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Experience, reviews, discussions

Environmental and Safety Concerns for Nuclear Power Generation in Ghana

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Misconception about nuclear reactor safety has led several nuclear power projects to be abandoned. Safety was taken into consideration even before the first fission chain reaction was initiated. These safety precautions coupled with half a century of experience in nuclear power generation have made nuclear power the best choice for base load electricity generation in several countries across the globe. The storage of nuclear waste has been extensively studied over the years and several opportunities of fuel disposal and treatment have engineered the industrial growth of several countries. Nuclear power production has reduced the carbon emissions of several countries. The history of nuclear reactor safety and the management of nuclear waste are discussed along with the comparison with other sources of electricity to give a clear reason for the promotion of nuclear power programme in Ghana. The experiences of safety practices currently observed at Ghana Research Reactor-1 Centre are also discussed. The effects of nuclear waste as well as their treatment are discussed to indicate the preparedness of nuclear scientists to adequately protect the public from any exposure to radiation from the waste. The international and local regulations that are available for ensuring safe nuclear practice are also discussed.

Key words: *safety, environment, nuclear power.*

1. Introduction

In relation to nuclear power, safety is closely linked with security and safeguards. Safety focuses on unintended conditions or events leading to a radiological release from authorized activities. It relates mainly to intrinsic problems or hazards. Security focuses on the intentional misuse of nuclear or other radioactive materials by non-state elements to cause harm. It relates mainly to external threats to materials or facilities. Whereas, safeguards focus on restraining activities by states that could lead to acquisition of nuclear weapons. It concerns mainly materials and equipment in relation to rogue governments. Misconception about nuclear reactor safety has led several nuclear power projects to be abandoned. Safety of nuclear reactors was taken into consideration even before the first fission chain reaction was initiated. These safety precautions coupled with half a century of experience in nuclear power generation have made nuclear power the best choice for base load electricity generation in several countries across the globe. The history of nuclear safety, environmental impact of nuclear and other electricity generation sources, nuclear waste management, safety barriers against nuclear incidents and a practical demonstration of nuclear safety practices at Ghana Research Reactor-1 Centre are discussed.

The history of nuclear safety is presented in the next section.

2. History of Nuclear Safety / Incidents versus Installed Capacity

While the United States had to wait until 1957 for the first commercial nuclear power plant, the ground work for nuclear safety began with the first major investigation into a controlled nuclear fission chain reaction that was performed by Enrico Fermi at the University of Chicago in 1942 (Ball et al. 1994; Hirschberg et al. 1996, 2001).

To address the possibility of a failure, multiple safeguard was designed into the experiment. In the setup there were three sets of control rods. The primary set was not used for safety at all but was designed for fine control of the nuclear chain reaction. The other two control rods served the safety functions. One set was automatic and could be controlled by manual interaction and the other was an emergency safety rod. The automatic control rod was operated by an electric motor and responded to a high instrument reading from a radiation counter. Attached to one end of the emergency rod was a rope running through the pile and weighted heavily on the opposite end. During testing, this rod was withdrawn from the pile and tied down by another rope. It was the job of the "Safety Control Rod Axe Man" to stand-by ready to cut this rope with an axe should something unexpected happen, or in case the automatic safety rods failed. The acronym SCRAM from "Safety Control Rod Axe Man" is still used today in reference to the rapid shutdown of a nuclear reactor.

The safety measures did not stop with the control rods. Not wanting to rely completely on mechanical devices, Fermi organized a liquid-control squad who were to stand on a platform above the pile and respond to mechanical failure of the control rods by pouring a cadmium-salt solution over the experiment.

Fortunately, Fermi and the team had done their homework. The experiment went off without any problems and at 3:25 pm on December 2, 1942, the nuclear age was born. The first man-made self-sustaining nuclear reaction had been achieved.

In the 1950s attention turned to harnessing the power of the atom in a controlled way, as demonstrated at Chicago in 1942 and subsequently for military research, and applying the steady heat yield to generate electricity. This naturally gave rise to concerns about accidents and their possible effects. In particular the scenario of loss of cooling which resulted in melting of the nuclear reactor core motivated the studies on both the physical and chemical possibilities and the biological effects of any dispersed radioactivity on the environment and other living organisms.

Those responsible for nuclear power technology devoted extraordinary effort to ensuring that a meltdown of the reactor core would not take place, since it was assumed that a meltdown of the core would create a major public hazard, and if uncontained, a tragic accident with likely fatalities.

In avoiding such accidents the industry has been outstandingly successful. In 12,000 cumulative reactor-years of commercial operation in 32 countries, there have been only two major accidents to nuclear power plants - Three Mile Island and Chernobyl, the latter being of little relevance outside the old Soviet Union.

It was not until the late 1970s that detailed analyses and large-scale testing, followed by the 1979 meltdown of the Three Mile Island reactor, began to make clear that even the worst possible accident in a conventional western nuclear power plant or its fuel could not cause dramatic public harm. The industry still works hard to minimize the probability of a meltdown accident, but it is now clear that no-one needs fear a potential public health catastrophe.

The decades-long test and analysis program showed that less radioactivity escapes from molten fuel than initially assumed, and that this radioactive material is not readily mobilized beyond the immediate internal structure. Thus, even if the containment structure that surrounds all modern nuclear plants were ruptured, it would still be highly effective in preventing escape of radioactivity.

It is the laws of physics and the properties of materials that preclude disaster, not the required actions by safety equipment or personnel. In fact, licensing approval now requires that the effects of any core-melt accident must be confined to the plant itself, without the need to evacuate nearby residents.

The two significant accidents in the 50-year history of civil nuclear power generation are Three Mile Island (USA 1979) where the reactor was severely damaged but radiation was contained and there were no adverse health or environmental consequences and Chernobyl (Ukraine 1986) where the destruction of the reactor by steam explosion and fire killed 31 people and had significant health and environmental consequences. The death toll has since increased to about 56. Figures 1 and 2 represent the schematic view of the Three Mile Island 2 and Chernobyl 4 (RMBK 1000), respectively.

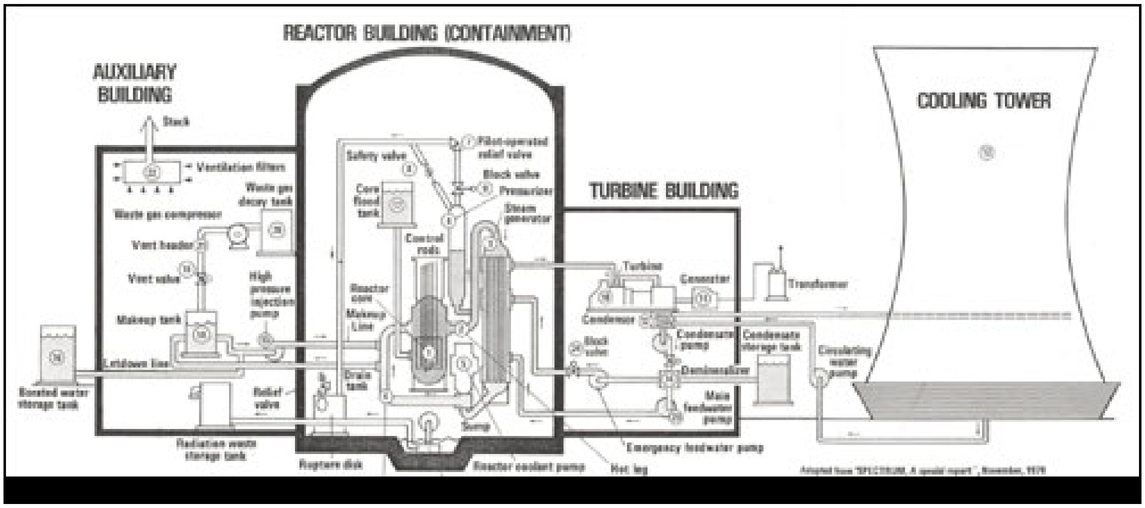

Fig. 1. Schematic view of Three Mile Island Plant 2 (Hirschberg et al. 1996, 2001)

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These two significant accidents occurred during more than 12,700 reactor-years of civil operation as shown in Figure 3 below. Of all the accidents and incidents, only the Chernobyl accident resulted in radiation doses to the public greater than those resulting from the exposure to natural sources. Other incidents and one 'accident' have been completely confined to the plant.

