Ethics of Nuclear Energy Technology

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Further contributions and case studies are invited in order to develop this draft report.

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<th>Description</th>
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<tbody>
<tr>
<td>DU:</td>
<td>Depleted Uranium</td>
</tr>
<tr>
<td>AREVA:</td>
<td>French public multinational industrial conglomerate founded in 2001</td>
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<tr>
<td>WNA:</td>
<td>World Nuclear Association</td>
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<tr>
<td>IAEA:</td>
<td>International Atomic Energy Agency</td>
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<tr>
<td>OECD:</td>
<td>Organization for Economic Cooperation and Development</td>
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<tr>
<td>IEA:</td>
<td>International Energy Agency</td>
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<tr>
<td>NEA:</td>
<td>Nuclear Energy Agency; a specialized agency within the OECD</td>
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<tr>
<td>WANO:</td>
<td>World Association of Nuclear Operators</td>
</tr>
<tr>
<td>GNEP:</td>
<td>Global Nuclear Energy Partnership</td>
</tr>
<tr>
<td>IMF:</td>
<td>International Monetary Fund</td>
</tr>
<tr>
<td>CTBT:</td>
<td>Comprehensive Test Ban Treaty</td>
</tr>
<tr>
<td>NRDC:</td>
<td>Natural Resources Defense Council</td>
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<tr>
<td>EPA:</td>
<td>Environmental Protection Agency</td>
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<tr>
<td>NEI:</td>
<td>Nuclear Energy Institute</td>
</tr>
<tr>
<td>NPT:</td>
<td>Non-proliferation Treaty</td>
</tr>
<tr>
<td>GHG:</td>
<td>Green House Gas</td>
</tr>
<tr>
<td>Millisievert(mSv):</td>
<td>Measure of the “dose” or amount of radiation received by people</td>
</tr>
<tr>
<td>ICRP:</td>
<td>International Council for Radiation Protection</td>
</tr>
<tr>
<td>ALARA:</td>
<td>“As low as reasonably achievable” - a concept by the ICRP for radiation risk assessment and management described in detail and substantiated in the recommendation of the ICRP of 1990.</td>
</tr>
<tr>
<td>PWR:</td>
<td>Pressurized water reactors. PWRs comprise the majority of nuclear power plants. Can be classified as LWR’s (light water reactors) that use light water as the primary coolant, and BWR’s (boiling water reactors) that use boiling water as the coolant.</td>
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<tr>
<td>PHWR:</td>
<td>Pressurized Heavy Water Reactor (also known as CANDU) use heavy water as the coolant.</td>
</tr>
<tr>
<td>CANDU:</td>
<td>Canada Deuterium Uranium Reactor uses uranium dioxide pellets with natural uranium (enriched with 0.7% U-235)</td>
</tr>
<tr>
<td>FBR:</td>
<td>Fast Breeder Reactors</td>
</tr>
<tr>
<td>MOX:</td>
<td>Mixed oxide fuel</td>
</tr>
<tr>
<td>D:</td>
<td>Deuterium (non-radioactive isotope of Hydrogen; used in heavy water as a moderator in a PHWR/CANDU reactor)</td>
</tr>
<tr>
<td>U₃O₈:</td>
<td>Triuranium octaoxide; Uranium ore commonly called uranium oxide or Pitchblende. Mined as a source of uranium for nuclear fuel.</td>
</tr>
<tr>
<td>U:</td>
<td>Uranium (radioactive element, U-235 isotope used as fuel in nuclear reactors). Nuclear fuel is enriched with 2-5% U-235.</td>
</tr>
<tr>
<td>Pu:</td>
<td>Plutonium (radioactive element, Pu-239 isotope is derived from U-235 in some reactors).</td>
</tr>
<tr>
<td>I:</td>
<td>Iodine (radioactive isotope I-131 has a half-life of 8.07 days). One of the principle sources of radiation in the Chernobyl nuclear plant accident.</td>
</tr>
<tr>
<td>Cs:</td>
<td>Cesium (radioactive element, Cs-137 has a half-life of 30.23 years). One of the principle sources of radiation in the Chernobyl nuclear plant accident.</td>
</tr>
<tr>
<td>Th:</td>
<td>Thorium (radioactive element, considered as an alternate fuel in breeder reactors).</td>
</tr>
<tr>
<td>kWh:</td>
<td>Kilo watt-hour is the amount of power generated or consumed in 1 hour</td>
</tr>
<tr>
<td>CCGT:</td>
<td>Combined Cycle Gas Turbine Power Plant.</td>
</tr>
<tr>
<td>IGCC:</td>
<td>Integrated Gasification Combined Cycle Power Plant.</td>
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</table>
Btu: British thermal unit. Defined as the amount of energy needed to raise the temperature of 1 pound of water by 1 degree Fahrenheit at 1 atmosphere of pressure.

Bq: Becquerel; unit of radioactivity. Defined as the activity of a quantity of radioactive material in which one nucleus decays per second.
1. Introduction

1.1 The focus and scope of nuclear energy in this report

Nuclear energy is one of the energy options for the future because in its day-to-day operations it does not produce CO₂ and other pollutants into the atmosphere, which cause global warming. In the ECCAP project there is comparative analysis of the ethics of nuclear energy compared with other energy options, in terms of efficiency, use of renewable energy, with discussion of new forms of energy production, or alternatives to manage greenhouse gas emissions such as carbon sequestration, to mention a few.¹

Nuclear energy technology can be applied for many different purposes. These include electricity production, weapons manufacture, production of medical isotopes, transportation (ranging from military submarine propulsion and space-based vehicle propulsion), industry (e.g., food irradiation and production of electronic components), and basic and applied research. While issues arising from all of these applications have significant consequences for society, this report focuses on ethical issues of energy production relating to climate change, and was developed initially under the Ethics of Energy Technologies in the Asia and the Pacific (EETAP)² project focusing on energy technologies. We therefore have foregone in-depth discussion of many of the ethical issues of other applications mentioned above.

The analysis in this report focuses on energy technologies for general consumption, rather than sources of transportation energy, for example, for submarine propulsion systems. The focus of this Working Group report is on the ethics of nuclear energy technologies for general electricity production. This is the vast majority of nuclear technology in use today. This report does not discuss all applications of nuclear technologies, such as for military uses.

This report on the ethics of nuclear energy technologies does not conclude by adopting one recommendation on whether nuclear energy should be used or not, and to what extent. This ethical analysis is not intended to provide single answers to specific policy options for contextually-sensitive decisions that each government needs to make, rather it aims to provide a framework for ethical analysis that can be used to examine nuclear energy technologies that can be applied for various cases and situations. Such analysis can be extended for particular situations and contexts. The scientific focus of the report attempts to depoliticize emotional debates over nuclear energy issues by examining aspects of nuclear technology from a neutral and scientific perspective.³

Examining these issues at a more fundamental level and analyzing policy options can reach greater consensus reached on policy regarding nuclear energy, which may reduce internal and international political tensions, which often hamper clear consideration of the ethics of nuclear energy. Mutual understanding of different perspectives, realizing that each perspective carries it own set of assumptions, which can be enriched with mutual recognition of other perspectives in order to discuss and implement policy.

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¹ In particular refer to ECCAP WG9 case studies.
² The EETAP projects that were coordinated by RUSHSAP, UNESCO Bangkok from September 2007 to September 2009, were incorporated under the ECCAP project in October 2009.
³ Science in terms of this report refers to both natural and social sciences.
1.2 Ethics of nuclear energy technology

The importance of nuclear energy technology is not limited to its widespread use nor the complex political and economic issues often present. The ethical analysis applied in this report is pluralistic, which “accepts different moral convictions and background while at the same time suggesting that a consensus on basic principles and rules in a certain social context can, and should, be reached” (Crane and Matten, 2007).

Pluralistic approaches have often been applied bioethics, business ethics, and environmental ethics. A *prima facie* approach to resolving a bioethical dilemma is often used in conjunction with ethical principles such as autonomy, beneficence, non-maleficence, and justice (Beauchamp and Childress, 2001). Ethics applies various ethical theories to choices including environmental issues, but a most significant issue is who or what is defined as a moral agent for ethical considerations. There are various schools of thought in environmental ethics including enlightened (or weak) anthropocentrism, animal liberation/rights theory, biocentrism, and ecocentrism (Yang, 2006).

The principle of non-maleficence is very important to people’s fears of nuclear technology. The ECCAP working groups 2 and 3 focus on examining different world views of nature, and visions of the future, respectively, which affect the balancing of the timescale and magnitude of risks and benefits expected from nuclear energy technology.

A comprehensive analysis of the ethical principles and goals adopted in international environmental instruments is in a parallel ECCAP working group (WG1) report. As stated in that report (Rai et al., 2010), there are a variety of views of the world, and depending on the view that people have there will be different conclusions. The academic literature is also replete with proposals for specific principles. For example, Robertson (2009) proposed principles including the principle of no absolutes, which also applies to general ethics, as a certain ethical aspect that cannot be either right or wrong. Specifically he included: the principle of no absolutes, principle of no acceptable risk, principle of no free lunch, principle of alternatives and consequences, principle of risk optimization, principle that good intentions are not good enough, principle that facts matter, and the principle of quantification where possible. Some of these are discussed in section 3.3. Many of the discussions that follow in this report are based on the application of one of these four basic principles of bioethics, namely justice, to the debates in nuclear energy as an energy option for the future.

1.3 Increased global significance of nuclear energy technology

Nuclear energy accounts for about 6 percent of primary energy supply and 15 percent of global electricity generation (IEA, 2008). Coal and hydroelectric sources dominate the market with about 40 and 20 percent shares respectively of world electricity production (IEA, 2008). Gas and oil produce about 25 percent (IEA, 2008). Renewable energy, such as solar and wind, account for less than 2 percent (IEA, 2008). States that use nuclear energy to provide a significant portion of their electricity (15% or more) include Armenia, Belgium, Bulgaria, Canada, the Czech Republic, Finland, France, Germany, Hungary, Japan, the Republic of Korea, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, the United Kingdom, and the United States (World Nuclear Association, 2009). Thus, while nuclear energy does not produce the level of electricity and energy of traditional fossil fuels, it is currently a significantly utilized alternative energy source.

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^4 ECCAP WG1 report, like other completed reports of the project, is openly available on the project website <http://www.unescobkk.org/rushsap/energyethics>
As of early 2009, global nuclear energy capacity was approximately 350 gigawatts, with 438 nuclear power reactors operating in 31 countries (European Nuclear Society, 2009). Of these, nearly half the reactors are found in three countries: the U.S., France, and Japan, which generate about 56 percent of the total global electricity originating from nuclear energy (IEA, 2008). Another 44 plants in 14 countries are under construction with a total capacity of approximately 39 GW (Figure 1). As Figure 1 shows, developing countries are planning to or are already building many new reactors.

Nuclear energy technology has become increasingly important in recent years, for a number of reasons, mainly:

First, it is widely accepted that rapid changes in energy prices can cause volatility in local and global economies. In fact, this idea is introduced routinely in microeconomics courses. Anecdotal evidence suggests that many countries are reassessing their energy security policies and contemplate including greater use of nuclear energy in the future because it may be more economically stable than fossil fuels (OECD, 2005).

Second, an increased focus on the effects of greenhouse gas (GHG) emissions and climate change has led to greater consideration of nuclear energy use because nuclear reactors do not emit GHG in daily operation, and in particular, carbon dioxide. The Kyoto Protocol to the UN Framework Convention on Climate Change (UNFCCC) created legally binding average GHG emissions between 6 to 8 percent below 1990 levels between the years 2008-2012 for 37 developed countries (UNFCCC, 2009). As countries look for clean alternatives to current energy sources, nuclear energy may help states achieve their targets under the Protocol (or other international and national commitments) and/or subsequent environmental agreements.

Figure 1. Number of reactors in operation, worldwide, January 2009 (IAEA 2009, modified)

Figure 2. Nuclear power plants under construction, January 2009 (IAEA 2009, modified).
Table 1: Nuclear power plants worldwide, in operation and under construction, as of January 2009 (IAEA Nuclear Technology Review 2009).

<table>
<thead>
<tr>
<th>Country</th>
<th>In Operation</th>
<th>Under Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Electr. net output</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MW</td>
</tr>
<tr>
<td>Argentina</td>
<td>2</td>
<td>935</td>
</tr>
<tr>
<td>Armenia</td>
<td>1</td>
<td>376</td>
</tr>
<tr>
<td>Belgium</td>
<td>7</td>
<td>5,824</td>
</tr>
<tr>
<td>Brazil</td>
<td>2</td>
<td>1,795</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>2</td>
<td>1,906</td>
</tr>
<tr>
<td>Canada</td>
<td>18</td>
<td>12,621</td>
</tr>
<tr>
<td>China</td>
<td>11</td>
<td>8,438</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>6</td>
<td>3,619</td>
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<tr>
<td>Finland</td>
<td>4</td>
<td>2,696</td>
</tr>
<tr>
<td>France</td>
<td>59</td>
<td>63,260</td>
</tr>
<tr>
<td>Germany</td>
<td>17</td>
<td>20,470</td>
</tr>
<tr>
<td>Hungary</td>
<td>4</td>
<td>1,829</td>
</tr>
<tr>
<td>India</td>
<td>17</td>
<td>3,782</td>
</tr>
<tr>
<td>Iran</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Japan</td>
<td>55</td>
<td>47,587</td>
</tr>
<tr>
<td>Korea, Republic</td>
<td>20</td>
<td>17,470</td>
</tr>
<tr>
<td>Lithuania</td>
<td>1</td>
<td>1,185</td>
</tr>
<tr>
<td>Mexico</td>
<td>2</td>
<td>1,300</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1</td>
<td>482</td>
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<tr>
<td>Pakistan</td>
<td>2</td>
<td>425</td>
</tr>
<tr>
<td>Romania</td>
<td>2</td>
<td>1,300</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>31</td>
<td>21,743</td>
</tr>
<tr>
<td>Slovakian Republic</td>
<td>4</td>
<td>1,688</td>
</tr>
<tr>
<td>Slovenia</td>
<td>1</td>
<td>666</td>
</tr>
<tr>
<td>South Africa</td>
<td>2</td>
<td>1,800</td>
</tr>
<tr>
<td>Spain</td>
<td>8</td>
<td>7,450</td>
</tr>
<tr>
<td>Sweden</td>
<td>10</td>
<td>8,995</td>
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<tr>
<td>Switzerland</td>
<td>5</td>
<td>3,220</td>
</tr>
<tr>
<td>Taiwan</td>
<td>6</td>
<td>4,921</td>
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<tr>
<td>Ukraine</td>
<td>15</td>
<td>13,107</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>19</td>
<td>10,097</td>
</tr>
<tr>
<td>USA</td>
<td>104</td>
<td>100,582</td>
</tr>
<tr>
<td>Total</td>
<td>438</td>
<td>371,569</td>
</tr>
</tbody>
</table>
Third, civilian nuclear technology can be used for military purposes, and increased proliferation concerns in recent international events focus attention on this “dual-use” aspect of nuclear technology. Recent disagreements between intergovernmental organizations, such as the International Atomic Energy Agency (IAEA) and the UN Security Council (Sagan, 2006; Hagel, 2008; Crail, 2008; Ikenberry, 2007), with particular states over safeguards highlight these concerns.

