THE SYSTEM FOR MONITORING OF MAIN DOSE RATE SOURCES FOR APPLICATION AT AREAS OF REHABILITATION WORKS.

V. N. Potapov, N. K. Kononov, O. P. Ivanov, S. M. Ignatov, V. E. Stepanov, V. G. Volkov
RRC "Kurchatov Institute"
Moscow

ABSTRACT

Remote monitoring of dose rate conditions on large areas is important task during large-scale activity with radioactive contamination/materials. The paper presents automatic system for remote measurements of radiological conditions at territory of rehabilitation activity, and results of its application for exposure dose rate monitoring at particular control points from separate strong sources located in the territory of activity. The apparatus is realized as computer controlled gamma-locator. The method of EDR calculation in 3-D space around territory of activity and analysis of relative input of main gamma-sources into EDR are presented. The results of application of the system during rehabilitation activity at territory of temporal storage of radioactive wastes of RRC Kurchatov Institute are presented and discussed.

INTRODUCTION

During rehabilitation activity in restricted contaminated areas, which borders with zones where normal dose rate conditions must be maintained, the very important task is exposure dose rate (EDR) control at perimeter of activity area. The knowledge on main sources giving the input into EDR and the relative value of this input helps to solve this task. This knowledge allows managing of the work with radioactivity in such a way that EDR outside area of rehabilitation activities will be in allowed limits.

The specific of problem is that situation on territory of temporal storage of radioactive wastes (TSRAW) of RRC KI is defined by complex structure of sources created additional EDR outside the territory and sources change their position and relative input with time. These sources are containers with radioactive wastes, waiting evacuation from area, contaminated soil. The territory has large perimeter, EDR control is necessary at different levels from the surface. For solving these tasks, method of remote radioactivity measurements with collimated spectrometric detector may be applied. On the basis of measurements of the EDR contribution from different locations, the summary EDR is calculated.

Previously, remote measurements of radioactivity distribution were carried out in conditions of high dose rate, when this was the only save way to solve the problem. The works [1-4] describe application of collimated detector technique for investigation of radioactive contamination inside rooms of unit #4 of Chernobyl NPP after reactor breakdown in 1986. In first works [1] simple handled collimated radiometer was applied for radioactivity mapping on the walls, roof and floor. These maps and calculated dose rate maps helped to select optimal ways of decontamination measures in rooms. The measurements with computer controlled scanning spectrometric detector at destroyed reactor hall have given estimation of radioactive contamination in inaccessible heaps. After measurements 3-D dose EDR map inside hall was calculated. That was the only way to solve problem, as estimated EDR in some areas was more then 100R/h.

Different instruments for remote radioactivity mapping -- gamma-imagers of AIL - GammaCam [5] and Cogema - Cartogam [6], gamma-scanner of BNFL - RadScan [7] were used during radioactivity distribution measurements in facilities of nuclear industry in USA [8]. After these measurements EDR maps were calculated too.

During activity for rehabilitation of the territory of TSRAW of RRC "Kurchatov Institute" the prototype of new collimated gamma-locator system was used for remote measurements of radiological conditions. The data of measurements of gamma-field characteristics (spectra of gammas registered by detector from different directions) was used for calculation of dose rate.

The construction and parameters of gamma-locator are presented below. The procedure of measurements and method of dose rate calculation are shortly described. The results of new system application for control of EDR during are presented and discussed. The results presented differ from results of similar works and are new in some respects. The distribution of sources, which radiological environment on territory of rehabilitation activity, has complex and varied character. For description of this distribution, the model of effective source is used. Application of this model for 3-D EDR maps calculation on basis of spectral measurements resulted in very effective and quick algorithm. The accuracy of EDR calculations is about 20-30%. The gamma-locator is placed far from main sources and collimated large-volume scintillating detectors are used for spectra acquisition in short exposure time.

GAMMA-LOCATOR DESCRIPTION

Gamma-locator is a spectrometric system, developed for remote radioactivity measurements using field radiometry methods. System consists of scanning head, pan and tilt table, and controlling PC. Special system controlling and data processing software has been developed. The scanning head is a spectrometric detector, placed in collimated lead shielding. Maximum shielding thickness is 30 mm. Angle resolution of the collimated detector can change from 3 to 7°. CsI(Tl) scintillator (volume ~80 cm^3) coupled to Si PIN (square 1 cm^2) photodiode is used as the detector [9]. A standard detector scintillator-PMT with size of scintillation crystal 2" was also used. A CCD video camera is placed on the scanning head, so that its axis of symmetry is parallel to collimator axis of symmetry. This video camera represents a field of view (FOV) of the detector.

