New Frontiers for Cleaning Up Nuclear Contamination: Phytoremediation

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Abstract

It seems like nuclear energy has been ephemeral yet, but the ideas about releasing energy which atoms hold inside dates back to earlier. Before Einstein, many people had carried out research in many different ways about atomic energy, but the thing is, they did not actually know what to do with that kind of tremendous power. Regarding the upswing of population around the world, discovering new ways of gaining bigger and cheaper energy is in many governments' agenda. Nowadays, sustainable energies such as solar, wind, biomass etc. are more popular, but nuclear power once had bigger reputation across the world. Nuclear power seems to be the most effective, clever and strong source for generating sufficient energy to keep up with our increasing consumption, but there are indelible marks on human history resulted from using that power in wars and plants unconsciously. Were we to use nuclear energy in various ways, we must calculate and try to foresee the possible consequences before all our plans, and no matter how we design safe plant to generate, we must take some measures in case of any failure. The nightmare scenario is an explosion in a nuclear plant, as it would be too difficult to clean up environment from radioactive molecules. Some recent research indicates that phytoremedial plants could be a solution to radioactive contamination. This is an eclectic study which includes a brief history of nuclear power, nuclear disasters and phytoremediation ways to cleanup environment after a possible contamination.

Keywords: *Nuclear energy, nuclear pollution, phytoremediation.*

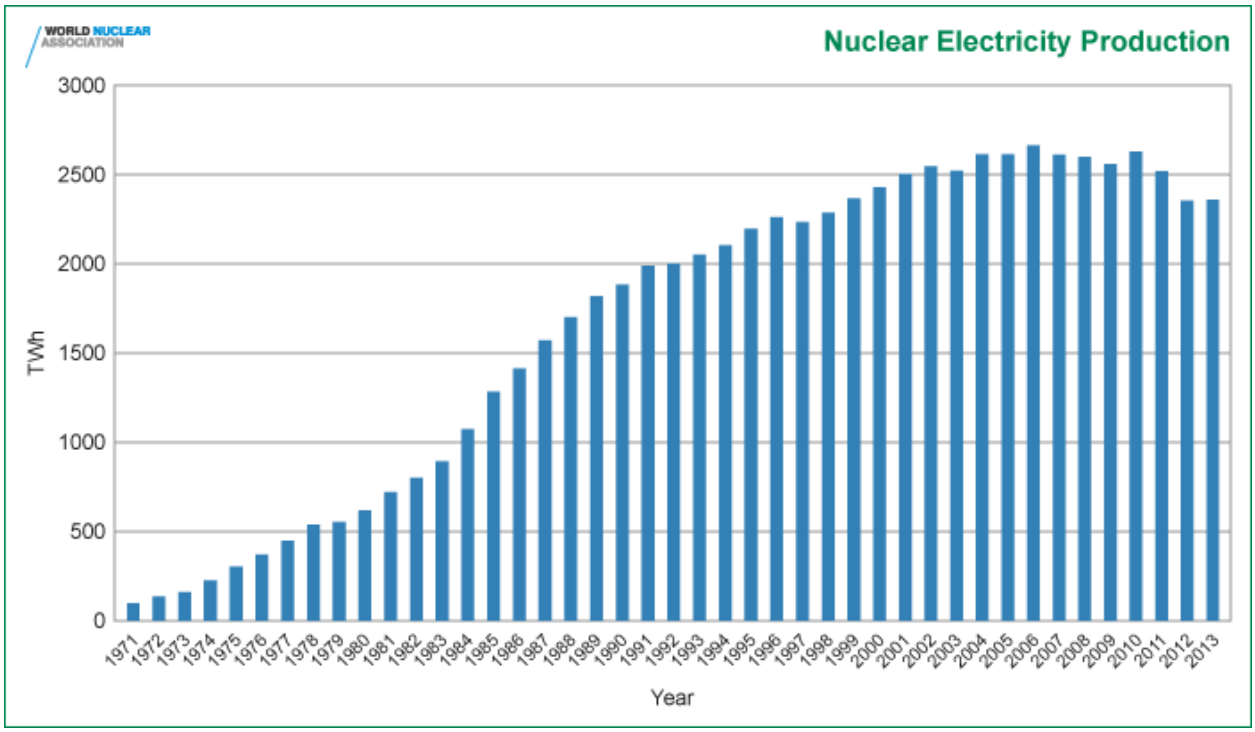
INTRODUCTION

Current trends in energy supply and use are unsustainable. Without decisive action, energy related emissions of carbon dioxide will nearly double by 2050 and increased fossil energy demand will heighten concerns over the security of supplies. We can change our current path, but this will take an energy revolution in which low carbon energy technologies will have a crucial role to play. Energy efficiency, many types of renewable energy, carbon capture and storage, nuclear power and new transport technologies will all require widespread deployment if we are to sharply reduce greenhouse gas (GHG) emissions. Every major country and sector of the economy would need to be involved. The task is urgent if we are to make sure that investment decisions taken now do not saddle us with sub-optimal technologies in the long term (Anonymous, 2015 a).

