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Dose Assessment for a Hypothetical Accident at a Gamma Irradiation Facility

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Abstract:*Facilities which use intense radiation gamma sources, such irradiators for sterilization and preservation of foodstuff, require special care in the design and operation in order to prevent radiation injury to workers and/or public. Experience has shown that although strong safety measures are taken in this technology, serious radiological accidents were occurred. This work aims at assessing one of the worst case scenarios that may take place in which a complete loss of ^{60}Co source shielding outside the building of a gamma irradiator facility occurs***.***Although there is a very small probability of such event, however accurate assessment of this case is still essential for emergency preparedness and mitigation purposes. Monte Carlo calculation methodis utilized to generate dose rate mapping around the gamma irradiator facility,assumingthe absence of any shielding due to any other surrounding buildings. Protective actions to mitigate the consequences of such accident were discussed and the characteristics of the required shield are presented*

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I. Introduction

Gamma irradiator technology has covered a broad area of applications from crosslinking/polymerization and sterilization of health care products to food irradiation and environmental applications. Although very reliable and widely adopted by the industry, gamma irradiators present challenges in terms of supply, transport, waste disposal and security. The recent challenge due to heightened security concerns because of presence of intense ^{60}Co radioactive sources in gamma irradiators is quite daunting. Possibility of theft, or attack on gamma irradiator itself or transport container are different scenarios for accidental exposure from gamma irradiators that must be taken into consideration during emergency preparedness and response [1].

Survey on the past accidents occurred in gamma irradiators showed that, there are potential radiation hazards at these facilities including contamination from damaged radioactive sources, sources were out from their racks, accidents in handling sources, fires and security breakthroughs[2].

Many causes of accidents in gamma irradiators include inadequacy of safety systems, ignoring or misinterpreting alarms provided. The over-exposure of the facility operators in many cases were due to entering the irradiation area when the radiation source was exposed [3-8]. The accidents at the Dover facility in USA, 1982 and in Egypt, 2012 were highlighted the contamination incidents in gamma irradiators where the pool water was contaminated due to the leakage from ^{60}Co source [9&10].

The overexposure of workers at irradiation facility, Bulgaria 2011 was due to violation of the quality assurance program, since no work plan had been developed and respective responsible officers were not designated [11].

This work aims at assessing one of the worst case scenarios due to malicious act during loading of the source to its location inside the facility. The act led to a complete loss of ^{60}Co source shielding. Although there is a very small probability of such event, however accurate assessment of this case is still essential for emergency preparedness and mitigation purposes. Monte Carlo calculation method is utilized to generate dose rate mapping around gamma irradiator facility taken into consideration no shielding from other building was generated. Protective actions to mitigate the consequences of the accident were discussed and the characteristics of the required shield are presented.

II. Material And Methods

Description of the scenario and Modeling

Gamma Irradiator based on ^{60}Co source with total activity 1.0 million Ci was subject to a malicious act during its loading into the main building of the gamma irradiator. The act leads to lose of the complete shielding around the source. Monte Carlo calculation methodwas used to draw an accurate map for dose rate distribution which could be used to determine the level of emergency response.

Irradiation unit design and source specifications

The design of industrial Mega Gamma-1 facility based on J-9600 ^{60}Co flat panaramic wet source storage industrial irradiator is taken in the modeling procedures (figure 1) [12]. The construction and specifications of the modeled irradiation unit are described in [13]. It was assumed that all walls are made of heavy concrete (density 3.53 g/cm^3). The unit is designed in such a way that the radiation doses outside is almost background, even when the unit is in operation. Figure 2 is a longitudinal cross section of the unit illustrating the location and direction at which the source has to be arriving for replacement at the unit. The scenario involves the release of the source outside the unit upon arrival.

The source rack in the Mega Gamma-1 facility designed and built by MDS Nordion comprise 6 modules with ^{60}Co source pencils C-188 which were mounted by 3 modules in two levels [13]. Each module comprise various number of the active ^{60}Co source pencils from 15 up to 37.