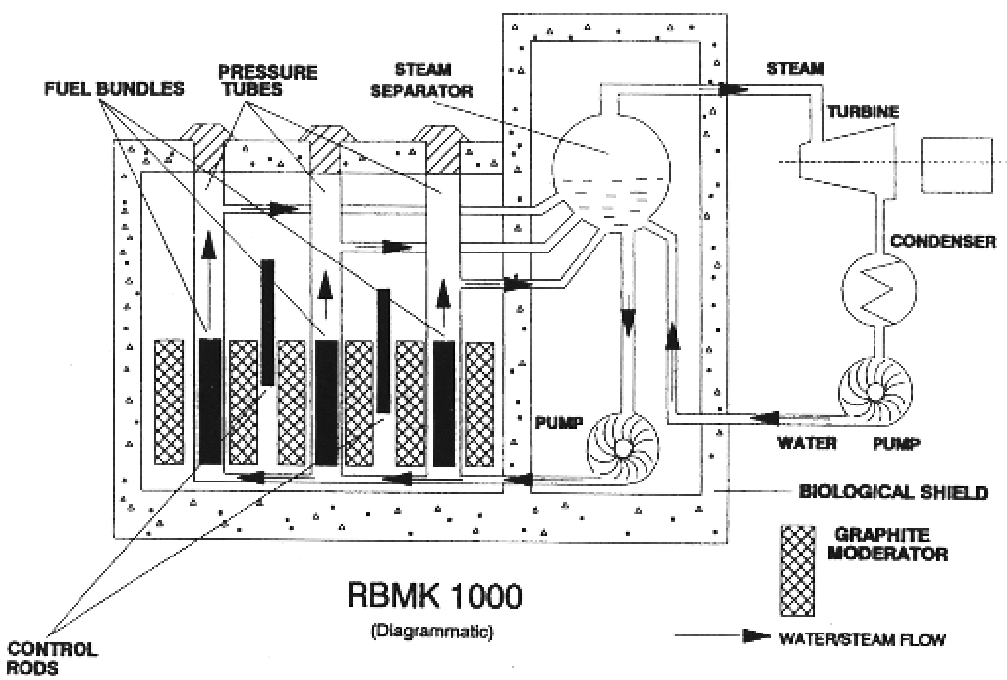

Fig. 2. Schematic view of Chernobyl Plant 4 (OECD, 1995)

Apart from Chernobyl, no nuclear workers or members of the public have ever died as a result of exposure to radiation due to a commercial nuclear reactor incident (Levenson and Rahn 1981). Most of the serious radiological injuries and deaths that occur each year (2-4 deaths and many more exposures above regulatory limits) are the result of large uncontrolled radiation sources, such as abandoned medical or industrial equipment. It should be emphasized that a commercial-type power reactor simply cannot under any circumstances explode like a nuclear bomb.

The International Atomic Energy Agency (IAEA) was set up by the United Nations in 1957. One of its functions is to act as an auditor of world nuclear safety. It prescribes safety procedures and the reporting of even minor incidents. Its role has been strengthened since 1996. Every country which operates nuclear power plants has a nuclear safety inspectorate and all of them work closely with the IAEA.

While nuclear power plants are designed to be safe in their operation and safe in the event of any malfunction or accident, no industrial activity can be represented as entirely risk-free. However, a nuclear accident in a nuclear reactor is now understood to have severe financial consequences for the owner but will give rise to minimal off-site consequences.

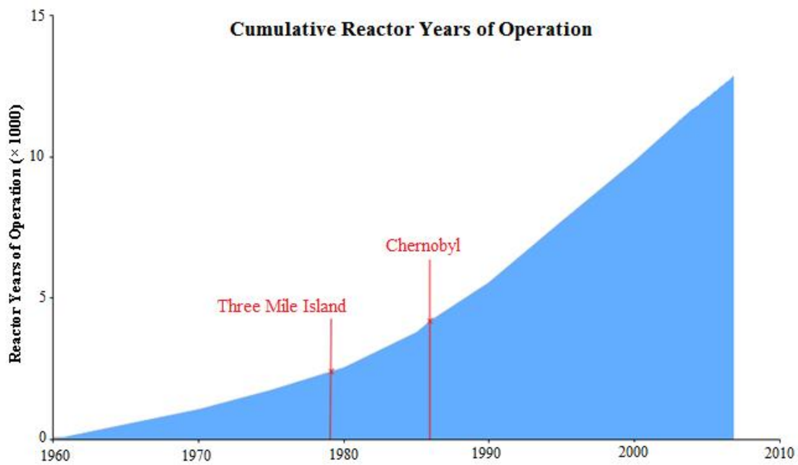

Fig. 3. Cumulative Reactor Years of Operation (IAEA 2006)

Operational safety is a prime concern for those working in nuclear plants. Radiation doses are controlled by the use of remote handling equipment for many operations in the core of the reactor. Other controls include physical shielding and limiting the time workers spend in areas with significant radiation levels. These are supported by continuous monitoring of individual doses and of the work environment to ensure very low radiation exposure compared with other industries.

Concerning possible accidents, up to the early 1970s, some extreme assumptions were made about the possible chain of consequences. These gave rise to a genre of dramatic fiction (e.g. *The China Syndrome*) in the public domain and also some solid conservative engineering including containment structures in the industry itself. Licensing regulations were framed accordingly.

Regulatory requirements today are that the effects of any core-melt accident must be confined to the plant itself, without the need to evacuate nearby residents.

The main safety concern has always been the possibility of an uncontrolled release of radioactive material, leading to contamination and consequent radiation exposure off-site. Earlier assumptions were that this would be likely in the event of a major loss of cooling accident (LOCA) which resulted in a core melt. Experience has proved otherwise in any circumstances relevant to Western reactor designs. In the light of better understanding of the physics and chemistry of material in a reactor core under extreme conditions it became evident that even a severe core melting coupled with breach of containment could not in fact create a major radiological disaster from any Western reactor design. Studies of the post-accident situation at Three Mile Island (where there was no breach of containment) supported this.

It has long been asserted that nuclear reactor accidents are the epitome of low-probability but high-consequence risks. Understandably, with this in mind, some people were disinclined to accept the risk, however low the probability. However, the physics and chemistry of a reactor core, coupled with but not wholly depending on the engineering, mean that the consequences of an accident are likely in fact be much less severe than those from other industrial and energy sources.

To achieve optimum safety, nuclear plants operate using a defence-in-depth approach, with multiple safety systems supplementing the natural features of the reactor core. Key aspects of the approach are high-quality design and construction, equipment which prevents operational disturbances developing into problems, redundant and diverse systems to detect problems, control damage to the fuel and prevent significant radioactive releases and provision to confine the effects of severe fuel damage to the plant itself.

The safety provisions include a series of physical barriers between the radioactive reactor core and the environment, the provision of multiple safety systems, each with backup and designed to accommodate human error. Safety systems account for about one quarter of the capital cost of such reactors.

The barriers in a typical plant are: the fuel is in the form of solid ceramic (UO_2) pellets, and radioactive fission products remain bound inside these pellets as the fuel is burned. The pellets are packed inside sealed zirconium alloy tubes to form fuel rods. These are confined inside a large steel pressure vessel with walls up to 30 cm thick - the associated primary water cooling pipe-work is also substantial. All this, in turn, is enclosed inside a robust reinforced concrete containment structure with walls at least one metre thick.