Detector impulses received by pre-amplifier go to the shape amplifier and finally are transferred to the PC unit. An ADC card and a Video grabber card are installed in the PC. They are used to digitize impulses of the detector and the video data. The pan and tilt table is also controlled by PC via COM-port (RS-485 interface). A distance from the scanning head to the PC may be up to 200 meters.

The gamma-locator controlling program has different scenarios of gamma-locator operation. The scenario consists of series of movements in specified direction, measurements of spectra and video frames recording. A trajectory of movement, gamma-locator and video camera settings are set up interactive or read from settings file in the PC. Current parameters and system status at current measurements, current video image and last spectrum measured are shown in user interface of the program.

METHOD OF EDR CALCULATION

Gamma-locator with collimated detector allows measurement the spectrum of gamma-rays that have passed from solid angle, corresponding to aperture of the collimator. Having effectiveness function of the detector and acquired spectrum, man can calculation EDR contribution from said solid angle. If an element of contaminated surface is located in this angle, the calculated EDR includes a contribution from straight quanta, radiated from the surface, but doesn't include scattered in air practically. The scheme of remote measurements of radioactive sources is presented in figure 1.
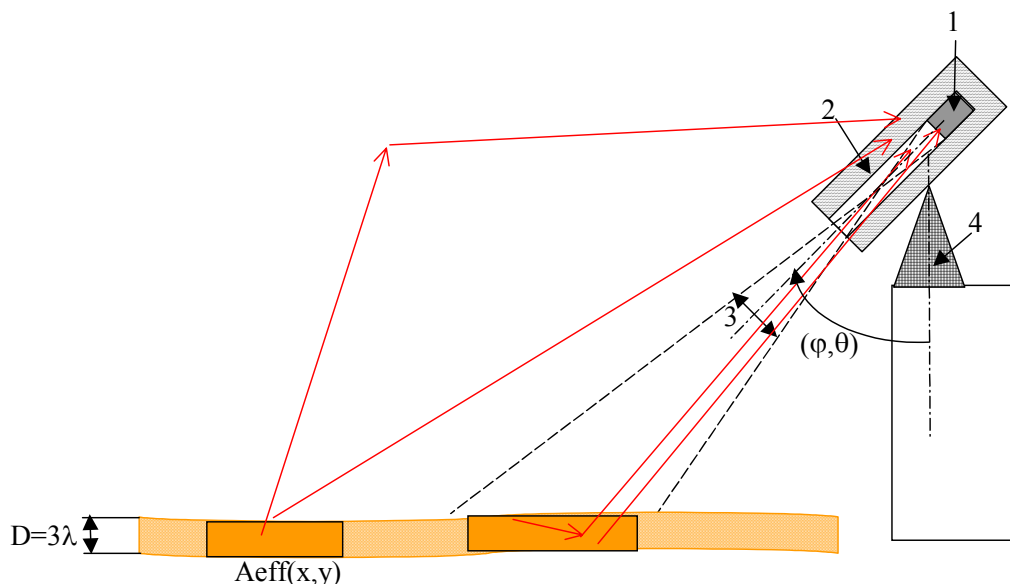
Fig. 1 The scheme of remote measurements of characteristics of radioactive sources
in area of rehabilitation activity with gamma-locator. 1 - scintillating probe, 2 -
collimator and shielding, 3 - angle of view of collimator, 4 - pan and title table.

While source – detector distance is more than 50 meters, scattering is essential. In that case it is necessary to have some description of gamma sources, sufficient for modeling the EDR, created by them at large distances. Ideal description gives angle and energy resolution of radiation flux on gamma-ray source surface - air boundary. An exact solution of this task using measured by scintillation detector spectra is difficult. Modeling experience and EDR measurements from extended gamma-ray sources show that for solving this task with accuracy 20-30%, man can use an approximate description of extended sources, which describes their basic characteristics. For example it may be density of surface activity of gamma contamination. The description of distribution of this activity in soil or its screening by some shielding must be taken from assumptions.