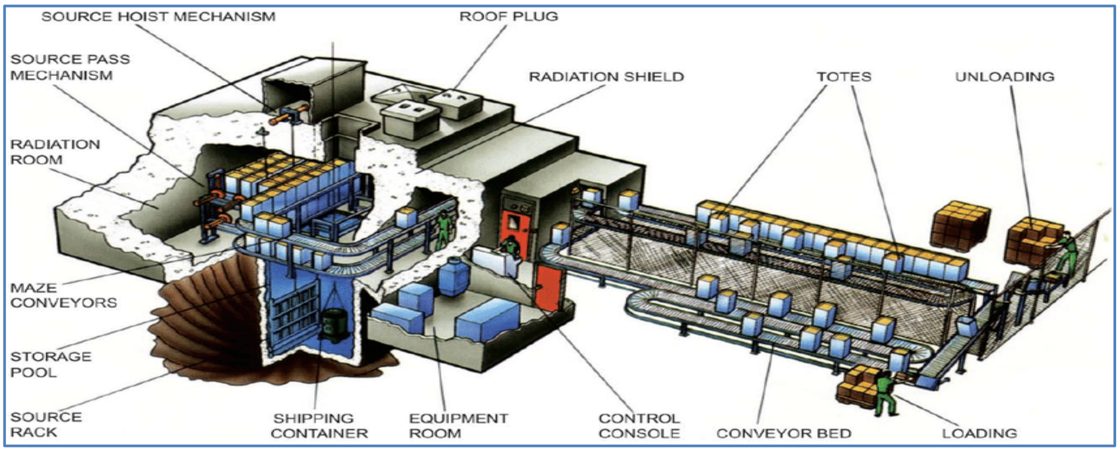


Figure 1: Schematic diagram of a typical panoramic, wet storage gamma industrial irradiator (courtesy of MDS Nordion-Canada)

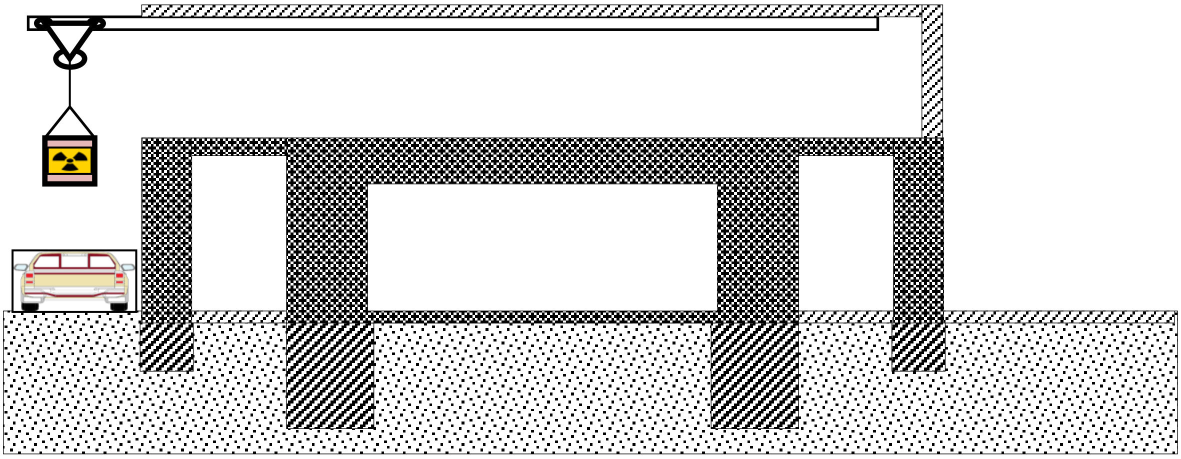


Figure 2: longitudinal cross section of the unit illustrating the location and direction at which the source has to be arriving for replacement at the unit

Monte Carlo Calculations

The general Monte Carlo Code, MCNP5, has the feature of calculating the radiation flux (gamma and neutrons) at a specified point using the point detector "F5" tally. The energy distribution of the gamma rays emitted from the source (^{60}Co in the current study) are identified using a distribution number "Dn" in the energy variable of the source definition card "SDEF". The distribution itself is defined in the source information "SI" and source probability distribution "SP" cards. The main two gamma energies of ^{60}Co, 1.1732 and 1.3325 MeV with their corresponding probabilities of 0.999736 and 0.999856; respectively are inserted in the source information and probability distribution cards. Finally conversion of the calculated flux at the specified points into dose is accomplished using the "flux-to-dose conversion factors" listed in the DE/DF cards. The multiplier card "FMa" was used to modify the results such that they are directly given in units of μSv/hr. The Table of gamma flux-to-dose rate conversion factor given in the MCNP manual was used [14&15].