Fourth, an increasing number of countries without previous nuclear energy experience are showing interest in developing nuclear energy capacity for various reasons. Twenty-five countries have shown interest in building at least one large nuclear reactor by 2030 (Sokolski, 2009). This will cause a different international relations picture with regards to nuclear technology, including nuclear fuel supply, in the future.
2. The ethics of nuclear energy technology

2.1 Nuclear science

Nuclear energy can be harnessed from one of two types of nuclear reactions, fusion and fission. In nuclear fusion, atoms are fused or combined to form different atoms. This reaction powers stars such as the sun. It is currently uneconomical as a source of electricity, although it has been harnessed in thermonuclear weapons. Current projects, such as the ITER fusion research collaboration (ITER, 2009), are working on developing nuclear fusion as an electricity source. While estimates vary, this technology is several decades away from commercial use (see for example Sharp, 2007). Moreover, even if and when it arrives for commercial electricity production, it may be expensive (Nuttall, 2008). However, fusion has the potential to generate larger amounts of electricity at lower prices and with minimal impact to the environment. In addition, the source of fuel, tritium, is extremely abundant and inexpensive; very little radioactive waste would be produced; and it will not use uranium nor plutonium which can be diverted for weapons manufacture unlike nuclear fission (Nuttall, 2008).

The second type of nuclear reaction is fission. In nuclear fission, atoms are split and energy is generated. This form of energy has been utilized in both electricity production and weapons. It is the focus in the remainder of this report.

Nuclear fusion and fission have not given rise to any significant intrinsic ethical debate, because atoms themselves are not moral agents. This is in contrast to fields such as biotechnology, biology and the life sciences, where complex ethical issues involving animal use, or genetic modification of DNA of plants and bacteria to produce biofuels, arise.

However, when nuclear science is applied as an energy technology, a number of ethical concerns are generated. Most of these stem from the potentially dangerous effects of radiation, the reactor technology used to harness nuclear energy, potential diversion for military use, the cost of such technology, and international control of nuclear technology.

2.2 Nuclear radiation

The risks of radiation from nuclear technology are difficult to assess. While general agreement exists on the dangerous effects of high-dose radiation, effects of radiation at low-dosages (less than 100 millisieverts) remain uncertain. One hypothesis, the linear no-threshold (LNT) hypothesis, posits that harmful radiation effects are linearly proportional to the radiation dose (IAEA, 2007). Competing hypotheses posit that radiation is harmless below certain thresholds but harmful above them. Yet another hypothesis, called radiation hormesis, posits that low radiation doses are actually beneficial below a certain threshold and harmful above it (Kaiser, 2003). Thus, it is difficult for policy-makers and the general public to understand radiation safety options when even experts cannot agree on low-dose radiation effects.

The International Council for Radiation Protection (ICRP) is a guidance setting authority for radiation protection, comprised of biologists, physicians, and physicists, among others (ICRP, 2009). The ICRP proposes “as low as reasonably achievable” (ALARA) as being a goal for risk assessment and management (ICRP, 2005). However, the precise definition is unclear, and varied legal and ethical interpretations can be applied. A common understanding on ALARA or safety level of low radiation doses may therefore assist policy-makers, the general public, and even workers in the nuclear industry, to understand and formulate policy options.
2.3 Nuclear Energy Plants

The nuclear energy plant generates electricity from nuclear energy. More specifically, the nuclear reactor, housed within the plant, converts the heat energy generated from nuclear fission to electricity. Nuclear fuel is formed into pellets that are stacked inside fuel rods (WNA, 2009). Nuclear reactors can contain tens of thousands of such fuel rods. The heat is captured by moderators, which also cool the fuel rods and prevent them from melting (WNA, 2009). The most common moderator is pressurized water, because it has a high capacity to absorb heat. The pressurized water, which travels in a primary loop, moves through a heat exchanger, transmits the heat energy to a secondary water loop. The water in the secondary loop is then turned to steam, which drives a turbine in a heat engine. The turbine generates electromagnetic energy, which is converted to electricity. The steam is often seen evaporating from the large cooling towers of nuclear energy plants.

Control rods are used to regulate the amount of energy produced by the reactor. Usually, the more the control rods are inserted into the core, the more the fission reaction is inhibited. They are also able to stop the nuclear reaction in the reactor in an emergency. One design has them hanging over the cores by a mechanism such as magnetic clamps such that when an emergency occurs, the magnets automatically turn off and the control rods fall into the core, stopping the nuclear reaction (Online Ethics Center, 2009).

Nuclear plants are considered an ethical issue because of this possibility of a nuclear meltdown. A nuclear meltdown can occur if fission creates too much energy and overheats, causing damage to the surrounding structures and releasing radiation into the environment. It can also occur if the structures surrounding the nuclear reactor themselves suffer a malfunction, allowing radiation leaks. Finally, it can occur if cooling systems, such as the pressurized water moderator, malfunctions, damage the structures surrounding the nuclear reactor, and release radiation into the environment. Accidents at Three-Mile Island in the United States (1979) and Chernobyl in Ukraine (1986) have prompted the public to raise serious questions about nuclear safety (OECD, 2005).

However when we consider the types of risk inherent in most energy options it may be difficult to argue that nuclear energy should be absolutely prohibited simply because accidents can occur. Nuclear energy can be considered as an extremely safe source of electricity. As a comparison, several thousand persons die in coal mine accidents each year; not to mention the added complications of health to miners and the public in general, and environmental effects.

However on the other hand, it is equally difficult to argue that such accidents should be downplayed and are “rare”. Utilitarianism may consider a simple multiplication product of the magnitude of the harm multiplied by the probability of its occurrence. In the case of nuclear meltdowns, the magnitude of the harm can be enormous. While Three-Mile Island did not produce any direct recorded deaths from radiation, the indirect health and environmental damage was inconclusive. The accident in fact demonstrated the importance of safety systems. Even though half the reactor core melted, the radionuclides that were released mostly plated out on the inside of the plant or dissolved in the condensing steam. The containment building housing the reactor also prevented any significant release of radioactivity. The reactor’s other protection systems also came into action.

In 1966, A US Fermi-1 prototype fast breeder reactor (FBR), near Detroit was closed down due to a blockage in coolant flow and the consequent melt down of some fuel. However, no radiation was released and no injuries were reported (WNA Encyclopedia of Earth, 2010).
The nuclear disaster in Chernobyl in April 1986 (WNA 2010), however, was a unique event in recent times that actually led to radiation-induced fatalities. Over 50 confirmed deaths due to radiation burns or people developing cancer after the accident have been reported. 28 people died within weeks due to radiation exposure, and it caused radiation sickness in 200-300 fire fighters and staff and contaminated large areas of Belarus, Russia and beyond. It is estimated that about 5% of the radioactive material from the Chernobyl-4 reactor core was released from the plant.\(^5\)

Chernobyl and Three-Mile Island are the only major accidents of a nuclear meltdown. More recently, comprehensive safety systems have evolved, embracing defense-in-depth, multiple redundant safety systems, and inherent and passive safety systems. Moreover, many documents considering ethical issues and guidelines exist, such as those from the World Association of Nuclear Operators (WANO) and the International Atomic Energy Agency (IAEA). The IAEA Nuclear Security Guidelines published in 2006, provides eleven guiding principles and includes guidance on design, testing qualifying and purchasing of radiation monitoring equipment to all its Member States. It includes tools and procedures for nuclear forensic investigations, identification of radioactive sources and devices and so on (IAEA: Nuclear Safety and Security)). However, perhaps more comprehensive, integrated, and measurable safety cultures can be implemented through mechanisms ranging from safety guidelines to employee performance appraisals (WNA, 2010).

Table 2, below shows some international nuclear event scale (INES) which are nuclear power related accidents and their associated impacts. The data was collated by the IAEA and OECD to communicate and standardize the reporting of nuclear accidents to the public (WNA Encyclopedia of Earth, 2010, European Nuclear Society) in the aftermath of the Chernobyl accident. The INES scale runs from “0” (no safety significance) to “7” (major accident) and was initially used to classify events occurring at power plants only.\(^6\)

A second issue arising from nuclear plants is low-level radiation leaks into the environment. There have been studies showing that there are such possible leaks, but the overall results have been inconclusive. For instance, a recent German study found that children under the age of five living less than five kilometres from nuclear plant exhaust stacks had twice the risk for contracting leukaemia as those residing more than five kilometres (Nussbaum, 2009). However, such studies are contracted by the conclusions of other studies, as the report admits (Nussbaum, 2009). The scientific issue may revolve around study methodologies and what “statistically significant” really means. As to the scientific cause, this may be from the water being used to drive the turbines in the secondary loop.

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\(^5\) The Chernobyl (Ukraine) nuclear power plant disaster in April 1986 was the result of a flawed RBMK-1000 reactor, which was a Soviet design. It was a boiling water reactor using uranium dioxide (enriched with 2% U-235). A series of operator actions including the disabling of auto shut down mechanisms prior to an attempted testing of the reactor turbines led to a dramatic power surge. This caused the reactor to become extremely unstable, resulting in a violent steam explosion and release of fission products into the atmosphere. While most of the released material was deposited nearby as dust and debris, the lighter material was carried by wind over Belarus, Russia, Scandinavia and other parts of Europe. Radiation doses on the first day were estimated in the range of 20,000 millisieverts (mSv), causing 28 deaths - 6 of which were firemen. The initial radiation exposure in contaminated areas was due to short-lived (half-life of 8 days) radioactive iodine (I-131) and later cesium (Cs-137, half-life of 30 years) which are the main hazards.

\(^6\) The INES was subsequently extended to rate events at any nuclear facility and during transport of radioactive material thereby covering incidents of radiation exposure in people involved. Since 2008, the INES has also been extended to cover any event associated with the transport, storage and use of radio-active material and radiation sources from those occurring at nuclear facilities (European Nuclear Society). More information on nuclear events from radiation sources, transport and other nuclear facility related accidents can be found in the IAEA publications (www.IAEA.org)
containing low levels of radiation, which are carried away into the environment, or in the waste produced by the plant, which may inadvertently be leaked into the surroundings. These are also subject to an ethical calculation, but the information on magnitudes and probabilities are inconclusive. Nuclear fallout from accidents decades ago may have also resulted in low-level radiation, although this would be at a reduced level today. For instance, strontium-90, which is considered hazardous, was dispersed from Chernobyl (EPA, 2009).

Table 2: International Nuclear and Radiological Event Scale (IAEA-OECD publication; see www-news.iaea.org for more information)

<table>
<thead>
<tr>
<th>Level, Descriptor</th>
<th>Off-Site Impact</th>
<th>On-Site Impact</th>
<th>Defence-in-Depth Degradation*</th>
<th>Examples</th>
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</thead>
<tbody>
<tr>
<td>7 - Major Accident</td>
<td>Major Release: Widespread health and environmental effects</td>
<td></td>
<td>Chernobyl, Ukraine, 1986 (fuel meltdown and fire)</td>
<td></td>
</tr>
<tr>
<td>6 - Serious Accident</td>
<td>Significant Release: Full implementation of local emergency plans</td>
<td></td>
<td>Mayak at Ozersk, Russia, 1957 (reprocessing plant criticality)</td>
<td></td>
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<tr>
<td>5 - Accident with Off-Site Risks</td>
<td>Limited Release: Partial implementation of local emergency plans</td>
<td>Severe damage to reactor core or to radiological barriers</td>
<td>Windscale, UK, 1957 (military). Three Mile Island, USA, 1979 (fuel melting).</td>
<td></td>
</tr>
<tr>
<td>2 - Incident</td>
<td>Nil</td>
<td>Significant spread of contamination, overexposure of worker</td>
<td>Incidents with significant failures in safety provisions</td>
<td></td>
</tr>
<tr>
<td>1 - Anomaly</td>
<td>Nil</td>
<td>Nil</td>
<td>Anomaly beyond the authorized operating regime</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Nil</td>
<td>Nil</td>
<td>No safety significance</td>
<td></td>
</tr>
<tr>
<td>Below Scale</td>
<td>Nil</td>
<td>Nil</td>
<td>No safety relevance</td>
<td></td>
</tr>
</tbody>
</table>

*Defence-in-depth covers events that did not directly impact people or environment, but for which the range of measures put in place did not function as intended.
1 Denotes events without safety significance- called deviations and are classified “Below Scale” or “Level 0”

The above issues should, however, be considered in light of zero GHG emissions of nuclear plants. The environmental benefits of nuclear energy can be seen clearly in France. In the 1980s, because of concerns over imported oil, France more than tripled its nuclear energy production. During the same period, total pollution from the French electric power system dropped by 80-90 percent (Nuclear Energy Institute, 2009).

2.4 Nuclear Fuel

Uranium, the most commonly used nuclear fuel, exists as one of several isotopes in nature. The nuclear fuel extracted from nature is U\textsuperscript{-235}, which is present in small percentages in uranium ore. Most of the uranium in the ore is found as U\textsuperscript{-238}, which will not undergo fission with current technology.

It is useful to speak of the nuclear fuel cycle, which traces the steps of nuclear fuel from its inception to its eventual destruction. Nuclear experts often divide the nuclear fuel cycle into two parts, the “front end” and the “back end”. Before it can be used in a nuclear reactor, the U\textsuperscript{-235} is mined, milled, converted, enriched, and fabricated into fuel assemblies. Collectively, these steps comprise the front end of the nuclear fuel cycle (WNA, 2009). The fuel undergoes fission in a nuclear reactor, produces energy, which is converted to electricity, and becomes “spent fuel”. Spent fuel enters the back end of the nuclear fuel cycle (WNA, 2009). The back end comprises the steps of temporary storage, reprocessing, and recycling, and waste disposal (WNA, 2009).