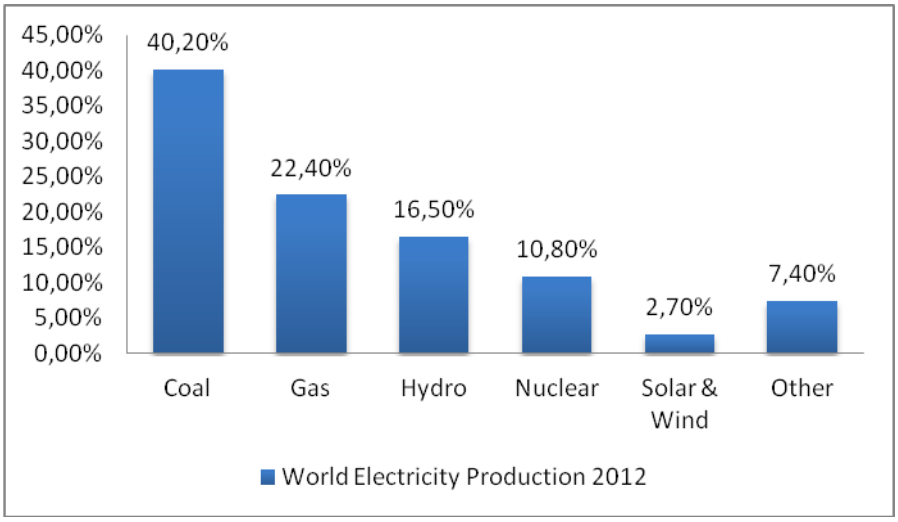
Nuclear technology uses the energy released by splitting the atoms of certain elements. It was first developed in the 1940s, and during the Second World War to 1945 research initially focussed on producing bombs by splitting the atoms of particular isotopes of either uranium or plutonium. In the 1950s attention turned to the peaceful purposes of nuclear fission, notably for power generation. Today, the world produces as much electricity from nuclear energy as it did from all sources combined in the early years of nuclear power. Civil nuclear power can now boast over 16,000 reactor years of experience and supplies almost 11.5% of global electricity needs, from reactors in 31 countries. In fact, through regional grids, many more than those countries depend on nuclear-generated power (Anonymous, 2015 b).

The first commercial nuclear power stations started operation in the 1950s. There are over 435 commercial nuclear power reactors operable in 31 countries, with over 375,000 MWe of total capacity. About 70 more reactors are under construction. They provide over 11% of the world's electricity as continuous, reliable base-load power, without carbon dioxide emissions. 56 countries operate a total of about 240 research reactors and a further 180 nuclear reactors power some 140 ships and submarines (Anonymous, 2015 b).

Today, only eight countries are known to have a nuclear weapons capability. By contrast, 56 operate about 240 civil research reactors, over one thrid of these in developing countries. Now 31 countries host 437 commercial nuclear power reactors with a total installed capacity of over 375,000 MWe. This is more than three times the total generating capacity of France or Germany from all sources. About 70 further nuclear power reactors are under construction, equivalent to 20% of existing capacity, while over 160 are firmly planned, equivalent to half of present capacity (Anonymous, 2015 b).



Graph 1: Electricity generating by nuclear plants between 1971 and 2013 (Anonymous, 2015 b).



Graph 2: World electricity production according to sources (Anonymous, 2015 b).

Sixteen countries depend on nuclear power for at least a quarter of their electricity. France gets around three-quarters of its power from nuclear energy, while Belgium, Czech Republic, Finland, Hungary, Slovakia, Sweden, Switzerland, Slovenia and Ukraine get one-third or more. South Korea and Bulgaria normally get more than 30% of their power from nuclear energy, while in the USA, UK, Spain, Romania and Russia almost one-fifth is from nuclear. Japan is used to relying on nuclear power for more than one-quarter of its electricity and is expected to return to that level. Among countries which do not host nuclear power plants, Italy and Denmark get almost 10% of their power from nuclear (Anonymous, 2015 b).

