J.Korean Asso. Radiat. Prot.
Vol.26 No.3 : 249-253(2001)

■Papers■

APPLICATION OF WHOLE BODY COUNTER TO NEUTRON DOSE ASSESSMENT IN CRITICALITY ACCIDENTS

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ABSTRACT - Neutron dose assessment in criticality accidents using Whole Body Counter (WBC) was proved to be an effective method as rapid neutron dose estimation at the JCO criticality accident in Tokai-mura. The 1.36MeV gamma-ray of ^{24}Na in a body can be detected easily by a germanium detector. The Minimum Detectable Activity (MDA) of ^{24}Na is approximately 50Bq for 10miniute measurement by the germanium-type whole body counter at JNC Tokai Works. Neutron energy spectra at the typical shielding conditions in criticality accidents were calculated and the conversion factor, whole body activity-to-organ mass weighted neutron absorbed dose, corresponding to each condition were determined. The conversion factor for uncollied fission spectrum is 7.7 [(Bq^{24}Na/g^{23}Na)/mGy].

INTRODUCTION

Measurement of sodium-24 (^{24}Na) in the body had played an important role in the neutron dosimetry in the past some criticality accidents. At the criticality accident at Oak Ridge in 1958, the ^{24}Na content in the body measured by an assay of the blood sample provided the only available information on individual doses because no personal dosimeters were available [1]. In this accident, an animal (burro) was exposed to neutron by the mock-up reactor to determine the relationship between sodium activity in the blood and the neutron radiation dose.

At the JCO criticality accident on September 30th, 1999 in Tokai-mura Japan, individual dosimeters were available for only few workers. Therefore, JNC carried out the individual dose estimation based on ^{24}Na activity measured by WBC as a part of support for countermeasures of the Science and Technology Agency (STA) and the Accident Investigation Committee of the Nuclear Safety Commission of Japan (NSC)[2].

This paper describes the methods for measurement of ^{24}Na by WBC from the knowledge of the JCO criticality accident and the whole body activity of ^{24}Na -to-neutron dose conversion factor for various neutron spectra for a rapid dose assessment.

MEASUREMENT OF 24NA IN HUMAN BODY

1. Germanium-type whole body counter

^{24}Na can be measured by either a whole body counting or taking a blood samples. Whole body counting is a more sensitive and an invasive method, however, high resolution detectors and a shield were required for precise measurement of ^{24}Na. Therefore, JNC applied the WBC with 2 germanium detectors (50% relative efficiency for each detector, hereinafter Ge-WBC) and a special shield room (20cm thickness of iron) in the JCO case. The germanium detectors equipped with Ge-WBC are manufactured by Canberra Co(Type:GC-5021, 3.400 mm^2 (window area) (54.5mm (length)) and have a enough resolution to separate out two energies, 1.36 MeV gamma- ray of ^{24}Na and 1.46MeV gamma-ray of ^{40}K, a natural radionuclide. The geometry of Ge-WBC is a chair type and a view field of two detectors are chest/thorax and abdomen respectively. Fig.1 shows the Ge-WBC system used in JNC Tokai Works. **Fig.2** shows an observed spectrum of a subject in the JCO case.

Fig. 1. Germanium-type whole body counter of JNC Tokai Works

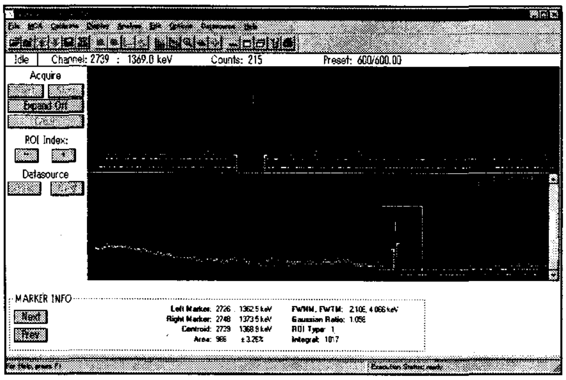

Fig. 2. Spectrum of a subject in the JCO case

2. Measurement of ^{24}Na

For the ICRP reference man the ^{23}Na contents of the body is 100g in 70kg, i.e. 1.4g/kg[3]. This sodium will be activated by thermal neutrons or by neutrons thermalized in the body.

