Novelty Journals

ISSN 2394-7357

International Journal of Novel Research in Civil Structural and Earth Sciences
Vol. 2, Issue 3, pp: (1-7), Month: September-December 2015, Available at: www.noveltyjournals.com

NUCLEAR AND RADIOLOGICAL INCIDENT SCENARIOS: CASE STUDY MODELS AT A NUCLEAR RESEARCH REACTOR AND AT A COBALT-60 RADIATOR IN THE REGION OF ATTICA-GREECE

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Abstract: **This study aims to present hypothetical nuclear and radiological event scenarios of a nuclear research reactor and a Cobalt-60 radiator at the region of Attica, Greece, through a local civil services perspective. The results aspire to present general mapping of consequences, while establishing a precise method of relevant incident management at Municipality level. Scenarios concerning the nuclear reactor have demonstrated vast results within the first 10 minutes - a necessary time frame to assess direct effects on human lives [1], which differentiate by wind speed, direction, terrain features and can influence areas about 10 km away from the reactor. To present these effects, risk maps were created for Municipalities of Northern Suburbs of Attica, based on data from scenarios and GIS tools. The Cobalt-60 radiator scenario has presented severe results mainly inside the facility hosting the radiator. Regarding protection levels of employees inside the facility, the use of HotSpot model has indicated a type of "average" protection that will mandatorily fulfill specific standards inside the facility. After quality research and bibliographical reference, we faced significant lack in briefing issues concerning local administrative bodies, when in parallel, administrative legal voids, basically legislative measures, were noted. Greek competent bodies, utterly unaware of those aspects, have proceeded to creation and implementation of specialized protection plans of public from radiological threats. On this basis a radiological incidents response plan was created for Municipalities that are affected on a medium scale. The aforementioned led to remarks and suggestions about facilitating response and prompt activation of Municipalities and citizens in the event of radiological and nuclear incidents.**

Keywords: **Civil protection, Cobalt-60, Local response plan, Nuclear reactor, Nuclear scenarios, Radiological events.**

1. INTRODUCTION

In order to assess the potential use of nuclear energy in Greece, relative problems and effects need to be considered, so as for public and local civil services to adopt common civil protection management plans and be aware of self-protective measures and immediate response actions [2]. The outcomes and suggestions of this assessment will lead to a prompt response from Municipalities and citizens, in case of a radiological or/and nuclear incident.

1.1 Aims:

The study's aim is to display a series of event scenarios concerning radiation incidents, after an analysis of relevant data (weather conditions, land formations, etc.) from the region of Attica, Greece. Firstly, a large scale scenario was presented, given that the experimental reactor at the Municipality of Agia Paraskevi is actually an only choice. Then, a small scale scenario was presented at a Cobalt-60 sterilizer radiator near the Municipality of Aspropirgos. The scenarios' analysis and their outcomes will detect vast spatial effects of a possible radiological incident in Greece, where nuclear energy was rejected as fuel[3] and is being accepted only for scientific purposes. The presentations help us to conclude to action plans at local level that would activate both civil services and citizens in case of a radiological emergency. An emergency management plan at local level will broaden imminent response of civil protection services to a regional/state level, along with the guidance and indications of specialized scientists and civil protection authorities to ensure the safety of human lives [4] and the local ecosystem [5].

