Nuclear Facilities, Radiological Safetyand Radiation Exposure to Public: Concerns and Facts

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ABSTRACT

Man is living with radioactivity and exposure to ionising radiation and the usage of radioisotope or radiation for the benefit of mankind is on increase. There is understandably a high level of public interest in any 'Nuclear/Radiation' related news. On the other hand, timely availability of authentic / factual / credible information on the subject is limited. Due to this, there are several common misconceptions to the extent that any event immediately conjures up visions of deformed children, high cancer incidence, a Chernobyl type event or even a nuclear explosion like Hiroshima and Nagasaki. It is essential that any possible nuclear / radiation emergency especially in public domain is addressed in rational manner without any preconceived notion / bias. Due to the wide applications and usage of radioactive sources for the benefit of society, large number of radiological accidents (Goiania, Morocco, Mayapuri etc) has occurred, world over, compared to a few nuclear accidents. The number of deaths reported due to radiological emergencies is many times higher compared to the total number of deaths (58) due to nuclear emergencies (Chernobyl& Fukushima). Inthe accident at Chernobyl reactor release oflarge quantity of radioactivity to the environment took place due to the errors in design, operating procedures and lack of adequate containment to retain the pressure build-up.Inthe accident at Fukushima nuclear plants,release of radioactivity to the environment took place due to the unexpectedly severe Tsunami waves (more than 14m high) affecting the required continuous cooling for the removal of decay heat in the reactor fuel of the reactor cores though they survived the large magnitude earthquake. Inspite of the release of large quantity of radioactivity into the environment, which generated fear on the possible health effects among the exposed persons, there are no indications of occurrence of fatal cancer or other deleterious effects tothe member of public except few thyroid cancer casesdue to the exposure to radioiodinereleases.

I FACTS ON EXPOSURE TO IONISING RADIATION

By living in this world, we all are subjected to an average radiation exposure due to natural radioactivity/radiation of ~2.4mSv (0.0024Sv) per year. All persons emit radiation from the ^{40}K natural radionuclide present in their body which gives an effective dose of ~ 0.40mSv in a year to the person himself and also deliver radiation dose to the persons nearby depending on their proximity. Some parts of Kerala have got high radiation background areas (due to natural thorium) where people get exposed to radiation dose of more than 15mSv (0.015Sv) in a year. Eating a banana or drinking milk also can lead to intake of the ^{40}K radionuclide. But noradiation induced harmful health effects are reported among the people receiving the radiation exposure from the High Background Radiation Area (HBRA)).If the exposure exceeds 1Sv, receivable in a short duration; there is chance for the victim to show symptoms of nausea and vomiting. If the exposure exceeds 3-4.5Sv, there is 50% chance that person may die in 60 days (Fig-1) and if the exposure exceeds 10 Sv there is no chance of person's survival.

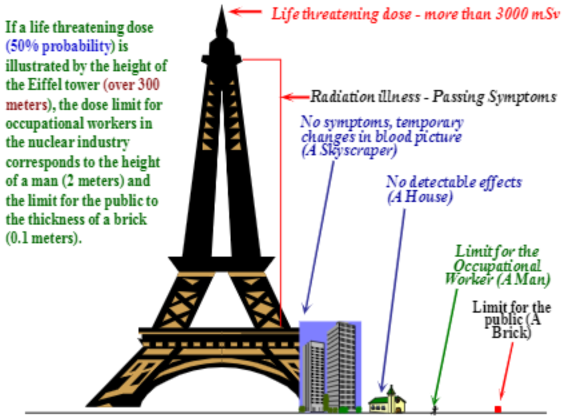

Fig1: Comparison of Radiation Exposure (Ref: IAEA)

Regarding the radiation exposure due to nuclear energy programmeand nuclear facilities, the members of public, in general, are not having adequate awareness due to which many havewrong notions about the effects of radiation, reactors and the radiological safety. Most of the persons are not aware that all of them are living with natural radiations right from the beginning of their birth receiving radiation doses every year (2.4mSv) which is at least 60 times the radiation dose they may get by staying very near to any operating nuclear power plant(Venkataraman, 2010) (Fig-2). Many believe that people living near nuclear power plants give birth to deformed children or getting cancer due to the radiation from the plants. As demonstrated by the detailed studies undertaken byvarious agencies neither at the reactor site nor at high background radiation areas(HBRA) ofKerala,no genetic effect or increase in the caner incidences attributable to the radiation exposure have been detected.

