© 2015 IJSRST | Volume 1 | Issue 4 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

A Review on Optimal Method of Nuclear Waste Management and Generation of Electricity from Nuclear Waste

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ABSTRACT

Today, Nuclear power-plants are vital and indispensable source of energy. But, the waste management and reprocessing of the wastes and the radiation hazards have been the matter of concern. This work provides a unique perspective on the progress of remediation, experience gained and issues that still need to be resolved particularly associated with management of the huge quantities of waste generated and also on Fukushima remediation it's status and overview of future plans. To make the best use of the nuclear energy, the wastes can be converted into electricity by using carbon nano tubes doped with the traces of silicon, can be used to convert the radiations like beta and gamma particles into electricity, using the principles of beta voltaic and photo voltaic effect. If this theoretical presumption is practically put into use, the nuclear power plants could generate additional power and reduces the cost of management and risks of radiations. This could generate electricity for a life time of about 30 to 40 years or even more.

Keywords : Hazards, Commercial Nuclear Reactors, Nuclear Power Plants

I. INTRODUCTION

In the context of global warming, nuclear energy is a carbon-free source of power and so is a meaningful option for energy production without CO2 emissions. Currently, there are more than 440 commercial nuclear reactors, accounting for about 15% of electric power generation in the world. The world's fleet of nuclear power plants is, on average, more than 20 years old. Even though the design life of a nuclear power plant is typically 30 or 40 years, it is quite feasible that many nuclear power plants will be able to operate for longer than this.

Effective waste management is another challenge for sustainable nuclear energy today; more precisely, a solution is needed for the management of high-level and long-lived intermediate-level radioactive waste over the very long term. Most nuclear countries are currently gathering the data needed to assess the feasibility of a deep geological waste repository, including the prediction of the behaviour of materials over several thousands of years.

II. NUCLEAR WASTE DISPOSAL

The generally accepted strategy for dealing with high-level nuclear waste (HLNW) is deep underground burial in stable geological formations. The purpose of the geological repository is to protect both man and the environment from the possible impact of radioactive waste by interposing various barriers capable of confining the radioactivity for several hundreds of thousands of years. These barriers include packages containing the waste, repository installations and the geological medium. The multi-barrier concept, which involves the use of several natural and/or engineered barriers to retard and/or to prevent the transport of radionuclides into the biosphere, is applied in all the geological repositories across the world. These issues have been already discussed, compared and explored with the corrosion community, which faces the challenge of predicting corrosion over millennia on a scientific and technical basis. The scientific and experimental approaches of various organizations worldwide have been compared to predict long-term corrosion phenomena.

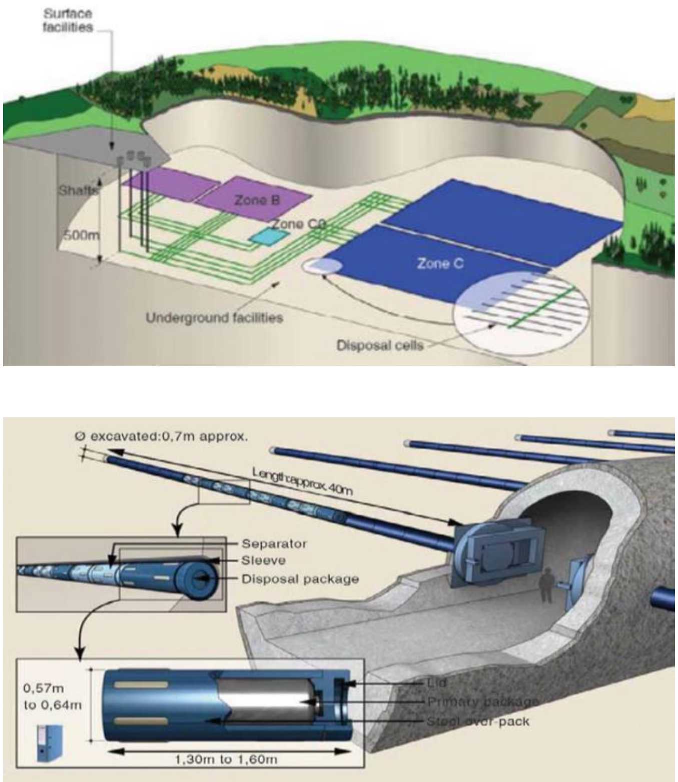

Figure 1 : French clay geological concept and schematic view of a vitrified disposal cells.