For the estimation of ^{24}Na activity in the whole body, calibration using a phantom is required. The Ge-WBC of JNC is calibrated with the anthropomorphic phantom (170cm height) which is filled with composite radionuclides solution (^{40}K,^{60}Co,^{137}Cs and ^{133}Ba) in an acrylic resin container. Full-energy peak efficiency curve is determined from a photoelectric peak efficiency of each nuclide and a. polynomials in log(e) against log(E) is applied for the efficiency curve function. The MDA (Minimum Detectable Activity) of ^{24}Na is about 50Bq for 10miniute measurement.

^{24}NA ACTIVITY-TO-NEUTRON DOSE CONVERSION FACTORS

The production of ^{24}Na in the whole body is very dependent on the neutron energy spectrum, the individual body size and body weight and the person's orientation during the accident. In practice, it is difficult to obtain such detailed information within a few hours after the accident. However, a rapid dose assessment is important for medical treatments to victims as soon as possible. Therefore, the ^{24}Na activity-to-neutron dose conversion factors were calculated for a rapid dose assessment.

1. Neutron Energy Spectra

The important step in the rapid dose assessment is to determine a neutron spectrum in the criticality system of concern. Because, it varies considerably, depending on the type of critical assembly, moderator and shielding. But for a rapid dose assessment, it is convenient to calculated neutron spectra in several typical criticality systems previously. The leakage neutron spectrum from various criticality systems was computed as an expected criticality accident. The method of calculation is as follows.

(1) ANISN code with JSD 120 nuclear data library is adopted for calculation of a neutron transportation in this study.

(2) A broad beam of fission neutron spectrum penetrating, through an infinite concrete slab

Table.1 Set of the neutron spectrum form the various criticality system

Case	Criticality System (radius of solution)	Thickness of a concrete slab[cm]	Average Energy [MeV]	K_D [(Bq^{24}Na/g^{23}Na)/mGy
1	Metal	-	2.35	7.7
2		10	1.66	11.1
3		20	1.19	14.7
4		50	0.73	20.6
5		100	0.61	22.9
6	(10cm)	-	1.33	13.2
7	Solution(30cm)		1.18	14.5
8	(50cm)		1.16	14.6
9	(10cm)	10	1.17	15.1
10	Solution(30cm)		1.12	15.5
11	(50cm)		1.11	15.5
12	(10cm)	20	0.96	17.2
13	Solution(30cm)		0.95	17.3
14	(50cm)		0.95	17.3
15	(10cm)	50	0.70	21.0
16	Solution(30cm)		0.72	20.7
17	(50cm)		0.72	20.6
18	(10cm)	100	0.62	22.7
19	Solution(30cm)		0.63	22.4
20	(50cm)		0.64	22.3

with a thickness of 10, 30, 50 and 100cm, is considered as a spectrum from a metal criticality system.

(3) In case of a solution system, leakage neutron spectrum from water spheres with a radius of 10, 30 and 50cm is used as source spectrum. Then a broad beam of this source spectrum after penetrating through an infinite concrete slab with a thickness of 10, 30, 50 and 100cm is considered as a spectrum from a solution criticality system.

In this study, as a typical spectrum from the criticality system, the set of the neutron spectrum in 20 cases was prepared, and it was shown in Table.1

2. Whole body activity-to-organ mass weighted neutron absorbed dose

The relation between neutron fluence and the specific activity of ^{24}Na has been studied and the latest results were obtained from calculations by Cross[4] as "capture probability", the fraction of neutrons incident on the phantom that is captured (mainly by hydrogen). The capture probability given by Cross was verified with many of the measurements of sodium activation in phantoms at various experimental reactors.