U\textsuperscript{-235} is found within ore deposits around the world. More than 50% of the world’s uranium production is derived from mines in Canada, Australia, and Kazakhstan (Tradetech, 2009). The uranium ore is mined from the ground using conventional mining techniques: open-pit, underground, in-situ, and as a by-product of mining other minerals such as phosphates (Tradetech, 2009). As such, uranium extraction is subject to all of the ethical issues that conventional mining entails, as it can inflict harm on human health and the environment.

Although different mining techniques produce different effects, there are three general categories of direct detrimental effects. The first is physical, and includes unstable waste rock piles, old buildings, open mine workings, pits and tunnels, derelict buildings and machines, and water filled voids (IAEA, 2008). The second is chemical, and includes ponds of contaminated water, acid drainage from reactive waste, old processing chemicals and residues (IAEA, 2008). Physical and chemical hazards can represent significant human health and environmental problems to the local community and surrounding areas, especially if they are not addressed immediately. Chemical problems, in particular, can cause large ecological and economic damage if not properly treated and/or remediated.

A third detrimental effect of uranium mining, which is not shared by conventional mining, is radiological, and includes uranium mill tailings, unprocessed uranium-bearing ore, scale and sludge in old plants, contaminated scrap metal, and release of uranium dust and radon gas into the environment (IAEA, 2008). Some radiological hazards can be addressed as with physical and chemical problems, but if they are not addressed quickly, they can cause economic and ecological damage to the local community and surrounding areas. Other radiological hazards require specialized methods of remediation and treatment.

One widely documented study showed the radiological effects of uranium mining on human health. During the 1950s, many Navajo uranium miners in the U.S. later developed
cancer due to radon gas exposure (Miller, 2007; Brugge, 2002). While former miners have been partially compensated, there have been reports that hundreds of abandoned mines have not been cleaned up and present environmental and health risks in many communities (Los Angeles Times, 2006). There have been other instances where radioactive contamination has affected uranium miners. For instance, Areva, a French state-owned nuclear power company, did not inform its affected mine workers in Niger about the health risks of uranium mining despite detrimental health effects (Public Eye, 2008).

Aside from the human health and environmental effects of uranium mining, there are also equity issues. Although many formulations of equity exist, one divides intragenerational equity from intergenerational equity (see for example, Okrent, 1999). Intergenerational equity, a concept popularized by the Brundtland Commission Report (WCED, 1987), can be formulated as being equivalent “to the rejection of a ‘time preference’ that would allow the living to take advantage of their position and strength” (Agius, 2006) over future generations. If uranium mines are not remediated, a cost is imposed on future generations. In terms of intragenerational equity, which is similar to the concept of economic equity, it may not be fair or just for those who benefitted from nuclear power, who are in one part of the world (e.g. certain parts of the US, Japan, and France) and who benefit from the relatively clean generation of nuclear power, to be exempt from the relatively dirty, and sometimes dangerous, effects of uranium mining.

Equity in sharing risks and benefits is a problem, which is shared with other power sources. For instance, wind turbines (in wind power) are generated on land close to those who must endure the noise and obstruction to their visual scenery. Many people are displaced by dams. However, the effects are particularly acute for uranium mining due to radiological effects. A counter consideration, however, is that mining villages and towns may benefit economically from mining activities.

A fourth detrimental effect of uranium mining is GHG emissions. Although nuclear reactors themselves do not emit GHGs, uranium mining is not completely GHG emission free. Mining is done using fossil fuel energy. Heavy machinery is often operated using fossil fuels, for instance. However, in comparison to fossil fuel production and consumption, the levels are likely significantly lower.

Soon after uranium ore is mined, it is crushed and ground to a slurry in the milling process. It is then recovered as uranium oxide (U₃O₈) concentrate (WNA, 2009). Because uranium needs to be gasified before it can be enriched in gas centrifuges, the uranium oxide is converted to gaseous uranium hexafluoride (UF₆) in the conversion process (WNA, 2009). While there are small amounts of radioactivity and chemicals produced into waste, there do not appear to be significant and particular ethical concerns with the technology.

While some kinds of nuclear reactors, such as the Canadian CANDU reactors (Defeyes, 2005), do not require enriched uranium, the vast majority of reactors in operation do. As the proportion of U-235 present in uranium hexafluoride is low (about 0.7%), it must be enriched to about 3.5% where it becomes usable in conventional nuclear energy reactors (WNA, 2009). This is almost always accomplished by a cascade of gas centrifuges, which successively increase the concentration of U-235 in the gas until it reaches an acceptable level (WNA, 2009). The remaining U-238 is called “tails” and they are often referred to as “depleted uranium”, or DU, known for high density. DU is often used to form yacht keels (WNA, 2009), counterweights in aircraft, and radiation shielding. It is also used in weapons manufacture as defensive armour plating and armour-piercing rounds (WHO, 2003).
Enrichment is one of the most ethically controversial areas of the nuclear fuel cycle. Two ethical issues relate to its possible use in producing weapons-grade uranium and the use of depleted uranium.

Gas centrifuges are a bottleneck technology to producing weapons-grade uranium, as the technology is highly complex (Burton, 2008). However, once mastered for the purposes of producing reactor-grade uranium, it can be easily modified to produce weapons-grade uranium. If the gas centrifuges used by Pakistan for its uranium weapons were to be used to make enough fuel to power Iran’s Bushehr 1-GWe reactor, an estimated 100,000 centrifuges would be required. However, it only takes about 1,500 more such centrifuges to produce 90%-enriched uranium (i.e., weapons-grade uranium) in one year (Burton, 2008). A centrifuge three times more efficient would require 35,000 centrifuges to produce reactor-grade uranium, and only 250 additional centrifuges to produce one weapon (Burton, 2008).

The ethics of so-called “dual-use” technologies has been debated. On the one hand, restraining civilian use of nuclear energy is difficult for a number of reasons. It is guaranteed under the so-called third pillar of the Nuclear Non-Proliferation Treaty (NPT), Article IV, which provides the “inalienable right of all Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination”, a quasi-deontological ethic. It even provides for “due consideration for the needs of the developing areas of the world”, which includes states such as Iran which are currently under much scrutiny. Restraining access to an abundant source of energy from persons in the developing world is ethically challenging. Moreover, such nuclear energy may displace use of fossil fuel consumption, which may be beneficial to the environment considering nuclear energy’s non-existent GHG emission. Finally, energy security in the form of enrichment is not considered to be morally objectionable per se, especially when other nations possess such capabilities.

On the other hand, such technology can bring nuclear energy-using countries, which enrich their own uranium into nearly de facto nuclear weaponpossessing states. This may catalyze a regional arms race in volatile regions of the world, which may more than offset any international benefit that would be initially seen from reduced GHG emissions.

The possibility of proliferation-prone enrichment has led to a discussion on how to render it more proliferation-resistant. Here, the focus has been on preventing new nations from enriching and creating attractive alternatives (Burton, 2008). For instance, the Republic of Korea obtains 39% of its electricity from nuclear power and elects not to enrich nuclear fuel itself because it is a financially sound decision. However, other states such as Malaysia, Indonesia, and Brazil have voiced suspicions of potential suppliers (Burton, 2008).

DU weapons are widely criticized as being unethical. DU is weakly radioactive and due to a long half-life, remains radioactive. The aerosol produced by DU weapons can potentially contaminate wide areas as they become scattered and can be inhaled (Mitsuakou, 2003). At least one scientific study has shown that DU has carcinogenic potential (Miller, 2007). International NGOs, such as the International Campaign to Ban DU, have taken up the cause to ban such weapons. As further information, the appendix contains a response to the Depleted Uranium (DU) Resolution adopted at the United Nations General Assembly that was developed at the EETAP Conference held in 2008 in Hiroshima, Japan.

Once the uranium is enriched, it is transferred to a fuel fabrication plant, where it is eventually formed as part of nuclear fuel rods and fuel rod assemblies (WNA, 2009). While there are small amounts of radioactivity and chemicals produced into waste, there do not appear to be significant and particular ethical concerns with the technology.
Once the nuclear fuel assemblies have been produced, the front end of the nuclear fuel cycle comes to an end, and the nuclear fuel assemblies enter the reactor. The U-235 fissions and produces heat which is converted to electricity. It is eventually turned into plutonium and wastes (WNA, 2009). Depending on the reactor design, fuel, and operation, about one-third of the spent fuel is removed every year or 18 months, to be replaced with fresh fuel (WNA, 2009).

### 2.5 Nuclear Waste

Freshly spent nuclear fuel assemblies are highly radioactive and are stored in ponds usually located at the power plant. The rods stay in the ponds for several years. The ponds act as a barrier against radiation and absorb the heat from the fuel (water has a high capacity to absorb heat). Eventually, the spent fuel becomes less radioactive. The longer it is stored, the easier it is to handle, due to the decay of radioactivity (Richter, 2008). However, there is enough radiation leftover to act as a deterrent against nuclear theft or diversion (Richter, 2008). There are two alternatives for spent fuel. The first is to reprocess, and the second is long-term storage.

During reprocessing, the uranium and plutonium are separated from the wastes. The uranium is returned to the nuclear fuel cycle at the point of conversion (WNA, 2009b). This fuel contains about 50% Pu-239 (WNA, 2009b). The 3% wastes are eventually turned into solid wastes (WNA, 2009b). This waste can be a source of concern, as it needs to be stored.

Reprocessing has been criticized as being expensive, posing security threats, harming the environment and not eliminating the need for geological repositories. Non-government organizations (NGO) quote the economic and environmental disaster of the West Valley reprocessing facility in the U.S., the fuel leak from the Sellafield THORP reprocessing plant in the U.K. and the massive cost overruns of the Rokkasho reprocessing plant in Japan as some of the examples to highlight the risks of the reprocessing option (Public Citizen, 2008). A standard 1-GWe reactor produces roughly 200 kg of plutonium per year, enough in principle for about 20 weapons (Richter, 2008). Reactor-grade plutonium can be in theory used to build a “dirty bomb” which is a sub-nuclear or non-nuclear weapon causing significant loss of life and environmental damage. If the reactor-grade plutonium were available to rogue elements, it could also be used to manufacture a fission weapon, although it may be unreliable (Richter, 2008).

If the spent fuel is not reprocessed, it must be stored. This raises several ethical issues, which include the inadequacies of current waste management decision-making, under-utilized ethical principles including intergenerational equity concerns, and the perceived lack of information by the public.

First, current waste management decisions\(^7\) are often criticized because they do not incorporate social uncertainties. Current radiation waste risk modeling is based on probabilities of equipment and structural failures, natural disasters, and other physical variables. They often do not consider constantly changing attitudes and ethical opinions, and when they do, it is often subjective. For instance, a detailed study of three different participative decision-making processes employed by France, U.K. and Republic of Korea for their long-term radiation waste management showed that current methods of determining social risk perceptions are predominantly subjective (Rao, 2008).

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\(^7\) For example, cost benefit analysis (CBA), best available technology (BAT), and best available technology not entailing excessive costs (BATNEEC).
Second, ethical principles such as the precautionary principle are often under-utilized when applied to radiation waste management. For instance, in the UK, some of the criteria in formal decision-making models used by the Committee on Radioactive Waste Management (CoRWM) correspond to the precautionary principle, but this was more an ad hoc approach (Rao, 2008). The principle is not explicitly acknowledged and modelled into the decision-making process (CoRWM, 2006). In fact, a study of long-term radiation waste management decisions involving geological repositories in the UK, France, and Korea reveal there is no systematic and objective consideration of all the Rio Declaration principles. The study also found that there is inadequate consideration of risk issues, legal principles, and ethical standards. With respect to risk issues, countries did not use objective risk trade-off considerations. With respect to legal principles and ethical standards, key legal principles and ethical standards were discussed on an ad hoc basis but not objectively incorporated into their decision-making (Rao, 2008).

Radioactive waste lasts a long time and therefore intergenerational equity is one of the prime ethical considerations for waste management. As an illustration, the intergenerational ethical issues posed by repositories span risks pertaining to underground aquifer layers, agriculture in the vicinity of the repository site, radiation risks in the event of accidents, risks of earthquakes, and other natural calamities. The IAEA’s principles on radioactive waste management (IAEA, 1995) have two specific references to intergenerational equity. Principle 4 states that “radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today”. Principle 5 states, that “radioactive waste shall be managed in such a way that will not impose undue burdens on future generations”. Yet, implementing these principles in radioactive waste policy decision-making, given the scientific uncertainties associated with long-term health risk assessment in principle 4, and ethical considerations of what constitutes “undue burden” in principle 5, is a challenge. On the one hand, medical research is progressing on radiation-induced diseases such as cancer, and on the other hand, the health profile of the population as a whole is changing due to changing food and lifestyle habits. To avoid imposing an ethical burden on future generations with a legacy of wastes buried underground, reversibility and retrievability technologies are frequently positioned as a solution, but the costs of such options are substantial.

Third, the general public often feels that it does not have access to appropriate safety information. For instance, a 2002 joint study of the French nuclear research agency Institut de Radioprotection et de Surete Nucleaire (IRSN) and the Belgian nuclear research agency Studiecentrum voor Kernenergie (SCK), based on interviews of over 1000 members of the public each in France and Belgium, revealed that more than 60% of the population do not believe that they possess truthful knowledge about nuclear waste risks (Carle et al., 2003). Moreover, while experts can process nuclear information, have access to the latest information, and can ask for the opinions of their colleagues, the general public does not. It may therefore be difficult for the public to grasp the complexity and extremely long timeframes involved in radioactive waste management. To provide an example of the complexity, the US Department of Energy developed a Probabilistic Risk Assessment of the proposed Yucca Mountain repository, which involved 177 variables (Cohen, 2001).

The timeframes are an issue for the “public” for societies in the future that we cannot yet imagine. For instance, it takes thousands of years for the high level waste, which is produced by the reactor to reach the radioactivity levels of the original uranium ore (WNA, 2001). Further, the media often negatively portrays the generation of radioactive waste.