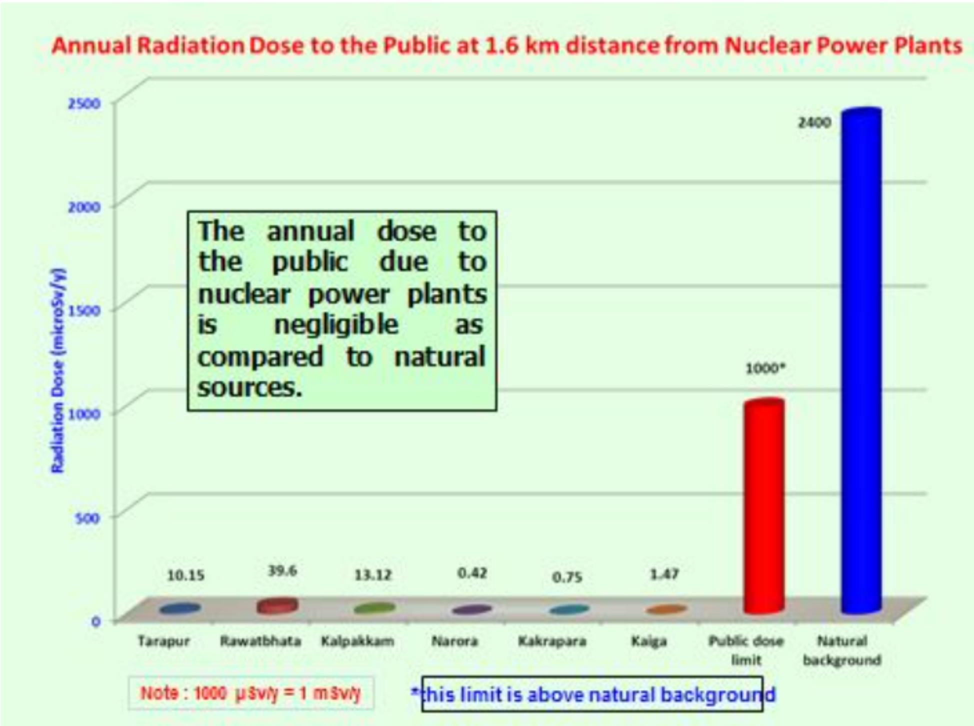

Fig-2: Comparison of radiation exposure at NPP's site boundary (1.6km) with Annual dose limit for the member of public

II ENSURING RADIOLOGICAL SAFETY AT NUCLEAR REACTORS

For nuclear facilities, safety is given the top most priority right from the site selection stage and then all through the design and operational stages of all nuclear facilities. The sites are selected preferably away from densely populated areas,at areas with adequate water resource to meet the cooling requirement of the facilities and negligible environmentalimpact due to radioactivity releases. The risks due to external parameters such as earthquakes, flooding, air accidents and any malevolent acts are taken into account when the facility is designed. In India, the Nuclear Power Plants (NPPs) are designed and operated ensuring safety to the operating staff, member of the public and environment. All NPPs in India have a three tier system to

(a) reduce the probability of accidents by incorporating many engineering safety features

(b) reduce the quantity of radioactivity release to the environment by having adequate containment (to contain the pressure built-up following a major accident/ retain the radioactivity even if core meltdown occur)

(c) have emergency preparedness in place for nuclear facilities which will enable quick assessment of radiological status following any accident to enable implementation of countermeasures for reducing the radiological consequences and protection of member of the public and environment.

Nuclear reactors, while in operation, continuously generate energy from the controlled fission reaction, fission products that are highly radioactive and the radioisotopes produced by neutron activation (including those used in medical and industrial applications). Each reactor will have large inventory of radioactivity i.e., millions of Curie activity (1 Ci = 3.7 x 10^{10}Bq) contained within the reactor. Even during an accidental scenario, large number of barriers needs to be penetrated for the activity to come out of the reactor and to reach the public domain. Detailed safety measures at various stages, i.e., site selection, design, construction and operation, are incorporated in all nuclear facilities to ensure that the radiation exposure to occupational workers as well as to the member of public is much below the prescribed limits.