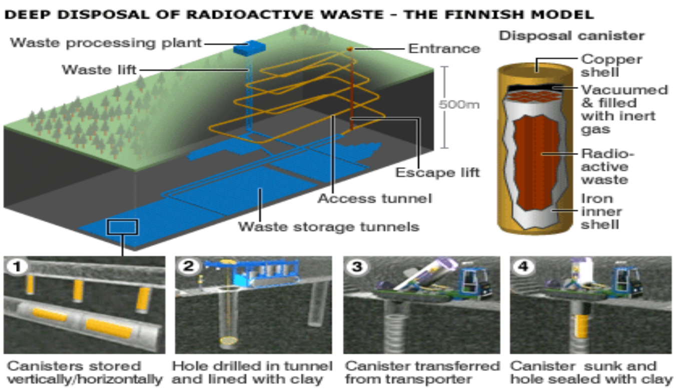

Figure 2 : existing method of nuclear waste disposal

III. WASTE MANAGEMENT CLASSIFICATION OF WASTES

Wastes generated by the clean-up process include “inert” contaminated solids, “reactive” and organic solids, water and fluids used for washing plus some equipment contaminated during the remediation process. It should be noted that for individual remediation processes, it is important to quantify the volumes of all such primary waste streams along with the average concentration of radio caesium within them as, within a holistic assessment, this allows their subsequent management to be optimised.

Liquid waste management was a key consideration for all washing actions and also for ponds and swimming pools: the limit for release into domestic drainage was 100 Bq l_1 for total radio-caesium and, above this level, treatment was required. Cleaning of surfaces avoiding use of fluids (dry-stripping of paint combined with HEPA air filtration, shot blasting, dry ice blasting) and minimising use of fluids by increasing efficiency (high pressure jet with recirculation of water; use of surfactants, micro-bubbles and ozonation) have been tested at the demonstration sites and supporting lab studies For dissolved Cs, removal by selective ion exchange is well established and approaches using both ferric ferro-cyanide and zeolites were used. These were combined with filtration to remove particulates when required (although filtration was generally found to be sufficient).

IV. WASTE VOLUME REDUCTION

For solid wastes, volume reduction was also implemented wherever practical. For trees, high pressure washing was an option but, for most other vegetation, cutting, trimming or uprooting was found to be the most effective method for reducing dose. For foliage, in particular, significant volume reduction was achieved by mechanical shredding/chipping, and was implemented at several of the demonstration sites. It should be mentioned here that the volume and weight of organic material could also be reduced by drying, and further, be combined with high temperature fermentation. This approach would have the additional potential benefit that dried organic material would have a reduced rate of biodegradation during storage. Plants and animal manure could also be treated to reduce volume by various forms of composting. However, to date all such technology has been tested on the laboratory scale only.

For reduction of the volume of soil requiring disposal, the main approach used involved using measured profiles to determine the depth of penetration of radio-caesium and then using a technique which removed only the most contaminated material. Indeed, when contamination levels were low, deep ploughing or rotovation was tested as a management option and had the added advantage of producing no waste whilst simultaneously allowing radiation doses to be reduced by the natural shielding of uncontaminated soil. Note that, in principle, soil with low levels of contamination could be transported for use as cover in areas with higher activity levels but, due to restrictions during the demonstration projects, this option could not be implemented. Additionally, a scanning technique was tested at one location that allowed excavated soil to be separated into higher activity material (which was packaged for disposal) and lower activity material, which was returned to the field.