All of this may result in low social acceptability of radiation waste management decisions. Public protests ranging from mild demonstrations to violence on the streets have been observed (Choi et al., 2008). To improve societal acceptability, many stakeholder
models are evolving, especially with reference to long-term geological disposal. Despite these efforts however, much of the public is not yet persuaded.

2.6 Nuclear fuel supply

A closely related issue to the nuclear fuel cycle is the supply of nuclear fuel. The main source of nuclear fuel is U-235 as mentioned before. While plutonium-239 (Pu-239) is used in reactors, it is derived ultimately from U-235 and is not considered an originating fuel. It cannot be extracted as part of an ore, and its supply depends on U-235. Another possibly nuclear fuel for commercial use in the future is thorium, to be used in commercial breeder reactors.

Because about 65,000 tonnes of uranium per year are used, the amount of uranium available may be expected to last for approximately 80 years at current rates. However, such a forecast leaves out many considerations. It does not reflect the significant percentage of nuclear fuel traditionally derived from the highly enriched nuclear fuel of decommissioned nuclear weapons (from the year 2000 the dilution of 30 tonnes of military high-enriched uranium has been displacing about 10,600 tonnes of uranium oxide per year from mines, which represents about 13% of the world's reactor requirements) (WNA, 2009c). It does not also factor in unknown uranium deposits (which is expected to increase significantly (WNA, 2009c)), which typically increase when energy prices increase because exploration is intensified; increasing efficiency of nuclear reactors; and new technology (WNA, 2009c). Finally, greater and more efficient reprocessing is likely to extend the amount of usable nuclear fuel (WNA, 2009c). Nuclear experts have expressed confidence in the supply (Deffeyes, 2006).

Most of the world’s uranium is obtained from Canada (20.5%), Kazakhstan (19.4%) and Australia (19.2%) (WNA, 2009). The current supply of uranium is therefore stable, as these countries tend to have lower political and economic risk. For instance, the UN Conference on Trade and Development Index (TDI) in 2007 ranked Canada as 10th and Australia as 16th (data on Kazakhstan was not available) (WNA, 2009d). Table 3 presents the data obtained from the World Nuclear Association of the known recoverable amount of uranium (from mines) as of 2007.

However, there will be significant political differences in the manner in which such resources are controlled. For instance, some states, such as Malaysia, Indonesia, and Brazil are suspicious of their potential suppliers (Richter, 2008). The GNEP and Nuclear Supplier’s group, present complex issues because is it fair that the GNEP supplier nations are the only states to supply? In the same way, is it sure by all person’s standards and worldview that the Nuclear Supplier’s Group is fair?

There have been many proposals to guarantee fuel supplies to countries without uranium enrichment facilities or those who must purchase their uranium fuel. One such proposal is the Global Nuclear Energy Partnership (GNEP). Another well-known proposal, which has recently gained momentum, is the private Nuclear Threat Initiative (NTI). Mohammed ElBaradei, the former director-general of the International Atomic Energy Agency (IAEA), has laid out three principles for a fuel guarantee framework (Pomper, 2009). First, the fuel bank mechanism should be non-political, non-discriminatory, and open to any state in compliance with its IAEA safeguards obligations (Pomper, 2009). This ensures that nuclear material and technology are not diverted from peaceful to military uses (Pomper, 2009). Second, any release of the material should be determined by non-political criteria established in advance and applied objectively and consistently (Pomper, 2009). Third, "no state should be required to give up its rights under the nuclear Nonproliferation Treaty (NPT) regarding any part of the nuclear fuel cycle." (Pomper, 2009). Finally, "one part of a possible
new framework is to reach agreement that all new enrichment and reprocessing activities should be placed exclusively under multilateral control, to be followed by agreement to convert all existing facilities from national to multilateral control as well” (Pomper, 2009).

Table 3: Data showing the distribution of recoverable Uranium reserves.

<table>
<thead>
<tr>
<th>Country</th>
<th>Tonnes U</th>
<th>Percentage of World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>1,243,000</td>
<td>23%</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>817,000</td>
<td>15%</td>
</tr>
<tr>
<td>Russia</td>
<td>545,000</td>
<td>10%</td>
</tr>
<tr>
<td>South Africa</td>
<td>435,000</td>
<td>8%</td>
</tr>
<tr>
<td>Canada</td>
<td>423,000</td>
<td>8%</td>
</tr>
<tr>
<td>USA</td>
<td>342,000</td>
<td>6%</td>
</tr>
<tr>
<td>Brazil</td>
<td>278,000</td>
<td>5%</td>
</tr>
<tr>
<td>Namibia</td>
<td>275,000</td>
<td>5%</td>
</tr>
<tr>
<td>Niger</td>
<td>274,000</td>
<td>5%</td>
</tr>
<tr>
<td>Ukraine</td>
<td>200,000</td>
<td>4%</td>
</tr>
<tr>
<td>Jordan</td>
<td>112,000</td>
<td>2%</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>111,000</td>
<td>2%</td>
</tr>
<tr>
<td>India</td>
<td>73,000</td>
<td>1%</td>
</tr>
<tr>
<td>China</td>
<td>66,000</td>
<td>1%</td>
</tr>
<tr>
<td>Mongolia</td>
<td>62,000</td>
<td>1%</td>
</tr>
<tr>
<td>Other</td>
<td>210,000</td>
<td>4%</td>
</tr>
<tr>
<td>World total</td>
<td>5,469,000</td>
<td></td>
</tr>
</tbody>
</table>

Another way to control nuclear fuel export and transfer is through less formal political groups, such as the Nuclear Suppliers Group (NSG), which according to its website is a “group of nuclear supplier countries which seeks to contribute to the non-proliferation of nuclear weapons through the implementation of Guidelines for nuclear exports and nuclear related exports” (NSG, 2009). Nuclear fuel, along with nuclear technology, is the group’s focus.

2.7 Nuclear proliferation

Nuclear energy is intimately linked to nuclear weapons, as the science and engineering for civilian purposes can be adapted for military uses. The issue of such “dual-use technologies” and proliferation is an issue, which is absent in discussions of the ethics of most other energy technologies. For some, nuclear proliferation should be absolutely prohibited. For others, over-reaction to such concerns may conflict with their rights to civilian nuclear energy use.

Using proliferation-resistant nuclear technologies may play a key role in seeking to minimize proliferation risks. Since there is no completely proliferation-resistant fuel cycle or nuclear facility, proliferation resistance is evaluated in relative rather than absolute terms. In nuclear fission, proliferation resistance means getting state actors to stop or reduce uranium enrichment and reprocessing and the spread of these technologies, and preventing non-state actors from obtaining fuel at any point in the nuclear fuel cycle.

The Nuclear Non-Proliferation Treaty (NPT) guarantees peaceful use of nuclear technology, and enrichment and reprocessing fall under this category. Moreover, the spread of these technologies, when used for purely civilian purposes, is also allowed under the NPT.
Thus, the reduction of these activities and spread of the technology must be built-in to the technology itself, such as the GNEP plans to research, and/or international political pressure must be applied. The use of export controls and IAEA technical verifications are also tools to be used in this regard.

However, traditionally ever since the Atoms for Peace Programme saw unintended consequences of nuclear proliferation, the world is quite wary when it comes to nuclear technology cooperation. There was intense debate between 2008-2009 over the risks and implications of nuclear fuel trade. The recent rhetorical debates on both sides when India, a non-Nuclear Non-Proliferation Treaty (NPT) signatory, signed the 123 agreement with the U.S for peaceful nuclear cooperation, is a case in point.

The costs and benefits of nuclear cooperation are no longer limited to closed-door discussions of scientists or strategic analysts or government bureaucrats - an omnipresent media, Internet and other social interaction mechanisms lead to rapid formation and influence of public opinion on these issues. Under such pressures, maintaining diplomacy and cooperation without compromising on the ethics of cooperation is an extremely challenging task for both the cooperating governments and the beneficiary governments alike.

The use of export controls and technical verifications here may also reduce any risks of proliferation, chiefly directed at non-state actors such as terrorists. Advancements in proliferation-resistant technologies may also help. While Nunn (2008) and others have proposed steps to curtail nuclear terrorism, such risks and prevention measures as well as technological investments may be costly, and the risk still is non-zero. It may be beneficial to take a more integrated approach to countering this threat. For instance, tactics may need to shift from a predominantly technology and fissile material stock monitoring approach to targeting terror financing and social capital.

The IAEA (2007) has released an advisory on countering nuclear terrorism. Apart from providing an overview of legal instruments, this advisory also includes initiatives of international organizations such as WCO, Interpol, Europol, and the Universal Postal Union in countering terrorism. A paradigm shift in terms of how the world community looks at the security of nuclear assets and material, ranging from technological advancements in material detection to raising social capital, may be underway. Governments may benefit from designing a complex fabric of nuclear security on a socio-technical basis. This may involve educating citizens, politicians, and policy-makers to the security implications of nuclear technologies and implementing complex security measures without causing alarm.

The success of proliferation resistant technologies would ease fears over the development of newer nuclear power plants. The availability of existing fission technologies, which are not proliferation resistant, needs to be carefully monitored, if it is not phased out.

2.8 Nuclear international relations

Theories of international relations explain the way international politics works, but each of the currently prevailing theories is incomplete when taken alone (Snyder, 2004). In particular, none of these theories provide a means to discern proliferation intentions and

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8 Despite being a non-signatory to the Non-Proliferation Treaty, India has consistently allowed safeguards on its nuclear sites. It has thus far abided to the general procedural conditions by regulations imposing inspections on a regular basis, more specifically safeguards by the IAEA involving six of its fourteen nuclear reactors. Nevertheless it is feared by some that although India will use given fuel for peaceful energy purposes it does leave room for India to use its present domestic fuel sources to further develop further nuclear weapons.
behaviours of states. This suggests that rather than forcing nuclear driven policies based on a particular approach, policy-makers may benefit from modelling international impacts using multi-disciplinary inputs. According to one defence expert, “what technologies must we develop to understand and influence nation states...WMD proliferators...the path to understand people, their cultures, motivations, intentions, opinions and perceptions lies in applying interdisciplinary quantitative and computational social science methods from mathematics, statistics, economics, political science, cultural anthropology, sociology, neuroscience, and modelling and simulation” (Popp 2005). Innovative computer modelling approaches based on complex social computing could be developed that could serve as an ethical platform to objectively evaluate proliferation intentions of states (Rao, 2008).

International Relations experts such as Snyder (2004) suggest three different theoretical approaches - realism, liberalism and constructivism. Realism depicts international affairs as a struggle for power among self-interested states and is generally pessimistic about the prospects for eliminating conflict and war. Refinements of realistic schools of thought include neo-realism and offense defence theory. Theories under the liberalistic approach imply that cooperation was more pervasive but each view offers a different recipe for promoting it. Economic interdependence spread of democracy and creating incentives for cooperation to multilateral agencies such as the IEA and IMF are some of the recipes suggested by the liberalists.

Snyder (2004) suggests that constructivist approaches emphasize the impact of ideas upon society. The common theme of constructionist strands is the capacity of societal discourse to shape how political actors define themselves and their interests, and thus modify their behaviour. Constructivists believe that international politics is shaped by persuasive ideas, collective values, culture and social identities. The destructive power of nuclear technologies has an uncanny ability to affect all the three theories in a complex manner and still pose difficult questions for world peace.

Nuclear technology cooperation between developed and developing countries exists in various fields, most notably technology transfer and funding. Such cooperation, however, come with proliferation concerns. Collective approaches such as the GNEP (Global Nuclear Energy Partnership) were purportedly designed for peaceful purposes while simultaneously minimizing the attendant risks. Through GNEP, the United States will work with other nations possessing advanced nuclear technologies to develop new proliferation-resistant recycling technologies in order to produce more energy, reduce waste and minimize proliferation risks. Partner nations will develop a fuel services program to provide nuclear fuel to states not possessing enrichment and reprocessing capabilities, which tend to be mostly developing countries, allowing them access to sources of nuclear energy in a cost effective manner in exchange for their commitment to forgo enrichment and reprocessing activities (Department of Energy, 2006). However, the envisaged mechanism of establishing a group of fuel supplier states raises ethical questions of selective technology sharing and dominance that discriminate between states. As the fuel recipient states tend to be mostly developing countries, a further ethical dilemma is raised: whether nuclear energy cooperation really provides enhanced energy security for developing states or merely shifts their dependencies from fossil fuel countries to nuclear fuel countries.

Dependency of developing countries on the developed countries for nuclear fuel, funding, and nuclear commerce inevitably influences recipient states. In the event of increased use of nuclear energy, in particular as envisaged in developing countries such as India and in the simultaneous event of denial of reprocessing technology transfers and rights under regimes such as GNEP, the issue of how to deal with spent fuel would create regional concerns with complex geopolitical issues. Such developments should perhaps be monitored and an environment for free and positive relations among states be fostered.
Empirical findings by Asal and Beardsley (2007) using international crisis behaviour datasets have suggested that while the probability of a full-scale war declines sharply if the number of nuclear powers involved in a crisis increases, it still does not rule out minor clashes. Probability of serious clashes is more or less immune to the number of nuclear actors involved in the crisis. Consequently an important observation for policy makers is that while the role of credible nuclear deterrents can probably avert full-scale wars, it still cannot assure peace since minor and serious clashes are still likely to continue. Hence it becomes necessary to look at de-escalation mechanisms in tandem with deterrence mechanisms. This marks another key complex attribute of nuclear technologies wherein non-nuclear mechanisms surround the nuclear issue, making ethics based policy action interventions quite challenging.

The advent of the atomic bomb has changed the face of international relations conclusively. While nuclear-influenced foreign policies are inevitable, sufficient checks and balances need to be institutionalized by organizations such as the U.N. in order to avoid runaway reactions of nation states to nuclear challenges.

