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A 3D Model-based Estimation Method of Radiation Source Activity from Dose Rates Measured in the Field

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Contents

1. Introduction

- **Background**
  - **Radiological characterization for decommissioning of nuclear facilities**
  - **Obtain information on quantity, type, and distribution of the radionuclides**
  - **Used for estimation of waste inventory and cost, planning, and radiation exposure management**

  - **Radiation sources induced by neutron irradiation: by computer codes**
  - **Radiation sources by contamination: measurements and/or additional sampling and analysis**

  - **Beneficial if the activities of radiation sources can be determined without requiring the extraction of samples and laboratory analysis.**

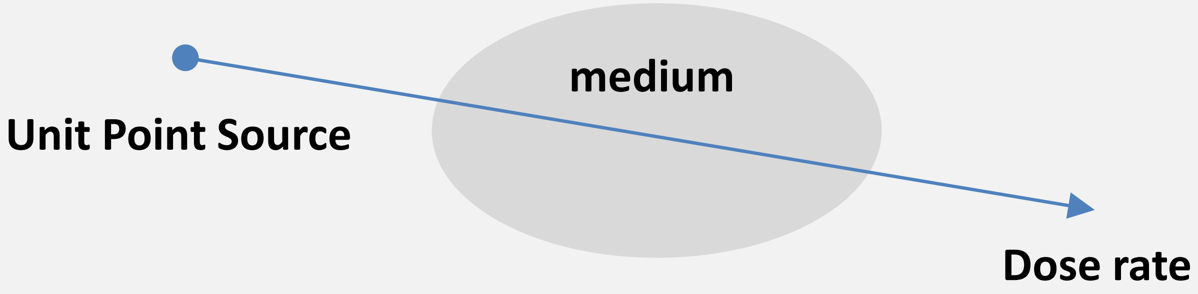
- **Prior Studies**
  - **Dose rate measurements of radiation fields can provide an acceptable estimate of the activity if the relationship between activity content and radiation field is well established [IAEA TRS-389]**
  - **3D modeling is in common use to visualize the decommissioning process**
  - **EPRI dose rate estimating algorithm with integration into 3D software models**
  - **etc.**

2.1 Solution for Source Strength from Measured Dose Rates (1)

- **Dose rate response** (R_{mj}) **from a point kerel source**

  - $$R_{mj} = \int_{V_j} \int_E \left\{ \frac{\chi(E) \cdot C(E) \cdot B(E,\mu T) \cdot e^{-\mu T}}{4\pi (r_j - r_m)^2} \right\} dE dV$$

  - χ(E) = the gamma energy spectrum of source,
  - C(E) = the flux-to-dose-rate conversion factor,
  - μ = the attenuation coefficient of the shielding medium,
  - T = the path length through the shielding medium,
  - B(E,μT) = the buildup factor,
  - $(r_j - r_m)$ = the distance between the source and the measurement point



2. Methods

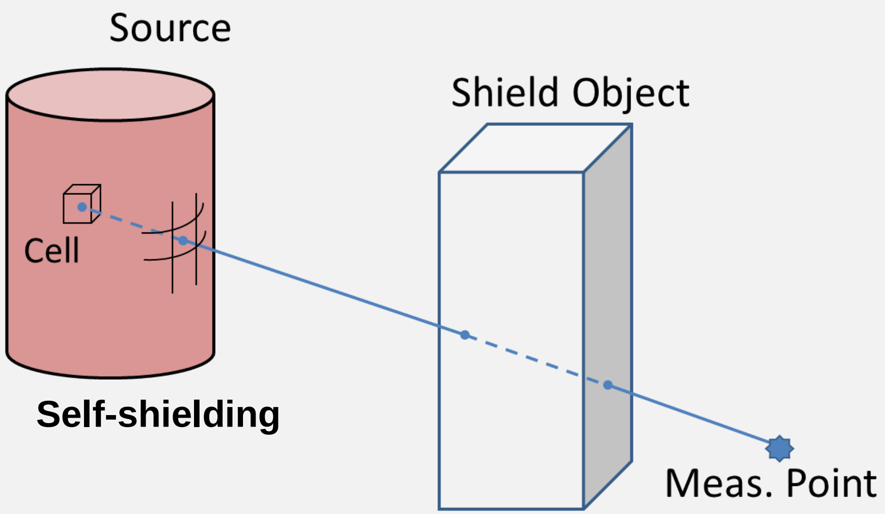
2.1 Solution for Source Strength from Measured Dose Rates (2)