But the main safety features of most reactors are inherent - negative temperature coefficient and negative void coefficient. The first means that beyond an optimal level, as the temperature increases the efficiency of the reaction decreases (this in fact is used to control power levels in some new designs). The effect of temperature coefficient is as shown in Figure 4 below. The second means that if any steam has formed in the cooling water there is a decrease in moderating effect so that fewer neutrons are able to cause fission and the reaction slows down automatically.

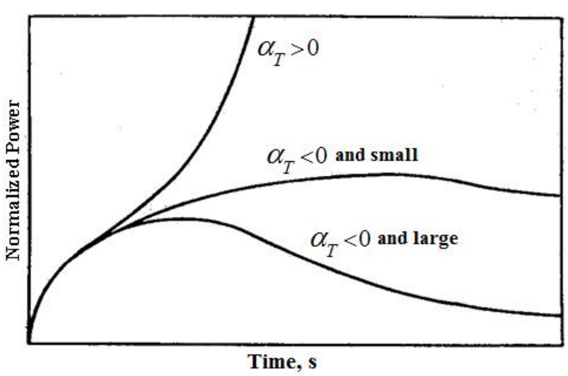

Fig. 4. Reactor Power Response to different temperature coefficients (Akaho 2008)

Beyond the control rods which are inserted to absorb neutrons and regulate the fission process, the main engineered safety provisions are the back-up emergency core cooling system (ECCS) to remove excess heat (though it is more to prevent damage to the plant than to public safety) and the containment.

Traditional reactor safety systems are active in the sense that they involve electrical or mechanical operation on command. Some engineered systems operate passively, e.g. pressure relief valves. Both require parallel redundant systems. Inherent or full passive safety design depends only on physical phenomena such as convection, gravity or resistance to high temperatures, not on functioning of engineered components. All reactors have some elements of inherent safety as mentioned above, but in some recent designs the passive or inherent features substitute for active systems in cooling, etc.

The basis of design assumes a threat where due to accident or malign intent (e.g. terrorism) there is core melting and a breach of containment. This double possibility has been well studied and provides the basis of exclusion zones and contingency plans. Apparently during the Cold War neither Russia nor the USA targeted the other's nuclear power plants because the likely damage would be modest.

Nuclear power plants are designed with sensors to shut them down automatically in an earthquake, and this is a vital consideration in many parts of the world.

The Three Mile Island accident in 1979 demonstrated the importance of the inherent safety features. Despite the fact that about half of the reactor core melted, radio-nuclides released from the melted fuel mostly plated out on the inside of the plant or dissolved in condensing steam. The containment building which housed the reactor further prevented any significant release of radioactivity. The accident was attributed to mechanical failure and operator confusion. The reactor's other protection systems also functioned as designed. The emergency core cooling system would have prevented any damage to the reactor but for the intervention of the operators.

Investigations following the accident led to a new focus on the human factors in nuclear safety. No major design changes were called for in Western reactors, but controls and instrumentation were improved and operator training was overhauled.

By way of contrast, the Chernobyl reactor did not have a containment structure as seen in Figure 2 above like that presented in Figure 1 for the Three Mile facility.

3. Environmental Impact of Nuclear and other Power Generation Sources

No form of energy production or use is without environmental impact. This is true for all energy chains: from extracting resources, building facilities and transporting material through the final conversion to useful energy services. The principal environmental impacts associated with nuclear power and sustainable development are radiation, air pollution, greenhouse gas (GHG) emissions and radioactive waste.

Among the alternatives for generating electricity, fossil fuelled technologies (coal, oil and natural gas) have the highest CO_2 emission rates per kW·h (Figure 5) and create the majority of energy related GHG emissions (NASCCDA 1983). The figure shows emission rates for the complete fuel cycle, including facility construction, equipment manufacture, resources extraction, transport, processing and conversion. The complete nuclear power chain, from resources extraction to waste disposal including reactor and facility construction, emits only 1–6 grams of carbon equivalent per kilowatt-hour (g Ceq/kW·h). This is about the same as wind and hydropower, including construction and component manufacturing. All three, together with solar power and biomass, are well below coal, oil and natural gas (60–460 g Ceq/kW·h) even taking account of carbon capture and storage. Figure 5 indicates that stabilizing CO_2 concentrations in the atmosphere will require significant reductions in emissions from fossil fuelled power plants, either by reducing their emissions directly, by more efficient energy use, or by greater use of renewable technologies and nuclear power.

Figure 6 presents the sources of emission free generation of electricity in the United States as shown below.

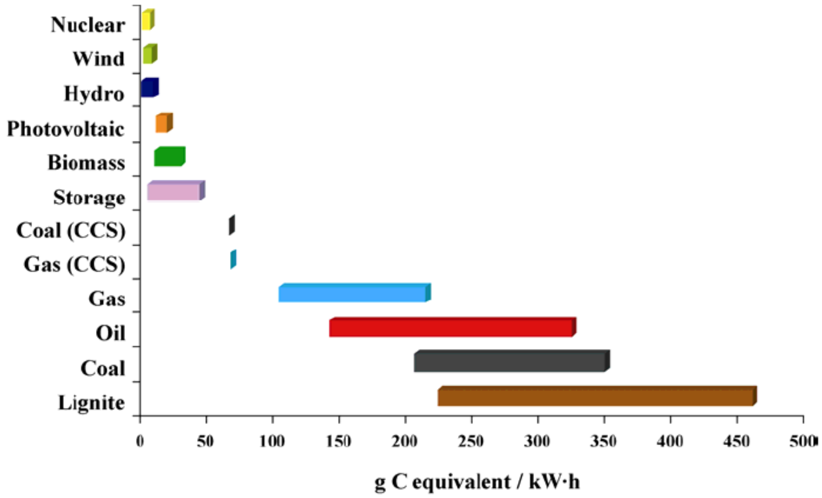

Fig. 5. CO_2 emission rates for electricity generating alternatives (storage: batteries, pumped hydro, compressed air storage; CCS: carbon capture and storage) (IAEA, 2006)

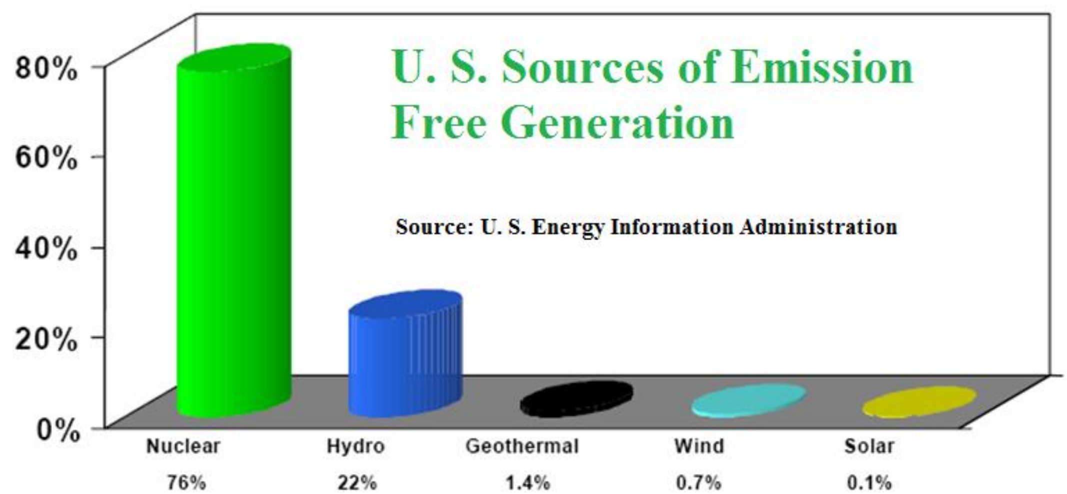

Fig. 6. United States Sources of Emission Free Generation of electricity (U.S. EPA 1977, 1979, 1980, 1981)

Concerning air pollutants, nuclear power reactors emit virtually none of the traditional air pollutants associated with fossil fuel combustion, principally sulphur dioxide (SO_2), nitrogen oxides (NO_x) and suspended particulate matter (PM). Nor do they emit trace heavy metals, like arsenic and mercury, associated with coal combustion. SO_2 and NO_x contribute to human morbidity and mortality, reduce crop yields and are the principal cause of acid rain. In turn, acid rain damages forests, broader ecosystems, agricultural crops and building materials. NO_x is a precursor of ground level ozone, which has further adverse health impacts. Particulate matter, which is both emitted directly and formed in the air as the result of SO_2 and NO_x emissions, directly increases human mortality and morbidity. The effects of the pollutants are as presented in Table 1.