A BRIEF HISTORY OF NUCLEAR ENERGY

From the discovery of radiation to nuclear weapons and power plants, a concise history is given below as milestones throughout history (Anonymous, 2015 c):

- 1895, Roentgen discovers X-rays
- 1896, Becquerel discovers rays emitted spontaneously from uranium salts
- 1898, The Curies identify 2 radioactive nuclides, coin term "radioactive"
- 1899, Rutherford distinguishes alpha and beta radiation and discovers half-life
- 1909, Rutherford discovers that most mass is concentrated in a small nucleus
- 1920, Rutherford theorizes a "neutron"
- 1935, Chadwick identifies neutrons
- 1938, Hann and Strassman split uranium atoms with neutrons, Meitner and Frisch explain what's happening and name it "fission"
- 1939, Fermi and Szilard measure neutron multiplication, conclude that a nuclear chain reaction is possible
- 1939, Szilard, Wigner, and Teller convince Einstein to sign a letter warning Roosevelt of possibility of nuclear weapons
- 1939, Roosevelt authorizes creation of Advisory Committee on Uranium, begins US nuclear bomb effort (though not vigorously)
- 1942, Fermi achieves first nuclear chain reaction in a squash court at U. of Chicago. Manhattan project in full swing. Secret cities are built in Oak Ridge TN (to enrich uranium), Hanford WA (to produce plutonium), and Los Alamos NM (to design and assemble bomb)
- July 1945, The world's first nuclear weapon test, the Trinity shot, is successful
- Aug 6 & 9, 1945, Atomic bombs Little Boy and Fat Man dropped on Japanese cities, Hiroshima and Nagasaki. Up to 240,000 people died.
- Aug 15, 1945, Japan surrenders unconditionally, ending WWII
- 1951, EBR-1 reactor is the first to generate electricity in Arco, ID
- 1953, Eisenhower gives Atoms for Peace speech, launching civilian program
- 1954, Obninsk reactor in the Soviet Union becomes the first commercial nuclear power plant
- 1954, USS Nautilus launches, the first nuclear-powered submarine
- 1957, Shippingport reactor begins operation, first commercial nuclear power
- 1974, French Prime Minister Messmer launches huge nuclear power program in response to oil crisis. In 2004, 75% of France's electricity is nuclear
- 1979, Three Mile Island reactor suffers a partial meltdown. Radiation largely contained
- 1986, Chernobyl reactor suffers a large power excursion resulting in the release of large amounts of radiation. 50+ fire-fighters die, up to 4000 civilians estimated to die of early cancer
- 1986, EBR-II reactor demonstrates that advanced, sodium cooled reactors can passively shut down without backup systems
- 1994, Megatons to Megawatts program started, turns 20,000 nuclear weapons into electricity. By 2000, ~10% of US electricity comes from dismantled Russian warheads
- 2004, After decades of electricity generation with no deaths in the US, a Nuclear Renaissance discussed, with talks of more reactor builds to offset carbon emissions
- 2011, 4 reactors at Fukushima Daiichi lose backup generators due to tsunami and suffer core meltdowns, hydrogen explosions. Radiation release estimated 10-30% of Chernobyl. Zero people's health affected by dose, but land is evacuated
- 2013, Climate guru James Hansen publishes paper claiming nuclear has saved 1.8 million lives total (including worst-case estimates for all accidents) by offsetting air-pollution related deaths
- 2013, Voyager I enters interstellar space after travelling the solar system for 36 years. It is powered by a Plutonium-238 radioisotopic thermal generator

The most dangerous and arguable thing about nuclear power is radioactive contamination and adverse effects on living things. Regardless there are many pros and cons of nuclear power, big nuclear disasters have happened so far and they cannot be overlooked.

The long term effects of nuclear disasters can often spread over thousands of years. It is estimated that Chernobyl will not be inhabited for at least another 20,000 years. With 437 Nuclear Power Plants worldwide, there are bound to be incidents every now and again. Small incidents occur and can be rectified, but when there are large incidents, the impact can often be catastrophic (Anonymous, 2015 d).