- **Dose rate** (D_m) **related to Source Strength** (S_j)
  - $D_m = \sum_{j=0}^{N} [R_{mj} \cdot S_j] \ (m = 1, \cdots, M; M \geq N)$
  - M = the number of measured dose rates
  - N = the number of sources
- **Inverse equation set for** S_j **with the least square error**
  - $\sum_{j=1}^{N} [(\sum_{m=1}^{M} R_{mk} R_{mj}) \cdot S_j] = \sum_{m=1}^{M} [D_m R_{mk}]$

    (k=1, ⋯,N)
- **Activity** (A_j) **of source j**
  - $A_j = S_j V_j.$

2.2 Extraction of Geometric Parameters and Material Properties (1)

- **Radiation sources and shielding objects in 3D space**
  - **3D CAD space formed by BIM-RAD**
  - **Objects represented by solid STL models**



- **Path length calculation in BIM-RAD**
  - **Finding pairs of points on the inlet and outlet surface meshes of shielding objects**
  - **Source object is represented as a phantom of equivalent volume in simple geometrical shapes which can be subdivided into multiple cells**
  - **Self-shielding length is determined algebraically by finding the intersection of the radiation ray from the center of each cell with the outer surface of the phantom**
- **Library for attenuation coefficients and buildup factors: ANSI/ANS 6.4.3-1991**
- **Dose rate conversion factors: ICRP-51**
- **Nuclide data of gamma energies and branching ratios: IAEA's Live Chart of Nuclides**
- **Material properties of the objects: linked by BIM data management method**

3. Experimental Results

3.1 Test for a Volumetric Source Problem (1)

- **Problem Description**
  - **Source : 1 Ci of 137Cs in water**
  - **Cylindrical container with ϕ10 cm x 30 cm**
  - **Receptor : 1 m apart from the center of the source**
  - **Shield : 3 cm thick lead**

