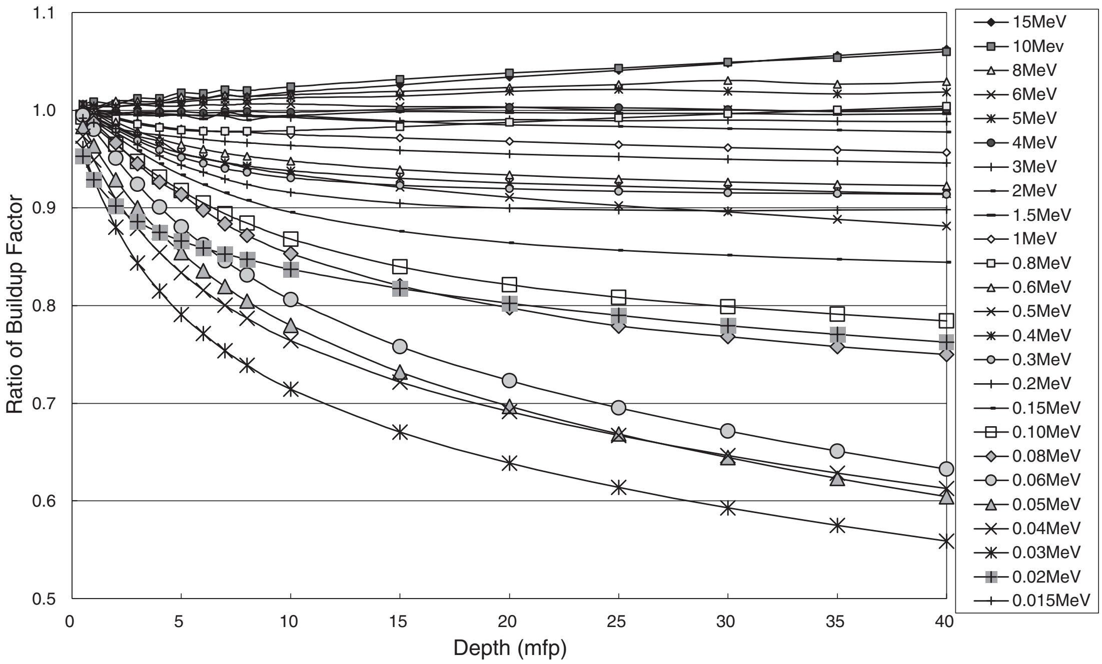

Fig. 3 Ratio of exposure buildup factor based on PHOTX to that based on NBS29 for carbon
Both buildup factors are calculated without bremsstrahlung.

Figures 4 and **5** give the ratio of the exposure buildup factor with bremsstrahlung to that without bremsstrahlung at the source energy of 10 MeV for all materials. The figures show clearly the dependence of the bremsstrahlung effect on the atomic number. It is confirmed in the previous paper[4] that the ratio of the exposure buildup factor with bremsstrahlung to that without bremsstrahlung at 10 MeV for lead obtained by the IE method agrees with the value obtained by Hiraya-