Emission levels of these pollutants have been reduced in recent decades through technological improvements and by capturing emissions from stack gases. The vertical scale of Figure 7 presents a qualitative comparison of the various technologies currently used in the European Union.

Table 1. Health effects of fossil releases (IAEA, 1997)

Pollutant	Health Effects
Sulphur dioxide (SO_2)	Respiratory disorders, impaired breathing
Nitrous oxide (NO_x)	Respiratory disorders, infections, pulmonary (lung) diseases
Carbon monoxide (CO)	Fatal angina (throat disorder), various other effects
Ozone (O_3)	Respiratory disorders, impaired breathing, asthma, edema
Particulate matter (PM_{10})	Various toxic particles (organic matter, carbon)

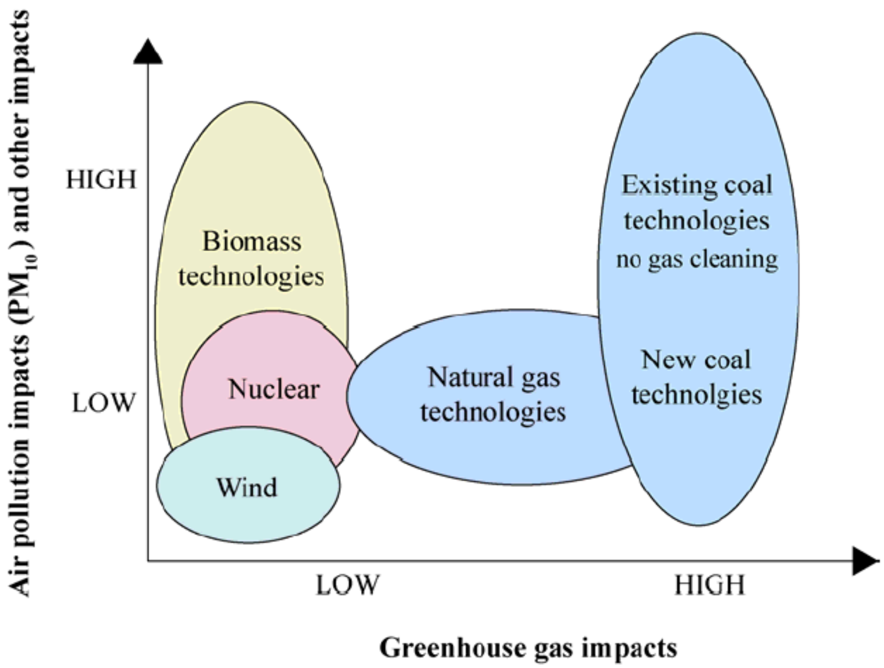

Fig. 7. Relative environmental impacts from emissions of different electricity generating technologies (IAEA, 2006)

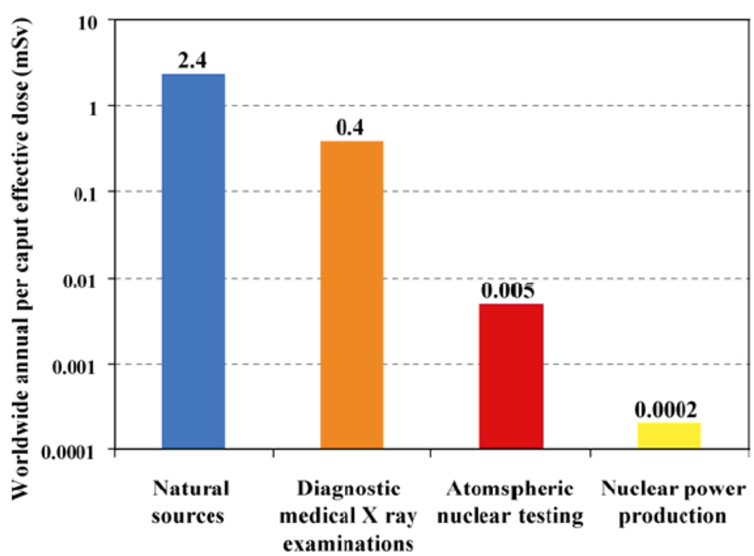

Fig. 8. Worldwide average annual per capita dose from natural and anthropogenic radiation (IAEA 2006)

Radiation is relevant for nuclear, coal, oil, gas and geothermal power plants. All bring radioactive material in the Earth's crust to the surface. The US Environmental Protection Agency (EPA) estimates that someone living within 50 miles of a coal fired power plant receives an average dose of 0.3 μSv; someone living within 50 miles of a nuclear power plant receives 0.09 μSv. Both are more than one thousand times less than the average dose received by people in the USA from X rays and other medical procedures, and more than ten thousand times less than their average dose from natural background radiation.

Figure 8 presents a worldwide comparison, based on data from the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), showing, on a logarithmic scale, that the average radiation dose from nuclear power production is one ten-thousandth of the dose from natural background sources. Background sources include cosmic rays and naturally occurring radioactive substances in the air (mainly radon), in food and water (such as potassium), and in the Earth. Human activities create additional exposure, particularly from medical X rays (as shown in Figure 8) and nuclear medical procedures. But living in a brick, stone or concrete building; watching television or using a computer terminal; travelling in a jet airplane; and wearing a luminous wristwatch all add to the dose. The incremental dose from a home smoke detector is comparable to that from living within 50 miles of a nuclear power plant.

In some jobs, workers receive additional occupational exposure, for example, in industrial, medical and research jobs where radiation or radioactive material is used, in mining, in nuclear power plant operation and in high altitude jet travel by pilots and flight crews. The average level of occupational exposure in such jobs is normally comparable to the global average level of natural radiation exposure.

The three principal approaches to utilizing solar energy for generating electricity are photovoltaic (solar cells), solar thermal facilities and wind turbines. There are lots of poisonous chemicals used in fabricating solar cells which are used in solar electricity, such as hydrofluoric acid, boron trifluoride, arsenic, cadmium, tellurium, and selenium compounds, which can cause health problems. Also, there is much more construction work needed for solar installations than for nuclear; construction is one of the most dangerous industries from the standpoint of accidents to workers.

The comparison of accident statistics in primary energy production is as presented in Table 2 below.

The industrial safety accident rate of the USA is presented in Figure 9 below

Table 2. Comparison of accident statistics in primary energy production (Ball et al, 2001)

Fuel	Immediate fatalities 1970 – 92	Who?	Normalized to deaths per TWy* electricity
Coal	6400	Workers	342
Natural gas	1200	Workers and public	85
Hydro	4000	Public	883
Nuclear	31	Workers	8

* *Basis: per million MWe operating for one year, not including plant construction, based on historic data which is unlikely to represent current safety levels in any of the industries concerned.*