A number of soil decontamination treatments were tested at the laboratory scale including:
_ High temperature (1300 _C) Cs extraction
_ Washing to remove fine clay particles
_ Milling and washing to remove fines, with or without additional heat treatment at 700 _C
_ Cavitation jet and micro bubble separation processes
_ Organic acid extraction.

Although high decontamination effects were noted in some cases, these were generally considered to be impractical for large scale implementation due to high running costs, treatment requirements for secondary wastes and potential environmental impacts. The first and last of these methods could also be applicable to sewage sludge. A special problem was presented by contaminated tsunami debris, due not only to its heterogeneity, but also the possibility that it was contaminated by non-radioactive toxins (e.g. oil products, heavy metals). Some basic, small scale tests indicated reduction of concentrations of radio-caesium on separated concrete, wood and plastic by a washing technique and separation of more contaminated debris sludge by sieving of frozen material (using dry ice).

V. PREPARATION FOR STORAGE

In most cases, apart from the volume reduction measures listed in the previous section, solid waste was simply placed into large flexible containers, labelled and then transported to temporary storage locations. These flexible containers had a volume of up to about 1 m3 and were strong enough to be lifted even when full of wet soil (up to about 2.5 tonnes). Whilst these bags were impermeable, they were not considered to be gas or water-tight. They were labelled with either a robust conventional tag or an electronic readable chip which contained a sample location code, date, description of contents, estimated radio-caesium content and surface dose rate. Waste was either bagged at the point of production or moved in 4 or 10 ton trucks to a central bagging location. Waste bags were then stored for a short period of time with only minimum cover (tied/weighted-down heavy plastic sheeting) and control (barrier to prevent close approach), until they were transported to the temporary storage sites.

VI. TEMPORARY STORAGE FOR REMOVED CONTAMINANTS

For regulatory and acceptance reasons, it was necessary to establish temporary storage facilities at each of the demonstration sites e at locations agreed with local communities and land owners. Currently temporary storage is meant to last for a period of no more than 3 years, after which all temporary wastes are to be moved to a centralised interim storage facility (currently envisaged to be required for 30 years). The process for planning and implementing final disposal facilities for such wastes has not been defined thus far. Nevertheless, it seems prudent to assume that containment must be assured for a period of a few decades, thus requiring a relatively robust surface/near surface facility.

It is important to realise that, even over 3 decades, the inventory of radio-caesium will decrease only by a factor of about 4, so that the problems of moving, conditioning/packaging and final disposal of the waste will not decrease significantly over this period. Indeed, for some wastes, it is possible that waste handling will become significantly more problematic with time e for example due to internal processes such as biodegradation.

Storage site designs vary in detail depending on the location made available, but a typical example is shown. In all cases, an impermeable base and surface cover were used and soil backfill utilised to provide shielding. It is not possible to make such structures completely watertight, so drainage was incorporated in all cases either with gravity flow or a pump. Drainage was/is monitored and captured in a sump for any required treatment to ensure clearance levels are met for any releases to domestic or industrial sewage systems. Note that a venting system was also implemented to avoid over-pressurisation by gas resulting predominantly from biodegradation of organic materials.

VII. REMEDIATION PLANNING

Practical aspects of project planning and implementation for the demonstration projects ran within established QA norms in Japan (equivalent to ISO 9001, 14001, etc.), which were complemented by procedures specified to Japanese Industrial Standards, wherever relevant. Problems resulted from the unique nature of many of the activities involved, which required a certain degree of subjective assessment of different approaches to clean-up. The knowledge base provided by the demonstration projects will allow this to be carried out in a more rigorous manner in the future. This does, however, require that the knowledge base is made available in a form that is easily accessible to all interested parties and that key parameters that quantify the pros and cons of different options can be assessed in an integrated manner. Japan is a recognised world leader in the knowledge management field as applied to radioactive waste management so transfer of such technology to the remediation field would seem to be extremely beneficial.