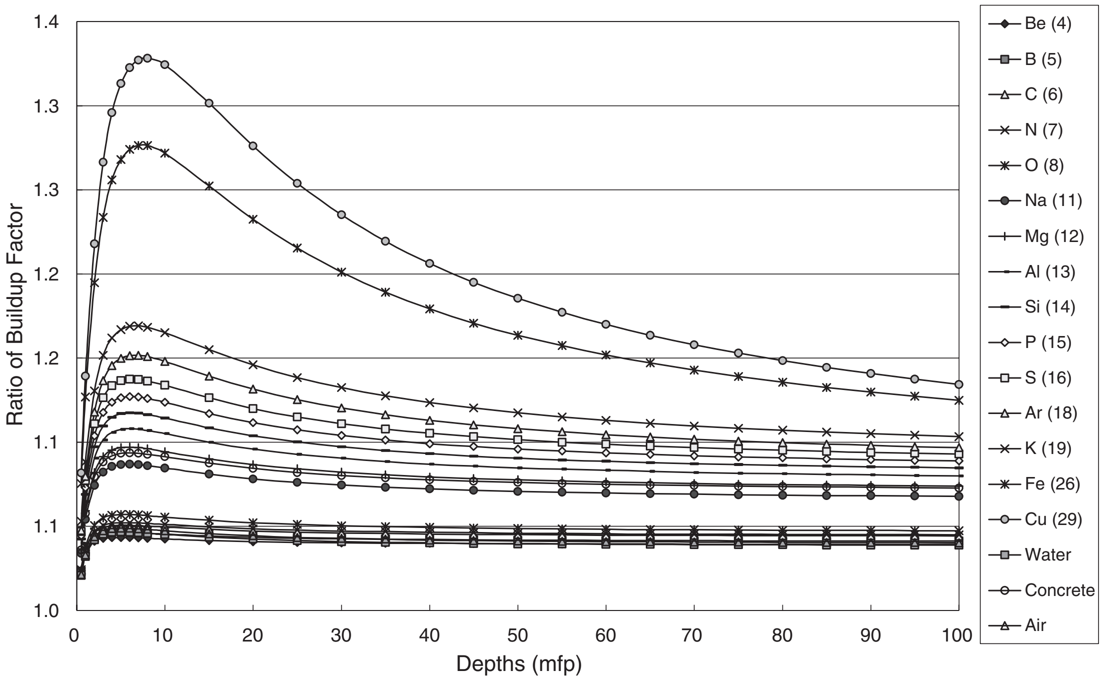

Fig. 4 Ratio of exposure buildup factor with bremsstrahlung to that without bremsstrahlung for low-Z materials at source energy of 10 MeV

The exposure buildup factors are calculated based on PHOTX. The number in the parensis rihgt after the symbol for element indicates atomic number.

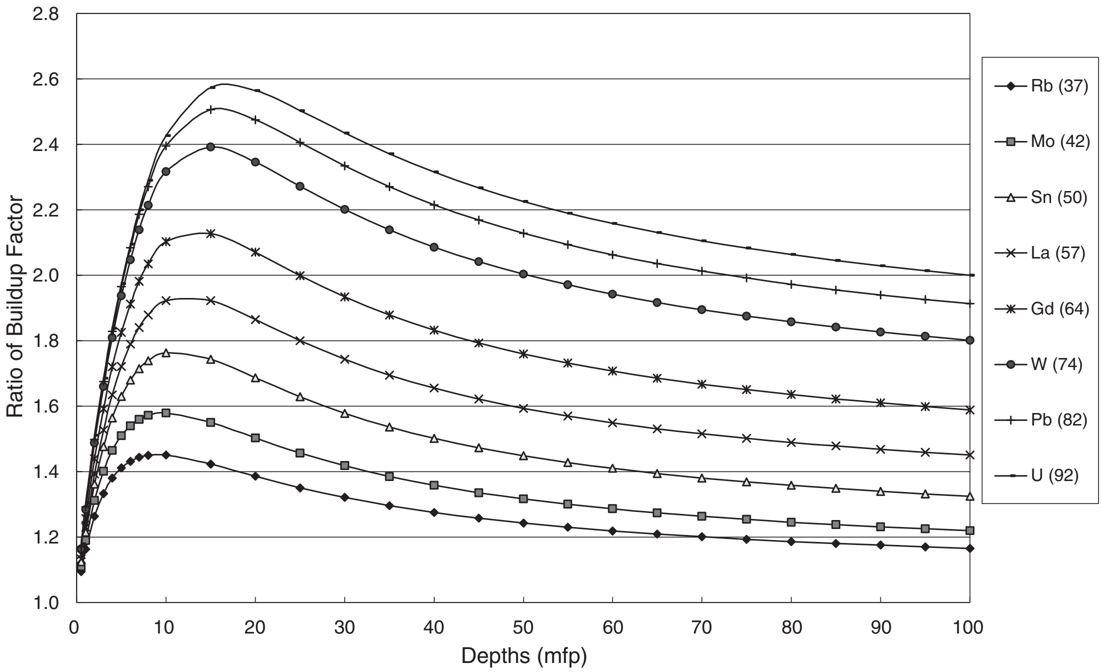

Fig. 5 Ratio of exposure buildup factor with bremsstrahlung to that without bremsstrahlung for high-Z elements at source energy of 10 MeV