The architecture used in reactor consists of a metal enclosure (cladding) to the nuclear fuel, a steel vessel which protects the reactor core (extended by the metal envelope formed by the pipes of the primary heat transport system) and the containment building which surrounds the whole reactor. During the operation of the nuclear facilities, it is always ensured that the releases to the aquatic as well as atmospheric environment will not lead to any significant exposure to the member of public. The radiation exposure to any member of public due to the operations of NPPs falls into a small fraction of the annual limit of exposure to the members of the public(1mSv) which by itself is less than 50% of the natural radiation exposure(2.4mSv) we receive every year by living in this world.

Strict administrative control is also exercised to ensure safety of the reactor as well as the protection of member of the public against any possibility of large scale radioactivity releases. It is always ensured that 'The annual risk to the most exposed member of the public due to accidents in a reactor to be extremely small in comparison to his/her total risk of premature death'.

III RADIOLOGICAL IMPACT PARAMETERS

The radiological impact of any nuclear/radiological emergency depends on the following parameters (Pradeep kumar, 1998):

(a) Source term of the accident (quantity of radioactivity release)
(b) Height of the release for the gaseous effluents
(c) Topography (of the area to which it is released)
(d) Characteristics of activity release,
  (i) Isotopic composition,
  (ii) Physicochemical form,
  (iii) Delay and duration of release
(e) Meteorological conditions during the release –
  (i) wind direction
  (ii) wind speed
  (iii) stability class

(f) Population distribution with respect to direction and distance from release point
(g) Level of radioactive deposition / contamination on ground
(h) Implementation of countermeasures (if carried out in time)

All the above factors are taken into account to assess the maximum possible exposure and for strengthening the emergency preparedness for nuclear facilities.

The risk to member of public from any major accidents in a NPP, though probability is extremely small, will be mainly attributed to exposure to ionising radiation. Experiences from Chernobyl and Fukushima accidents have demonstrated that the psychological trauma may be much more than any other health effects the releases can cause to the member of public. Radiological consequences can be avoided or significantly reduced if countermeasures can be implemented effectively which require preparedness for emergency response in place for all nuclear facilities.

The fundamental logic for all emergency preparedness is that: money to be spent for response with 'preparedness for emergency response' will be very small compared to the money required for responding to an emergency without 'preparedness for the response'. The zoning concept followed in NPP helps in enforcing the emergency preparedness as well as periodic exercises for such facilities. Systems and methodologies for quick assessment of radiological impact, developed in BARC (Pradeepkumar,1998, Pradeepkumar,2003) and kept in readiness have very important role in helping the decision makers on the appropriate countermeasures at the desired locations.

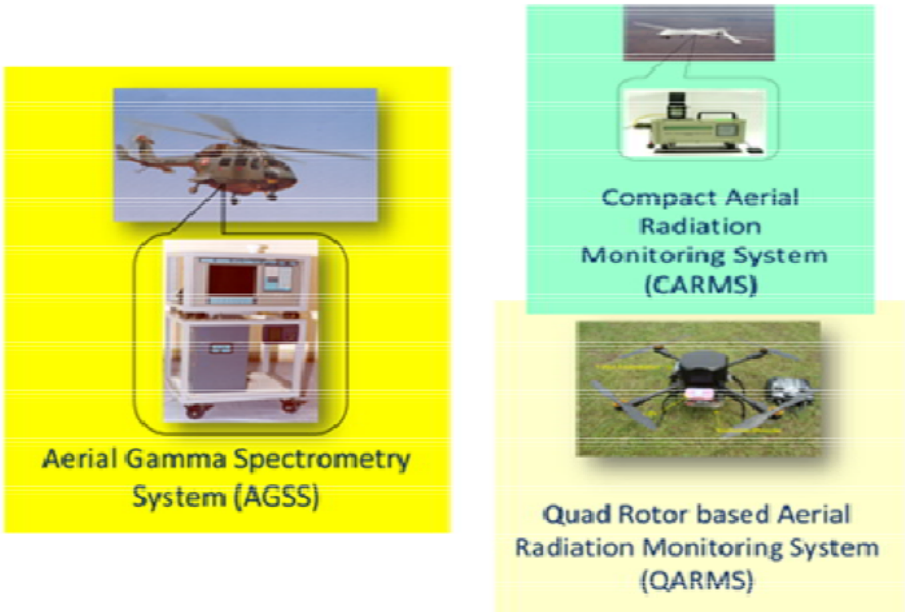

Fig-3: State of the art radiation monitoring Systems Developed in BARC for meeting the challenges of 'Orphan sources' and Radiological Emergencies