VIII. SITE CHARACTERISATION

Due to extreme time pressure, measurements were carried out with equipment to hand (or easily available) and generally not covered by strict standards or procedural guidelines and little supported by specific training of the staff involved. JAEA did implement a quality audit procedure for radiometric procedures and radiological data from the demonstration projects; the feedback from this audit is summarised above and is also captured explicitly in guidelines being developed for future remediation. This will require development of equipment and protocols tailored to the specific environments found in Fukushima prefecture and also staff training/provisions of standards and reference materials which will allow measurement uncertainties to be rigorously quantified.

IX. IMPLEMENTATION OF FURTHER CLEAN-UP ACTIONS

The next stage of regional remediation will be managed by the Ministry of the Environment and again carried out by general contractors. It is important that not only the documentation from the demonstration projects is taken over to help implementation, but also worker experience (tacit knowledge) is captured. Indeed, this will be a continuous process as further experience is gained during clean-up work. To some extent modern media can help here, complementing text documents with pictures, videos and animations.

X. WASTE MANAGEMENT

The facilities for waste storage described above were developed under considerable time pressure and subject to tight constraints in terms of facility siting and movement of waste. If such constraints were relaxed, there would be great potential for optimisation with respect to performance, cost and environmental impact. The opportunities are particularly evident for the large volumes of relatively low activity soil or other inert contaminated material, which could well be utilised in construction projects associated with tsunami remediation, where there is a need for bulk material to build tsunami barriers and raise the height of potentially vulnerable infrastructure and this could actually provide a permanent management

solution for this material as overlying layers could reduce radiation levels to background levels. Another useful example would be to use less contaminated material as shielding in more contaminated areas, either close to or on the FDNPP site.

Other options to provide optimisation include much larger centralised storage facilities, which would benefit from advantages of scale and also allow more flexibility for partitioning different kinds of waste within the site. To minimise environmental impact, such facilities could well be sited in existing degraded areas such as abandoned quarries or industrial “grey sites” that may, themselves, be in need of remediation with respect to other environmental impacts

XI. COMMUNICATION

Communication immediately following the Fukushima accident was a major failure and has given rise to a huge loss of public trust and confidence .The goal of allowing the displaced populations to return to normal lifestyles means that public fear of all things nuclear is a real issue that needs to be actively addressed in remediation work. The demonstration projects form the basis for rebuilding trust, but canonly be effective if they are presented in an accessible, attractive and user-friendly form.

A key problem is defining the level of clean-up required to be defined not on the basis of health impact, but rather on consensus with local communities. Here it needs to be explained that, although the original evacuation was driven by concerns about safety decay of the most hazardous short-lived isotopes and a certain degree of “natural cleaning” of longer lived contaminants has reduced radiological health hazards considerably.

Radiation is very easy to measure and the presence of radio-caesium is easy to demonstrate. Whether such an increase is a hazard to health or not is, however, is a much harder question to answer and this must be communicated in a clear manner. In Japan, total background radiation dose is about from external radiation. This natural background varies considerably, mainly as a result of local geology and altitude, but also lifestyle and diet.

Such variations need to be explained and put in context, for example explaining that radiation at high altitudes can be up to 20 times that at sea-level and that many naturally high background radiation areas exist on Earth (e.g. Kerala in India where average annual background radiation doses can be up to 70 mSv y_1 areas of Guarapari, Brazil can reach 175 mSv y_1 and Ramsar, Iran, up to 260 mSv y_1 Only on the basis of such an understanding can residents make decisions on a residual dose level that is acceptable

XII. SUMMARY AND RECOMMENDATIONS

The demonstration projects described in this contribution have been seen to serve their primary purpose of development of a knowledge base to support more effective planning and implementation of stepwise regional remediation of the evacuated areas and facilitate safe return of displaced residents as quickly as possible. A range of established, modified and newly developed techniques have been tested under realistic field conditions and their performance characteristics determined.