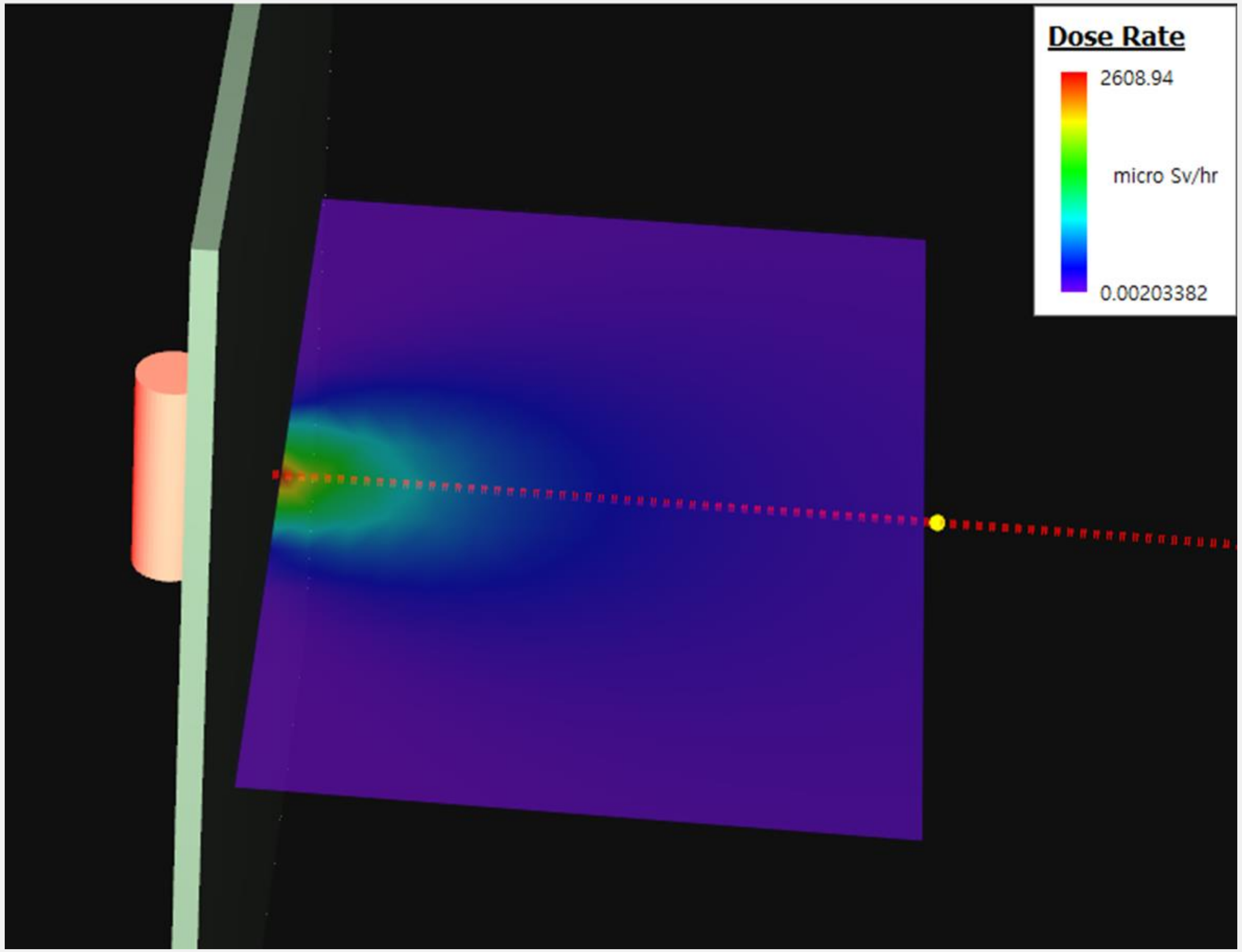


Fig. 1. BIM-RAD Image of the configuration of the problem.

3.1 Test for a Volumetric Source Problem (2)

- Dose rate at the receptor position calculated by MCNP : 100.63 μSv/hr

- BIM-RAD estimation results

Source phantom	Case of Single cell	Case of 48 cells
Source strength	16.68 MBq/cm^3	15.64 MBq/cm^3
Source activity	1.062 Ci	0.9961 Ci
Estimation error	6.2 %	-0.4 %

- Observations for the case of 48 cells
  - Activity estimation was improved
  - Volumetric source was more finely subdivided
  - Attenuation and buildup of the gamma ray were reflected more precisely

3. Experimental Results

3.2 Field Test for Multiple Sources (1)

- **Test Scene Description**
  - **Sources**
    - **- S_1 : ^{137}Cs of 1.01528 MBq**
    - **- S_2 : ^{60}Co of 2.8476 MBq**
  - **Dose rate meter : CsI(TI) scintillation detector of Mirion Technologies Inc. (acc. ±20%)**
  - **Mounted on a 0.86 m high movable stand**
  - **Measurement points : 8**