During measurements and EDR calculations for territory of TSRAW of RRC "Kurchatov Institute", a simplified contamination distribution model was used. This model was based on presentation all gamma-ray sources in the form of effective model source. In the model every source is presented as Cs-137 isotope, uniformly distributed in ground layer, with width of 3 mean free paths of 662-keV gamma-quanta. This model is close to real physic situation, because basic dose-creating contaminator is Cs-137, and it is available everywhere in a screened form. So, Cs-137 in such form is in contaminated ground, in containers with radioactive waste, contaminated constructions heaps, located in opened or closed temporary waste storages. Also, the model takes into account a presence of second basic dose-creating contaminator – Co-60. At this approach, Co-60 source would be replaced by Cs-137 source with 4 times greater activity.

Calculated estimations and measurement processing results show that this model is quite suitable for solving the task of EDR contribution calculation and EDR maps creation within 20-30% accuracy.

PROCEDURE OF MEASUREMENT AND RADIATION FIELDS CALCULATIONS

Measurements and calculations were conducted in the following way. At first, apparatus spectrum $S_a(\varphi,\theta,E)$ for every measurement point in spherical coordinate (φ,θ) is obtained. Measurement points in spherical coordinate (φ,θ) are defined by the measurement scenario. In case of need, measurement of background spectrum with closed collimator is conducted. The need of such measurement appears when there are powerful sources, located at large angle from each other, and the scanning head of gamma-locator may turn sidelong to these sources. A selective EDR $D_a(\varphi,\theta)$ in (φ,θ) position is determined using integration product $S_a(\varphi,\theta,E)$ and special detector function $F(E)$ by energy:

$$D_a(\varphi,\theta) = \int_0^{E\max} F(E) \times S_a(\varphi,\theta,E)dE \qquad \text{(Eq. 1)}$$

$D_a(\varphi,\theta)$ value characterizes a partial contribution to total EDR in the measurement point from gamma-ray sources, visible within collimation angle. But to calculate a full EDR from separate sources (and for calculation of 3-Dimensional distribution map) it is necessary to define surface density of effective contaminated source activity $A_{eff}(x,y)$. $D_a(\varphi,\theta)$ gives an opportunity to define $A_p(\varphi,\theta)$ - surface density of effective contaminated source activity in gamma-locator angle coordinate at appropriate measurement. This is done within the condition that this effective source has contributed $D_a(\varphi,\theta)$ to EDR. All geometric parameters and radiation attenuation in the air are considered. Then this distribution transforms to linear coordinates on ground surface and is interpolated to fine grid, making available following calculations $A_p(\varphi,\theta) \Rightarrow A_p(x,y)$.

Flat surface approximation was used in this work. A relief of contaminated surface may be used for more accurate analysis.

Having $A_p(x,y)$ distribution, an addition D_{ad} to the natural EDR D_n at point of gamma-locator position is calculated. Usually there is small difference between $(D_{ad}+D_n)$ and D_m - EDR, measured with dosimeter in corresponding coordinate. The difference is caused by approximations used (effective source model, flat surface assumption). A correction coefficient K_{cor} is determined to correct obtained $A_p(x,y)$ distribution:

$$K_{cor} = (D_m - D_n)/D_{ad} \qquad \text{(Eq. 2)}$$

Thus, a final distribution of surface activity density is formed:

$$A_{eff}(x,y) = K_{cor} \times A_p(x,y) \qquad \text{(Eq. 3)}$$

The correction procedure eliminates calculation inaccuracy, concerned with deviation from effective source model. This is as if the calculated coefficient K_{cor} corrects a sensitivity of the detector depending on current gamma-ray sources distribution. If there are no essential changes in gamma-ray sources distribution in contaminated zone, a same K_{cor} may be used for different series of measurement.

Reliability and accuracy of selected dose rate calculations, based on gamma-locator measurements, was verified. The calculations were compared with dosimeter measurements, carried out in different points of examined contaminated area. The best coincidence was obtained for greater distances from collimated examined zone to gamma-locator. The comparison results are shown in Table I . The points, where the dose rate was measured, are situated on the front side of the building with gamma-locator, but on the different altitude from ground. In other points the coincidence comes to 20-30%. The most significant difference is obtained for the ground surface. This can be explained so, that during calculations the flat-surface approximation is used, but the surface often significantly differs from flat while contaminated area rehabilitation activities (due to soil and containers displacements).

Table I   The comparison of calculated and measured dose rates on the front side of the building (H − altitude of measured point from ground surface, S − distance from corner of the building).