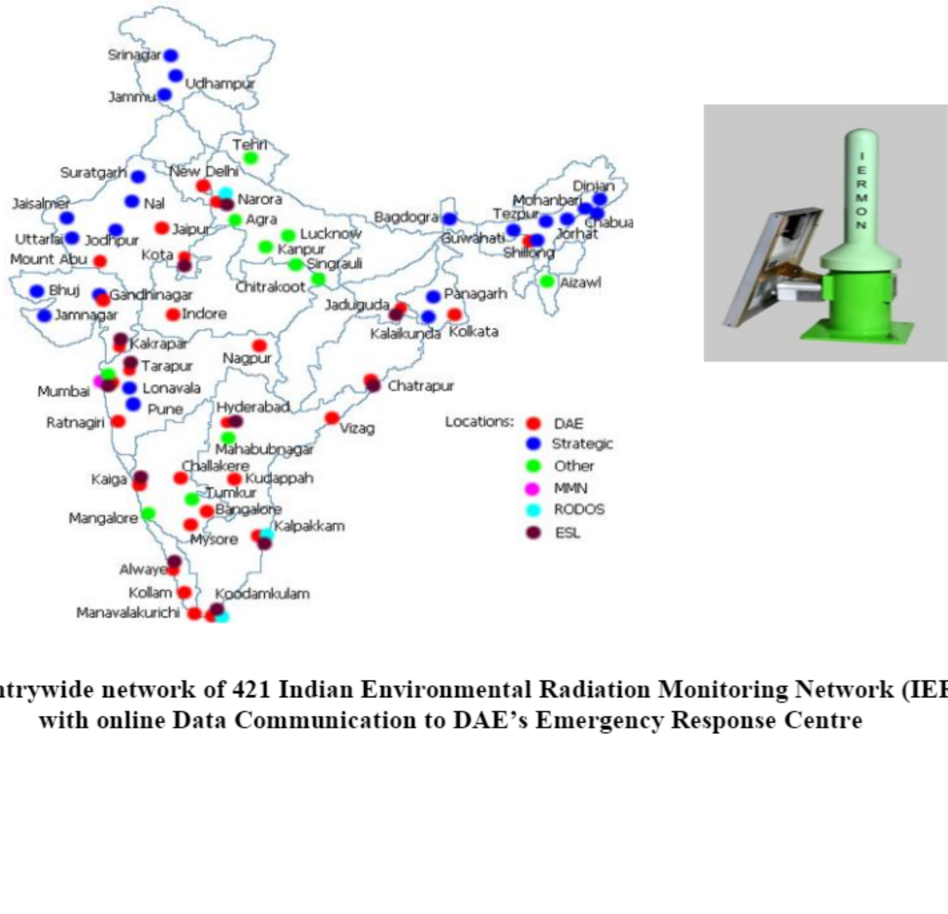

Fig-4: Countrywide network of 421 Indian Environmental Radiation Monitoring Network (IERMON) with online Data Communication to DAE's Emergency Response Centre