1.2 Background:

In sequence of a brief analysis of basic principles of radiation [6], radioactivity [7], radionuclides [8] and nuclear fission [9], basic tools are introduced, essential for civil servants to concisely comprehend information about nuclear reactors [10] and nuclear research reactors [11], the International Nuclear Events Scale (INES) Scale of radiological events [12] and the "ALARA" principle (time, distance, shielding) [13]. Furthermore, the most common causes of nuclear and radiological accidents (LOCA type accidents) [14], are categorized at an Ishikawa "cause and effect" diagram [15]. The use of a radiological dispersal device (RDD) is also considered [16][17]. In parallel, a brief description of significant nuclear and radiological accidents and incidents is being presented, relative to the large scale scenario of this study; mainly accidents at Fukushima Daiichi (2011), Chernobyl (1986) [18], Three Mile Island (1979) and SL-1 (1961). A terse report will mark the outcomes for the smaller scale scenario, referring to radiological incidents such as the explosion of nuclear waste at Kyshtym Russia (1957), a medical radiotherapy incident of Cobalt-60 release at Costa Rica (1996) [19], an accident of lost source of Iridium-192 at Marocco (1984) and Samut Prakarm (2010) and an accident after dissembling and selling an experimental Cobalt-60 radiator at Mayapuri, India (2010) [20][21].

SWOT Analysis [22], that was used to estimate nuclear energy as fuel, has indicated that ensuring safety in all facilities for radioactive materials is of great importance and also that we need to make all necessary efforts, at scientific and local management level, so as for citizens to become familiar with relevant means of self-protection.

2. METHODOLOGY

Following an extensive bibliographical research, we preceded conducting 6 profound interviews with relevant actors in Civil Service bodies. Our target was to discover further reasons that might prohibit or facilitate an emergency response plan at local level; and so we needed to configure basic problems and differences of perspectives at relevant public authorities. The statistical program Minitab was used in order to validate results from the above-mentioned qualitative survey. Cluster analysis has pointed out the formation of two basic clusters: (a) scientific public bodies, supporting that non-scientists and local civil servants lack knowledge and skills to respond in case of a radiological emergency and (b) regional/local civil authorities, carrying the idea that facilitating any directive from scientists depends integrally on them.

Therefore, we concluded to the fact that a realistic local emergency management plan is connected to certain tools and information accessible to any local civil servant. We chose the specialized software HotSpot of NARAC (https://narac.llnl.gov/HotSpot/HotSpot.html) which allows an inexperienced user to assess initially radiological effects, relevant to an atmospheric release of radioactive materials, and additionally helps first responders to quickly assess initial results of such an incident. HotSpot is used for low radiation incidents and assessments during a small period of time (10 minutes)[23]. HotSpot software uses dosimetry and methodology proposed by the International Commission on Radiological Protection (ICRP), incorporated on U.S. Federal Guidance Report No.11, FGR-11" . Moreover, HotSpot establishes three Protection Zones, according to the dosage (Sv) [24] and the representation of those zones (Red-Hot, Green-Warm and Blue-Cold) at a map, associated with a Geographic Information System (GIS) database of terrain features and meteorological data. Thus, GIS database and ArcGIS software were used to combine each zone with basic information for necessary protective actions [25].

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2.1 Hypothesis:

A fundamental hypothesis for the scenarios is to present all basic scientific information of a radiological or nuclear incident simplified, in order for a non-specialist civil servant of a Municipality to be able to comprehend and act upon. Also due to data confidentiality, we limited our scenarios at a level accessible to local civil servants. Data is used at primary conceptual and practical level. This study focuses on estimating consequences of a nuclear or radiological incident within a Municipality areait also shows potential feedback to a local emergency plan, concerning civil protection and self protective measures in accordance with scientific and civil protection services instructions.

Basic hypothesis is as follows: An explosion of 100lb (about 45 kg) of TNT takes place at the heart of an experimental nuclear reactor of 5 MW, with 18 kg of 20% Low Enrichment Uranium) Uranium-235 [26] a total activity of $9.36*10^{-6}$ Ci/g. Scenarios take place 10 minutes after the explosion and calculate consequences of a 10 km radius area, after taking into account meteorological data, terrain and natural properties of the emitted material [27]. A timeframe of 15-45 minutes after the incident is considered vital, in order to inform citizens promptly and effectively [2], therefore immediate information about the expanded results of a radiation release is of great significance. Scenarios are selected on the basis of "worst-case" scenario considering the most influential factors. Then, results are divided into two meteorological periods, summer and winter conditions, utilizing essential meteorological data of the region and mainly the maximum wind intensity.