2.9 Nuclear Agreements

The governing regime that regulate the development and use of nuclear technology, nuclear materials and related equipments, their export and trade, whether for nuclear power or non-power application, and the prevention from the diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices, consists of numerous bilateral, regional and multilateral agreements. Predominated by safety and security related norms, there 166 comprehensive safeguards agreements and 140 additional protocols, this regulatory mechanism together with a highly institutionalized, quasi jurisdictional system of safeguards and verification under the national and international monitoring, constitute a complex structure of specialized legal and institutional framework - nuclear law. Defined as “the body of special legal norms created to regulate the conduct of legal or natural persons engaged in activities related to fissionable materials, ionizing radiation and exposure to natural sources of radiation”, nuclear law is well established domain in public international law. By contrast to this ‘broader’ definition, to highlight at this point, other sources in a more traditional fashion refer it as a non-proliferation regime. On this ground, for example, it is classified into: i) bilateral treaties between the two former superpowers, the USA and the USSR, ii) regional treaties on nuclear weapon free zones and, iii) multilateral global agreements on non proliferation and peaceful use of nuclear technology (Bassiouni, 2000). Legal and ethical implications of these two approaches is discussed in the “Non-proliferation: safeguards and nuclear export control” section below.

11 This section is devoted to legal regulations. For historic evolution and the current state of institutional framework, including: IAEA, The Zangger Committee, Nuclear Suppliers Group and OECD, see International Nuclear Law: History, Evolution and Outlook. pp.13-91. OECD 2010. NEA No.6934. Also, MCIS CNS NPT Briefing Book 2010 Annecy Edition, Part II, Sections H and M. For the role and status of Ten-Nation Disarmament Committee and Eighteen-Nation Committee on Disarmament, see also UN General Assembly Official Records: Tenth Special Session, Supplement No. 2 (A/S-10/2)
Apart from disarmament and non-proliferation regimes, the Office of Legal Affairs of IAEA, European Atomic Energy Community, Nuclear Law Committee of OECD/NEA and International Nuclear Law Association are amongst the key contributors in the advancement and harmonization of international nuclear law, in a substantive part, the development of nuclear science and technology, nuclear liability and compensation regimes with due contribution of the USA, German and French national legislations as standard setters. The evolution of nuclear law and its scope of coverage correspond to the general tendency observed in the development of international public law; that is, the expansion and specialization of rules, characterized as:

“… fragmentation of the international social world has attained legal significance especially as it has been accompanied by the emergence of specialized and relatively autonomous rules or rule-complexes, legal institutions and spheres of legal practice. What once appeared to be governed by “general international law” has become the field of operation for such specialist systems as “trade law”, “human rights law”, “environmental law”, “law of the sea”, “European law”…”. (UNILC, 2006).13

In a relatively short period of time from its original intention to prohibit nuclear disarmament and non-proliferation, dated back to the 1950s, it has been expanded to address management of radiological crisis, management of radioactive waste and sources, transportation and storage of nuclear and radioactive materials, physical protection of nuclear facilities including from terrorist attack, nuclear installation and decommissioning, and liabilities from nuclear damage and compensation. In other words, this expansion aimed to “… encompass all aspects of the use of radioactivity” (Leger, 2007).14

Diversification of nuclear law is another attribute of its evolution. Based on objectives and substantive content of norms, and principles applied, development of this legal domain can be grouped into the following (relatively) distinct clusters of specialization: i) non-proliferation regime, ii) the liability and compensation for nuclear damage, iii) safety, radiological protection and emergency response, iv) spent nuclear fuel and radioactive waste management. These areas of functional specialization, with exception for liability and compensation regime, also correspond with their chronological order. Whereas, the liability for nuclear damage significantly preceded the compensation and dated back to the 1960s when Paris Convention on Third party Liability in the Field of Nuclear Energy (1960) and Vienna Convention on Civil Liability for Nuclear damage (1963) were adopted. The Chernobyl accident in 1986 and the terrorist attack on 11 September 2001 in the USA had “…brought to light the limitations and deficiencies of the legal regimes in place, both in terms of preventing nuclear accidents and in terms of compensating victims thereof in the event of their occurrence… [T]he insurance cover of damage resulting from a nuclear accident caused by a terrorist attack.”15

Before the closer analysis of these clusters, a few remarks on equally important and growing spheres of nuclear affairs, namely: transport of nuclear and radioactive materials, environmental protection related to nuclear activities, scientific, commercial and industrial application, and nuclear trade and export. Yet none of them evolved to such a level to constitute a rule-specific cluster as they are ruled out by safety-liability and security-non-proliferation regimes.


Notwithstanding the fact that development of nuclear law had preceded the modern environmental law, we refer to the Stockholm Conference on the Human Environment (1972) and emergence of the ‘first generation’ of environmental laws, yet common approach among the nuclear lawyers is that nuclear activities should be the subject of environmental law and governed by its principles, rather to establish specific rules driven by this ‘technical’ law. In fact, number of environmental principles recognized and incorporated into the nuclear law under the rules-complexes for safety - waste management as a preventive measures, and damage - liability related instruments for emergency response and effective mitigation of caused damages. Nevertheless, “…the dominance of the traditional anthropocentric approach of nuclear law, which focuses on protecting people and property instead of the environment…” rooted back to its origin, “…to guide and regulate the development of nuclear activities for civil use.” (Emmerechts, 2010:122)\textsuperscript{17}

Trade and export of nuclear technologies and related materials, and scientific cooperation - nuclear energy for electricity production, is likely to form an independent cluster of rules. Among the driving factors, a growing investment from the private sector in parallel with strengthening environmental standards require a stronger tie with the financial sector of insurers. Provided that current “minimum competition rules” (Michel, 2010)\textsuperscript{18} apply and the global nuclear power market is liberalized, then a major challenge for nuclear law is to articulate its prohibitory and regulatory measures with an account to balance legitimate interests of environment, society and a development of nuclear industry. An ethical issue is how to prioritize these interests.

Despite this wide area of cross-sectoral and multi level application, norms and rules of nuclear law remains interdependent. Dictated by the nature of the risks associated to the use of nuclear and radioactive materials, this strong interdependence is only observed in environmental law (Leger, 2007). This interdependence secured by fundamental concepts of nuclear law: security, safety, and safeguards. So-called ‘Three-S’ concept, it reflects the key “…technical [emphasize is added] areas which need to be addressed in establishing an adequate legislative and regulatory framework.” (Stoiber et al. 2010:4)\textsuperscript{19} Hence no total


\textsuperscript{18} Ibid., p. 275. Quentin Michel, The control of International Nuclear Trade -Difficult to Balance between Trade Development and Non Proliferation of Nuclear Weapons.


Other sources, see the footnote reference No.7, suggests relatively longer list of fundamental concepts, namely: security, safety, responsibility, permission, continuous control, compensation, sustainable development, compliance, independence, transparency and international cooperation.
illumination of potential risks and associated damages, nuclear liability (supplemented by compensation) is regarded to be one of the fundamental concepts of nuclear law, in addition to the ‘Three-S’.

**Non-proliferation: safeguards and nuclear export control**

In the course of long lasting negotiations between the USSR and USA from 1955 to 1963 on arms control and disarmament, which was temporarily suspended in 1960 due to the first French nuclear test and limited to exchanges of views, the three nuclear-weapon States held that agreement on non-proliferation should not be dependent on the implementation of other disarmament measures. Giving the urgency and higher importance on preventing the proliferation of nuclear weapons, UN by its Resolution 2028 (XX) from 1965 called the Conference of the Eighteen-Nation Committee on Disarmament - a broker between the USSR and USA, for urgent consideration of the question of non-proliferation of nuclear weapons and to negotiate international treaty. In three years, draft text of the Treaty on the Non-proliferation of Nuclear Weapons was ready for voting; and after this occasion of voting by 95 countries were in favour, 4 against with 21 abstentions, the Treaty became open for signature and entered into force in 1970. In addition to the Limited Test Ban Treaty (1963), it was another significant step to further the goals of general and complete disarmament and, more particularly, nuclear disarmament at the global level. In 1995, at the Review and Extension Conference, the duration of the Treaty was extended indefinitely by a consensus decision and with 190 states as the parties to the Treaty (as of June 2010) it had became the most widely accepted arms control treaty.

The Treaty does distinguish nuclear weapon states (NWS) and non-nuclear weapon states (NNWS) as it was mandated by UN and laid out in its Resolution 2028 (XX) through the list of five principles that had have served as the basics at the time of NPT negotiation. One of these principles stipulated that “the treaty should embody an acceptable balance of mutual responsibilities and obligations of the nuclear and non-nuclear Powers" and embodied into the Articles I and VI of NPT, accordingly, NWS obliged not to transfer nuclear weapons or explosive devices and to pursue “… negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament…” With regard to NNWS, the Article II of the Treaty imposed them not to receive, transfer or manufacture nuclear weapons and other explosive devices. Furthermore, in compliance with the paragraph 1 of the Article III, the NNWS must accept the full scope safeguards to allow international and unilateral (the country of origin) inspection “… on all source or special fissionable material in all peaceful nuclear activities within the territory of such State, under its jurisdiction, or carried out under its control anywhere.” Articles IV and VII of the Treaty contains other substantial elements, accordingly, the right to conclude nuclear weapon free zone, though no security assurance

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22 As defined by NPT, this is a state which has not manufactured and exploded a nuclear weapon or other nuclear explosive device prior to 1 January 1967. Whereas, NNWS are any state that manufactured and exploded a nuclear weapon or other nuclear explosive device prior to 1 January 1967. Including, the Russian Federation (as successor state to the Soviet Union), the United States, the United Kingdom, China and France. Therefore, by NPT definition India, Israel and Pakistan, are not a nuclear-weapon state under the NPT definition See MCIS CNS NPT Briefing Book, 2010 Annecy Edition. p.25 on Abbreviations, Acronyms and Glossary of Terms.

23 UN General Assembly, Resolution 2028 (XX), the 1382nd plenary meeting, 19 November 1965.
from NWS and acknowledgement of “the inalienable right” for the peaceful uses of nuclear energy.

The two approaches to nuclear law highlighted earlier in “Nuclear law: overview” section of this report, have different emphasizes when to define and weight the status of the core elements, chiefly in a view of their interrelation. The most fundamental distinction, that is, equity in status and significance amongst the core elements of NPT as opposed to the solo supremacy of non-proliferation, had its origin from contesting views on value superiority between partial measures – non-proliferation of nuclear weapons and ban of a nuclear test, and comprehensive measures to pursue complete and general disarmament including nuclear weapons.

From the perspective of military doctrine and policy debate, these two approaches do reflect two contrary positions on general disarmament; on the one hand, it is argued that arms races will be in lead to a tension and war. The opposing view suggests that military spending is just a reflection of existing insecurities and conflicts, which have to be settled first. From the latter perspective, while some military strategists continue to support arsenals with more destructive power to help achieve their objectives, there is increasingly less support for the possession and threat of use of nuclear weapons (Advisory Opinion 1996, Para 62). As an example, the bilateral agreements between the United States and USSR, now Russia, have led to actual reduction of nuclear weapons and associated technology. The Treaty between the USA and the USSR on the limitation of anti-ballistic missile systems (ABM Treaty), 1972, on the limitation of strategic offensive arms (1979), on the elimination of their intermediate-range and short-range missiles (1988), the limitation of their underground nuclear weapons tests (1990) have brought about notable reductions in both the countries belligerent nuclear capability. With the expiry of an earlier Treaty on strategic offensive arms reduction (2002), a fresh treaty has been signed in April 2010 by Russia and the United States pledging further reductions (START II, 2010).

**The “three pillars” as the core elements**

The NPT key elements that embodied in the Articles I and III for NWS, along with the Articles II and IV, that primarily concerned to NNWS, have come to be described as ‘three pillars’ of the Treaty – non-proliferation, disarmament and peaceful use (Kuppuswamy, 2006). This concept ascribes that the three elements constituting the central structure of NPT are equal in significance and therefore, a balance among these three components must be maintained. Proponents of this position include NWS and NNWS; however, objections related to the operational environment of safeguards and export control rules are divisive issues between the NWS plus NNWS exporters as opposed to the NNWS recipients.

A substantial part of the dispute focused on a procedural matter. On the ground of lack of transparency it is argued that safeguards and export control rules are discriminatory towards the nuclear recipients; and they impose unjustified burden and barriers, and thereby, hindering one of the core elements of NPT - the peaceful use of nuclear energy. It is fact that number of rules on safeguards and export control has been discussed outside of UN, and the NPT governing forum - the Review Conference and IAEA, but through the ‘Zangger Committee’ and ‘London Club’ or the Nuclear Suppliers Group informal groups24 which has no status in international law. The Zangger Committee was set to reach a common

24With 37 Members as of the year 2010 including all NWS, the Committee, named after its first Chairman Prof. Claude Zangger, was formed following the coming into force of the Nuclear Non-Proliferation Treaty (NPT), to serve as the "faithful interpreter" of its Article III, paragraph 2, to harmonize the interpretation of nuclear export control policies for NPT Parties. Source: http://www.zanggercommittee.org/Seiten/default.aspx
understanding among the nuclear exporters on the terms of the Article III.2 of NPT: “(a) source or special fissionable material” and “(b) equipment or material especially designed or prepared for the processing, use or production of special fissionable material.” Perhaps it is natural that those who possess know-how on nuclear technology are technically in a relevant position to define it, so did the Zangger Committee; who unilaterally had set the conditions for nuclear export through enlisting nuclear equipments and materials, based on its ‘understanding’ of thereof, on a ‘Trigger List’ which meant to trigger safeguards requirements in case of their export. The outcome of its decision communicated to IAEA Director in a form of a letter along with a request to inform IAEA Member States about the decision.25

The Conference of Parties to NPT, on the other hand, through a series of recommendations adopted at its Review Conferences, while acknowledging the Zangger Committee’s contribution on non-proliferation of the nuclear weapons, has requested for a dialogue with NPT State Parties and underlined that balance between the core elements of NPT should be maintained. For example, at the Fourth NPT Review Conference in 1990, it was stressed that:
“... the Conference requests that the Zangger Committee should continue to take appropriate measures to ensure that the export requirements laid down by it do not hamper the acquisition of such items by states parties for the development of nuclear energy for peaceful uses.” 26

Another recommendation from the NPT Review and Extension Conference, 1995, stated that:
“The Conference notes that the application by all States of the understandings of the Zangger Committee would contribute to the strengthening of the non-proliferation regime. The Conference calls for wider participation in international consultations among all interested States parties concerning the formulation and review of such guidelines [emphasis is added], which relate to the implementation of States parties obligations under article III, paragraph 2.” 27

As a response to the critics on lack of transparency, the Zangger Committee has launched an Outreach Programme between the Committee and the nuclear recipient countries, 2001. One of the objectives of this Programme is “to provide opportunities for open dialogue on issues of common interest and concern on non-proliferation and nuclear export controls,” yet underlining that “the outreach programme reflects the fact that the Zangger Committee is a technical body with a remit to interpret article III.2 of the NPT and as such outreach will not be a political dialogue.” 28 Furthermore, the Committee has prepared a Working Paper on Multilateral Nuclear Supply Principles of the Zangger Committee, in 2000 and 2005; wherein, its role has been seen to “… essentially contributes to the

25 For example, Annex to INFCIRC/209/Rev.1 from 1990 on Zangger Committee’s decision Regarding the Export of Nuclear Material and of Certain Categories of Equipment and other Material: “I have the honour to refer to [relevant previous communication in which the Government of [Member State] informed you that it had decided to act in accordance with certain procedures in relation to exports of nuclear material and certain categories of equipment and other material which you circulated to all Member States of the Agency as document INFCIRC/209, and to [relevant subsequent communications] informing you of its desire to clarify certain items described in the Annex "Clarification of Items on the Trigger List" to Memorandum B and circulated as documents INFCIRC/209/Mods.1,2,3 and 4. […] I should be grateful if you would circulate the text of this letter and its attachment, together with the appended background paper, to all Member States for their information.
26 NPT/CONF.IV/DC/1/Add.3 (a), p. 5, paragraph 27
27 INFCIRC/482, attachment, paragraphs 5 and 7.
interpretation of article III, paragraph 2, of the Treaty and thereby offers guidance to all parties to the Treaty”, which in turn “… helps to prevent the diversion of exported nuclear material and equipment or material from peaceful purposes to nuclear weapons or other nuclear explosive devices, [thereby] furthers the objectives of the Treaty and enhances the security of all States.”