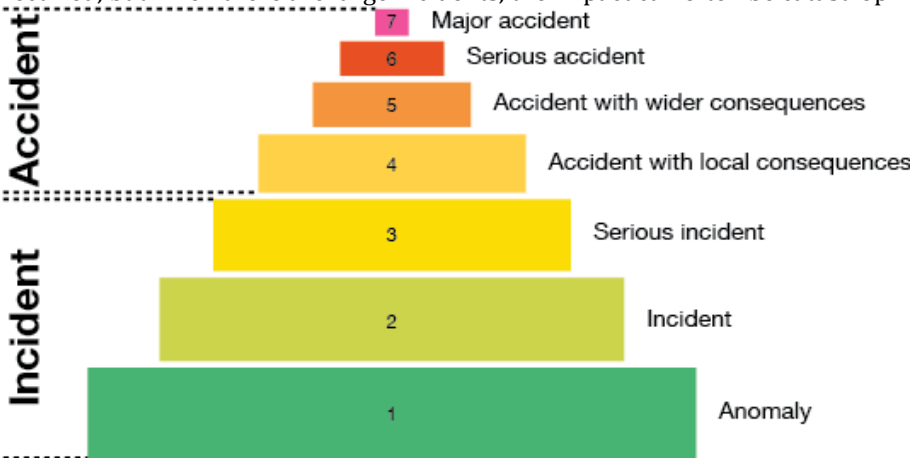


Figure 1: The International Nuclear and Radiological Event Scale (Anonymous, 2015 e).

Each nuclear disaster has been given a level on the International Nuclear Event Scale (INES). INES is a tool for promptly and consistently communicating to the public the safety significance of events associated with sources of ionizing radiation. INES uses a numerical rating to explain the significance of events associated with sources of ionizing radiation. Events are rated at seven levels as shown in Figure 1; Levels 1–3 are "incidents" and Levels 4–7 "accidents". The scale is designed such that the severity of an event is approximately ten times greater for each increase in level of the scale (Anonymous, 2015 e). According to INES, the worst nuclear disasters are given below (Anonymous, 2015 f):

- *Mayak or Kyshtym nuclear complex (Soviet Union): 29 September 1957***:** A fault in the cooling system at the nuclear complex, near Chelyabinsk, results in a chemical explosion and the release of an estimated 70 to 80 tonnes of radioactive materials into the air. Thousands of people are exposed to radiation and thousands more are evacuated from their homes. It is categorised as Level 6 on the seven-point International Nuclear Events Scale (INES).
- *Windscale nuclear reactor (UK): 7 October 1957***:** A fire in the graphite-core reactor, in Cumbria, results in a limited release of radioactivity (INES Level 5). The sale of milk from nearby farms is banned for a month. The reactor cannot be salvaged and is buried in concrete. A second reactor on the site is also shut down and the site decontaminated. Subsequently part of the site is renamed Sellafield and new nuclear reactors are built.
- *Idaho National Engineering Laboratory (USA): 3 January 1961***:** A steam explosion in reactor SL-1 during preparation for start-up destroys the small US Army experimental reactor and kills three operators.
- *Three Mile Island power plant, Pennsylvania (US): 29 March 1979***:** A cooling malfunction causes a partial meltdown in one reactor, resulting in a limited release of radioactivity (INES Level 5). The site's first reactor (TMI One) on the Susquehanna river was closed for refuelling. The second was at full capacity when two malfunctions occurred: first there was a release of radioactive water, and then radioactive gas was detected on the perimeter. No deaths or injuries were reported. It is considered the United States' worst nuclear accident and led to major safety changes in the industry.
- *Chernobyl power plant (Soviet Union): 26 April 1986***:** One of four reactors explodes after an experiment at the power plant (INES Level 7). The resulting fire burns for nine days and at least 100 times more radiation than the atom bombs dropped on Nagasaki and Hiroshima is released into the air. Radioactive deposits are found in nearly every country in the northern hemisphere. Two people die in the explosion and another 28 from acute radiation sickness in the immediate aftermath. Some experts predict thousands of extra cancer deaths as a result of the disaster. A huge cover, known as the New Safe Confinement, is being built over the existing sarcophagus. It is expected to cover the site by 2013.
- *Severesk, formerly Tomsk-7 (Russia): 6 April 1993***:** A tank at a uranium and plutonium factory inside the plant explodes, resulting in radioactivity being dispersed into the atmosphere contaminating an area of over 120 sq km (INES Level 4). A number of villages are evacuated and left permanently uninhabitable.
- *Tokaimura nuclear fuel processing facility (Japan): 30 September 1999***:** Workers break safety regulations by mixing dangerously large amounts of treated uranium in metal buckets, setting off a nuclear reaction (INES Level 4). Two of the workers later die from their injuries, and more than 40

others are treated for exposure to high levels of radiation. Hundreds of residents living nearby were evacuated from their homes while the nuclear reaction continued, but were allowed home two days later.