3. RESULTS AND DISCUSSION

Worst-case scenario during summer conditions with SW winds at 6m/s, presents an explosion which will have a height of 240 meters. The necessary safety distance for immediate thermal injuries is 414 meters. A blast wave of 100psi will be created at 4.9-8.3 meters from sources, leading to 99% fatality at the first 10 minutes. Radiation at TEDE[1] dosage of $5.09*10^{-4}$ Sv. Ground deposition does not exceed 3km. Safety zones are: Red (Hot zone) at 0.017 square km at $1*10^{-4}$ Sv maximum TEDE, Green (Warm zone) at 0.30 square km and $1*10^{-5}$ Sv maximum TEDE and Blue (Cold zone) at $1*10^{-6}$ Sv maximum TEDE.

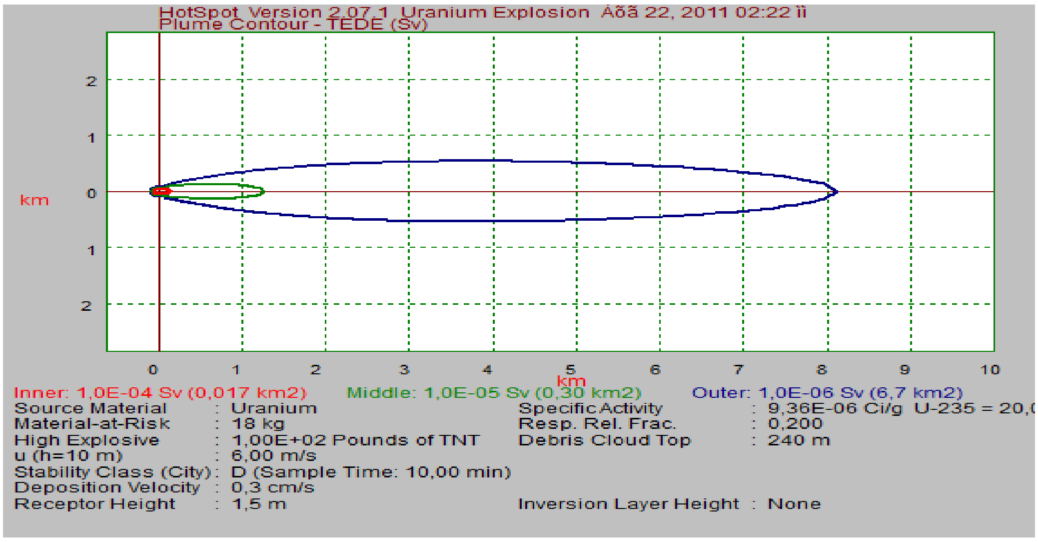


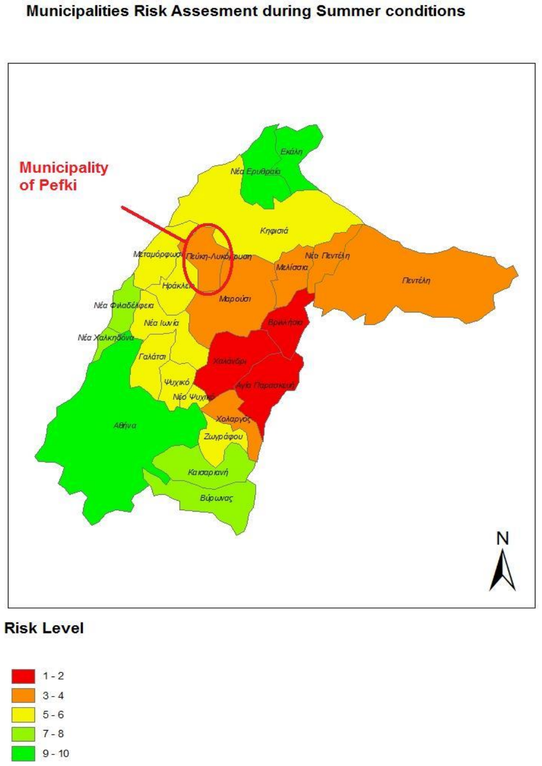
Fig.1: Safety zones for Summer conditions

According to similar literature scenarios [28], we must also calculate the impact of the following radionuclides: Cobalt-60, Cesium-137, Iodium-131 and Strodium-90.