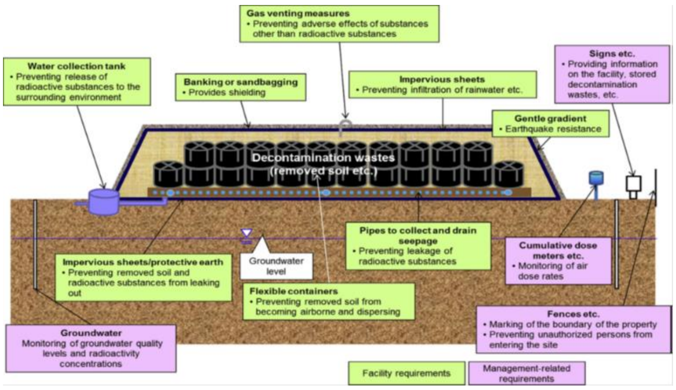

Figure 3: Schematic diagram illustrating the essential components of the specially engineered temporary storage sites for wastes generated from the remediation activities

This toolkit covers site characterisation, clean-up, waste minimisation and waste storage. Equally importantly, limitations in the technologies applied have been identified via such testing and the associated quality audit, so that required improvements can be incorporated into future implementation procedures, tools and guidelines. The output from these projects must, however, be considered "living documents" that will evolve as more experience is gained during further clean-up work. As such, they should be maintained within an effective Knowledge Management System that facilitates:

- ✓ Communication both between those involved in the remediation but also dialogue with stakeholders, especially local officials and residents
- ✓ Access via a user-friendly front-end (e.g. accessible by i-pad, smart phone, etc.)
- ✓ Capture of tacit knowledge making use of modern multimedia, e.g. videos, interviews and animations
- ✓ Consistent updating via a formal change management procedure
- ✓ Robust archiving of the rapidly expanding knowledge base

As procedures become sufficiently well-established they can be fixed, e.g. as formal JIS specifications. Full remediation of the area contaminated by FDNPP will require a huge effort over a long period of time but, based on experience to date, there seems to be no obvious technical reason that this cannot be achieved. Effective and acceptable implementation will, however, require social and political will to "think laterally" and develop new regulations, support structures and possibly even lifestyles. This will only be possible if the trust of the general public is regained and they are brought as full partners into the process which probably means that improving communication is the single largest challenge for the future. It must not be forgotten, however, that off-site remediation is only one part of the challenge. This must be integrated with clean up and decommissioning of the highly contaminated Fukushima Dai- ichi site e containing three reactors with partially melted cores. The experience from off-site remediation will help a little, but major additional challenges in terms of waste handling and disposal will need to be addressed. Ideally, these two remediation actions should be coordinated in order to maximise synergies and avoid duplication of efforts. As a simple example, lightly contaminated soil from off-site could be used as surface cover onsite, reducing doses and minimising waste production at both Location.

XIII. GENERATION OF ELECTRICITY FROM NUCLEAR WASTE CONVERSION, ENRICHMENT, FUEL FABRICATION AND REPROCESSING

Uranium oxide concentrate from mining, essentially 'yellowcake' (U3O8), is not significantly radioactive – barely more so than the granite used in buildings. It is refined then converted to uranium hexafluoride gas (UF6). As a gas, it undergoes enrichment to increase the U-235 content from 0.7% to about 3.5%. It is then turned into a hard ceramic oxide (UO2) for assembly as reactor fuel elements. The main by product of enrichment is depleted uranium (DU), principally the U-238 isotope, which is stored either as UF6 or U3O8. About 1.2 million tonnes of DU is now stored. Some is used in applications where its extremely high density makes it valuable, such as the keels of yachts and military projectiles. It is also used (with reprocessed plutonium) for making mixed oxide fuel and to dilute highly-enriched uranium from dismantled weapons which is now being used for reactor fuel There are about 270,000 tonnes of used fuel in storage, much of it at reactor sites. About 90% of this is in storage ponds (smaller versions of that illustrated above), the balance in dry storage. Much of the world's used fuel is stored thus, and some of it has been there for decades. Annual arising's of used fuel are about 12,000 tonnes, and 3,000 tonnes of this goes for reprocessing. Final disposal is not urgent in any logistical sense.