H, m	Calculation	Dosimeter	Calculation	Dosimeter	Calculation	Dosimeter	Calculation	Dosimeter
25	68.6	68	63.2	56	46.1	42	33.7	33
10	46.6	50	43.2	40	33.6	36	24.8	22
5	33.8		31.9	31	26.5	25	18.5	20
1	24.8	17	23.9	20	21.3	18	17.4	15
S, m	1		20		40		60	

SYSTEM APPLICATION DURING THE ACTIVITIES AT THE TSRAW OF RRC "KURCHATOV INSTITUTE"

The system is mounted on the building, located outside the perimeter of current rehabilitation activities. The system scans the area of said activities. A horizontal scan stepwidth is 3.6^o, vertical scan stepwidth is 2.7^o. 25 horizontal steps and 12 vertical steps allow covering of all objects located in contaminated zone. If the time of one measurement at a single step is 60 sec, then overall time of successive scanning is approximately 5 hours. Primary data of measurements are:

- grabbed video image of gamma-locator's field of view (FOV);

- acquired spectra;

- calculated selective dose rate.

These primary data are presented as the series of images, shown in fig. 2.

Fig. 2 Presentation of primary data, obtained with gamma-locator

This figure includes video image with selected collimator aperture, selective addition to dose rate, corresponded to the aperture, date and time of measurement. Below man can see the map of measurements, carried out during successive scanning. Relative dose rate contribution is shown as rectangles with different color depth.

After effective gamma-ray sources distribution has been found, the dose rate map is calculated. Also, the dose rate contribution from basic gamma-ray sources is defined. Samples of these calculations are shown in fig. 3, 4. Besides, on the basis of these results, man can define predictable personal radiation dose while rehabilitation activities.

THE DISCUSSION OF THE OBTAINED RESULTS

Gamma-locator application shows the effectiveness of selected approach for following actions:

- Remote dose rate mapping in contaminated zone;

- Evaluation of dose rate contribution from different areas in contaminated zone;

- Evaluation of dose rate contribution if dynamic changes in gamma-ray sources space distribution is taken place.

The measurement data, obtained during automatic scanning of contaminated zone within some hours,

give enough information for dose rate calculating both inside the contaminated zone, and outside it. There is an opportunity to analyze dose rate contribution from different points of particular interest. Dose rate contribution map at altitude 1 meter above ground surface is shown in fig.3. Relative dose rate contributions from several most contaminated areas in rehabilitation activity zone are also shown in fig.3. They correspond to different gamma-ray sources spatial distribution in the zone, obtained in different days. Man can see that location of containers with radioactive wastes and state of unloaded temporal waste storage was significantly changed.