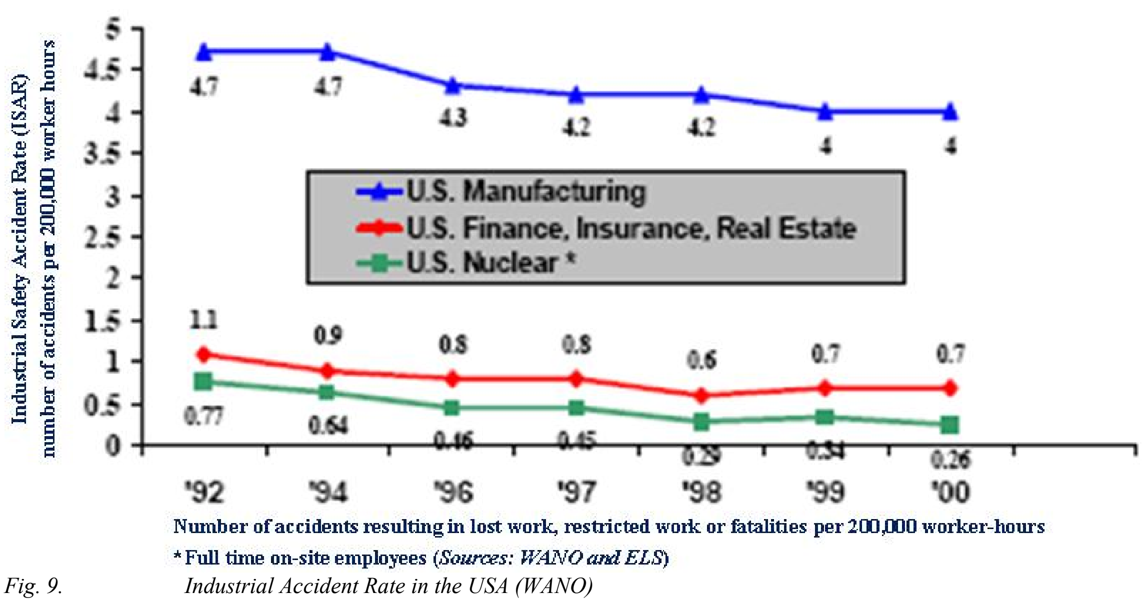

Fig. 9. Industrial Accident Rate in the USA (WANO)

From the above discussion, it is imperative that nuclear power generation has outclassed her competitors and can be used to provide electricity without extreme hazards to both humanity and the environment. It can be used to support the quest of Ghana to satisfy the conditions of the Kyoto Protocol while harnessing nuclear technology for the socio-economic development of the country.

The efforts at handling nuclear waste are discussed in the next section.

4. Nuclear Waste Management

There has been a continuous public concern that nuclear waste cannot be safely managed (IAEA, 1997). However, managing nuclear waste is less of a problem because the quantities are remarkably small relative to the energy produced. The small quantities permit a *confinement* strategy for the radioactive material, beginning with the nuclear fission process and through to waste disposal, essentially isolated from the environment. Disposal techniques exist and the hazard decreases with time owing to radioactive decay. The main disposal options are simple near surface, engineered structures, mined cavities, and deep geological repositories. Some thirty countries currently operate licensed repositories for low and intermediate level radioactive waste.

In sharp contrast, disposal of the large quantities of fossil fuel waste follows an alternative *dispersion* strategy. Most of the waste (noxious gases and many toxic pollutants) is dispersed directly into the atmosphere while some solid waste containing toxic pollutants is buried in shallow ground, there being no practical alternative.

The waste is dispersed or buried at concentrations considered not harmful. While the resulting impact can be small, the cumulative waste over many years from a large number of waste producing activities can easily overburden the natural environment, locally as well as globally.

Confinement is preferable to dispersion, but is economically feasible only when waste volumes are small and arise under easily controlled conditions. Most nuclear waste consists of relatively short lived low and intermediate level waste, annually some 450 and 350 tonnes, respectively from a 1000 MW(e) plant. Low level waste, which consists largely of minimally contaminated clothing, machine parts and industrial resins, can be placed in containers and disposed of in trenches covered by soil. The waste does not require shielding during handling or transportation and can be less radioactive than the equivalent weight of coal plant fly ash or even coffee beans, and fertilizer which contain natural radioactive material. While not necessary for radiation protection purposes, waste can be isolated in engineered structures such as concrete lined trenches and vaults.

Intermediate level waste, which includes reactor parts and contaminated equipment, is packaged in cement inside steel drums. In a similar way to low level waste, it can be safely disposed of in near surface facilities.

Nuclear power is not responsible for all radioactive waste. In the USA, nearly 50% by volume of non-defence related low and intermediate waste originates from government, industrial and medical activities. High level waste consists of liquid waste from reprocessing after the recovery of uranium and plutonium or spent fuel for ultimate disposal if it is not to be reprocessed.

The spent fuel, some 12 000 tonnes from all operating plants, can be readily stored above or below ground awaiting decisions on long term disposal options. An interim storage period is necessary to allow the residual heat generated in the spent fuel to decrease, disposal being more practical after several decades. The volume of high level liquid waste from the reprocessing of 30 tonnes of spent fuel released annually from a 1000 MW(e) plant, containing more than 99% of the radioactivity, is some 10 cubic metres. The waste can be vitrified to a glass solid and stored awaiting long term disposal.

Final repositories for low level radioactive waste from nuclear power plants and from medical, research, and other applications have been licensed and are in operation in many countries (IAEA, 2006). There is no operating repository for the final disposal of high level waste (HLW) from civilian nuclear power plants, although the scientific and technical communities generally agree that such waste can be disposed of safely in stable geological formations. There is one operating geological repository, for the disposal of long lived transuranium waste generated by research and the production of nuclear weapons, the Waste Isolation Pilot Plant in New Mexico, USA.

Currently, spent fuel generated by operating nuclear power plants is either reprocessed or stored. Reprocessing extracts usable uranium and plutonium from the spent fuel for use in new fuel. What remains is HLW that is currently stored pending final disposal. China, France, India, Japan and the Russian Federation reprocess most of their spent fuel. Canada, Finland, Sweden and the USA have opted for the alternative of direct disposal of spent fuel as HLW, although the USA has recently proposed a third approach in which spent fuel would be recycled not to extract usable uranium and plutonium, but to immediately 'burn' the plutonium and reduce the volume and toxicity of the waste requiring permanent disposal. Countries that have not yet chosen a strategy are currently storing spent fuel and keeping abreast of developments associated with all alternatives.

There is now over half a century of experience with spent fuel storage technology. The amount of spent fuel is relatively small: the spent fuel produced in one year by all the world's operating reactors would cover a soccer field to a depth of about 1.5 metres. And it is relatively easy to add incremental storage capacity. Hence, there is no strong technical reason to expedite creation and operation of a deep geological repository. There may be good political and symbolic reasons to do so, but storage means that politicians and the public have time to exhaustively debate, explore and determine each country's preferred solution. Where it is politically acceptable, multinational disposal can be considered a potentially more cost effective option, especially in small countries with small nuclear programmes and limited repository sites.

The Finnish, Swedish and US repository programmes have made the most progress, but none is likely to have a repository in operation much before 2020. All of these programmes are designed to isolate waste from the environment by means of a series of engineered and natural barriers, as shown in Figure 10 for the Swedish programme. The first barrier is the waste matrix and initial waste package (in the Swedish case solid fuel pellets and fuel rod cladding). Second are additional engineered barriers (copper canisters, iron inserts and bentonite clay backfill in the Figure). Third is the host geological formation (crystalline bedrock in Sweden) chosen for proven geological stability over hundreds of millions of years, favourable geochemical conditions and limited water movement.

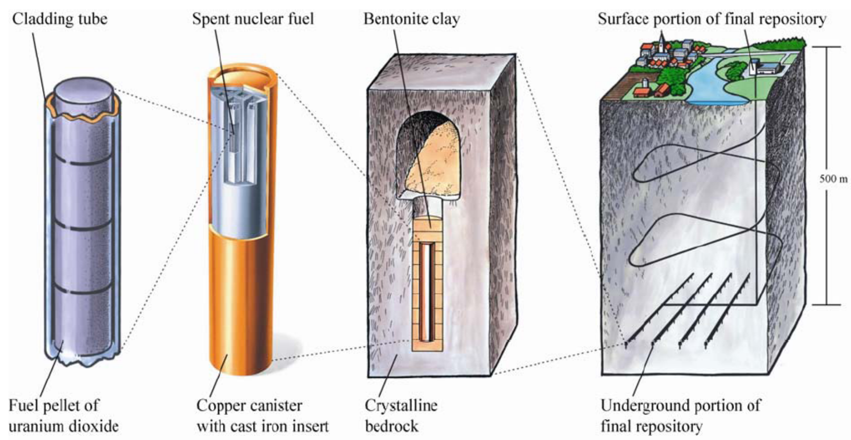

Fig. 10. The Swedish concept for the disposal of spent nuclear fuel as an illustration of the multi-barrier concept (IAEA, 2006)

Waste disposal is an area in which nuclear power is generally ahead of alternatives. Nuclear waste is small in volume, well confined and highly monitored, unlike solid and toxic waste produced by other fuel chains. The cost of containing, storing and disposing of nuclear waste is in most countries included in the price of electricity. These internalized expenses include the cost of managing waste, disposing of the waste in long term repositories and decommissioning the plant at the end of its life.