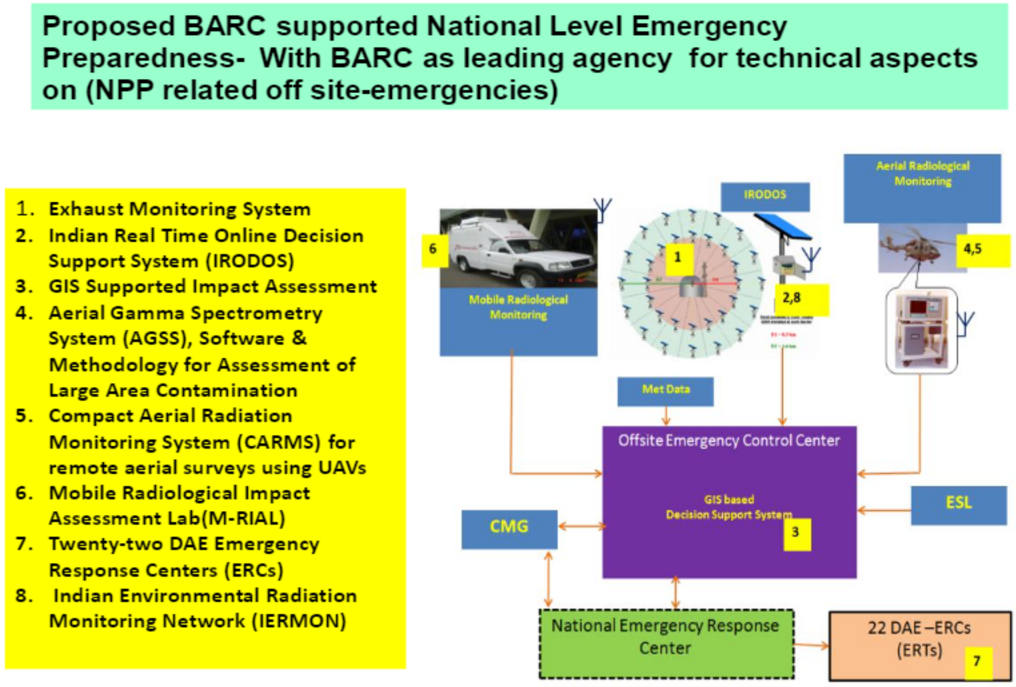

Fig-5: Systems and Monitoring Methodology for prevention and response to Nuclear Emergencies

IV RADIOLOGICAL IMPACT FROM FUKUSHIMA ACCIDENT AND THE PUBLIC CONCERN

A massive earthquake and the subsequent Tsunami created disaster in Japan in March 2011, killing thousands of persons, making large number of people homeless as well as huge economic loss to Japan. The impact of the Tsunami with level of water crossing 14 m height was felt very seriously at NPPsat Fukushima compared to other reactor sites. It led to failure of electric power (extended station blackout), failure in the removal of decay heat and subsequent release of radioactivity to environment from 4NPPs at Fukushina, Dai-ichi. Though the nuclear emergency has not led to lethal radiation exposure to anyone including the emergency workers, Japan had to implement emergency countermeasures including evacuation, sheltering and control over the consumption of food products etc.

The assessed radiation exposure to member of public from releases at NPPs at Fukushima is not significant enough to generate any radiation injury. Immediately after the nuclear accident, Japan government got prepared for Iodine prophylaxis (to protect persons from intake of radio Iodine) and evacuated people as a matter of precaution to respect the psychological issues which are sure to follow later. Based on the lessons learnt from the large number of radiological accidents (including 'Mayapuri radiological emergency at Delhi' where exaggeration lead to spread of 'fear of the unknown' and radiation phobia even in qualified persons) and nuclear accidents like Chernobyl and Fukushima, it is to be understood that even for very small level radiation exposure, many may believe that they are all affected. There are cases where even friends/ doctors believed that they should not touch / shake hands with the persons exposed to radiation. As demonstrated after Chernobyl accident, large number of pregnant woman in Europe, were worried of deformed births and wentfor abortion, even when they were assured by the authority that they had not received significant radiation exposure from Chernobyl fallout cause. Even after 25 years of the accident, no increase is detected so far in leukaemia, congenital abnormalities, adverse pregnancy outcome or any other radiation induced disease at Chernobyl or anywhere in the world (though increase in carcinoma of the thyroid was reported for very high intake of radio-Iodine by children UNSCEAR, 2015).

V COMPARISON OF NUCLEAR EXPLOSION AND NUCLEAR REACTOR ACCIDENT

On many occasions, it is found that nuclear emergency due to nuclear reactor accidents are compared to nuclear disaster due to nuclear explosion. It is highly unlikely for a nuclear reactor to explode like an atomic bomb and in a nuclear explosion the immediate damage and casualties are caused by blast (35%) and thermal effects (50%), which is absent in a reactor accident. Even if the highly unlikely event of reactor explosion occurs, most of the blast and thermal energies will be absorbed by the reactor containment itself. The radiation field due to reactor accident will depend upon the type of fuel and the burn-up of the fuel.In case of nuclear explosion, as the mushroom (radioactive cloud) rises to a height of 8-10 km depending upon yield, the impact of fallout is at very large distances which is not so in case of a reactor accident.