An isometric 3D MCNP model for the unit is illustrated in Figure 3. MCNP built-in plane and Rectangular Parallelepiped (RPP) macrobody surfaces (73 surfaces) were used to construct the cells (15 cells). The view models of the unit surface top and side as well as surface and cell numbers are illustrated in figure 4 (a and b).

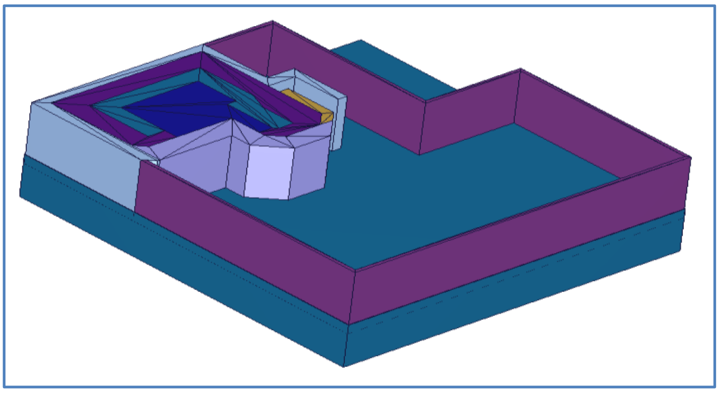
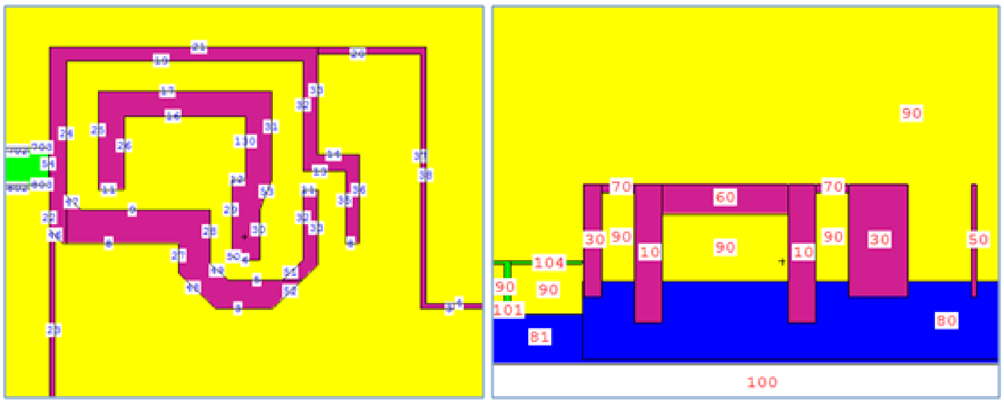


Figure 3: Isometric 3D MCNP model for the irradiation unit.



(a) **(b)**

Figure 4: MCNP model (a) XY section with surface numbers and (b) XZ section with cell numbers.

III. Result

A contour diagram for the calculated dose rates in μSv/hr due to the ^{60}Co source located at 3.0 meters just outside the left side wall of the irradiation unit is illustrated in figures 5. The dose rate mapping was created by estimating the dose rates at 130 locations distributed in XY plane using the F5 detector tally and taken into consideration the absence of any shielding from the existing buildings. The calculated dose rates ranged from 6.8E+3 Sv/h at 1.0 m from the source to 40.0 μSv/h at 1.0 km away from the source.

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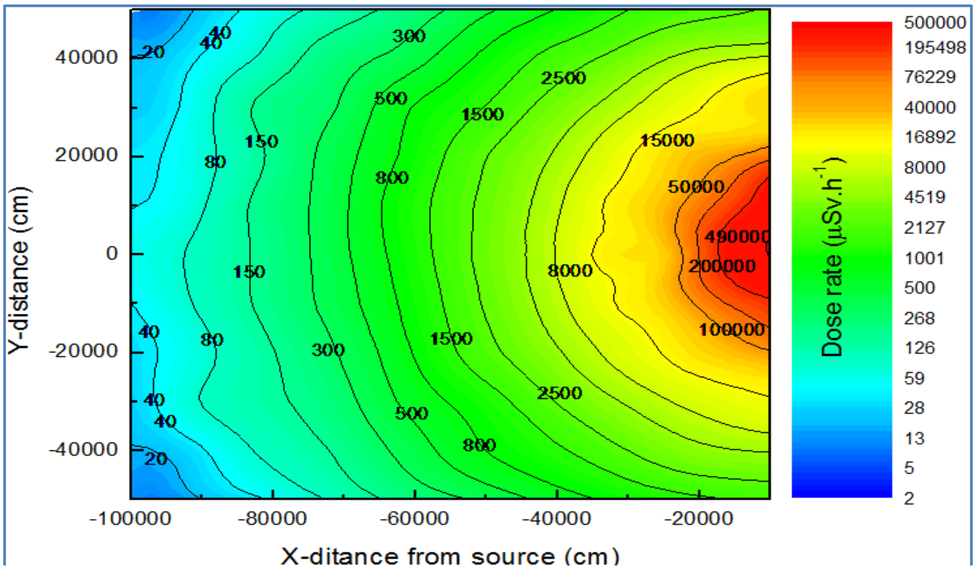