A common apprehension about radioactive waste concerns its long lived nature. Waste from reprocessing facilities, where much of the very long lived materials such as plutonium is removed, would decay to radioactive levels below that of natural uranium ore in less than one thousand years compared to more than ten thousand years without reprocessing. Waste pollutants from coal such as cadmium, lead or mercury — much of which is dispersed or disposed of in near surface facilities — remain toxic indefinitely. There is a growing recognition that management of indefinitely toxic waste and radioactive waste warrant a harmonized approach. However, managing toxic wastes from fossil fuels to standards proposed for high level radioactive wastes is not economically feasible.

Indicators to compare radioactive waste hazards with fossil fuel waste hazards have been developed. One such indicator is based on admissible concentrations of radioactive and toxic pollutants in water. For similar amounts of energy generated, in some one hundred years the amount of water necessary to dilute reprocessed radioactive waste to admissible concentrations would be less than the amount to dilute lignite waste to admissible concentrations, the reason being the relatively small quantity of radioactive material and the relatively rapid decay of reprocessing waste owing to the removal of long lived elements (Figure 11).

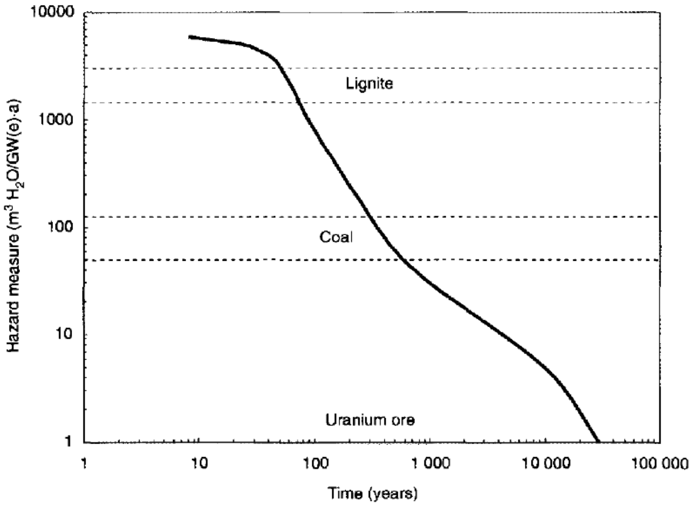

Fig. 11. Comparison of radioactive waste hazards with fossil fuel waste hazards (European Commission, 1995)

5. Safety Barriers against Nuclear Incidents / Pollution

The designs for nuclear plants being developed for implementation in coming decades contain numerous safety improvements based on operational experience. The first two of these advanced reactors began operating in Japan in 1996.

The main feature they have in common (beyond safety engineering already standard in Western reactors) is passive safety systems, requiring no operator intervention in the event of a major malfunction.

These designs are one or two orders of magnitude safer than older ones in respect to the likelihood of core melt accidents, but the significance of that is more for the owner than the neighbours, who - as Three Mile Island showed - are safe also with older types.

There is a great deal of international cooperation on nuclear safety issues, in particular the exchange of operating experience under the auspices of the World Association of Nuclear Operators (WANO) which was set up in 1989. In practical terms this is the most effective international means of achieving very high levels of safety through its four major programs: peer reviews; operating experience; technical support and exchange; and professional and technical development. WANO peer reviews are the main proactive way of sharing experience and expertise.

The IAEA Convention on Nuclear Safety was drawn up during a series of expert level meetings from 1992 to 1994 and was the result of considerable work by Governments, national nuclear safety authorities and the IAEA Secretariat. Its aim is to legally commit participating States operating land-based nuclear power plants to maintain a high level of safety by setting international benchmarks to which States would subscribe.

The Convention is an incentive instrument. It is not designed to ensure fulfillment of obligations by Parties through control and sanction, but is based on their common interest to achieve higher levels of safety. These levels are defined by international benchmarks developed and promoted through regular meetings of the Parties. The Convention obliges Parties to report on the implementation of their obligations for international peer review. This mechanism is the main innovative and dynamic element of the Convention.

In relation to Eastern Europe particularly, since the late 1980s a major international program of assistance has been carried out by the OECD, IAEA and Commission of the European Communities to bring early Soviet-designed reactors up to near western safety standards, or at least to effect significant improvements to the plants and their operation. The EU has also brought pressure to bear, particularly in countries which aspired to EU membership.

Modifications have been made to overcome deficiencies in the 11 RBMK reactors still operating in Russia (ROSATOM, 2009) . Among other things, these have removed the danger of a positive void coefficient response. Automated inspection equipment has also been installed in these reactors.

The other class of reactors which has been the focus of international attention for safety upgrades is the first-generation of pressurized water VVER-440/230 reactors. These were designed before formal safety standards were issued in the Soviet Union and they lack many basic safety features. Some are still operating in Bulgaria, Russia and Armenia, under close inspection.

Later Soviet-designed reactors are very much safer and the most recent ones have Western control systems or the equivalent, along with containment structures.

The International Nuclear Event Scale (INES) was developed by the IAEA and OECD in 1990 to communicate and standardize the reporting of nuclear incidents or accidents to the public. The scale runs from a zero event with no safety significance to 7 for a "major accident" such as Chernobyl. Three Mile Island rated 5, as an "accident with off-site risks" though no harm to anyone, and a level 4 "accident mainly in installation" occurred in France in 1980, with little drama. Another accident rated at level 4 occurred in a fuel processing plant in Japan in September 1999.

Since the World Trade Centre attacks in New York in 2001 there has been concern about the consequences of a large aircraft being used to attack a nuclear facility with the purpose of releasing radioactive materials. Various studies have looked at similar attacks on nuclear power plants. They show that nuclear reactors would be more resistant to such attacks than virtually any other civil installations. A thorough study was undertaken by the US Electric Power Research Institute (EPRI) using specialist consultants and paid for by the US Department of Energy (EPRI, 2002). It concludes that US reactor structures "are robust and (would) protect the fuel from impacts of large commercial aircraft".

The analyses used a fully-fuelled Boeing 767-400 of over 200 tonnes as the basis, at 560 km/h - the maximum speed for precision flying near the ground. The wingspan is greater than the diameter of reactor containment buildings and the 4.3 tonne engines are 15 metres apart. Hence analyses focused on single engine direct impact on the centerline - since this would be the most penetrating missile - and on the impact of the entire aircraft if the fuselage hit the centerline (in which case the engines would ricochet off the sides). In each case no part of the aircraft or its fuel would penetrate the containment. Other studies have confirmed these findings.

Penetrating (even relatively weak) reinforced concrete requires multiple hits by high speed artillery shells or specially-designed "bunker busting" ordnance - both of which are well beyond what terrorists are likely to deploy. Thin-walled, slow-moving, hollow aluminum aircraft, hitting containment-grade heavily-reinforced concrete disintegrate, with negligible penetration. But further, realistic assessments from decades of analyses, lab work and testing, find that the consequence of even the worst realistic scenarios - core melting and containment failure - can cause few if any deaths to the public, regardless of the scenario that led to the core melt and containment failure.