The exposure buildup factors are calculated based on PHOTX. The number in the parensis rihgt after the symbol for element indicates atomic number.

ma[12] by using the EGS4 code within a discrepancy less than 5% up to depths of 40 mfp.

4. Comparison of Buildup Factor for High-Z Elements

The present standard data for high-Z elements are compared with the ANS data. Substantial discrepancies are ob-

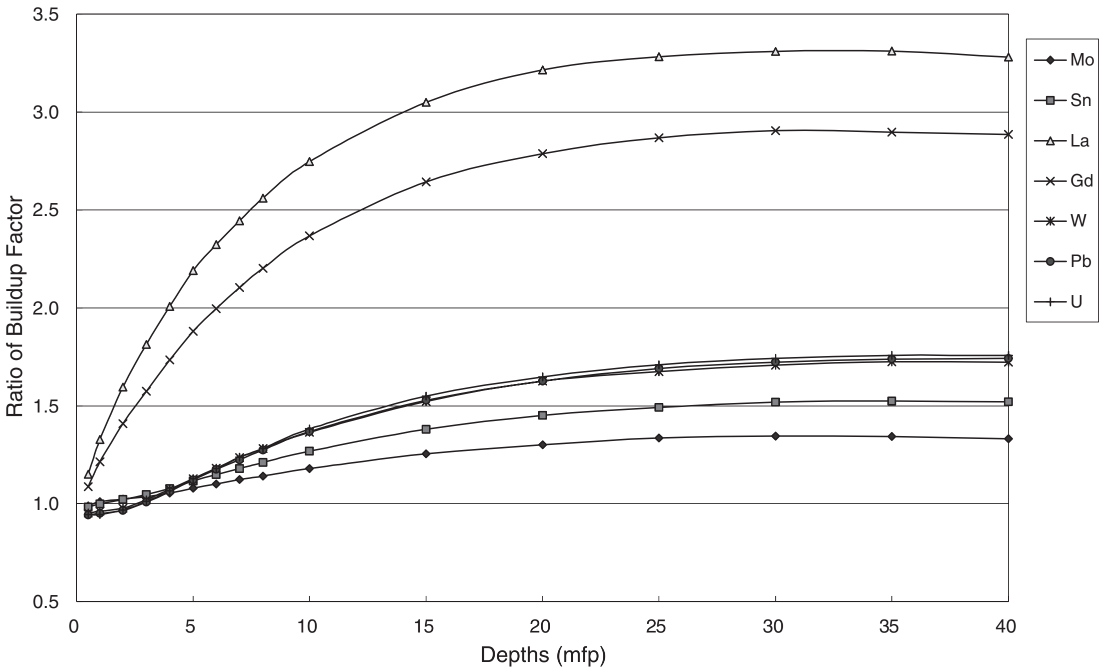

Fig. 6 Ratio of exposure buildup factor in the ANS data[1)] to the present data for high-Z elements at source energy of 15 MeV
Both data are calculated with bremsstrahlung based on PHOTX.