Figure 5: Dose rate mapping due to 10E+6 Ci^{60}Co source outside irradiation unit.

Figure 6 illustrates the back scattered gamma radiation in the area surrounding the source. It is shown that, the irradiation facility plays as a strong shield in the side of the source. To mitigate the doses and back scattered radiation on the other directions, specific shield is recommended to be used in which the source should be completely surrounded.

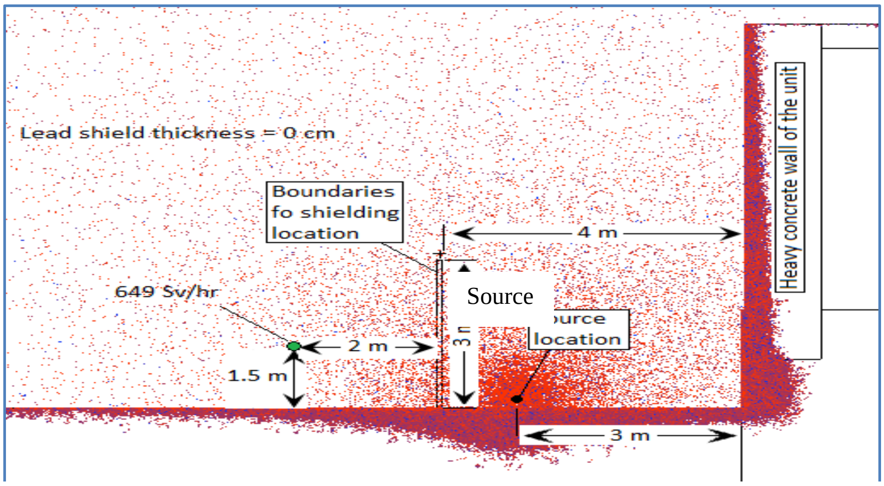

Figure 6: Particle display in as drawn using MCNP illustrating scattered radiation without shielding

IV. Discussion

For radiation emergencies including uncontrolled sources, Operational Intervention Levels (OILs) can be used to define the immediate protective actions required to protect the public and the workers [16]. These operational levels are based on the measured gamma ambient dose rate in the accident scene. Table (1) illustrates the radiation control zones and perimeters as well as their protective actions recommended by various international agencies for responding to radiological emergencies.

According the calculated dose map of the studied accident, without the installed shield, dangerous zone area with radius 200.0m (does rate is > 100.0 mSv/h) and a hot zone with radius 800.0 m (dose rate >0.1 mSv/h) are established. Based on OIL described in Austrian recommendations [16], the evacuation of personnel, isolation of the area by cordon and control access and egress are required protective actions in the hot zone. While the work in dangerous area is restricted to live saving and recovery process taking into account the time allowed for the emergency workers.

To reduce the radiation level from the source, a lead shield of an estimated thickness of 20 cm (at least) is recommended to be used and surround the source. The recommended shield will reduce the dose rate to about 4.9mSv/hr at a distance of 5.0 m from the source. Figure 7 show the effect of the suggested shield on the distribution of gamma radiation. As shown from figures 6&7, the irradiation unit itself makes a shield to the inner workers, so it is recommended that, the installing procedure of the lead shield is carried out from the facility site using suitable crane to allow the safe recovery operation to the workers.

