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Beta Reduction Factors For Protective Clothing At The Oak Ridge National Laboratory

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Gregory L. Franklin and Pedro L. Gonzalez
Oak Ridge National Laboratory, P.O. Box 2008, MS-6354, Bldg. 6010,
Oak Ridge, Tennessee 37831-6354

ABSTRACT

Beta reduction factors (f_β) for protective clothing (PC) at the Oak Ridge National Laboratory (ORNL) have been determined for a variety of protective clothing combinations. Data was collected to determine the experimental f_β for several combinations of PCs under laboratory conditions. Radiation dose rates were measured with an open window Bicron® RSO-5 ion chamber for two distinct beta energy groups ($E_{max} \doteq 1.218 \times 10^{-13}$ J (0.760 MeV) and 3.653×10^{-13} J (2.280 MeV)). Data points determined, as the ratio of unattenuated (no PCs) to attenuated (PCs), were used to derive a set of equations using the Microsoft® Excel Linet function. Field comparison tests were then conducted to determine the validity of these beta reduction factors. The f_β from the field tests were significantly less than the experimental f_β, indicating that these factors will yield conservative results.

INTRODUCTION

The range of a beta particle in matter is a function of its energy and the thickness of the absorber(s) through which it travels. Theoretically it is possible to stop all of the incoming beta particles if a shield of sufficient density thickness, where density thickness is defined as the product of the density of the absorber material and the linear thickness of the material, is placed between the source and the area of interest. By determining the density thickness of various materials it is possible to determine the degree of shielding provided by that material, and for the purposes of this document, the degree of protection provided to the worker.

DISCLAIMER

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DENSITY THICKNESS DETERMINATION

The density thickness of the protective clothing in use at ORNL was determined by weighing one cm^2 cuttings of the various samples of protective clothing, an average of five of these was then taken and a density thickness, mg/cm^2, was assigned to each specific piece of protective clothing. Table 1 lists the density thickness of protective clothing in use at ORNL

Table 1

Clothing	Density thickness (mg/cm^2)
Standard cotton coveralls	29.9
Labcoat	16.5
Surgical scrubs	16.6
Yellow anti-C gloves (North ATCP.1815)	49.7
Khakis	18.6
Safety glasses (Crews, Inc. Vision-Masters)	234.0
Full face respirator lens	332.6
Yellow Tyvek® suit	7.7
Latex surgeons gloves (Andsell SEG)	20.3
Cotton glove liners	15.9
Yellow anti-C gloves (Andsell)	51.2

BETA REDUCTION FACTORS (f_β) DETERMINATION

Data was collected to determine the experimental f_β for a specific combination of protective clothing under laboratory conditions. Radiation dose rates were measured with an open window Bicron® RSO-5 ion chamber for two distinct beta energy groups. The energy groups represented were: $^{90}Sr/^{90}Y$ (source activity 74 MBq (2 m*Ci*)) and ^{204}Tl (source activity 18.5 MBq (0.5 m*Ci*)). A consistent geometry between the source and the detector was maintained by the use of the Physikaliish-Technischen Bundensanstalt (PTB) Beta Irradiator (see Figure 1). This geometry resulted in the center of the detector being exposed under parallel beam conditions at a distance of 30 cm with the beta window facing the source and perpendicular to the beam axis. This experimental set-up duplicates the method used to determine the beta response factor for the RSO-5.

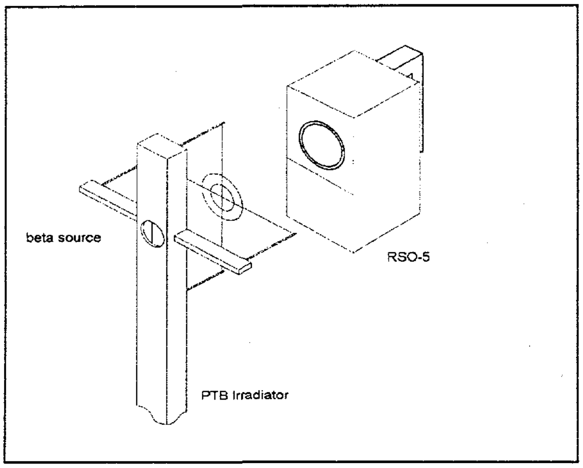

Figure 1

Unshielded radiation dose rates (mSv_oh^{-1}) were first taken using the PTB Beta Irradiator, then compared to the attenuated dose rates ($mSvh^{-1}$) which resulted from interposing protective clothing between the source and the chamber. The ratio of the attenuated measurement divided by the unshielded measurement was then expressed as the f_β for that specific combination and energy range. Table 2 lists specific f_βs for use at ORNL.