Anisotropy of radiation from deepened gamma-ray sources and a character of gamma-radiation in space result in some a priori non-evident properties of dose rate distribution in space. The dose rate distribution in y-z plane is shown on fig.4 (z – vertical axis). The section plane crosses two bright sources in contaminated zone and gamma-locator coordinate. As may be seen from the figure according to isolines, the dose rate increases with vertical coordinate. Dose rate measurement using a dosimeter on the wall of the building corresponds well to calculated dose rate in the same points. The use of regular dosimeters, located at low altitude doesn't give an opportunity to notice an excess of dose rate in high floors of the building. This fact indicates that used method allows to determine dose rates with complicated distribution. For discovering such distribution using traditional methods, man has to conduct series of measurements for a large amount of points.
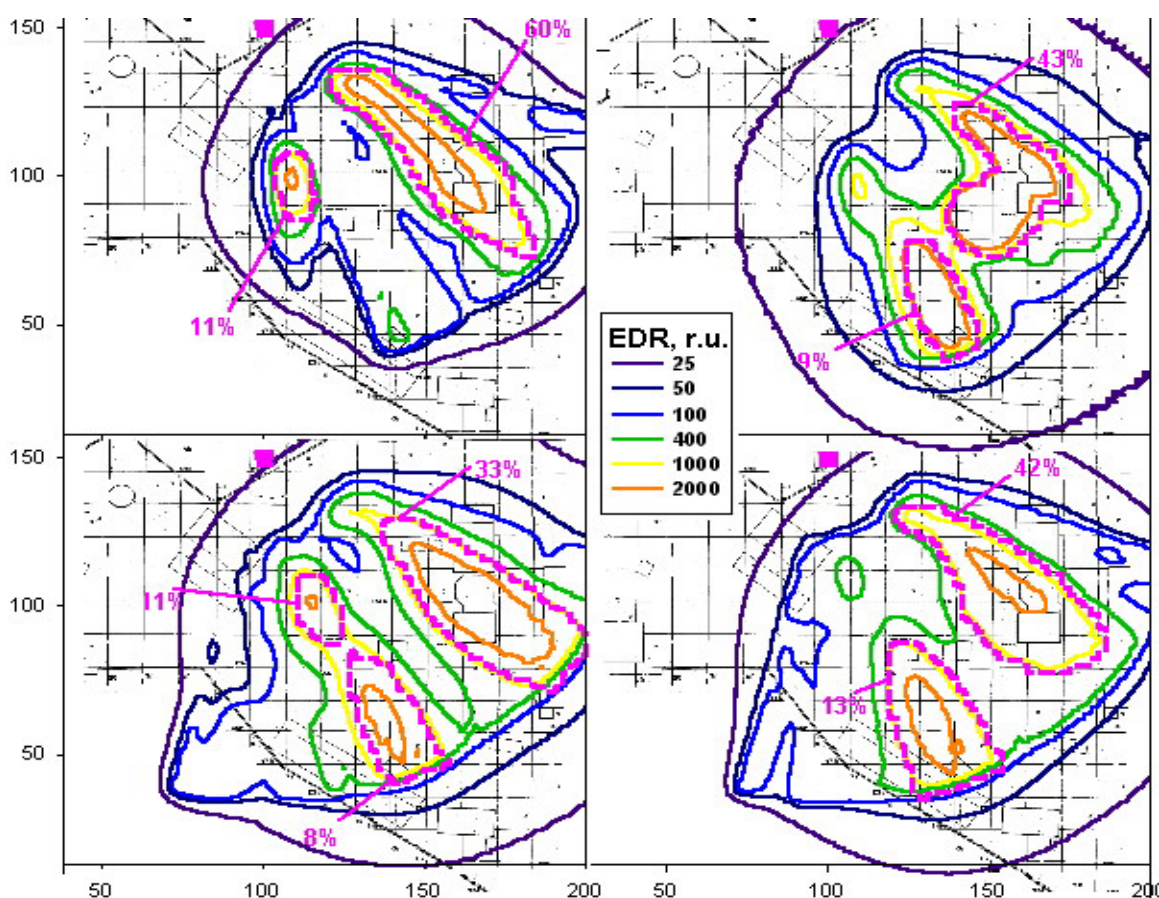

Fig. 3   Dose rate contribution in rehabilitation activities zone. EDR isolines at altitude 1 meter above ground surface and relative dose rate contributions at Gamma-locator position (purple square) from several most contaminated areas. Areas are marked by ping dash lines, relative dose rate contribution is given in percents.

The disadvantage of the method is a long measurement time. Besides, during the real measurement the gamma-ray sources may be displaced. This can result in additional errors in dose rate estimation.

The larger volume detector or some detectors assembly can be used for accelerating the measurements. Lesser number of measurement directions can be used as well.

CONCLUSIONS

New method of dose rate situation distant control was developed and approved. The method allows evaluating 3-dimensional dose rate distribution, and analyzing the dose rate contribution from different gamma-ray sources in contaminated zone.