Another myth people believe that are actor can explode like a nuclear bomb (Hiroshima) and create the same level of damage. While a nuclear explosion above the surface release all the radioactivity generated by the fission, even in Chernobyl, a large amount of radioactivity was retained as a matrix and did not get released to environment.

In India, we have emergency preparedness for nuclear and radiological emergencies which include nuclear accidents and radiological accidents that could affect public domain. Various radiation emergency scenarios are identified and preparedness for response is strengthened based on the potential threat including malicious acts involving use of radioactive materials. In addition to Department of Atomic Energy (DAE's) expert emergency response teams at the 23 DAE-Emergency Response Centres established in the country over the last few years, National Disaster Response Force (NDRF) teams of NDMA are also being trained in radiological emergency response.

VI LESSONS FROM RADIATION EMERGENCIES

News related to radiation generates curiosity and concern whether it is related to environmental release of radioactivity or due to suspected presence of a radioactive material in public domain. As demonstrated after the nuclear accidents at Three Mile Island (TMI), Chernobyl and Fukushima as well as during and after radiological emergencies at Goinaia, Tammiku, Liloreported from world over and from Mayapuri, India, the number of people believing they are affected or will be affected by radiation or contamination is found as extremely large in comparison to those actually affected. During such occasions, the response personnel find it difficult to match with the requirement of monitoring and implementation of countermeasures in anticipation of worsening emergency scenario.

Hiroshima and Nagasaki nuclear explosion created the fear factor among the public of the radiation, its effects, possible radioactive fallout and contamination of wide area. The data from Japan, from the large number of persons affected by the radiation exposure, helped in the generation of the risk factors by ICRP, the conservatively used Linear No Threshold (LNT) concept for large collective dose scenario creates lot of misconception and fear among the society to that extent that the loss due to Tsunami in Japan is forgotten compared to relatively insignificant radiological consequences from Fukushima. Even though there was widespread radioactive contamination in Japan, the radiation exposure to public due to Fukushima accident is not expected to produce any harmful health effect. Except thyroid cancer, actual number of Cancers so far detected among public and attributable to radiation exposure are almost nil even 28 years after Chernobyl accident.

Radioactivity releases into the atmosphere from NPPs at Fukushima was detected over Japan, US and even in Europe due to the highly sensitive radiation detectors, gave a false impression that the radiological impact from these releases is wide spread and is very significant. Though the inventory of radioactivity for the 4 Units of NPPs at Fukushima-Dalichi which got into serious accident were much higher than the Chernobyl reactor whose core was melted and did not have a proper containment, deposited activity on land is significantly smaller in comparison to Chernobyl.

Since radiation cannot be seen or smelt following any radiation incidents/accidents, rumours can create panic till radiological monitoring is carried out to assess the actual status to remove the 'fear factor'. Those who are not affected but believing 'as affected' will be many folds (examples: Mayapuri, Goiania, Fukushima, Chernobyl). The case study of nuclear emergency at Fukushima has demonstrated that though the reactors have undergone significant damage, the radiologicalexposure in public domainis not very high. The release from the facilities have not lead to any dangerous level of environmental contamination, though fission products like Cesium-137 and Iodine-131had reached thousands of km from the NPPs.

VII CHALLENGES FROM ORPHAN SOURCES

World over millions of radiation sources are in use/ available, wherein majority of sources are relatively harmless. Considering the large number of sources reported as missing and many 'orphan sources' (Gonzalez, 1999) detected in public domain, prevention of illegal trafficking of radioactive sources are to be given top priority to prevent radiological emergencies.