Density thickness values from Table 1 should be used in conjunction with equations 1 and 2 (see Determination of Empirical Equations, pages 4 and 5) to determine the f_β for combinations of protective clothing not listed in Table 2.

Table 2

Max Energy Range ($\geq 1.218 \times 10^{-13}$ J $\leq 3.653 \times 10^{-13}$ J) **$^{90}Sr/^{90}Y$** (≥0.760 MeV ≤2.280 MeV)	mSv_oh^{-1}	$mSvh^{-1}$	f_β	**Max Energy Range** ($\leq 1.218 \times 10^{-13}$ J) **^{204}Tl** (≤0.760 MeV)	$\mu Sv_o h^{-1}$	μSvh^{-1}	f_β
Rubber anti-C gloves and liners	4.50	3.60	0.80	Rubber anti-C gloves and liners	48	10	0.20
Scrubs or khakis	4.50	4.30	0.96	Scrubs or khakis	48	33	0.69
Labcoat	4.50	4.20	0.93	Labcoat	48	32	0.66
Labcoat over scrubs or khakis	4.50	3.90	0.87	Labcoat over scrubs or khakis	**	**	0.44
Yellow Tyvek® suit only	4.50	4.40	0.98	Yellow Tyvek® suit only	48	42	0.88
Yellow Tyvek® and scrubs or khakis	4.50	4.20	0.93	Yellow Tyvek® and scrubs or khakis	48	30	0.63
Coveralls	*	*	0.88	Coveralls	48	23	0.48
Coveralls and scrubs or khakis	4.50	4.00	0.82	Coveralls and scrubs or khakis	48	15	0.32
Safety glasses	4.50	1.60	0.36	Safety glasses	**	**	0.003
Full face respirator lens	4.50	1.00	0.22	Full face respirator lens	48	0	0
2 pair rubber anti-C gloves and liners	4.50	3.20	0.71	2 pair rubber anti-C gloves and liners	48	3	0.06
2 yellow Tyvek® suits only	*	*	0.94	2 yellow Tyvek® suits only	**	**	0.69
2 pair coveralls	4.50	3.50	0.77	2 pair coveralls	48	11	0.23

Scrubs, coveralls, and Tyvek®	4.50	3.80	0.84	Scrubs, coveralls, and Tyvek®	48	13	0.27
Scrubs, 2 coveralls, and Tyvek®	4.50	3.30	0.73	Scrubs, 2 coveralls, and Tyvek®	48	7	0.15

* beta reduction factor determined from equation 1

** beta reduction factor determined from equation 2

DETERMINATION OF EMPIRICAL EQUATIONS

Data points measured using the PTB Irradiator were then used to develop two empirical equations. The equations were determined using the Microsoft® Excel LINEST function which utilizes the "least squares" method to calculate an equation which best describes the line that fits the data points. These equations should be used to determine the f_β for facility specific protective clothing combinations not listed in Table 2. The experimentally determined data points were then compared to the calculated results to determine if an acceptable fit existed between the two data sets (see Figures 2 and 3).

Equation 1 (for maximum energies $\geq 1.218\times10^{-13}$ J (0.760 MeV) $\leq 3.653\times10^{-13}$ J (2.280 MeV))

$$f_\beta = e^{-0.00435X}$$

Where f_β = beta reduction factor

x = protective clothing density thickness (mg/cm^2)