The Nuclear Suppliers Group (NSG), a nuclear exporting countries set up in 1975, put forward two sets of guidelines for nuclear transfers and for nuclear related dual-use items and technology: the first set of guidelines, governs those items that are especially designed or prepared for nuclear use while the second, for dual-use items and technologies - missing elements in NPT. Compared to the Zangger Committee, the NSG has broader objectives (INFCIRC/539);30 not restricted with the Article III.2 of the NPT, that is nuclear equipment and material, the NSG also does meant to regulate the technology and know-how, termed as sensitive facilities, technology and weapons-useable materials,31 in addition to the dual use items. Like in case of the Zangger Committee, concerns on discriminatory approaches over the safeguards transparency and nuclear trade, inclusiveness and open dialogue remains one of the main demands of a large number of NNWS – nuclear recipient states in particular; and was called for by the NPT Review and Extension Conference (1995) and embodied in the final document on “Principles and Objectives.”

These procedural ‘barriers’ have had an effect on substantive matters as well. The NSG’s strengthened rules originated from a proliferation concern; as they were introduced to counter noncompliance states, but also to counter with the ‘free-riders’ on the system; those, who did share the benefits of a global and regional security derived from non-proliferation regime, while remains free from any commitments and responsibilities; unlike the NPT state parties, whose “inalienable right” for the peaceful uses of nuclear energy which is recognized under the NPT had become the subject of a tighter control and regulations. These stringent requirements on safeguards and export control include:

i) The principle of universality - the full scope safeguards agreement with IAEA is a condition to transfer nuclear materials, whether the recipient country is the NWS, NNWS or non party to the Treaty;

ii) Dual-use regime - a list of nuclear related dual-use equipment, materials, software and related technology that can be used for nuclear and non-nuclear purposes. This List supplements the Trigger List;

iii) ‘Catch-all’ clause - any nuclear items, materials and related technologies not included in Trigger and Dual-Use lists, but with a potential to be used for proliferation are under the subject of authorization;

iv) Non-proliferation principle - when there is an unacceptable risk of diversion and/or when there is an unacceptable risk of diversion to acts of nuclear terrorism, no authorization to transfer of dual-use nuclear material, equipment, software and related technology; notwithstanding the safeguards agreement with IAEA and the recipient government’s assurances of peaceful use and physical protection measures.

Rules under the items ii), iii) and iv) implies that existing safeguards mechanism – full scope safeguards, which is based on declared information and data related to imported (and exported) items is not sufficient, but to widen it to undeclared or in-country inspectorate.

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31 Guidelines for Transfers of Nuclear-Related Dual-Use Equipment, Materials, Software and Related Technology. INFCIRC/254
While item iv) shifts the burden of proof from international regime - IAEA assurance, into the judgment of nuclear suppliers. This received as interference with sovereignty, in a manner that “...manifestly contradicted one of the fundamental principles of the NPT which granted NNWS the right to develop research, production and use of nuclear energy for peaceful purposes,” and “… the intention of industrialized countries to continue their monopoly” over the nuclear know-how based on a “minimum competition rules;” while for others, as a tool of industrial espionage by advanced nuclear states. Contrary, NSG rules on export control characterized as “… they have no single orientation (Thorn, 1996);” in a sense that NSG is neither trade promoter or to restrict it, and that is, an implied adherence to non-proliferation. While others more explicit, suggesting that NSG with its new export regulations apparently changing existing balance between non-proliferation and peaceful use, and replacing it by priority rankings (Michel, 2010).

The original intent as the core element

In contrast to the three pillars concept, it is argued that “... the language pointing to the three pillars as essential and equal components of the non-proliferation is not just misleading - it poses a danger to the security of those nations [...] The other two elements [disarmament and the peaceful use] of the treaty are not really pillars at all; they are subordinate clauses under the central purpose of nuclear non-proliferation” (Spring, 2010). Proponents of this concept mainly rely on original intent method when interpret the NPT, that is an attempt to ascertain what the negotiators meant when they agreed on NPT, and on historic documents. On this ground, especially in attempt to frame ‘the original intent’, it is said that it was the most ambitious attempt ever made by the nuclear weapon states in their efforts to constrain the acquisition and use of nuclear weapons (Perkovich, 2006). In this regard, we can recall the remarks of the late U.S. President John F. Kennedy’s interview from March 1963, who said: “[...] I am haunted by the feeling that by 1970 [...] there may be 10 nuclear powers instead of 4 and by 1975, 15 or 20 [...] I would regard that as the greatest possible danger and hazard” (Graham Jr., 2010), amongst the popular quotations in computing the ‘original intention’.

In the same spirit, one of the principles laid down in the UN Resolution 2028 “the treaty should embody an acceptable balance of mutual responsibilities and obligations of the nuclear and non-nuclear powers” is claimed to be the central bargain of NPT. (Graham Jr., 1996; Graham Jr., 2010). This balance of responsibilities and obligations has been seen as a strategic arrangement founded on a ‘central or grand bargain’: wherein, nuclear energy for peace was made available in exchange for nonnuclear weapon state’s commitment not to obtain and manufacture the nuclear weapons. The nuclear weapons states, in return, pursue

33 Ibid., p. 275.
nuclear disarmament to grant the participation of NNWS, industrialized countries in particular. (Graham Jr., 1996; Graham Jr., 2010; Miller and Scheiman, 2002 – emphasis in italics is added).\(^\text{39}\)

The NPT is a framework agreement: a flexible instrument to accommodate an evolving security environment and to timely address new proliferation threats as an outcome of advancement in nuclear technology, for example, NPT does not address nuclear technology but equipment and material, this and other gaps were addressed without amending the text of the Treaty; arguments on ‘bargain’ are not credible from a legal perspective. In this regard, and at the first level argument, derived from the framework nature of the Treaty; examination of the operation of the Treaty takes place every five years during the NPT Review Conference, suggesting that NPT is legally open for interpretation by its 190 signatory state parties rather to attempt to ‘reveal’ the original intent or its dominance. Otherwise, and the second argument, a validity of NPT from a perspective of its source could be questioned. Indeed, despite the fact that general and complete disarmament was co-sponsored by all UN Members and was mandated by UN General Assembly Resolution 2028 (XX). Importantly, a significant part of the NPT negotiation process went outside of the UN system through the Eighteen-Nation Committee on Disarmament - a negotiating body of restricted membership, which had composed exclusively of representatives that agreed by USSR and USA.\(^\text{40}\)

Other grounds of the critique of ‘the original intention’ point towards horizontal proliferation, whereas the NPT, is more or less but a reflection of misleading notion of those few states who had have a know-how in building the nuclear weapons and prohibition of a vertical proliferation seem to be achieved. It is natural that ‘the original intention’ had been accused for it’s sought to preserve the status quo, in other words, a legalization of military and technological advances, and a post-ratification division into the ‘haves’ and the ‘have-nots’.\(^\text{41}\) As earlier as in 1965, eight members of the Eighteen-Nation Committee on Disarmament\(^\text{42}\) had emphasized that non-proliferation, as a partial measure, should run in parallel with comprehensive measures in order to achieve the goals of general and complete disarmament of nuclear weapons. These two contesting positions on value priorities, partial and comprehensive measures, put in query existing international customary and humanitarian law practices and principles.

\(^{39}\) Marvin Miller and Lawrence Scheinman, *Israel, India, and Pakistan: Engaging the Non-NPT States in the Nonproliferation Regime*, Arms Control Today, December 2003. See also, the reference number 29 and 30.


\(^{41}\) During the Cold War, as an example, International Industrial list was designed to impose trade and export restrictions on non-proliferation uses of nuclear materials and related equipments.

3. Economics of Nuclear Energy Technology

3.1. Feasibility of Nuclear Energy

There are various economic and financial forecasts regarding the cost of different energy sources. Often, these comparisons include traditional fossil fuels, such as oil and gas with hydropower and nuclear, for instance. More recently, many calculations including solar, wind, geothermal, and other sources have been published. Equally important as the calculation themselves are the assumptions under which they are made, as many of these raise ethical issues. While there are many accusations of “hidden costs” in nuclear energy, such as the cost of decommissioning plants and insurance guarantees, this depends on what these terms mean, or what “total costs” actually include. Nuclear energy production might constitute such considerations, as well as any non-monetary “safety” costs and environmental costs. The bulk of the costs associated with nuclear energy lie with the fuel, which includes mining of Uranium ore, the conversion and enrichment of $^{235}$U and its fabrication into fuel assemblies. However, one cannot ignore the significant costs involved in nuclear waste management and its ultimate disposal that have major consequences on the society and environment. One may also need to include the substantial investments made in basic and applied research in nuclear technology, at least in comparison with other energy technologies.

It is well known that nuclear energy is relatively carbon-free, when viewed as a capital-intensive undertaking, despite its standard long construction periods. The competitiveness of a nuclear plant depends on the economic and investment conditions of a country. In present times, the proportion of the total lifetime capital investment for a nuclear facility is approximately 60% of the lifetime generation costs, with fuel costs at 20%, operation and maintenance (O and M) making up the remaining 20% (IAEA: Sustainable Development and Nuclear Power). In comparison, the capital requirements to build a fossil fuel plant can be significantly lower with fuel making up a major portion of the lifetime capital costs- 70% for natural gas and some 50% for coal. In order to accurately compare the cost of nuclear energy with other renewable sources, it is imperative to consider the assumptions and costs in greater detail.

This chapter examines in particular the economic issues, but does not negate the importance of other factors in policy making. Even sources such as solar and wind energy that are considered “Green” have hidden costs. For instance, wind turbines can kill birds and bats. It is estimated that about 100,000 birds are killed each year in the United States from wind turbines, and if wind power increases to 20 percent of electricity, the number of bird kills will increase 30 times (Cohn, 2008). Although this is a relatively small number in comparison to other sources of inadvertent bird deaths (e.g. from communication towers), it still represents a significant concern. Hydroelectric dams may release more GHG emissions

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43 Natural Resources Defense Council, Feb 2007. *Sustainable Development and Nuclear power*. IAEA Publication. There are no particulates released or emission of greenhouse gases during the actual operation of a nuclear power plant. However the use of fossil fuels at other stages of the nuclear energy chain (such as uranium mining and transportation) might result in some emissions that would have to be factored in a “full chain energy” assessment.

44 Fossil fuel plants produce vast quantities of toxic pollutants and waste. For instance, a 1000MW (e) coal plant without abatement technology annually produces an average of 44,000 tonnes of sulphur dioxides and 22,000 tonnes of nitrous oxides into the atmosphere. With modern abatement technology, there is a ten-fold reduction in noxious gases but nevertheless about 500,000 tonnes of solid wastes are produced. In contrast, a nuclear plant of similar power generating capacity, about 30 tonnes of high level radioactive wastes along with 800 tonnes of low to intermediate radioactivity are discharged annually. It is expected that innovative actinide burning reactors in future may be able to transmute long-lived radioactive species to short lived ones.
(taking into account the construction phase) than many coal plants (see for example: Beam, 2005), although actual comparisons are not conclusive, and the longer a dam operates the more favourable it will be compared to fossil fuel plants. The same is true for the GHG emissions from construction of nuclear plants and mining of ore as discussed below in detail.

Electricity produced from nuclear power plants can be controlled to a set level, unlike wind and solar energy, which require upgraded electrical grids, as they are intermittent power sources. The current generation of electrical grids has inefficient high-voltage long-distance transmission lines, may not be able to deal effectively with demand and supply effectively, and have outdated monitoring and control technology (see for instance, Hendricks, 2009). There is research on the manner in which solar and wind energy production facilities can effectively integrate with grids at high capacity levels (Winters, 2009), compared to nuclear, for example.

To arrive at sound decisions regarding energy policies in any country, policy makers need to make monetary comparisons of the costs and benefits of different types of power generating sources, taking into account the full range of research evidence and ethical assumptions that are implicit in choice of any technology that has potential and actual environmental consequences.

3.2 Nuclear fuel costs

Fuel cost essentially takes into consideration the annual “burn-up” of nuclear fuel during reactor operation. The inclination towards harnessing nuclear energy is its seemingly low fuel prices as compared to fossil fuels, and includes the cost of purchasing uranium, its conversion, enrichment and fabrication. Additional costs are also incurred due to transportation, storage and inventory charges. For a 1000 MWe BWR or PWR based on an eighteen-month fuel cycle, the approximate cost of one reload (defined as replacing one-third of the core) is about USD 40 million. Thus, the average fuel cost at a nuclear facility in 2009 was 0.57c/kWh (WNA, 2010). Since nuclear plants refuel every 18-24 months, they are not affected by short term fluctuating uranium prices, unlike fossil fuel plants (Nuclear Energy Institute). Moreover, fuel costs constitute only 28% of the overall production costs while for fossil fuel plants they make up about 80% of the total cost.