Wide use of radioactive materials in industry, agriculture, power- generation, medicine, research and possibility of terrorism has increased the potentiality of radiological emergencies. During the last 50 years, 400 accidents are reported from which led to more than 3000 persons injured and 120 fatalities including the 28 victims from the Chernobyl accident. Though the WTC attack led to the strong belief over the terrorists intentions, concern over the malicious use of radioactive sources by terrorist groups to deliberately make societal havoc was expressed in many international platform even before. The likelihood of the use of radioactive sources as Radiological Dispersal Device (RDDs)(ICRP, 2005, FEMA, 2010) is much higher compared to the use of an improvised Nuclear Device(Brooke, 2010) or the attack on a Nuclear Power Plant. Usage of an RDD may trigger panic out of proportion of actual risk to human health and safety. The possibility that terrorists may try to use radioactive materials requires that public officials, emergency services, and medical facilities be prepared to identify and cope with a potentially wide range of problems.

Table-1
Major Radiological Accidents and Health Consequences
(Compiled from IAEA reports)

Country	Source	Source Strength (TBq)	Health consequences
Istanbul	Co-60	23.5	Severe injury–life threatening
SamutPrakarn	Co-60	15	3 deaths
Tammiku	Cs-137	7.4	1 death
Goiania	Cs-137	50	4 deaths
Lilo	Cs-137	0.164	Severe injury
Lilo	Cs-137	0.126	Severe injury
Yanango	Ir-192	1.37	Severe injury–life threatening
Gilan	Ir-192	0.185	Severe injury
Morocco	Ir-192	1.2	8 deaths
Georgia(RTGs)	Sr-90	~1000	Severe injury–life threatening
Mayapuri(Delhi)	Co-60	0.74	1 Death

Approximately 86,000 atomic bomb survivors in Japan had a 5.4% increase in cancer mortality in 40 years; but 10,000 irradiated residents in Taiwan had a 97% decrease in cancer mortality. Radiation Exposure In Taiwan (The true health effects of radiation,Luan YC, et al.) was caused due to ^{60}Co-source inadvertently mixed in metal scrap, melted and drawn into steel bars which were used in the construction of 1700 apartments for about 10,000 residents in 1982-84.Residents were irradiated at least for 9 years, some up to 20 years. Annual dose in the first year 1983 was from about 50 - 600 mSv/y. Total averaged dose started at 0.4 Sv - 6 Sv. Based on the analysis of exposure cases and the effects observed the conclusions arrived by the scientific community are

(a) chronic radiation exposure may actually be beneficial to humans,

(b) lower incidence of cancers compared to that expected,

(c) lower incidence of congenital anomalies compared to that expected.

Based on the concern of the public and possible nuclear and radiological emergency scenario, national level emergency preparedness (Pradeep kumar, 2008, IAEA, 2007, IAEA,2011) is upgraded:

(a) For immediate assessment of any suspected large area radioactive contamination

(b) For the search of lost sources or suspected stolen sources,

(c) Monitoring of large number of persons, who believe they are contaminated

(d) Monitoring of large number of environmental samples suspected of radioactive contamination

(e) Requirement to large number of Emergency Response teams, monitoring and protective equipment, First Responders etc

(f) State of the art radiation detection and assessment systems and methodology

(g) Network of Radiation Emergency Response Centres with DAE and Government organizations

(h) Public awareness for Common man and media

(i) Medical management of victims of Nuclear and Radiological emergencies.

The existing DAE-ERCs and the DAE's Emergency Response Teams have carried out many radiological response activities independently and collectively during suspected radioactive material in public domain, search of sources(Chatterjee, 2008), aerial survey exercises and prevention and response to radiological emergencies during Commonwealth Games.

VIII CONCLUSIONS

Nuclear accidents like Chernobyl and Fukushima,though had led to release of large quantityof radioactivity to the environment, the harmful health effects in member of public is found to be extremely small, except it generated unimaginable trauma among the public. During any radiation related emergencies, in the absence of adequate awareness,number of people who may believe they are affected by the exposure to ionizing radiation and may live with a fear of getting cancer can be extremely largein comparison to the possible victims.This is mainly due to the belief that any level of exposure to radiation is harmful, and that the effects of high doses of radiation can be extrapolated to low doses of radiation based on LNT model, though below 100mSv of radiation dose there is no scientific observation support it.

It is observed internationally that challenges from orphan sources are on increase. Hence storage, transportationand usage of radioactive sources requires strict administrative control to ensure safety and security of the sources to prevent inadvertent exposure due to radiological emergencies or by malicious acts leading to radiation injuries.

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