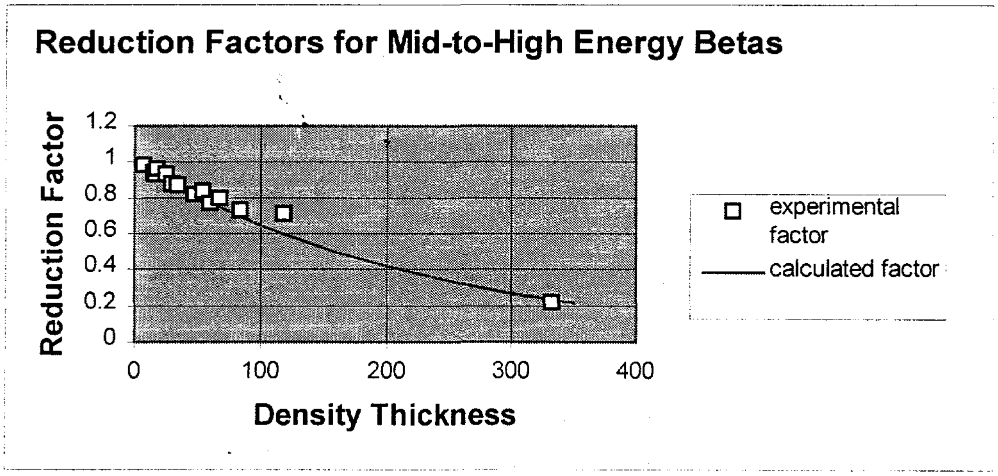

Figure 2

Equation 2 (For maximum energies ≤ 1.218×10^{-13} J (0.760 MeV))

$$f_\beta = e^{-0.0243X}$$

Where f_β = beta reduction factor

x = protective clothing density thickness (mg/cm^2)

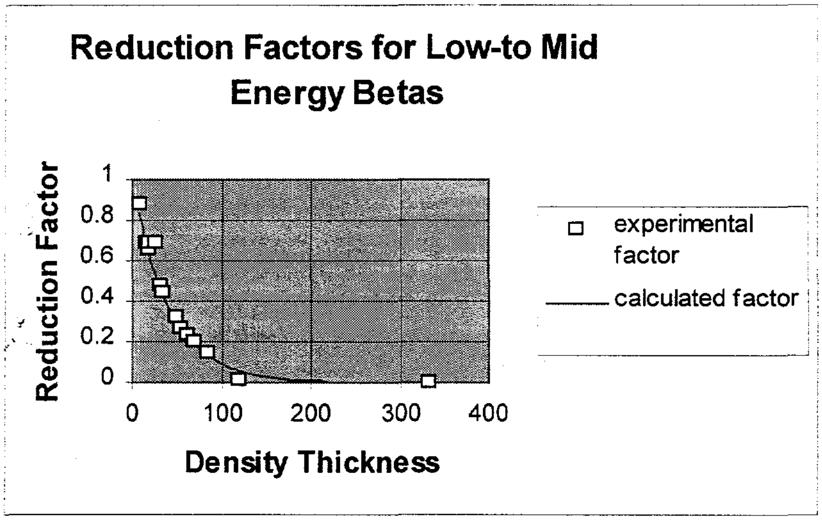

Figure 3

FIELD TESTS

Field comparisons of experimental f_βs were conducted at several locations to determine the validity of these factors under actual field conditions. Field tests were conducted with a source-to-detector geometry as close to the original experimental set-up as possible using the same protective clothing samples. Case one was characterized by ^{90}Sr/^{90}Y point source, consisting of contaminated waste oil which had collected in a plastic bag attached to a drain line. Case two was characterized by an uniformly distributed ^{90}Sr/^{90}Y plane source, consisting of contaminated floor tiles covered by several layers of wax. And finally, case three was characterized by a ^{90}Sr/^{90}Y collimated beam. In most cases, actual field conditions represent an isotropic source geometry and therefore do not approximate the parallel beam conditions under which the experimental f_βs were determined. Beta reduction factors determined under field conditions were significantly less than the experimental laboratory results and indicate that the calculated f_{β}s will yield conservative results in field applications. By comparison it can be seen that cases 1and 2, which represent isotropic source geometries, are much more conservative than case three which more closely approximates the parallel beam conditions under which the experimental f_{β}s were determined.