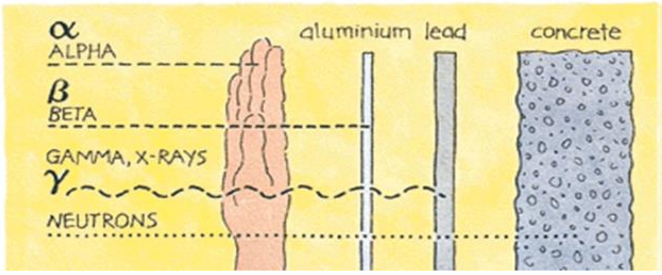

Figure 4: radiations from nuclear material

Storage ponds at reactors, and those at centralized facilities such as CLAB in Sweden, are 7-12 metres deep, to allow several metres of water over the used fuel comprising racked fuel assemblies typically about 4 m long and standing on end. The circulating water both shields and cools the fuel. These pools are robust constructions made of thick reinforced concrete with steel liners. Ponds at reactors are often designed to hold all the used fuel for the life of the reactor.

Some storage of fuel assemblies which have been cooling in ponds for at least five years is in dry casks, or vaults with air circulation inside concrete shielding. One common system is for sealed steel casks or multi-purpose canisters (MPCs) each holding about 80 fuel assemblies with inert gas. Casks/ MPCs may be used also for transporting and eventual disposal of the used fuel. For storage, each is enclosed in a ventilated storage module made of concrete and steel. These are commonly standing on the surface, about 6m high, cooled by air convection, or they may be below grade, with just the tops showing. The modules are robust and provide full shielding. After a period of 12 years these fuels are reprocessed and can be used in d form of U 238 or pu 240 for powering the nuclear weapons.

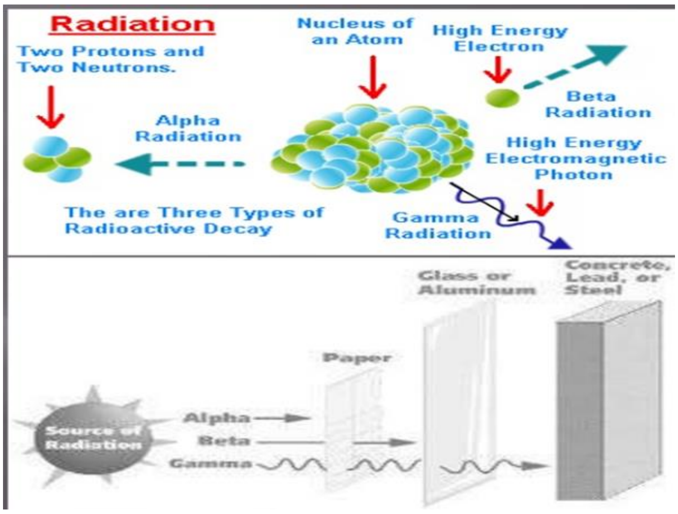

Figure 5 : radiations from a nuclear waste to be used in electricity generation.

XIV. SUGGESTED METHOD

Since the above method involves the large investment of money and material and manpower, it is not economical and safer in the case of radiation emission. The waste management always has been a great challenge and threat that the power plants are facing. There is an optimal way of reducing the radiation besides, generating the electricity, in addition.