In 1988 Sandia National Laboratories in the USA demonstrated the unequal distribution of energy absorption that occurs when an aircraft impacts a massive, hardened target. The test involved a rocket-propelled F4 Phantom jet (about 27 tonnes, with both engines close together in the fuselage) hitting a 3.7m thick slab of concrete at 765 km/h. This was to see whether a proposed Japanese nuclear power plant could withstand the impact of a heavy aircraft. It showed how most of the collision energy went into the destruction of the aircraft itself - about 96% of the aircraft's kinetic energy went into the its destruction and some penetration of the concrete, while the remaining 4% was dissipated in accelerating the 700-tonne slab. The maximum penetration of the concrete in that experiment was 60 mm, but comparison with fixed reactor containment needs to take account of the 4% of energy transmitted to the slab.

The study of a 1970s US power plant in a highly-populated area is assessing the possible effects of a successful terrorist attack which causes both meltdown of the core and a large breach in the containment structure - both extremely unlikely. It shows that a large fraction of the most hazardous radioactive isotopes, like those of iodine and tellurium, would never leave the site.

Much of the radioactive material would stick to surfaces inside the containment or becomes soluble salts that remain in the damaged containment building. Some radioactive material would nonetheless enter the environment some hours after the attack in this extreme scenario and affect areas up to several kilometers away. The extent and timing of this means that with walking-pace evacuation inside this radius it would not be a major health risk. However it could leave areas contaminated and hence displace people in the same way as a natural disaster, giving rise to economic rather than health consequences.

Looking at spent fuel storage pools, similar analyses showed no breach. Dry storage and transport casks retained their integrity. "There would be no release of radionuclides to the environment". Similarly, the massive structures mean that any terrorist attack even inside a plant (which are well defended) and causing loss of cooling, core melting and breach of containment would not result in any significant radioactive releases (EPRI, 2002).

Switzerland's Nuclear Safety Inspectorate studied a similar scenario and reported in 2003 that the danger of any radiation release from such a crash would be low for the older plants and extremely low for the newer ones.

The conservative design criteria which caused most power reactors to be shrouded by massive containment structures with biological shield has provided peace of mind in a suicide terrorist context. Ironically and as noted earlier, with better understanding of what happens in a core melt accident inside, they are now seen to be not nearly as necessary in that accident mitigation role as was originally assumed.

There is strong empirical evidence that learning from nuclear power plant operating experience has led, and continues to lead, to improvements in plant safety. This safety culture has been demonstrating its effectiveness for nearly two decades (see Figures 12 and 13), and it is this safety record that provides the basis for countries now considering constructing new nuclear power plants.

The number of unusual events reported to the Nuclear Regulatory Commission of the United States is presented in Figure 14 below.

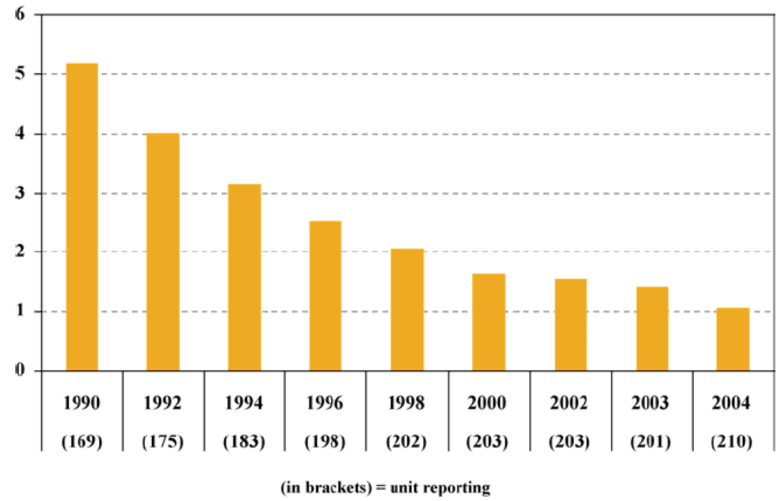

Fig. 12. Industrial accidents at nuclear power plants per 1 000 000 person-hours worked (IAEA 2006)

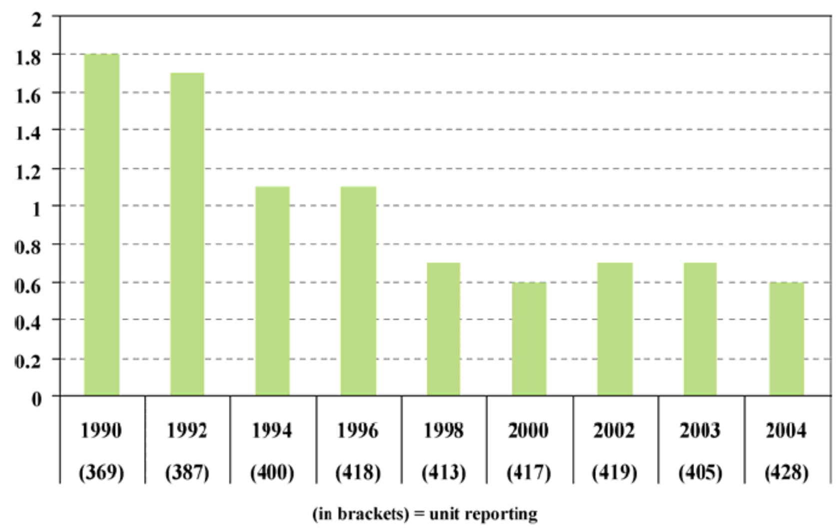

Fig. 13. Unplanned scrams per 7000 hours critical (IAEA, 2006)

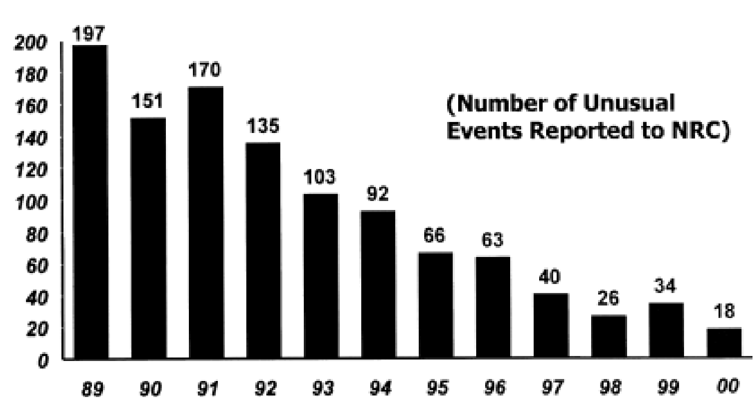

Fig. 14. Number of Unusual Events Reported to the Nuclear Regulatory Commission of the US

6. Safety Practices at Ghana Research Reactor-1 Centre

Ghana Research Reactor-1 (GHARR-1) is a 30 kW Chinese-built tank-in-pool reactor that was commissioned on 15th March 1995 (Akaho et al. 1995). It is cooled and moderated with light water. Light water and beryllium are used as reflectors. It is mainly used for Neutron Activation Analysis, production of short-lived radioisotopes, education and training. The diagram of the reactor is as shown in Figure 15 below.

The Atomic Energy Act 204 of 1964 established the Ghana Atomic Energy Commission (GAEC). Act 588 of 2000 which superseded Act 204 provided the basis of establishing research institutes to perform ten functions including: to make proposals to the Government of Ghana for legislation in the field of nuclear radiation and waste management and to advise the Government on questions relating to energy, science and technology.