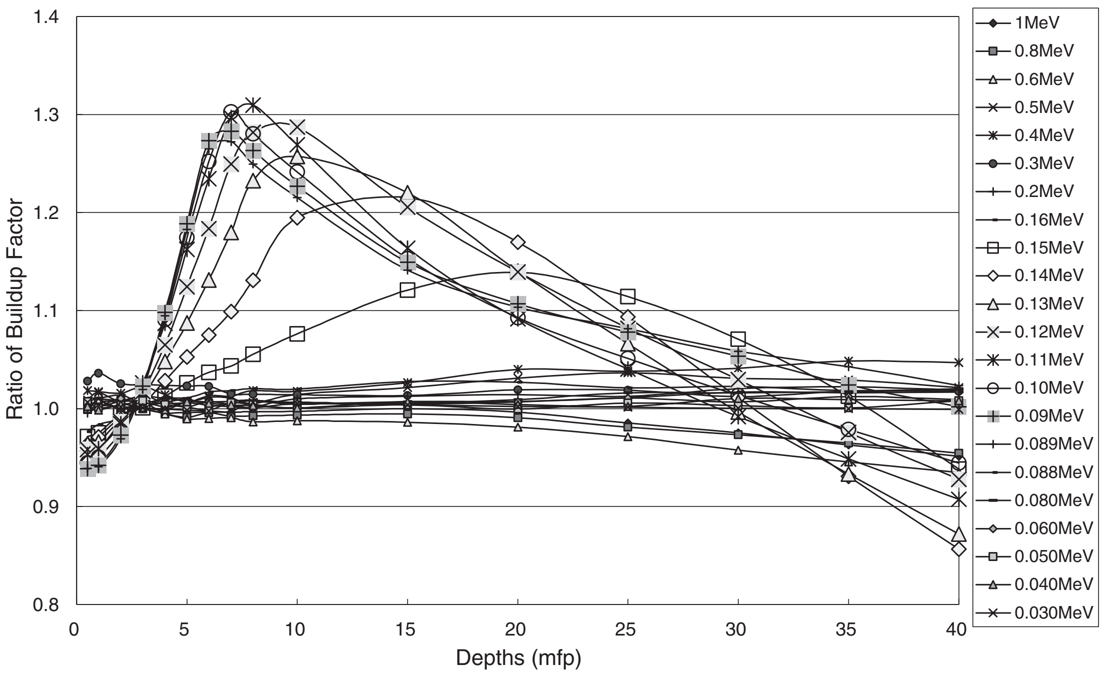

Fig. 7 Ratio of exposure buildup factor in the ANS data[1)] to the present data for lead in the energy range below 1 MeV
Both data are calculated with K Xrays based on PHOTX.

served in the energy range above 1.5 MeV and in the vicinity of K edge.

Figure 6 gives the ratio of the exposure buildup factor in the ANS data to the present data at the source energy of 15 MeV. The discrepancy between both data amounts to about factor 3 for La and Gd. The simple model adopted in the calculation of the ANS data assuming that all the secondary photons are emitted in the same direction as the primary photon is considered to result in such large discrepancy. A similar discrepancy is observed in the energy range 1.5 MeV to 10 MeV with magnitude less than that at 15 MeV.