A recent study by AREVA in 2008, suggested that 17% of the total kWh generation cost for its EPR (European pressurized reactor) was fuel costs (WNA 2010). The cost break down was shown to be 51% natural uranium, 3% conversion, 32% enrichment and 14% fuel fabrication. In January 2010, the approximate US dollar cost to get 1 kg of uranium as UO2 reactor fuel (at likely contract price for the natural uranium from a mine) was as shown in Table 4 (WNA, 2010). Fissionable isotopes like U235 are high energy density fuels and owing to the small quantities needed45 (IAEA: Sustainable development and Nuclear Power and WNA 2010), the environmental impact with regards to its extraction, transport requirements and quantities of environmental wastes released are also diminished.

Table 4. Approximate expenses (US dollars) associated with different stages of Uranium processing

<table>
<thead>
<tr>
<th>Processing Steps</th>
<th>cost involved</th>
<th>total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium mining:</td>
<td>8.9 kg U3O8 x $115.50</td>
<td>1028</td>
</tr>
<tr>
<td>Conversion:</td>
<td>7.5 kg U x $12</td>
<td>90</td>
</tr>
</tbody>
</table>

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45 High energy density fuels are normally used in small quantities to produce a large amount of energy. Hence, 1kg each of coal, oil and nuclear fuel generate 3 kW.h, 4 kW.h and 50, 000 kW.h of electricity, respectively (IAEA: Sustainable development and nuclear power).
In light of the above cost analysis, it can still be said that the total fuel costs of a nuclear power plant in the OECD, for example, are one third of a coal-fired plant with a similar electricity generating capacity, and between a quarter and fifth of those for a gas combined-cycle plant. In recent times, the efficient use of fuel and newer methods of reprocessing spent fuel have led to a decrease in the overall fuel cost. This was indicated in Spain, where the nuclear electricity cost was reduced by 29% over 1995-2001 as a result of boosting enrichment levels and burn-up to reach a 40% fuel cost reduction (WNA, 2010). The World Nuclear Association predicts that uranium mining will need to increase by almost 300% in the next 2 decades to meet the world’s energy demands (WNA, 2006). Data in Figure 6 indicate that the demand (consumption) for uranium since 2006 has far exceeded the supply and forecasts an increase by about 22% in 2010 with an expected increase of 3.7% per year to 2030 (ABARE). Moreover, the global need to be less dependent on fossil fuels coupled with economic growth in countries like China and India gives an impetus to invest heavily in nuclear energy due to which both demand and price of uranium will be expected to rise (IAEA, 2009). Conversely, the decline in global economy in recent years has also led to a drop in uranium fuel prices from USD 130 per pound (July 2007) to USD 45 per pound (October 2008) (UxC: The Uranium nuclear fuel price indicators) due to steady depletion of uranium reserves. At present, known uranium reserves worldwide are expected to last for another 30 years although, uranium extraction from oceans is a proposed long-term solution for the impending uranium shortage (Energy Watch Group). However, apart from the questions on the feasibility, such a project could send uranium prices soaring in the future because of higher mining costs. In the long term, it is expected that the implementation of carbon taxes and carbon trading scheme will give a new thrust to existing nuclear power plants due to their low running costs so that they compete favourably with fossil fuel plants (NRDC: Nuclear Facts).

Figure 6: Global uranium production and demand.

### 3.3 Operation and Maintenance (O&M) of nuclear power plants

Operation and maintenance costs include the cost of running and maintaining the power plant for the period of its lifetime. Allowance has to be also made for expenses related to labour, material and supplies, contractor services, licensing fees and other incidentals such as employee expenses and regulatory fees. As nuclear industries adopt a more global cooperative approach, mass production of nuclear plants will supposedly bring costs down (World-nuclear.org, NEI: Resources and Stats). Uranium is a highly concentrated source of
energy and easily transportable. One kilogram of fissionable uranium will yield about 20,000 times as much energy as the same amount of coal. Another advantage of using uranium over fossil fuels is the low impact that it will have on the overall electricity cost. For example, a doubling of the uranium market price would increase the fuel cost of a light water reactor by 26%, and the electricity cost by 7%. The use of alternate fission fuels (uranium-238, plutonium-239 and thorium) have been considered in recent times by developing fast breeder reactors (FBR). However, apart from being an expensive mode of generating electricity (80% higher), it is feared that the high amounts of plutonium produced could be potentially used for non-civilian purposes (Scientific American, 19 February 2010).

Most (fast) breeder reactor plants have either suspended or ceased their activities due to uncontrollable fission reactions, financial liabilities and safety issues like the risk of catastrophic accidents. From an economic aspect, a report published by the National Academy of Sciences of the United States (NAS) on the feasibility of plutonium reactors suggested that the cost of processing and fabricating uranium oxide fuel (MOX at 4.4% enrichment) at about 1400 US dollars in 1992 assuming a natural uranium price of US dollars 55 per kilogram. The cost of MOX fuel fabrication assuming the cost of plutonium is free (obtained in surplus from nuclear weapons) would be 1900 per kilogram in 1992 dollars (excluding taxes and insurance). The higher cost of MOX as compared to uranium would not only increase the overall annual fuel costs but also translate to a higher cost of reprocessing spent MOX. This is because it will be more radioactive than uranium spent fuel due to higher plutonium content.

3.4 Capital costs

The factors that account for the “total capital cost” for a nuclear plant includes many components such as “overnight plant construction cost”, the owner’s cost and other associated expenses such as capital cost, escalating construction costs (including site works, switch works and so on) over the time period of construction. In recent times, a number of capital cost estimates from different sources have been published ranging from a conservative approach to total capital estimates incorporating escalations due to factors such as construction delays, material cost fluctuations and capital cost for funds and so on (see Craig, 2009).

Fast Breeder Reactors (FBR) operate on the principle that Uranium-238, by neutron capture, converts to Plutonium (Pu) that can be subsequently reprocessed and used as reactor fuel. Neutrons are cooled by liquid sodium as the moderator (instead of water or helium) and hence have high thermal energy. Excess plutonium produced leads to problems of reprocessing and also generates large amounts of radioactive wastes- an uneconomical situation coupled with the likelihood of misuse for making weapons-grade plutonium in countries with a prolific nuclear program.

Plutonium as a fuel is being considered for use in FBR’s or in Generation IV reactors and currently being utilized in USA, Japan and France. The Generation IV International Forum (GIF) addresses non-proliferation by utilising a closed-fuel cycle FBR to minimise high-level wastes. Plutonium is generated in the core where the burn-up is high as well as the proportion of other plutonium isotopes besides Pu-239 remains high. Mixed oxide fuel (MOX) is a combination of weapons grade Pu with uranium to render Pu to “reactor grade” fuel. A process adopted by USA and Russia to convert their weapons stockpile innocuous.

Another alternate reactor fuel source is to convert non-fissile thorium-232 into uranium 233. However, this breeder technology is still being researched by many countries (IEER, Energy and Security) especially India.

Overnight construction costs refer to the cost incurred if the power plant could be built at “today’s prices” or literally “overnight”. This cost does not include financing charges during construction (since the plant is built “overnight”) and inflation rates. Overnight construction costs are different from total capital costs.

---

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49 Overnight construction costs refer to the cost incurred if the power plant could be built at “today’s prices” or literally “overnight”. This cost does not include financing charges during construction (since the plant is built “overnight”) and inflation rates. Overnight construction costs are different from total capital costs.
Usually, the economic assessment for funding a nuclear power plant construction is done by using a levelized energy cost (LEC) approach which is the average cost of producing electricity over the plant’s life-time. This includes initial investments, operation and maintenance (O and M), cost of fuel as well as costs of waste disposal and plant decommissioning. While a number of factors (costs of government subsidies, costs of public health and environmental impact and so on), known as “boundaries” have to be considered while calculating the LEC, the most important is the discount rate. The value of the discount rate chosen can often affect the results one way or another and depends on the cost of the initial capital.\(^\text{50}\) Hence, the economic competitiveness of a nuclear plant depends on the investment conditions as well as the interest and payback period of loans. In the present day competitive and liberalized markets, initial capital investments have to be recovered in a relatively short period of time at high discount (interest) rates. For discount rates of 5%, nuclear power has been competitive with fossil fuels, while at higher discount rates of 10%, it is difficult to compete with coal and gas fired plants (IAEA: Sustainable Development and Nuclear Power).

A 2010 OECD publication, *Projected Costs of Generating Electricity*, compared 2009 data for generating base-load electricity with estimates for 2015 as well as the costs of power from renewable sources. The data showed that nuclear power was very competitive at USD30 per tonne with low discount rates of both 5% and 10% (Tables 5-6). The study used average life-time costs and includes average costs of producing electricity as well as capital, finance, owners cost on site, fuel and operation over a plant’s life-time and provision for decommissioning and waste disposal.

It was further shown that at 10% discount rate,\(^\text{51}\) nuclear energy is still cheaper in all of the listed countries, but in Belgium, Czech Republic and Netherlands gas becomes cheaper than coal (Table 6).\(^\text{52}\) Detailed studies regarding the economic viability of nuclear power have been undertaken in many European countries (WNA, 2010).

Based on these studies, data on the projected costs from different energy sources were published as shown in Table 6. Given the fact that financing costs and construction of a nuclear power plant are relatively high due to the need to incorporate special materials, innovative safety features, and state-of-the-art features the cost of fuel is much lower.

\(^{50}\) Based on the “time-value” of money, the discount rate defines the present value of a future payment P. For example at 10% discount rate, payment P, expected in 15 years has a present value of \(P \times 1.10 \times 10^{-15} = 0.24P\).

\(^{51}\) At a 10% discount rate, this study found that nuclear energy was still cheaper than coal and gas except in Belgium, Czech R and Netherlands where gas is cheaper. Coal with carbon capture (CCGT) was more expensive than nuclear power.

\(^{52}\) Future competitiveness of nuclear power will depend on its virtue of being relatively carbon-free while additional costs may be loaded onto coal and gas-fired plants in the form of CO\(_2\) capture as well as expenses incurred due to the quenching of methane and noxious gases (sulphur dioxide and nitrogen oxides). In terms of equivalent grams of carbon emissions per kilowatt hour, gas plants are on par with coal plants. For fossil fuels, indirect costs such as waste management and plant decommissioning are not included into the electricity cost.
Table 5. The OECD electricity generating cost projections for 2010 at 5% discount rate, cents/kWh.

<table>
<thead>
<tr>
<th>Country</th>
<th>Nuclear</th>
<th>Coal</th>
<th>Coal with CCS</th>
<th>Gas CCGT</th>
<th>Onshore wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>6.1</td>
<td>8.2</td>
<td>-</td>
<td>9.0</td>
<td>9.6</td>
</tr>
<tr>
<td>Czech R</td>
<td>7.0</td>
<td>6.5-9.4</td>
<td>8.8-9.3</td>
<td>9.2</td>
<td>14.6</td>
</tr>
<tr>
<td>France</td>
<td>5.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>9.0</td>
</tr>
<tr>
<td>Germany</td>
<td>5.0</td>
<td>7.0-7.9</td>
<td>6.8-8.5</td>
<td>8.5</td>
<td>10.6</td>
</tr>
<tr>
<td>Hungary</td>
<td>8.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Japan</td>
<td>5.0</td>
<td>8.8</td>
<td>-</td>
<td>10.5</td>
<td>-</td>
</tr>
<tr>
<td>Korea</td>
<td>2.9-3.3</td>
<td>6.6-6.8</td>
<td>-</td>
<td>9.1</td>
<td>-</td>
</tr>
<tr>
<td>Netherlands</td>
<td>6.3</td>
<td>8.2</td>
<td>-</td>
<td>7.8</td>
<td>8.6</td>
</tr>
<tr>
<td>Slovakia</td>
<td>6.3</td>
<td>12.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Switzerland</td>
<td>5.5-7.8</td>
<td>-</td>
<td>-</td>
<td>9.4</td>
<td>16.3</td>
</tr>
<tr>
<td>USA</td>
<td>4.9</td>
<td>7.2-7.5</td>
<td>6.8</td>
<td>7.7</td>
<td>4.8</td>
</tr>
<tr>
<td>China*</td>
<td>3.0-3.6</td>
<td>5.5</td>
<td>-</td>
<td>4.9</td>
<td>5.1-8.9</td>
</tr>
<tr>
<td>Russia*</td>
<td>4.3</td>
<td>7.5</td>
<td>8.7</td>
<td>7.1</td>
<td>6.3</td>
</tr>
<tr>
<td>EPRI (USA)</td>
<td>4.8</td>
<td>7.2</td>
<td>-</td>
<td>7.9</td>
<td>6.2</td>
</tr>
<tr>
<td>Eurelectric</td>
<td>6.0</td>
<td>6.3-7.4</td>
<td>7.5</td>
<td>8.6</td>
<td>11.3</td>
</tr>
</tbody>
</table>

* For China and Russia a carbon emission cost of 2.5 cents /kWh is added to coal and 1.3 cents /kWh to gas to ensure a sound comparison with data in other fuel/technology categories.

Table 6: Cost comparison from alternate energy sources in EU at 10% discount rate

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>2005</th>
<th>Projected 2030 with EUR 20-30/t CO2 cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas CCGT</td>
<td>3.4-4.5</td>
<td>4.0-5.5</td>
</tr>
<tr>
<td>Coal - pulverized</td>
<td>3.0-4.0</td>
<td>4.5-6.0</td>
</tr>
<tr>
<td>Coal - fluidized bed</td>
<td>3.5-4.5</td>
<td>5.0-6.5</td>
</tr>
<tr>
<td>Coal IGCC</td>
<td>4.0-5.0</td>
<td>5.5-7.0</td>
</tr>
<tr>
<td>Nuclear</td>
<td>4.0-5.5</td>
<td>4.0-5.5</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>3.5-11.0</td>
<td>2.8-8.0</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>6.0-15.0</td>
<td>4.0-12.0</td>
</tr>
</tbody>
</table>

A cost study of existing energy technologies was undertaken by the IEA/NEA to understand the factors affecting the economics of electricity generation (IEA/NEA executive Summary). Cost data was collected from more than 130 power plants and also includes plants that could be decommissioned between 2010 and 2015. Their findings are presented below in Table 7.
Table 7: Cost data comparison for various energy sources.