- *Mihama power plant (Japan): 9 August 2004*: Five people die in an accident at the plant in the Fukui province (INES Level 1). Seven people are also injured when hot water and steam leaks from a broken pipe. Officials insist that no radiation leaked from the plant, and there is no danger to the surrounding area.
- *Fukushima Daiichi power plant (Japan): 11 March 2011*: A powerful tsunami generated by a magnitude-9.0 earthquake out at sea slams into the Fukushima Daiichi nuclear power plant, damaging four of six reactors at the site. A series of fires are set off, after cooling systems fail. Venting hydrogen gas from the reactors causes explosions, forcing engineers to use seawater in an effort to cool overheating reactor cores. Originally classified as INES Level 5, the severity was raised to INES Level 7 on 12 April 2011 when a new estimate suggested higher levels of radiation than previously thought had leaked from the plant. Despite the classification, the incident is said to be much less severe than Chernobyl, and officials insist there is only a minimal risk to public health.
- *Macoule nuclear site (France), 12 September 2011*: One person is killed and four are injured - one with serious burns - after an explosion in a furnace used to melt down nuclear waste and recycle it for energy. No radiation leaks or damage to the plant are detected.

RADIOACTIVE CLEAN-UP

Radioactive contamination, also called radiological contamination, is the deposition of, or presence of radioactive substances on surfaces or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable (Anonymous, 2015 g).

Such contamination presents a hazard because of the radioactive decay of the contaminants, which emit harmful ionising radiation such as alpha particles or beta particles, gamma rays or neutrons. The degree of hazard is determined by the concentration of the contaminants, the energy of the radiation being emitted, the type of radiation, and the proximity of the contamination to organs of the body. It is important to be clear that the contamination gives rise to the radiation hazard, and the terms "radiation" and "contamination" are not interchangeable. Contamination may affect a person, a place, an animal, or an object such as clothing. Following an atmospheric nuclear weapon discharge or a nuclear reactor containment breach, the air, soil, people, plants, and animals in the vicinity will become contaminated by nuclear fuel and fission products. Cases of widespread radioactive contamination include the Bikini Atoll, the Rocky Flats Plant in Colorado, the Fukushima Daiichi nuclear disaster, the Chernobyl disaster, and the area around the Mayak facility in Russia (Anonymous, 2015 h).

Radioactive, nuclear, or radiation clean-up is considered as the most dangerous, difficult, and costly remediation activity after a nuclear disaster or accident. The contamination may be found in the air, water, and soil, as wells as equipment and buildings. Radioactive material is unstable, while the nuclei of radioactive atoms emit *ionizing radiation (i.e., alpha particles, beta particles* and *gamma rays*). Under certain circumstances, any of the three can harm humans, stealing electrons from *atoms* and destroying chemical bonds (Atteberry, 2011). Unlike alpha and beta particles, however, gamma rays can pass directly through the body, wreaking havoc in the process and faulty attempts by the body to repair that damage can lead to cancerous cells (Atteberry, 2011). Scientists and engineers are still studying the process and the period of treating the environment contaminated with radioactive materials.