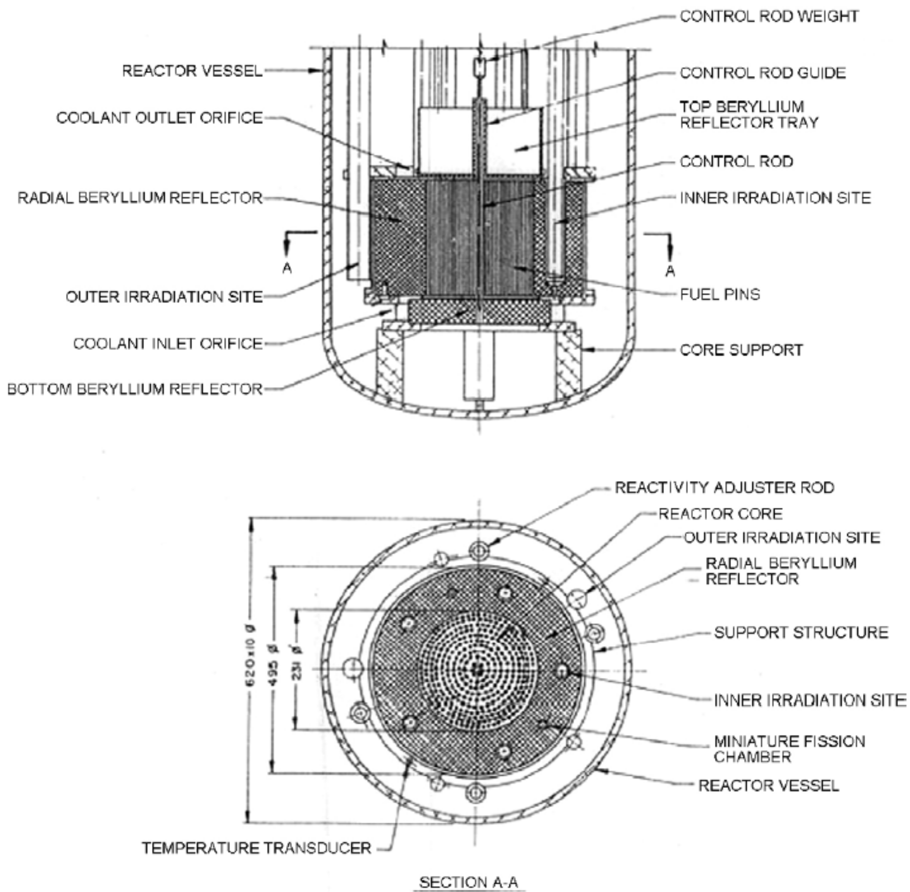

Fig. 15. Cross sectional view of GHARR-1 (Ampomah-Amoako et al, 2009)

The National Nuclear Research Institute (NNRI) is the Operating Organization of GHARR-1 and the Radiation Protection Board (RPB) which was established by the legislative instrument LI 1559 of PNDC Law 308 is the Regulatory Body that has issued license for the operation of the reactor. Both the NNRI and RPB are provided with Government of Ghana annual budgetary allocations for the operation and regulation of the reactor.

The organizational chart for GHARR-1 operation is as shown in Figure 16 below.

Safety documents that govern the day to day operation of the facility include the Safety Analysis Report, Emergency Plan, Periodic Inspection and Maintenance Plan, Maintenance and Quality Assurance Program, Operational Limiting conditions, Radiation Protection Procedures and Decommissioning Plan.

Records are properly kept for daily operations, maintenance and radiation monitoring to ensure that we obtain a fair idea of the gains made in radiation protection and safety practices. Regulations at the Centre are strictly adhered to. This has brought several commendations from the regulator and the International Atomic Energy Agency experts (IAEA, 1997). There is much collaboration with the Regulator in obtaining permission to apply the procedures in use at the Centre. Safety analysis is performed for every practice at the Centre. The Reactor Safety Committee (RSC) and Radiation Safety Committee (RadSC) have been playing advisory roles as well as reviewing procedures in use at the Centre. Both Committees meet four times in each year to assess the safety practices at the Centre.

Since training is the surest avenue for ensuring adherence to regulations, personnel are adequately trained to ensure safe practice. Every user of the facility undergoes Radiation Safety Training after which each one is assessed to ensure that the training has been effective.

The Radiation Protection Staff conducts regular monitoring in and out of the facility to obtain the effluence that emerges from the practice. Emergency Drills are performed annually to psychic the staff to react properly to emergency situations.

The above discussed practices coupled with the regular record keeping have helped the Centre to continue providing meaningful service to the Ghanaian community.

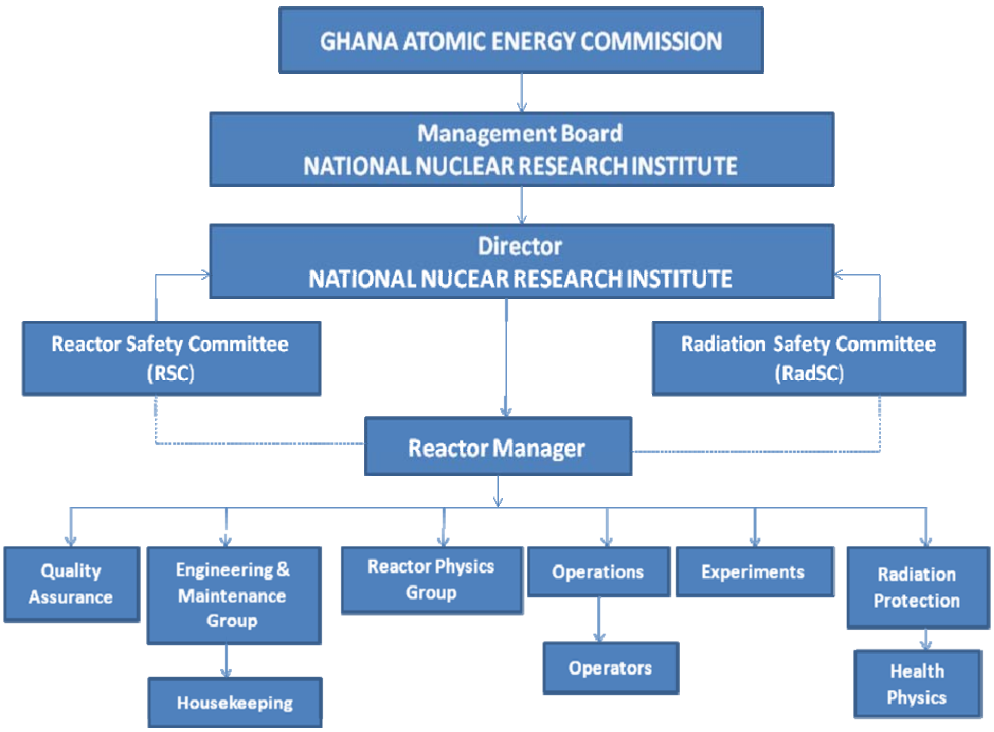

Fig. 16. Organizational Chart for GHARR-1 Centre (Akaho et al. 1995)

7. Conclusion

Nuclear power generation is a safe source of electric power that can be harnessed for the socio-economic development of Ghana. Countries that have tapped into this massive source of energy rank among the most developed in the world. Developing the technology today will cause future generations to commend our efforts. The safety practices at GHARR-1 Centre should serve as an encouraging beginning of the nuclear age in Ghana.

Global warming stirs the world in the face. The nation has to prepare for the future by getting involved in nuclear power generation.

Acknowledgement

The authors express appreciation to the Ghana Institution of Engineers for granting us the platform to inform the nation about the safety features of nuclear reactors and the concerns about the environmental impact of nuclear power. Participants at the Conference issued a communiqué in support of nuclear power in Ghana.

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Patirtis, apžvalgos, diskusijos

Atominės energijos gamyba Ganoje: aplinkosaugos ir saugos aspektai

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(gauta 2011 m. vasario mėn.; atiduota spaudai 2011 m. kovo mėn.)

Straipsnyje pateikiama apžvalga apie atominės energetikos gamybos ir su šia veikla susijusių atliekų saugos ir aplinkosaugos aspektus viso pasaulio mastu. Taip pat aprašyti eksperimentiniai tyrimai, atlikti Ganos atominiame turimų reaktoriuje. Apžvelgus mokslines studijas, daroma išvada apie atominės energetikos diegimo ir plėtros galimybes Ganoje.