The primary nuclear wastes ,such as uranium bye products and spent fuel, and the other preliminary by products, obtained from the power plant, as classified above, will have a life time ,each not less than 12.5years. During this duration, they undergo rare alpha decay, beta decay and delayed gamma decay, emitting radiations of energy 512kev during every beta decay and photons during gamma decay. During beta decay, it emits two types of particles: ELECTRONS (beta negative) & POSITRONS (beta positive) both the particles have same mass, equal energy, but opposite charges. Hence they equalize the nucleus numbers and obey the conservation law. During the process of beta decay, large amount of energy is liberated in form of kinetic energy. This kinetic energy of the electron regards to the properties of the beta radiations. The last radiation emission in decay will be gamma. Gamma radiations are nothing but the electromagnetic radiations, which are photons in nature. These energies are left unused in the above method of waste management. Since these particles are the carriers of energy, they can be utilized and converted into electrical energy using Multi – Walled Carbon Nano Tubes.

A. CARBON NANO TUBE

Multi-walled nano tubes (MWNT) consist of multiple rolled layers (concentric tubes) of graphene. There are two models that can be used to describe the structures of multi-walled nanotubes. In the Russian Doll model, sheets of graphite are arranged in concentric cylinders, e.g., a (0,8) single-walled nano tube (SWNT) within a larger (0,17) single-walled nano tube. In the Parchment model, a single sheet of graphite is rolled in around itself, resembling a scroll of parchment or a rolled newspaper. The interlayer distance in multi-walled nano tubes is close to the distance between grapheme layers in graphite, approximately 3.4 Å. The Russian Doll structure is observed more commonly. Its individual shells can be described as SWNTs, which can be metallic or semiconducting. Because of statistical probability and restrictions on the relative diameters of the individual tubes, one of the shells, and thus the whole MWNT, is usually a zero-gap metal.

Because of the symmetry and unique electronic structure of grapheme , the structure of a nano tube strongly affects its electrical properties. For a given (n,m) nanotube, if n = m, the nanotube is metallic; if n − m is a multiple of 3, then the nanotube is semiconducting with a very small band gap, otherwise the nanotube is a moderate semiconductor. Thus all armchair (n = m) nanotubes are metallic, and nanotubes (6,4), (9,1), etc. are semiconducting. However, this rule has exceptions, because curvature effects in small diameter carbon nanotubes can strongly influence electrical properties. Thus, a (5,0)

SWCNT that should be semiconducting in fact is metallic according to the calculations. Likewise, vice versa—zigzag and chiral SWCNTs with small diameters that should be metallic have finite gap (armchair nanotubes remain metallic).] In theory, metallic nanotubes can carry an electric current density of 4 × 109 A/cm2, which is more than 1,000 times greater than those of metals such as copper,[where for copper interconnects current densities are limited by electro migration. Because of their nano-scale cross-section, electrons propagate only along the tube's axis and electron transport involves quantum effects. As a result, carbon nanotubes are frequently referred to as one-dimensional conductors. The maximum electrical conductance of a single-walled carbon nanotube is 2G0, where G0 = 2e2/h is the conductance of a single ballistic quantum channel. There have been reports of intrinsic superconductivity in carbon nanotubes. Many other experiments, however, found no evidence of superconductivity, and the validity of these claims of intrinsic superconductivity remains a subject of debate[9].

B. CONVERSION OF BETA AND GAMMA RAYS INTO ELECTRICITY USING CARBON NANO TUBE

When an electron from the nuclear spent fuel or wastes, which undergo beta and gamma decays, strikes a particular interface between two layers of material, a current is generated, which use nuclear radiation to generate electricity (thermoelectric using a non-thermal conversion process. This device will be similar to that of beta voltaic cells, but rather uses high atomic numbered elements. When an electron or photon, travelling with a kinetic energy, strikes over a carbon nano tube containing traces of silicon (2-10), maintained at a normal temperature, it behaves as a semiconductor. Since the energy gap or band width of the carbon nanotubes is smaller than that of the semiconductors, the break down happens quickly and the break down will further result in avalanche break down. During this process, the electron transfers it energy to the neighboring electron and results in the conventional flow of current in the forward direction. If the fission product undergoes positive beta decay, then the emission would have positron that is a carrier of positive charge, will neutralize its charge with the electron in the rest on the surface of the nano tube. hence, the net charge will be zero. otherwise, if it collides with an electron moving with some energy, equal or less than that, it will undergo annihilation. if the energy of electron is greater than positron, the net charge is negative. but, majority of the decay are beta and gamma. So the major emitted particle would be electron or photon.