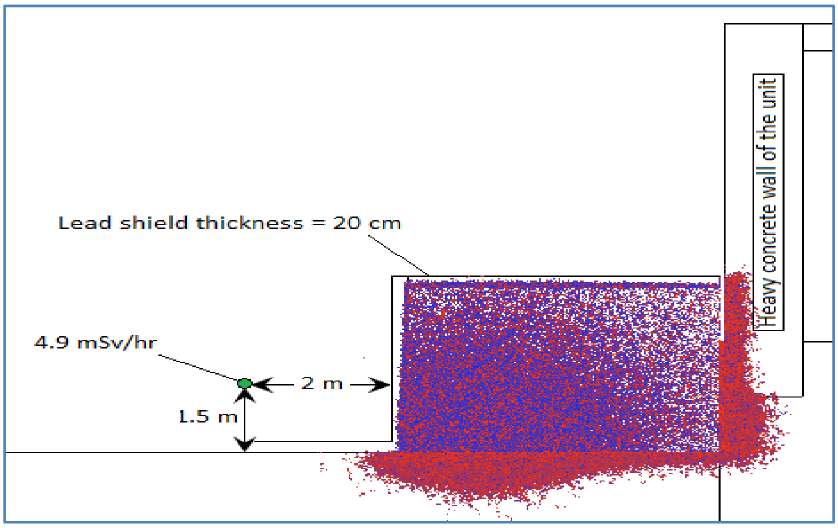

Figure 7: Particle display in as drawn using MCNP illustrating scattered radiation with 20.0 cm shielding

Upon the calculation of dose rate from the source after the shield was installed, the hot zone radius will be reduced from 800.0 m to 60.0m where the dose rate will be 94.0 µSv/h.

Table no 1: The types of international zones in the area of accident with their radiation level and corresponding intervention action

Agency	Zone Designation	Exposure levels	Intervention actions
IAEA [17&18]	Inside the inner cordoned area	Areas with >100 mSv/h	• Only lifesaving actions should be performed in this area • Limit staying time to <30 minutes, or less, depending on measured level of radiation.
	Inner Cordoned Area ("Hot zone")	>0.1 mSv/h	• Area around dangerous radioactive source where precautions should be taken to protect the responders and the public from potential external exposure and contamination.
	Outer Cordoned Area	--	• Access controlled, secure zone around the inner cordoned area. • Ambient dose rates in this area need to be at levels very close to background levels.
NCRP [19]	Dangerous Radiation Zone	>10 R/h (>0.1 Sv/h)	• Actions taken in this area should be restricted to time-sensitive, mission critical activities such as life-saving.
	Hot Zone	>10 mR/h (>0.1 mSv/h)	• Initiate early, adequate sheltering followed by delayed, informed evacuation using specific instructions from appropriate government officials. • Remember that until the level and extent of contamination can be determined, efforts should be made to avoid being outdoors in potentially-contaminated areas. • Isolate the area. • Minimize time each emergency worker spends inside the area. • Ensure that workers follow appropriate personal protection guidelines
	Cold Zone	Outdoor exposure rates < 10 mR/h (<0.1 mSv/h)	• The area outside the **outer perimeter** is where the command post and other support functions are located.
	Extreme Caution Radiation Zone	≥10,000 mR/h (≥100 Sv/h)	• Activities restricted to saving lives. • Total accumulated stay time for first 12 hours: minutes to hours
	High Radiation Zone	1000 mR/h (10 mSv/h)	Access restricted to authorized personnel performing critical tasks: - Firefighting - Medical assistance - Rescue - Extrication - Other time-sensitive activities

CRCPD [20]	Medium Radiation Zone	100 mR/h (1.0 mSv/h)	• Access restricted to authorized personnel entering the "High Radiation Zone" to perform critical tasks such as saving of lives and property. • Serves as a buffer zone/transition area between the "High Radiation Zone" and "Low Radiation Zones"
	Low Radiation Zone	≤10 mR/h (≤0.1 mSv/h)	• Access restricted to essential individuals. • Initial decontamination of first responders should occur near the outer boundary of this area.