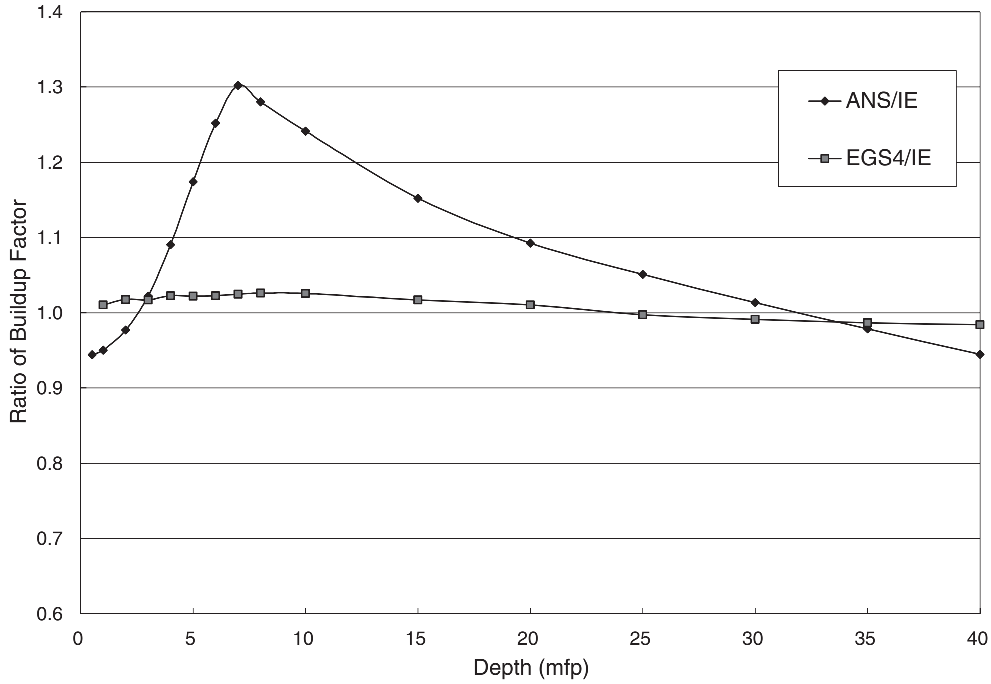

Fig. 8 Ratio of exposure buildup factor for lead at source energy of 0.1 MeV
ANS/IE: Ratio of exposure buildup factor in the ANS data[1] to the present data
EGS4/IE: Ratio of exposure buildup factor calculated by Hirayama[12] using the EGS4 code to the present data

Figure 7 gives the ratio of the exposure buildup factor in the ANS data to the present data for lead in the energy range below 1.0 MeV. Both data coincide within a discrepancy less than 10% except for the source energies including 0.15 MeV, 0.14 MeV, 0.13 MeV, 0.12 MeV, 0.10 MeV, 0.090 MeV and 0.089 MeV in the vicinity of K edge, where a discrepancy of about 10% to 30% is observed. A similar discrepancy is also observed for all other high-Z elements in the vicinity of the K edges. **Figure 8** gives the ratio of the exposure buildup factor obtained by Hirayama[12] by using the EGS4 code to the present data for lead at the source energy of 0.1 MeV. It is shown that the both data agree excellently (within a discrepancy of 3%). Figure 8 indicates that the present data is accurate enough to be used to correct the exposure buildup factor of high-Z elements in the vicinity of K edge in the ANS data.

IV. Conclusion

An improved data set for exposure buildup factors is generated for 26 materials including the effect of bremsstrahlung with the cross-section PHOTX by the method of invariant embedding. The data cover the energy range same as the ANS data and up to depths of 100 mfp extended from the ANS data.

The effect of bremsstrahlung upon the exposure buildup factor is evaluated systematically by calculating the exposure buildup factor both with and without bremsstrahlung for all 26 materials.

The influence of the cross-section upon the exposure buildup factors is also evaluated by calculating the exposure buildup factor both with the cross-sections NBS29 and PHOTX for 18 low-Z materials.

The exposure buildup factors obtained are compared precisely with the ANS data. The results of comparisons are as follows:

(1) The exposure buildup factors calculated by the IE method without bremsstrahlung based on the cross-section NBS29 for 18 low-Z materials agree excellently with those in the ANS data obtained by the moments method under the same condition. 95% of data out of 450 cases (18 materials × 25 source energies) agrees within a discrepancy of 10% up to depths of 40 mfp. It is confirmed that both the IE method and the moments method are dependable in the attenuation calculation of gamma-ray. It is also confirmed that the IE method is accurate enough to be used to correct some spurious oscillation in the moments method calculation.
(2) The exposure buildup factors of high-Z elements in the energy range above 1.5 MeV in the ANS data are corrected by substantial amount (about factor 3 or less) by the improved treatment of bremsstrahlung used in the present calculation.
(3) The exposure buildup factors of high-Z elements in the vicinity of the K edges in the ANS data are corrected by about 30%.

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