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Categorization of Radiation Sources

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Through one-parameter (factor) variance analysis it is proved a hypothesis that the expected value of a radiation source (RS) activity of an application correlates with the category (the rank) given to it although the main consideration in the IAEA categorization [1] is based on other parameters of the RS applications (practices like devices with radiation sources in industry, science, medicine and agriculture).

The International Atomic Energy Agency's (IAEA) initiative to prepare a document on the Safety of Radiation Sources resulted in the preparation of a draft-document "Categorization of Radiation Sources" [1]. The final document is planned to be ready in October 2000.

The IAEA categorization is seen as necessary in view of the wide variety of uses of radiation sources so that the controls to be applied will be commensurate with the radiological risks that sources present. Of particular concern are those radiation sources containing substantial levels of radioactivity which have the potential for causing significant harm to persons in a short term. Consideration may also need to be given to the potential for contamination. The recent occurrences of "orphan sources" are also envisaged to become better solved problem by strengthening the radiation protection control on the applications.

The categorization takes into account a number of attributes of the RS in an application as no one attribute can be the solely category determining parameter (factor).

The attributes are distributed in groups of parameters:

- radiological properties (types of emitted radiation);
- the form of the radioactive material (physical and chemical);
- peculiarities of the practice or conditions of use (fixed or mobile facilities, operational factors);
- probable exposure scenarios (the previous history of archived accidents as well);
- decommissioning (end of RS life, disposition options).

For the purposes of the IAEA categorization the source attributes are ranked (put in categories) according to the potential harm the sources may cause.

The protection of the patient is not considered in this categorization although patient protection is a key consideration for regulatory authorities in the authorization of use.

The resulting categories are as follows:

Category 1: Industrial Radiography, Tele-therapy, Irradiators;

Category 2: HDR Brachytherapy, Fixed industrial gauges involving high activity sources, Well Logging, LDR Brachytherapy;

Category 3: Fixed industrial gauges involving lower activity sources. Practices within a category are not ranked.

The above general categorization of RS provides an indication on the priority order in which the regulatory authority exerts strict regulatory control on the different RS applications.

In [1] it is displayed a table "Categorization of radiation sources: information concerning practices and radioactive materials." From the latter discrete random variables (the activity of Cs-137 sources in the three categories of applications) are derived and presented in Table 1.

As the subject of interest is the quantity of RS activity, Table 2 presents these data and the arrangement of the data is with a view to one-parameter variance analysis [3].

The null hypothesis H_o states: "the category of an application is not correlated with the RS activity" and that is against the alternative hypothesis H_a: "the category of an application correlates (is proportional) to the RS activity".

It is asumed that the discrete random variable [4] is the parameter "RS activity". It does not influence which category an application of RS is distributed in. The whole population comprises all types of RS applications (in industry, science, medicine and agriculture).

Table 2

Category (the rank of an application)	I	II	II
The quantity of RS activity in Bq devided to the exemption level of Cs-137 - 1.E+04 Bq [2]	500.10^9 51.10^9 200050.10^9 200050.10^9 200050.10^9	10015 275000 $50500.\ 10^3$ $10050.\ 10^3$ $1.\ 10^9$ $400.\ 10^3$ $20050.\ 10^3$	$10050.\ 10^3$ $1.\ 10^9$ 10050.10^3 $20050.\ 10^3$
	$n_1 = 5$	$n_2 = 7$	$n_3 = 4$

The auxilliary quantities are calculated as follows:

$n = n_1 + n_2 + n_3 = 5 + 7 + 4 = 16$

$\overline{x_1} = 120140.10^9$; $\overline{x_2} = 154469.10^3$; $\overline{x_3} = 260037.10^3$; $\overline{\overline{x}} = 7508.10^9$

$$\sum_{j=1}^{5}(x_{ij} - \overline{x_1})^2 = 4{,}789.10^{28};\ \sum_{j=1}^{7}(x_{ij} - \overline{x_2})^2 = 2{,}45.10^{18};\ \sum_{j=1}^{4}(x_{ij} - \overline{x_3})^2 = 0{,}73.10^{18}$$

$$\sum_{i=1}^{3}\sum_{j=1}^{n_i}(x_{ij} - \overline{x_j})^2 = 4{,}789.10^{28}$$

$$(\overline{x_1} - \overline{\overline{x}})^2.n_1 = 6{,}3.10^{28};\ (\overline{x_2} - \overline{\overline{x}})^2.n_2 = 0{,}0392.10^{28};\ (\overline{x_3} - \overline{\overline{x}})^2.n_3 = 0{,}0224.10^{28}$$

$$\sum_{i=3}^{3}(\overline{x_i} - \overline{\overline{x}})^2.n_i = 6{,}3616.10^{28}$$