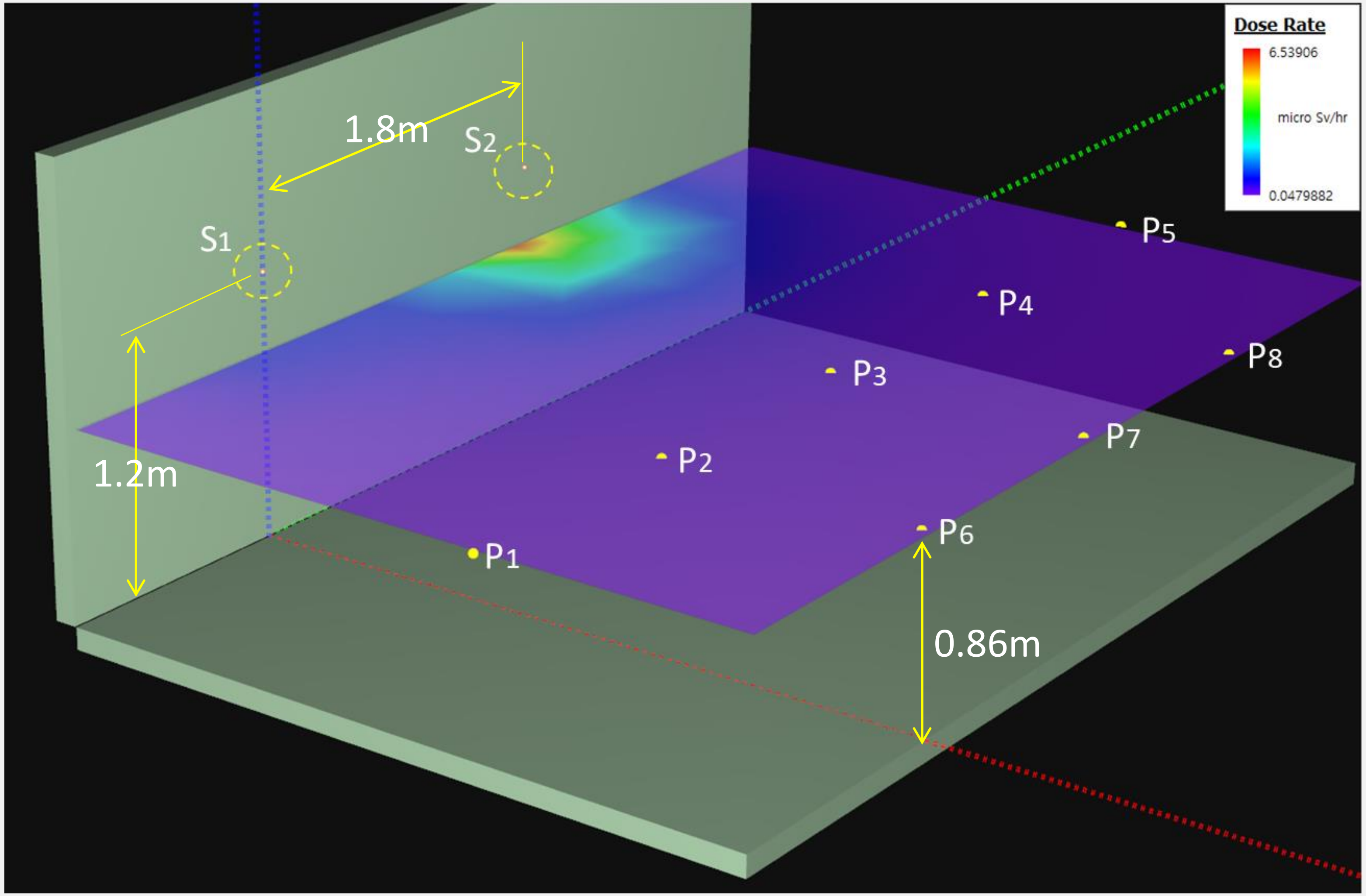


Fig. 2. BIM-RAD image of the field test configuration for two sources.

3. Experimental Results

3.2 Field Test for Multiple Sources (2)

- **Confirmation of sources by a gamma-ray imager**
  - **Source locations**
  - **Nuclide identification**
  - **Duration : ~300 sec**

Fig. 3. Compton image by a gamma-ray imager of PHDS Co.

3.2 Field Test for Multiple Sources (3)

- **Measured dose rates in µSv/hr (subtracted natural background of 0.11 µSv/hr)**

x \ y (m)	-1.2	0.0	1.2	2.4	3.6
2.05	0.071	0.130	0.197	0.175	0.137
3.25	--	0.076	0.072	0.062	--

- **Activity estimation results by BIM-RAD with single cell**

Source	Calibrated (MBq)	Estimated (MBq)	Error (%)
S_1	1.01528	0.932	-8.25
S_2	2.8476	2.761	-3.03

❖ **To be acceptable given the measurement uncertainty of ±20%.**

3. Experimental Results

3.2 Field Test for Multiple Sources (4)

- **Re-calculated dose rates by BIM-RAD with the estimated source activities**

x \ y (m)	-1.2	0.0	1.2	2.4	3.6
2.05	0.075 (6.1%)	0.127 (-2.0%)	0.191 (-2.9%)	0.186 (6.2%)	0.115 (-16.3%)
3.25	--	0.067 (-12.1%)	0.082 (13.4%)	0.080 (29.1%)	--

- **The re-calculated dose rates were within ±20% of the measured values except at point P_8.**
- **Dose rates for any location of the workplace are expected to be evaluated with comparable accuracy.**
- **Confirmed the consistency of the proposed method.**

4. Concluding Remarks

- **A 3D model-based software tool called BIM-RAD has been developed to estimate radiation source activities using the dose rates measured in the field.**
- **The proposed method can provide a reasonable estimate of the source activities when the measured dose rates are available.**

- **The estimation accuracy of radioactivity was well within measurement accuracy of ±20%.**
- **Reproducibility of the dose rates was acceptable, when the dose rates were re-calculated using the estimated radioactivity.**
- **By estimating source activities, dose rates can be easily calculated even for unmeasured points, and the radiation exposures can be assessed for a planned radiation work at the site.**

- **This study suggests an alternative method for assessing the radionuclide inventory due to contamination without need of sampling and laboratory analysis.**
- **The proposed method appears to be useful as a good guide for inventory estimation and exposure analysis of decontamination or dismantling works.**



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