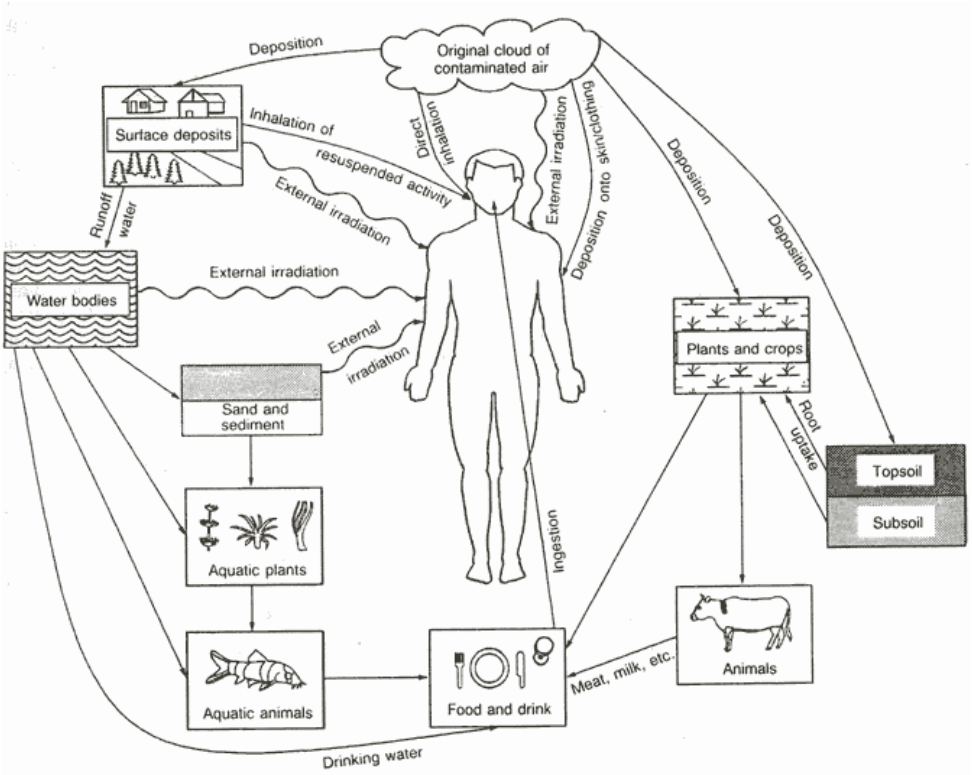


Figure 2: Main environmental pathways of human radiation exposure (Anonymous, 2015 i).

Cleaning up contamination results in radioactive waste unless the radioactive material can be returned to commercial use by reprocessing. In some cases of large areas of contamination, the contamination may be mitigated by burying and covering the contaminated substances with concrete, soil, or rock to prevent further spread of the contamination to the environment. If a person's body is contaminated by ingestion or by injury and standard cleaning cannot reduce the contamination further, then the person may be permanently contaminated. The complexity of the situations resulting from widespread and long-term contamination inevitably generates concerns and anxiety among the affected populations, who could feel helpless. If the experts and professionals in charge of managing the situations use scientific terms, measurement units, and technical procedures, which are difficult to understand by non-specialists, these could contribute to reinforce their feeling of loss of control of the situation. A commonly observed consequence is the progressive renouncement of individuals to involve themselves in the day-to-day management of such complex situations, and their confrontation with a multitude of questions, which usually remain unanswered. What are the long-term effects of radioactivity on health? Is it possible to protect oneself from the contamination? As a result, inhabitants of contaminated areas often face difficult personal choices concerning their future, and are particularly confronted by the dilemma of whether to leave the place or to stay. Experience shows that it is difficult to answer this dilemma solely on the basis of radiation protection considerations. Many personal aspects enter into the balance; people living in contaminated areas are generally very reluctant to leave their homes, and hope to improve their living conditions. This calls for authorities to not only develop protection actions but also to favour initiatives to enhance the quality of life of the residents of the areas (Anonymous, 2015 j).

Past experience of long-term contamination has also shown that, in the absence of good knowledge of the radiological situation, affected populations tend to adopt a denial or fatalist attitude. This is a way to further support the situation, which generally results in basic radiation protection advice and actions being neglected, and in increasing exposures. It is the responsibility of the authorities (both national and local) to create the conditions and provide the means favouring the involvement and empowerment of the population. This must be done taking local social and economic living conditions into account to provide individuals with information, thus allowing them to understand and assess their personal situation and to

maintain vigilance with the objective to improve their daily life and to protect themselves and their offspring for the future. The aim of the authorities should be to help individuals to regain control of their lives, in which radiation protection against the existing contamination is a factor to add to several other factors affecting the rehabilitation of living conditions (Anonymous, 2015 j).
In a situation of long-term contamination, it is essential to establish a radiation monitoring system allowing follow-up of the radiological situation and the implementation of adequate protection strategies. The key objective of monitoring systems is to assess current levels of human exposure (both external and internal) and environmental levels of contamination, and to allow the prediction of their evolution in the future. In practice, this supposes a radiation monitoring system providing measurements of ambient dose rates, concentrations of radionuclides in foodstuffs and the environment, and whole-body contamination of individuals. Following a nuclear accident or a radiation emergency, the exposed population should have had an initial medical evaluation. The first step of this evaluation is a census of the affected individuals, possibly with an early dose assessment. In addition, regardless of the level of dose, the affected population should also have been supplied with accurate and appropriate information regarding their level of exposure and potential type of risk (Anonymous, 2015 j).

WHAT IS PHYTOREMEDIATION?