Said system and method of measurements may be useful in distant radiographic survey during accidents and investigation of desolated contaminated zones.
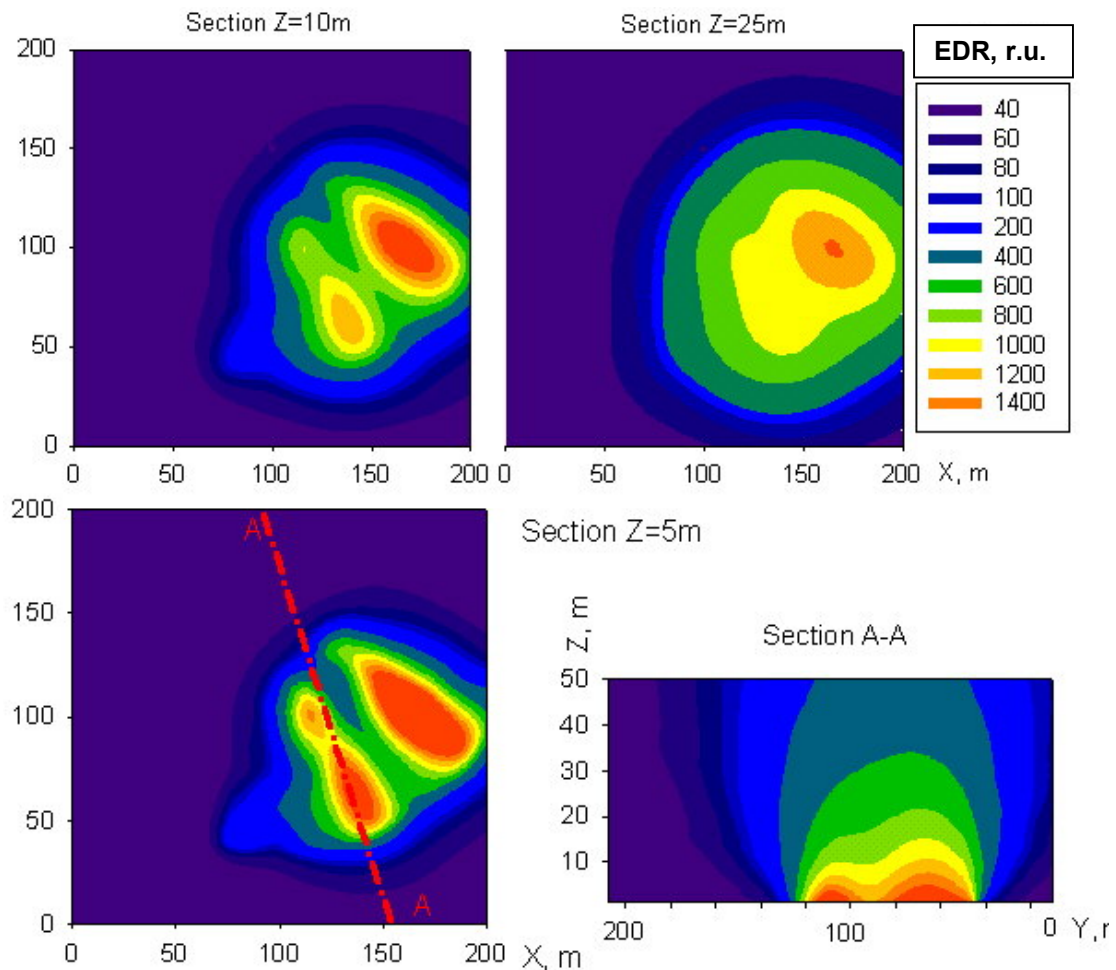
Fig. 4 Calculated 3-D EDR distribution. Three horizontal sections at different altitudes and vertical section along line AA.

REFERENCES

1   A.G.Volkovich, V.I.Liksonov et al., Application of collimated detector for removal of accident consequences in machine room of ChNPP unit #4, Atomic energy, v.69 (1990) no.6, 389-391 (in Russian).

2   A.V.Chesnokov, S.M.Ignatov, V.N.Potapov et.al. "Determination of Surface Activity and Radiation Spectrum Characteristics inside a Building by Gamma Locator," NIM A401 (1997) 414-420.

3   A.V. Chesnokov, V.I.Fedin, A.A.Gulyaev, V.N.Potapov, et al., "Surface Activity Distribution Measurements and Establishment of a Dose Rate Map inside the Destroyed Chernobyl Reactor," Preprint RISO-1074(EN), February 1999

4   A.G.Volkovich, V.N.Potapov, S.V.Smirnov et al., "Measurements of fields of photon ionizing radiation in reactor room of ChNPP unit #4", Atomic energy, v.88 (2000) no.3, 203-207 (in Russian).

5   AIL, GammaCam- http://www.ail.com/page13_gammacam.htm

6   Cogema, Cartogam: 3-D Gamma Imaging System
    http://www.fetc.doe.gov/dd/technologies/characterizations/cogema/cogema_body.htm

7   BNFL, RadScan 700 -- Gamma Scanner device:
    http://www.bnfl.co.uk/website.nsf/images/InstrumRadscan/$file/Inst_RADSCAN.pdf

8   Large-scale Testing programm in USA: http://www.fetc.doe.gov/dd/sitemap/sitemap.htm

9   L.J.Meng, D.Ramsden, V.M.Chirkin, V.N.Potapov. O.P.Ivanov, S.M.Ignatov, "The design and performance of large -volume spherical CsI(Tl) scintillation counter for gamma-ray spectroscopy", NIM A485 (2002) 468-476.