Worst-case scenario during winter conditions presents similar results, but since wind direction at winter is mainly NA at 6m/s and the explosion takes place by the hills of mountain Hemmitus, most radioactive pollutants are headed towards the

[1] TEDE: Total Effective Dose Equivalent is the sum of dosages received from materials outside and inside (mainly inhalation) an average human body [23]

mountain. That might lead to a local congestion of pollutants or perhaps different currents of air pollutants will be swept away towards different direction [29]. Such scenarios of atmospheric pollutants diffusion are estimated by specialists and go beyond the subject of this study and do not form part of this study. In this study we are particularly interested in preparing Municipal civil services for a possible radiological incident. GIS tools are used in order to display areas that should be informed of such potential risks [30] and, according to the spatial analysis; the results of these tools will be restricted to the northern suburbs of Attica. After having mapped maximum results of each radionuclide, we observed that the effect of Uranium-235 is, along with Strodium-90, the largest in size compared to other considerable radionuclides (Cobalt-60, Cesium-137, Iodine-131). We use variables from the scenario for risk assessment of each Municipality and 20 more minutes after the explosion (30 minutes later). Areas of higher risk level are shown in red colour (1-2), of medium risk with orange and yellow, while areas with extremely low risk level are in green (7-8, 9-10). (The map was digitized with ArcGIS).



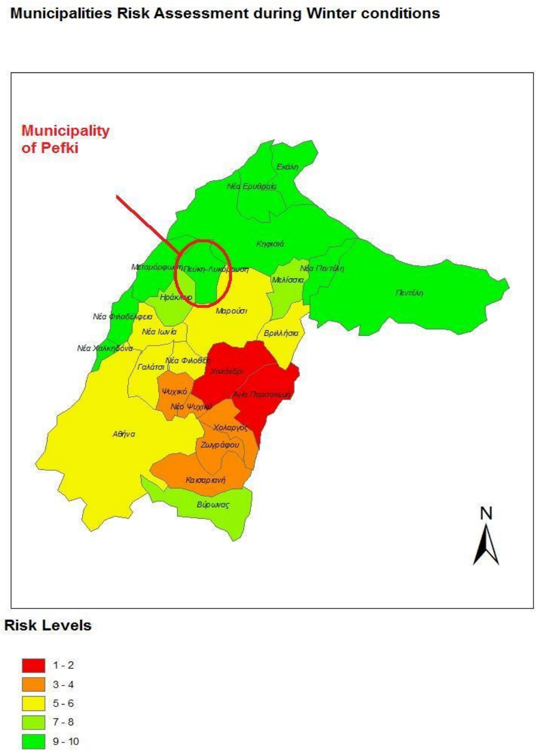


Fig.2: Risk assessment by municipality: Summer (left) and Winter (right) period

3.1 Cobalt-60 Radiator:

International Atomic Energy Agency (IAEA) reports various cases of Cobalt-60 exposure, mainly in hospitals and medical facilities. The majority of reports describe mostly mechanical accidents. The Cobalt-60 source, usually located within a mechanical radiation head to ensure the continuous flow of gamma-rays, "stucks" in a position of continuous irradiation [31].

The worst case scenario of a Cobalt-60 radiation accident is based on a source of Cobalt-60 at 340kCi or 1.2580 * 1016 Bq [32]. There is an explosion of 100 lb (about 45kg) of TNT and the scenario takes place in the next 10 minutes of the explosion, measuring its impact on the center point of the event, taking into account meteorological data, terrain and of course the amount and physical properties of Cobalt-60.