Phytoremediation is an emerging technology that uses various plants to degrade, extract, contain, or immobilize contaminants from soil and water. This technology has been receiving attention lately as an innovative, cost-effective alternative to the more established treatment methods used at hazardous waste sites. The term phytoremediation (phyto = plant and remediation = correct evil) is relatively new, coined in 1991. Basic information for what is now called phytoremediation comes from a variety of research areas including constructed wetlands, oil spills, and agricultural plant accumulation of heavy metals. The term has been used widely since its inception, with a variety of specific meanings. In this document phytoremediation is used to mean the overall idea of using plant-based environmental technologies, not any specific application (Anonymous, 2015 k).
As a result of the early information provided by some research and reported by the media, site owners and citizen groups are interested in phytoremediation as possibly the cleanest and cheapest technology that may be employed in the remediation of selected hazardous sites. Although current research continues to explore and push the boundaries of phytoremediation applications, there are certain limitations to plant-based remediation systems. Although some forms of phytoremediation involve accumulation of metals and require handling of plant material embedded with metals, most plants do not accumulate significant levels of organic contaminants. While metal accumulating plants will need to be harvested and either recycled or disposed of in compliance with applicable regulations, most phytoremediative plants do not require further treatment or disposal (Anonymous, 2015 k).
Most published phytoremediation pilot studies have utilized a block design, with a first-level assessment of all possible combinations of several key factors (e.g., several plant species/several pH levels/several chelators). A second series of tests could then evaluate the best combination of first-level factors (e.g., the best combination of plant/ pH/chelator) for another set of factors (e.g., plant-tolerated level of contaminant and rate of cleanup). Such an experimental design allows for the efficient use of time and funds, with assessment of multiple factors concurrently. Information can be collected on interactions between factors affecting phytoremediation, and an optimal field phytoremediation plan can be developed. Informations needed for a pilot treatability study are (Anonymous, 2015 k):

- Identification of contaminant(s)
- Level (concentration) of contaminant(s)
- pH
- Average monthly temperature, plus expected maximum and minimum temperatures
- Soil nutrient levels (P, K, N) and organic matter levels
- Average monthly rainfall
- Grade on site
- Aesthetic considerations (proximity to commercial or residential properties or recreational areas)
- Daily illumination
- Average relative humidity
- Wind patterns (prevailing direction and velocity)
- Presence of growth-suppressing contaminants

CONTAMINANTS CAN BE REMOVED BY PHYTOREMEDIATION

Heavy metals: Constituents amenable to phytoremediation include heavy metals like lead, cadmium, copper, nickel, zinc and chromium. Indian mustard (*Brassica juncea*) and water milfoil (*Myriophyllum spicatum*) are experimented on cleaning up those heavy metals from soil and water, and conclusions were successful. Most of the experiments carried out between 1995 and 1997 (Anonymous, 2015 k).
Radionuclides:

- Uranium: U was studied using sunflowers (*Helianthus annuus* L.) in bench-scale and pilot-scale engineered systems (Dushenkov et al. 1997).
- Concentration = 56 g/L, reduced by >95% in 24 hours.
- Concentration = 600 g/L, to 63 g/L in 1 hour; then down to 10 g/L after 48 hours.
- Concentration = several hundred g/L, went to below regulatory goal of 20 g/L.
- Concentration > 1,000 g/L, could not reach 20 g/L goal; went down to 40 to 70 g/L.

According to Huang et al. (1998), other plants used for removing uranium from soil and water are Amaranth (*Amaranth cruentus* L.), Indian mushroom (*Brassica juncea* - various cultivars), bush bean (*Phaseolus vulgaris* L.), Chinese cabbage (*Brassica chinensis* L.), Chinese mustard (*Brassica narinosa* L.), corn (*Zea mays*), cow pea (*Pisum sativum* L.), field pea (*Pisum sativum* L.), sunflower (*Helianthus annuus* L.), and winter wheat (*Triticum aestivum* L.). Amaranth, Indian mushroom, Chinese cabbage, and Chinese mustard had significant U concentration in shoots, when soil was treated with citric acid. Maximum shoot U concentrations were more than 5000 mg/kg. Different cultivars had significantly different accumulation of U. But for filtering water in order to get rid of uranium, sunflower is used mostly.

- Cesium: Cs was used with sunflowers in bench-scale and pilot-scale engineered systems (Dushenkov et al. 1997).
- Concentration = 200 g/L, decreased noticeably after 6 hours, then went below 3 g/L after 24 hours.
- Cs was accumulated in the roots of Indian mustard (*Brassica juncea*) in water concentrations of approximately 20 to 2,000 g/L, with bioaccumulation coefficients of 100 to 250 (Salt et al. 1997).

- Strontium: Sr was used with sunflowers (Dushenkov et al. 1997).
- Concentration = 200 g/L, went to 35 g/L within 48 hours, then down to 1 g/L by 96 hours.
- Sr was accumulated in the roots of Indian mustard (*Brassica juncea*) in water concentrations of approximately 20 to 2,000 g/L (Salt et al. 1997).

According to Dushenkov et al. (1997) and Salt et al. (1997), filtering strontium from ground water is being done best by sunflowers and Indian mustard. According to Entry et al. (1999), cleaning-up uranium from soil can be done with Bahia grass (*Paspalum notatum*), johnson grass (*Sorghum halpense*), switchgrass (*Panicum virgatum*).