Case 1 ($^{90}Sr/^{90}Y$ contaminated oil)

	Protective clothing	$\mu Sv_o h^{-1}$	$\mu Sv h^{-1}$	Measured f_{β}	Calculated f_{β}	%difference
1.	Rubber anti-C gloves and liners	17	10	0.59	0.80	-26.5
2.	Scrubs or khakis	17	14	0.82	0.96	-14.2
3.	Labcoat	17	14	0.82	0.93	-11.4
4.	Labcoat over scrubs or khakis	17	12	0.71	0.87	-18.9
5.	Yellow Tyvek® suit only	17	15	0.88	0.98	-10.0
6.	Yellow Tyvek® and scrubs or khakis	17	13	0.76	0.93	-17.8
7.	Coveralls	17	13	0.76	0.88	-13.1
8.	Coveralls and scrubs or khakis	17	12	0.71	0.82	-13.9
9.	Full face respirator lens	17	3	0.18	0.22	-19.8
10.	2 pair rubber anti-C gloves and liners	17	7	0.41	0.71	-42.0
11.	2 yellow Tyvek® suits only	17	14	0.82	0.94	-12.4
12.	2 pair coveralls	17	11	0.65	0.77	-16.0
13.	Scrubs, coveralls, and Tyvek®	17	11	0.65	0.84	-23.0
14.	Scrubs, 2 coveralls, and Tyvek®	17	10	0.59	0.73	-19.4

Case 2 ($^{90}Sr/^{90}Y$ contaminated floor tile)

	Protective clothing	$\mu Sv_o h^{-1}$	$\mu Sv h^{-1}$	Measured f_{β}	calculated f_{β}	%difference
1.	Rubber anti-C gloves and liners	37	20	0.54	0.80	-32.4
2.	Scrubs or khakis	37	32	0.86	0.96	-9.9
3.	Labcoat	37	28	0.76	0.93	-18.6
4.	Labcoat over scrubs or khakis	37	27	0.73	0.87	-16.1
5.	Yellow Tyvek® suit only	37	35	0.95	0.98	-3.5
6.	Yellow Tyvek® and scrubs or khakis	37	30	0.81	0.93	-12.8
7.	Coveralls	37	30	0.81	0.88	-7.9
8.	Coveralls and scrubs or khakis	37	27	0.73	0.82	-11.0
9.	Full face respirator lens	37	4	0.11	0.22	-50.9
10.	2 pair rubber anti-C gloves and liners	37	18	0.49	0.71	-31.5
11.	2 yellow Tyvek® suits only	37	33	0.89	0.94	-5.1
12.	2 pair coveralls	37	25	0.68	0.77	-12.2
13.	Scrubs, coveralls, and Tyvek®	37	26	0.70	0.84	-16.3
14.	Scrubs, 2 coveralls, and Tyvek®	37	22	0.59	0.73	-18.5

Case 3 ($^{90}Sr/^{90}Y$ point source)

	Protective clothing	$mSv_o h^{-1}$	$mSv h^{-1}$	Measured f_{β}	calculated f_{β}	%difference
1.	Rubber anti-C gloves and liners	1.95	1.15	0.59	0.80	-26.3
2.	Scrubs or khakis	1.95	1.75	0.90	0.96	-6.5
3.	Labcoat	1.95	1.65	0.85	0.93	-9.0
4.	Labcoat over scrubs or khakis	1.95	1.55	0.79	0.87	-8.6
5.	Yellow Tyvek® suit only	1.95	1.85	0.95	0.98	-3.2
6.	Yellow Tyvek® and scrubs or khakis	1.95	1.65	0.85	0.93	-9.0
7.	Coveralls	1.95	1.65	0.85	0.88	-3.8

8.	Coveralls and scrubs or khakis	1.95	1.55	0.79	0.82	-3.1
9.	Full face respirator lens	1.95	0.25	0.13	0.22	-41.7
10.	2 pair rubber anti-C gloves and liners	1.95	1.15	0.59	0.71	-16.9
11.	2 yellow Tyvek® suits only	1.95	1.75	0.90	0.94	-4.5
12.	2 pair coveralls	1.95	1.45	0.74	0.77	-3.4
13.	Scrubs, coveralls, and Tyvek®	1.95	1.45	0.74	0.84	-11.5
14.	Scrubs, 2 coveralls, and Tyvek®	1.95	1.35	0.69	0.73	-5.2