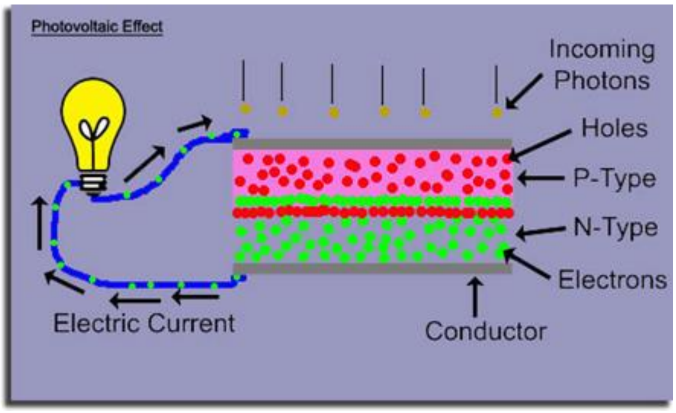

Figure 6: Photovoltaic Effect

Gamma decay occurs slower than beta and alpha. this is because of the energy variation in the nucleus of the element. During gamma emission, this has photons as the particle. During this process, the carbon nano tube will act as a photo voltaic cells and produces current. This is similar to all solar cells. The life time of these cells will not be less than the half life of the element produced. so, instead of wasting the wastes and dumping them into pools for 10 years, for it to reprocess, we can utilize the power and harness the hidden energy progressively.

This method is inspired from the beta voltaic and the new nano tube cells. The other advantage is, the carbon nano tubes, with doped silicon are highly radioactive resistance, which would not permit radiations to enter or leave. However in this process, the radiations are nullified by absorbing the particles responsible for it. So we need not bother about the effects of radiation leakage. When the several tones of radioactive wastes are utilized in such a manner, then we can minimize the problems involved in radioactive waste management. This process is superior and ,more economical than the traditional method. In the reprocessing of the spent fuel, plutonium benefit. The traces of silicon on the CNT will increase the heterogeneity of the surface and acts like a layer, similar to that of p-n junction in the solar cells. this helps in converting photonic energy into electricity kept in the spent fuel pool for about 10-12 years and then it is reprocessed to MOX and used for reprocessing to produce either U 238 or to power nuclear weapons. Is period of time, it involves wastage of time and money. In our method, we can generate a power of up to 24 WATTS PER HOUR PER Kg of nuclear spent fuel.

XV.CONCLUSION

Nuclear power plant, being one of the vital and important source of energy, for any country, there are large problems involved in managing its wastes. If the waste are being managed properly then nuclear power plant is the best method of producing electricity. The above suggested methods can be used to convert those nuclear wastes into useful energy and to reduce or rather nullify the effects of hazardous radiations. If this method is brought into practice successfully, then we can make the power plants more efficient and can obtain dual benefits of optimal way of nuclear waste disposal and even useful electricity produced from the nuclear waste.

Figure 7: a proposed model of the cells with wastes

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Cite this Article

R. Tamilarasi , "A Review On Optimal Method Of Nuclear Waste Management And Generation Of Electricity From Nuclear Waste ", International Journal of Scientific Research in Science and Technology (IJSRST), Online ISSN : 2395-602X, Print ISSN : 2395-6011, Volume 1 Issue 4, pp. 363-373, September-October 2015.
Journal URL : https://ijsrst.com/IJSRST218132