The following are examples of plants used in rhizofiltration[1] systems:

- Terrestrial plants can be grown and used hydroponically in rhizofiltration systems. These plants generally have a greater biomass and longer, faster-growing root systems than aquatic plants (Dushenkov et al. 1995). Seedlings have been proposed for use instead of mature plants because seedings do not require light or nutrients for germination and growth for up to 2 weeks (Salt et al. 1997).
- Under hydroponic conditions, 5 dicots (broadleaf crops), 3 monocots (cereals), 11 cool season grasses, and 6 warm season grasses were each effective in accumulating Pb in their roots after three days of exposure to 300 mg/L Pb. The maximum lead concentration on a dry weight basis was 17% in a cool season grass (colonial bentgrass), and the minimum was 6% in a warm season grass (Japanese lawngrass). The dicot Indian mustard (*Brassica juncea*) was also effective in taking up other metals (Dushenkov et al. 1995).
- Sunflowers (*Helianthus annuus L.*) removed concentrated Cr6+, Mn, Cd, Ni, Cu, U, Pb, Zn, and Sr in laboratory greenhouse studies (Salt et al. 1995). Sunflowers also were more effective than Indian mustard (*Brassica juncea*) and bean (*Phaseolus coccineus*) in removing uranium. Bioaccumulation coefficients for uranium in the sunflowers were much higher for the roots than for the shoots (Dushenkov et al. 1997).
- At a field site in Chernobyl, Ukraine, sunflowers were grown for 4 to 8 weeks in a floating raft on a pond. Bioaccumulation results indicated that sunflowers could remove 137Cs and 90Sr from the pond.

[1] *Rhizofiltration*: A phytoremediation way to filter soil or water by their roots.

- Aquatic plants have been used in water treatment, but they are smaller and have smaller, slower-growing root systems than terrestrial plants (Dushenkov et al. 1995). Floating aquatic plants include water hyacinth (*Eichhornia crassipes*), pennyworth (*Hydrocotyle umbellata*), duckweed (*Lemna minor*), and water velvet (*Azolla pinnata*) (Salt et al. 1995).
- The floating aquatic plant water milfoil (*Myriophyllum spicatum*), at a biomass density of 0.02 kg/L, rapidly accumulated Ni, Cd, Cu, Zn, and Pb. The plant accumulated up to 0.5% Ni, 0.8% Cd, 1.3% Cu, 1.3% Zn, and 5.5% Pb by weight.
- Wetland plants can be used in engineered or constructed beds to take up or degrade contaminants. Hydroponically-grown plants concentrated Pb, Cr(VI), Cd, Ni, Zn, and Cu onto their roots from wastewater. Lead had the highest bioaccumulation coefficient, and zinc the lowest (Raskin et al. 1994).

RECOMMENDATIONS

Contamination of soil and water by radionuclides due to natural processes, global fall-out from nuclear weapon testing, discharges from nuclear installations, disposal of nuclear waste and occasional nuclear accidents (i.e. Chernobyl in 1986 and Fukushima in 2011), poses serious problems to biological systems (Eapen et al., 2006). Phytoremediation is the using of plants to remove hazardous contaminants from the environment. However,the seeking of inexpensive methods has led to develop new technologies based on the utilization of plant in biosorption of hazardous elements such as radioisotopes. This trend is a growing application in remediation studies due to its numerous advantages, such as environmental friendliness, cost-effectiveness and high abundance (Agunbiade et al., 2009).

There are 4 nuclear power plant projects waiting to be constructed in Turkey. Sinop and Akkuyu will be the first two power plants of Turkey, which will serve 60 years and will cost $ 20.000.000.000 for each. It is aimed to generate 80 billion kWh electricity in a year (Anonymous, 2015 l).

Past experiences about nuclear power plants and nuclear weapons demonstrate that there are many cons as much as pros of nuclear energy to living things. In case of any failure in working of nuclear power plants, there could be irreversible consequences for both environment and humans. It is crucial to block possible adverse effect before anything happens and some measures must be taken like phytoremediation. There could be zone planning around nuclear power plants to soak up radioactive elements in case of emergency and prevent environment from a fast release of energy. To do so, more and more experiments should be done on different species if they are capable to store hazardous atoms. Research have been carried out about cleaning-up radioactive contamination so far are mostly in cleaning-up soil and water after a disaster. There has been no example of any zoning system around nuclear power plants yet through phytoremediation before a disaster; therefore further research are needed about this topic.

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