	Case 1 %difference	Case 2 %difference	Case 3 %difference
1.	-26.5	-32.4	-26.3
2.	-14.2	-9.9	-6.5
3.	-11.4	-18.6	-9.0
4.	-18.9	-16.1	-8.6
5.	-10.0	-3.5	-3.2
6.	-17.8	-12.8	-9.0
7.	-13.1	-7.9	-3.8
8.	-13.9	-11.0	-3.1
9.	-19.8	-50.9	-41.7
10.	-42.0	-31.5	-16.9
11.	-12.4	-5.1	-4.5
12.	-16.0	-12.2	-3.4
13.	-23.0	-16.3	-11.5
14.	-19.4	-18.5	-5.2

APPLICATON OF BETA REDUCTION FACTORS

The f_βs for personnel protective clothing were developed following the same methodology used to determine the beta response factor of the RSO-5 portable survey meter. The 30 cm distance used to determine the beta response factor of the RSO-5 is equal to the distance used to determine the general area dose rates in the workplace. Therefore, measurements made in the field should approximate the same conditions under which the f_βs were developed. Because of the differences in the geometry used to determine the contact beta response factor of the RSO-5, the f_β should not be applied to contact dose rates.

Doses which might result from contamination of the skin, or personnel protective clothing, should be evaluated using a computer code such as Varskin®, which is specifically designed to model skin doses under contact conditions. Ideally, the f_β will enable the field health physicist to evaluate the protection provided by personnel protective clothing used in the workplace. Once again, it is important to restate the fact that f_βs are not intended to be used to adjust the official beta doses as determined by the employees TLD, and should only be considered as an additional tool that the field health physicist can use to evaluate the radiological characteristics of a particular job or activity.

A potential field application of the f_β would be to evaluate and adjust stay times, or determine required ALARA reviews based upon that protection. For radiation fields including a significant beta component, the f_β could be used to account for the shielding provided by the various combinations of protective clothing. For example, consider the following:

> The ORNL " Administrative Action Levels of 0.30 Sv for the extremities, any organ or tissue and the skin, and 0.10 Sv for the lens of the eye" are established for all ORNL activities [RPP-210, "Administrative Control Levels and Dose Limits"]. Approval by the ORNL Steering Committee shall be required prior to allowing a person to exceed these action levels. In addition to these Administrative Action Levels, lower Administrative Investigation Levels of 0.15 Sv for the extremities, any organ or tissue and the skin, and .005 Sv for the lens of the eye are established for the initiation of an investigation involving the ALARA Engineering Group. The question now becomes how to evaluate the potential for a job or campaign to approach or exceed an administrative dose level for the skin or lens of the eye? Assume that a worker is assigned to perform a particular task within a High Radiation Area/High Contamination Area where the general area 30 cm dose equivalent rate is 10.1 $mSvh^{-1}$. Survey results indicate that the beta component of the general area dose equivalent rate is 10 $mSvh^{-1}$ and is the result of the decay of $^{90}Sr/^{90}Y$, while the gamma component is .10 $mSvh^{-1}$. If the job required 8 hours to complete, the worker would be expected to exceed the Administrative Investigation Level of 50 Sv (8 hours X 10.1 $mSvh^{-1}$ = 80.8 mSv) for the lens of the eye, and the job would require a review by the ALARA Engineering Group. However, if the same scenario was evaluated taking into account the protection provided to the worker by the f_β assigned to the full-face respirator lens, the expected dose to the worker could be adjusted accordingly (8 hours x 10 $mSvh^{-1}$ x 0.22 (f_β)) + (8 hours x .10 $mSvh^{-1}$) = 18.40 mSv). By accounting for the protection provided to the

worker by the full-face respirator lens the expected dose to the worker can be reduced from 80.8 mSv to 18.40 mSv, which falls below the ALARA Administrative Investigation Level for the lens of the eye.

It should be understood that any application of these factors will result in conservative results provided that the user stays within the experimental parameters used to develop these f_β s. For beta energies that fall below the maximum values of each energy range, the f_β would overestimate the dose as the energy of the beta spectrum decreases. Additionally, the results become more conservative in those cases where the worker is greater than 30 cm from the source since the f_β does not account for the air attenuation (beyond 30 cm) which would occur in this additional volume of air.