V. Conclusion

Worst case scenario in which a complete loss of gamma irradiator's ^{60}Co source shielding is described. Monte Carlo calculations are utilized to generate dose rate mapping around the facility taken into consideration no shielding from other building was generated. Urgent protective action to mitigate the consequences of the accident was discussed and the characteristics of the required shield are presented. The results showed that in the absence of any shield either from building or materials, the dose rate from the source ranged from 6.0E+3 Sv/h at one meter from the source to 50.0 µSv/h at 1.0 km away from the source. Two zones are suggested to take the intervention actions , first is 200.0 m radius at which the radiation level is greater than 100.0 mSv/h from the source where live saving and recovery operation of the source are carried out. The second area is 800.0 m radius at which the radiation level is approximately less than 1.0 mSv/h. The suggested zones are changed if the installed shield with thickness 20 cm is used to cover the source. The suggested shield will reduce the distance of the hot zone to be 60.0 m at which the dose rate is 0.094 mSv/h.

Even the discussed accident is not expected to occur, the gamma irradiator facilities are required to prepare themselves to such accident. Suitable lead blocks and suitable crane are required to be settled and tested in the facilities to intervene to such accident. Although the calculation is carried out taking into consideration the total activity (total number of ^{60}Co pencils), it is possible to redraw the dose rate map for partial loss of shielding (any number of pencils) by changing the source activity in the "FM" multiplayer card.

References

[1]. Anil Kumar Kohli, Gamma Irradiator Technology: Challenges and Future Prospects, Universal Journal of Physics and Application 12(3): 47-51, 2018 http://www.hrpub.org DOI: 10.13189/ujpa.(2018).120303

[2]. International Atomic Energy Agency, Radiation Safety of Gamma, Electron and X Ray Irradiation Facilities, IAEA Specific Safety Guide No. SSG-8, Vienna (2010).

[3]. US Nuclear Regulatory Commission, Fact Sheet on Commercial Irradiators (2004).

[4]. International Atomic Energy Agency, the Radiological Accident in San Salvador, Vienna (1990).

[5]. International Atomic Energy Agency, the Radiological Accident in Soreq, Vienna (1993).

[6]. International Atomic Energy Agency, the Radiological Accident at the Irradiation Facility in Nesvizh, Vienna (1996).

[7]. Shanghai irradiator accident, Database of Radiological Incidents and Related Events, Johnston's Archive (1990).

[8]. US Nuclear Regulatory Commission, NRC News Report no. I-04-049 (2004).

[9]. US Nuclear Regulatory Commission, Backgrounder on Commercial Irradiators, USNRC Report no. 301.415.8200. https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/commercial-irradiators.html (2016).

[10]. Unified System of Information Exchange (USIE), Leakage of Co-60 from a Module # 4 at NCRRT Gamma Irradiator, Egypt, IAEA (2012).

[11]. Unified System of Information Exchange (USIE), Overexposure of Workers at Irradiation Facility, Bulgaria, IAEA (2011).

[12]. International Atomic Energy Agency, Gamma irradiators for radiation processing, IAEA DGPF/CD, Vienna 2004

[13]. J.P. Sephton, P.H.G. Sharpe, R.D.H. Chu, K.P.J. O'Hara, F. Abdel-Rehim, A. Abdel Fattah, Dose Mapping of a 60Co Industrial Irradiation Plant using an Electronic Data Recording System, Static Measurements and Mathematical Modeling. Radiation Physics and Chemistry.V.76.p.1820-1825(2007).

[14]. X-5 Monte Carlo Team, MCNP - A General Monte Carlo N Particle Transport Code, Version 5, Volume I: Overview and Theory, LA-UR-03-1987 (Revised 10/3/05), (2003).

[15]. X-5 Monte Carlo Team, MCNP - A General Monte Carlo N Particle Transport Code, Version 5, Volume II: User's Guide, LA-CP-03-0245 (Revised 10/3/05), (2003).

[16]. Australian Radiation Protection and Nuclear Safety Agency, Intervention in Emergency Situations Involving Radiation Exposure Radiation Protection Recommendations, Series Publication No. 7 (2004).

[17]. International Atomic Energy Agency, Manual for First Responders to a radiological Emergency, EPR-first responder (2006)

[18]. International Atomic Energy Agency, Generic Procedures for Medical Response during a Nuclear or Radiological Emergency, EPR- medical (2005).

[19]. National Council on Radiation Protection and Measurements (NCRP), Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism (NCRP Commentary No. 19), Bethesda, MD, December (2005).

[20]. Conference of Radiation Control Program Directors (CRCPD), Handbook for Responding to a Radiological Dispersal Device (Dirty Bomb): First Responder's Guide: The First 12 Hours (CRCPD Publication 06-6), Inc. Frankfort, Kentucky,(2006) .

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