By using Cross's capture probability, ξ(E), the relation between the specific activity of ^{24}Na and neutron fluence is given by

$$S = 0.61\int \xi(E)\phi(E)dE \quad (1)$$

On the other hand, the meaning of the "dose" of concern should be stated. The absorbed dose at the depth where the maximum radiation damage could occur has been historically used for the criticality dosimetry, however, the organ mass weighted absorbed dose is defined in this study as an indicator of whole body absorbed dose. The organ mass weighted absorbed dose, D_M, are expressed as follows.

$$D_M = \sum_T M_T \cdot D_T \Big/ \sum_T M_T \quad (2)$$

$$D_T = \int d_T(E)\phi(E)dE \quad (3)$$

where, M_T and D_T is the mass of organ T and organ absorbed dose of organ T respectively. $d_T(E)$ is the fluence-to-neutron organ dose conversion coefficients for AP geometry stated in ICRP Publication 74[5]. From the equations of (1) and (2), the specific activity-to-organ mass weighted neutron absorbed dose conversion factor expressed in unit of [Bq^{24}Na/g23Na/mGy] can be obtained.

$$K_D = S/D_M \quad (4)$$

Fig.3 shows the conversion factors, K_D, as a function of concrete thickness for various neutron spectra. With increasing moderator thickness, the conversion factors also increase (indicating the decreasing of neutron doses) because the absorbed dose is decreasing, whereas there is not much change for the specific activity of ^{24}Na.

Fig.4 shows the specific activity of ^{24}Na-to-neutron effective dose conversion factor, K_E, as comparison.

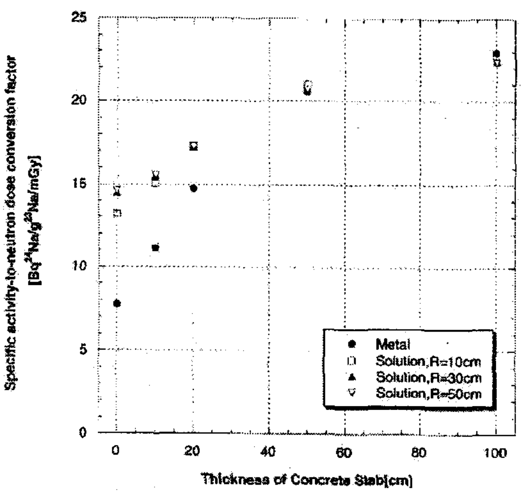

Fig. 3. Specific activity-to- neutron dose conversion factor

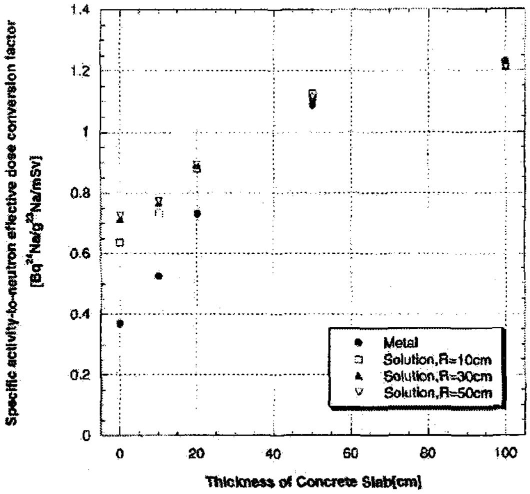

Fig. 4. Specific activity-to- neutron effective dose conversion factor

SUMMARY

The operating procedure was established for the measurement of ^{24}Na by the Ge-WBC. The MDA to ^{24}Na is 50 Bq for 10 minute measurement and it corresponds to 65μGy for an uncollided fission spectrum if the measurement were completed immediately after exposure.

The specific activity of ^{24}Na-to-organ mass weighted neutron absorbed dose conversion factors to various neutron spectra were calculated. If accident neutron spectrum can be approximated from the tabulated results, a rapid dose assessment within a few hours after the accident can be possible.

The scope of this paper restricts the rapid dose assessment and the calculated conversion factors are only valid for AP irradiation geometry. Therefore, at the final stage of dose assessment, the information on more realistic neutron spectrum and person's orientations should be considered.

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