On the base of the available data (in the probability distribution) the null hypothesis is checked. Level of significance is chosen $\alpha = 0.05$ after some considerations in [3].
In order to verify the null hypothesis it is calculated the sample statistiques of Fisher [3]:

$$F = \frac{\frac{1}{k-1}\sum_{i=1}^{k}(\overline{x_i} - \overline{\overline{x}})^2 n_i}{\frac{1}{n-k}\sum_{i=1}^{k}\sum_{j=1}^{n_i}(x_{ij} - \overline{x_i})^2}$$

In case the null hypothesis is true this sample statistiques has F-distribution with degrees of freedom $\nu_1 = k-1$ and $\nu_2 = n-k$.

Further it is calculated the observation quantity of F criteria and all data are presented in a variance analysis Tabel 3:

Table 3

Cause of variability	Summ of the square of the deviations	Degree of freedom	Variance of a sample	Observation quantity of F criteria (observed value)
Parameter (factor) A variance (among the categories)	$6{,}3616.10^{28}$	2	$3{,}1808.10^{28}$ (parameter)	$\frac{3{,}18.10^{28}}{0{,}36.10^{28}} = 8{,}833$
Remaining variance (inside the categories)	$4{,}789.10^{28}$	13	$0{,}36.10^{28}$ (remaining)	
Total variability	$11{,}1506.10^{28}$	15	$0{,}74.10^{28}$ (total)	

From Table 5 in [3] it is taken the quantile $F_{0,05;2;13} = 3{,}805$.

So $F_{observed} = 8{,}83 > 3{,}805$ and this result means that the null hypothesis is to be rejected.

The alternative hypothesis is in force: **the category of an application is proportional to the RS activity.** Nevertheless the RS activity in an application is not the solely significant parameter in the categorization.

References

1. IAEA draft document "Categorization of Radiation Sources", 12 April 1999
2. Safety Series No. 115, IAEA, Vienna, 1996, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources
3. Математическая статистика, А.И. Герасимович, Я.И. Матвеева, Минск, Вышэйшая школа, 1978
4. International Standard, ISO 3534-1: 1993

Table 1

Parctice Or application	Radionuclide	Decay Energy [keV] Half-life	Typical Activity	Dose rate at 1 m[a,b,c] [mSv/h]	Time at 1 m[a,b,c] ti exceed 1 mSv
Category 1					
Teletherapy	Cs-137	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y	500 TBq	3.E+04	< 1 s
Whole blood irradiation	Cs-137	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y	2-100 TBq	6.E+03	< 1 s
Industrial Radiography	(Cs-137)	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y			
Sterilization and food preservation (Irradiators)	Cs-137	□ (662)□ (max.: 512) e (624) $T_{1/2}$ = 30 y	0.1 - 400 PBq	2.E+07	< 1 s
Other Irradiators	(Cs-137)	□ (662) □ (max.: 512) e (624)$T_{1/2}$ = 30 y			< 1 s
Category 2					
Remote afterloading brachytherapy (High Dose Rate)	Cs-137	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y	0.03-10 MBq	6.E-04	70 d
Manual brachytherapy (Low Dose Rate)	Cs-137	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y	50-500 MBq	3.E-02	30 h
Well logging	Cs-137	□ (662)□ (max.: 512) e (624) $T_{1/2}$ = 30 y	1-100 GBq	6.E+00	10 s
Level gauge	Cs-137	□ (662) □ (max.: 512) e (624)$T_{1/2}$ = 30 y	0.1-20 GBq	1.E+00	50 min
Thickness gauge	Cs-137	□ (662)□ (max.: 512) e (624) $T_{1/2}$ = 30 y	1 TBq	6.E+01	1 min
Moisture/density detector	Cs-137	□ (662) □ (max.: 512) e (624)$T_{1/2}$ = 30 y	400 MBq	2.E-02	2 d
Conveyor gauge	Cs-137	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y	0.1-40 GBq	2.E+00	20 min
Category 3					
Level gauge[d]	Cs-137	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y	0.1-20 GBq	1.E+00	50 min
Thickness gauge[d]	Cs-137	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y	1 TBq	6.E+01	1 min
Density gauge[d]	Cs-137	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y	1-20 GBq	1.E+00	50 min
Conveyor gauge[d]	Cs-137	□ (662)□ (max.: 512) e (624)$T_{1/2}$ = 30 y	0.1-40 GBq	2.E+00	20 min