The results during winter conditions present a maximum TEDE of 0.414 Sv at a radius of 14 square meters around the source. A large area is polluted (approximately 20km), due to wind velocity and the natural dispersion properties of Cobalt-60. At summer conditions, maximum TEDE is at 0.352 Sv and an area of less than 20km is polluted.

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As a Cobalt-60 radiator accident is more likely to have results within its facilities, we implement the tool “Radionuclides in the Workplace” of HotSpot, in order to perceive which type of protection employees should follow to prevent lethality from a Cobalt-60 release incident. Both results, during winter and summer period, depict a necessary “Type 2 Workplace”, involving assurance of procedures at medium risk; adequate ventilation, protection of smooth surfaces from deposition of dangerous materials, use of protective clothing and gloves or equipment by staff and storage of radioactive materials within appropriate storage media. It also stipulates the use of monitoring receivers with varying indicators of mixed radionuclides in the workplace [23].

4. CONCLUSIONS

Scenarios stipulate radioactivity exposure which during the first ten minutes may have large spatial results. Depending on weather conditions, Municipalities may be more or less effected (i.e. Municipality of Pefki depicted on Figure 2). Radionuclides expected to affect the area (Cobalt-60, Cesium-137, Iodine-131, Strodium-90) will initially affect individuals by inhalation and ultimately by ground deposition. Consequently, a local emergency response plan for the Municipality of Pefki was created, focusing on timely and effective actions and being based on coordination (basic principle of emergency treatment and management). The plan reflects the necessity for all relevant public information to be presented strictly by competent scientific authorities [33], due to the complexity of a radiological incident. It emphasizes on coordination and cooperation among competent operators, distributing precise and clarifying roles, before, during and after an event has occurred.

Fig.3: Response actions for municipality civil services

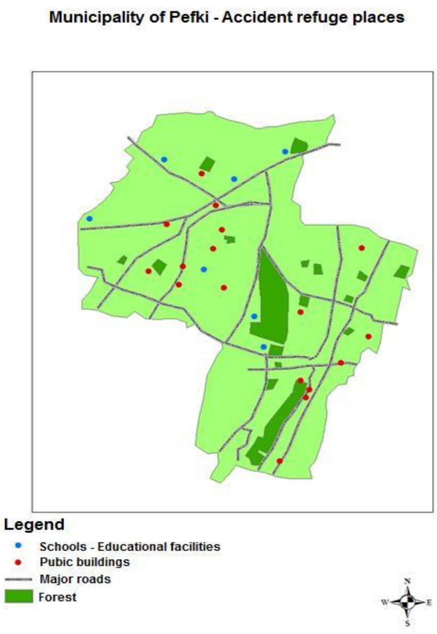

Fig.4: Map of refuge points at the Municipality of Pefki

The plan consists of:

1. Equipment: Description of general use equipment and personal protective equipment, telecommunication systems.
2. Administration: Specific roles of Civil Protection authorities and responsible personnel, municipal civil protection coordinating body, civil protection office, municipal volunteer emergency response team
3. Operations: Actions of Civil Protection Operations Center (at a Ministerial level)
4. Municipal actions: Preparation, Response (communication with relevant bodies, safe citizen departure plans, refuge places), Recovery.
5. Relative tables: Greek Atomic Energy Committee preventive instructions, Personnel and competent authorities' emergency contact information.

A municipality can use basic tools for a primary assessment of a disaster and perform, even roughly, scenarios in order to be prepared for an event. Municipal civil services should be aware of the possible risks affecting their area and have a working emergency response plan, in order to establish procedures which will enable prompt cooperation with competent authorities and appropriate assistance to their work. The plan must also take into consideration a recovery phase, promoting cooperation for projects including decontamination of the site and psychological support of victims and their families. Local civil servants, as they are not familiar with full dimensions of radiological incident, they need to admit that a plan – which enables immediate contact with relevant scientific and emergency response authorities – is actually of vital importance.

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