<table>
<thead>
<tr>
<th>Energy type</th>
<th>Average time of plant construction (years)</th>
<th>Overnight construction costs (USD/kWe)</th>
<th>Levelized costs (USD/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>4</td>
<td>1000-1500</td>
<td>25-50</td>
</tr>
<tr>
<td>Gas</td>
<td>2-3</td>
<td>400-800</td>
<td>37-60</td>
</tr>
<tr>
<td>Wind</td>
<td>1-2</td>
<td>1000-2000</td>
<td>35-95</td>
</tr>
<tr>
<td>Nuclear</td>
<td>4</td>
<td>1000-2000</td>
<td>21-31 (includes refurbishment and decommissioning)</td>
</tr>
</tbody>
</table>

Coal prices were found to fluctuate widely over the economic lifetime (40 years) of a plant by as much as a factor of 20 (expressed in the same currency) in the year 2010. The study excludes specific costs associated with wind power and the need for back-up power to compensate for low average availability factor. The average levelized costs presented are for 5% discount rates. While it is not possible to generalize the economics of power generation, the levelized costs of power in each country are dependent not only upon financial considerations such as discount rates, but also on fluctuating coal and natural gas prices (see section 2.8.2). Ensuring a steady supply of electricity hence depends on the choice of energy technology selected as well as financial stability of the country, such as costs of raw resources and measures such as the implementation of a carbon-tax. Although the calculations to estimate the true costs of electricity generated from any source are complex, and require various assumptions, it is possible and ethical to develop transparent mechanisms to calculate these costs. The IEA/NEA electricity cost studies are summarised in Figure 7.

![Figure 7: Regional ranges for levelized costs of electricity (LCOE) for coal, natural gas, wind and nuclear power plants at 5% discount rates.](image)

A cost analysis study of the existing energy technologies was also conducted in the UK by PB Power (Royal Academy of Engineering, 2004). Within this study, the actual costs
of building, maintaining and running various types of power stations in the UK were considered, and the costs of producing electricity at a discount rate of 7.5% was derived using a common financing model.\textsuperscript{53} The graph in Figure 6 shows the cost of generating electricity from different types of technology currently available in the UK. The present-day cost of generating electricity for each source was set at levels considered necessary to provide a dependable power supply.\textsuperscript{54}

![Figure 6](image1.png)

Figure 6. Present-day cost of generating electricity (pence per kWh) with no cost of CO\textsubscript{2} emissions included (The Royal Academy of Engineering, 2004).

![Figure 7](image2.png)

Figure 7. Data illustrating the effect on the cost of generating electricity with respect to CO\textsubscript{2} emission costs (The Royal Academy of Engineering, 2004).

Figure 7 illustrates how a fixed carbon dioxide emission (CO\textsubscript{2}) allowance will be assigned to new power generation plants for 2005-2007. The cost is calculated on the basis of pounds (£) per tonne of CO\textsubscript{2} released. The values range from 0 - £30 per tonne, wherein the upper limit indicates the cost of carbon dioxide sequestration. The cost of generating

\textsuperscript{53}In the study, the cost value includes the capital cost of the power generating plant and equipment, the cost of fuel burning (where applicable) as well as operation and maintenance costs. Decommissioning costs for nuclear power generation are included (internalised) in the capital cost estimate of a nuclear plant

\textsuperscript{54}For intermittent power generation sources such as Wind and Wave Energy, an additional amount has been included as a provision for standby generation since the generating capacity of these sources may often vary.
nuclear power, which is carbon-free in the operational stage, remains unchanged and hence will become more favourable as the cost of carbon emissions increases. Although this study was conducted in the UK, and thus is applicable to power plants in the UK, it gives an idea of the relative advantages of using renewable energy sources like nuclear power.

An inter-disciplinary MIT case study (NRDC) in 2003 titled “The Future Role of Nuclear Power” (Interdisciplinary MIT study, 2003), presents the most current economic comparison of nuclear and fossil-fuel plants in the United States. This study examines the growth of new generation nuclear plants with capacities of 360 GWe, scalable to 1000 GWe by mid-century thereby boosting the approximate 20% nuclear share in electricity generation of the US to about 30% (16% to 20% globally). Some important challenges that were considered for the development of emerging power technologies were 1) cost, 2) safety, 3) waste management, and 4) proliferation risk (for technologies like nuclear power). The study also makes recommendations to mitigate heavy monetary costs that will impact the viability and competitiveness of nuclear plants as well as the levying of societal and environmental price of carbon emissions that could tremendously improve the competitiveness of nuclear fuel.\(^{56}\)

Table 7. Data showing levelized cost of electricity generated from a new nuclear plant as compared to coal or gas-fired plants.

<table>
<thead>
<tr>
<th>CASE</th>
<th>REAL LEVELIZED COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Year 2002 $)</td>
<td>Costs/GWe-yr</td>
</tr>
<tr>
<td>Nuclear (LWR)</td>
<td>6.7</td>
</tr>
<tr>
<td>+ Reduce construction cost 25%</td>
<td>5.5</td>
</tr>
<tr>
<td>+ Reduce construction time 5 to 4 years</td>
<td>5.3</td>
</tr>
<tr>
<td>+ Further reduce O&amp;M to 13 mls/GWe-yr</td>
<td>5.1</td>
</tr>
<tr>
<td>+ Reduce cost of capital to gas/coal</td>
<td>4.2</td>
</tr>
<tr>
<td>Pulverized Coal</td>
<td>4.2</td>
</tr>
<tr>
<td>CCGP (low gas prices, $3.77/MCF)</td>
<td>3.8</td>
</tr>
<tr>
<td>CCGT (moderate gas prices, $4.42/MCF)</td>
<td>4.1</td>
</tr>
<tr>
<td>CCGT (high gas prices, $6.72/MCF)</td>
<td>5.6</td>
</tr>
</tbody>
</table>

\(^{a}\) Gas costs reflect real, levelized acquisition cost per thousand cubic feet (MCF) over the economic life of the project.

The MIT study points out that while existing nuclear plants are operating successfully, energy companies are sceptical about investing in new plants because they are uneconomical since electricity markets may well be subject to deregulation in some parts of the world in future. The comparison was based on a model using actual parameters than

\(^{55}\) Large power plants usually have an electrical output capacity of around 1GW; hence abbreviated as GWe. Gigawatt-year (GWe(-yr)) is commonly used in electricity production and 1GWe-yr = 8.76x10^9 kWh.

However, a 1GW capacity power plant does not generate 1GW-yr of electricity per year. The ratio of the actual power generated to the amount that could be generated per year if the plant were to operate at full capacity for one year is called the capacity factor. Typical power plants operate at a capacity factor of around 60 to 80%.

\(^{56}\) Some recommendations offered by the expert panel include: offering limited production tax-credit to “first-movers” who basically are private investors; an incentive extendable to other carbon-free electricity technologies, advancing a U.S department of energy (DOE) balanced long-term waste management R&D program, developing alternate carbon-free energy sources and carbon sequestration.
engineering estimates to compare the real cost of electricity from nuclear with pulverized coal and combined natural gas cycle plants over their economic lifetime. They assumed 85% capacity factor and a 40-year economic life for the nuclear plant. From the data shown in Table 7 it is clear that nuclear energy will become competitive as compared to coal and gas-fired plants only if all the cost-improvements for the nuclear plant are realized.

Table 8. Data shows power costs with carbon taxes.

<table>
<thead>
<tr>
<th>Power Costs with Carbon Taxes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CARBON TAX CASES</strong></td>
</tr>
<tr>
<td><strong>COST</strong></td>
</tr>
<tr>
<td>cents/kWe-hr</td>
</tr>
<tr>
<td>Coal</td>
</tr>
<tr>
<td>Gas (low)</td>
</tr>
<tr>
<td>Gas (moderate)</td>
</tr>
<tr>
<td>Gas (high)</td>
</tr>
</tbody>
</table>

Based on the values in Table 8, the study indicates that nuclear power does become cheaper if a social cost of carbon emission is internalized by a carbon tax or “cap and trade system”. The emissions costs are in the range of USD 50 – USD 200 per tonne of carbon. The ultimate cost levied depends on the carbon emissions permitted, technology developments and costs involved in the long-term carbon capture and sequestration.

The MIT study also pointed out that, “subsidies offered by the United States government in the form of tax-payer dollars to energy companies to “jump-start” their nuclear program with new uneconomic, nuclear plants would do little to mitigate the immediate problem of global energy crisis” (NRDC, April 2004). Their proposed solutions to the energy problem that can be generalized to any country, is firstly to discourage tax-subsidies and allow new, innovative energy technologies to compete with existing fossil fuel and nuclear energy programs on a “level playing field”. They advocate the internalization of environmental costs of the technologies considered so that taxpayers are appraised of the true-cost of electric power. A follow-up study in 2009 by the MIT group further showed that the global need for “clean” power has increased over the past 6 years due partly to rapid growth of economies in India, China and Mexico, and new technology developments like plug-in hybrids that depend on electricity. The need for a mutual decision between countries to adopt policy options to reduce green-house gas emissions has therefore stressed the importance of nuclear power, fossil fuel use deploying carbon capture and sequestration and exploring other renewable technologies like wind, hydropower, geothermal and solar as important options for achieving global power equity with low carbon foot-print.

Yet another European Union externality cost study conducted in the Philippines (Greenpeace Southeast Asia Study, 2003) noted the high external costs of coal-fired plants as opposed to wind and solar power. The study dismissed the fact that “cheap coal” was a myth and urged that external factors such as environment and human life-styles have to be accounted for before embarking on new coal-fired plants. As mentioned before, while nuclear plants involve high initial cost, fossil fuel plants have high fuel expenses and serious socio-environmental consequences.

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57 An externality study conducted by the European Commission in 2003 with different types of power generation and coal-fired plants in Philippines demonstrated the detrimental effect of coal burning on human mortality, human morbidity as well as bio-diversity due to hazardous toxic emissions. While condemning the proposed development of future coal-fired plants, the study revealed that alternate
The speculations about the cost-effectiveness of nuclear power programs in the future was highlighted in a recent Nuclear Energy Institute study (NEI, 2010) that indicated projected expenses involved in the construction of new nuclear plants in the United States. The proposed estimates range from USD 4 billion for a single plant to USD 18 billion (2010 US dollar rate) for a two-unit plant and includes the cost of engineering-procurement and construction (EPC) costs, transmission lines and other services. This wide variation in capital costs was attributed to factors such as: uncertainty in the escalation of commodity prices, use of different financial assumptions depending on the year (inflation or escalation) in which the costs are projected as well as estimates including comparisons between different power generating technologies. Independent cost analyses of new power generating plants have been undertaken by several academic institutions, research organizations and government agencies have found that future nuclear power plants will be competitive with traditional fossil fuel plants. The findings of one such company namely, the Brattle Group, under contract to Connecticut Light and Power and United Illuminating Inc. is presented in Table 9 (NEI, 2009).

Although nuclear plants had the highest overnight capital costs, the levelized costs are the lowest except in the case of Combined Cycle (CCG) gas plants (USD 7.14 per mmBtu, 2008 dollars) without carbon-capture. Additional analyses assuming different gas price scenarios, carbon dioxide prices and technology costs also resulted in nuclear technology being the most cost effective. Further information regarding cost analyses studies of new power generating plants can be found in the Nuclear Energy Institute (NEI, 2009) document.

Despite having some definite cost advantages over traditional fuel technologies, nuclear power comes with inherent problems such as proliferation, reactor safety and waste disposal. Countries need to address these pressing issues from an ethical and human rights standpoint before committing to nuclear power in the long term.

Table 9: Capital Cost Analysis (2008 US dollars) of new power generating companies by Brattle Group

<table>
<thead>
<tr>
<th></th>
<th>Nuclear</th>
<th>SCPC</th>
<th>SCPC w/CCS</th>
<th>IGCC</th>
<th>IGCC w/CCS</th>
<th>Gas CC</th>
<th>Gas CC w/CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost ($)/kWe</td>
<td>4,038</td>
<td>2,214</td>
<td>4,037</td>
<td>2,567</td>
<td>3,387</td>
<td>969</td>
<td>1,558</td>
</tr>
<tr>
<td>Levelized Cost ($) / MWh</td>
<td>83.40</td>
<td>86.50</td>
<td>141.90</td>
<td>92.20</td>
<td>124.50</td>
<td>76</td>
<td>103.10</td>
</tr>
</tbody>
</table>

SCPC = supercritical pulverized coal; CCS = carbon capture and storage; IGCC = integrated gasification combined cycle; CC = combined cycle

3.5. Externalities: The “hidden” costs

Some of the most significant impediments to nuclear energy becoming a sustainable, safe source of power are the “unseen” expenses that lead to speculations about the actual costs of nuclear energy. Though some scientists and advocates of nuclear power turn a “blind eye”, the potential long-term viability of nuclear power could decrease if financial and energy sources like Wind, Solar Power and Biomass should account for 10% of the country’s power capacity as the most economical way of power generation.
environmental risks are ignored. While the financial costs associated with different stages of the nuclear plant were discussed in the previous sections, nuclear power is inherently tied to “external costs and benefits”, termed as “externalities”. Liabilities include the cost of environmental damage, adverse radiation effects on human health following a nuclear accident, damage to human health during routine operation of nuclear facilities, and the long-term problems associated with nuclear waste disposal and plant decommissioning (ExternE, MEC publications).

According to holistic socio-economic welfare analysis, policies should ensure that prices reflect the total costs of electricity by incorporating taxes, subsidies and other socio-economic cost factors. This internalization of external costs is intended to bring the social and environmental variables and the economic aspects on an even page. The classification of what to consider from a cost perspective however requires a number of ethical assumptions.

To internalize electricity costs, which are usually busbar\textsuperscript{58} costs, socio-environmental damages need to be identified, estimated and assigned a financial value. When such variables are factored into the price of electricity, the actual cost of any product or service is higher, which in turn translates to a higher cost borne by consumers (and sometimes tax-payers in general). Besides technology and investments, externalities also arise from consumption of consumer goods, which are related to the existence of electricity - the end product of energy supply plants. From an ethical standpoint, most environmental groups and international organizations argue that many environmental problems are not quantified and thus remain as “external costs”. Such accounting systems may strengthen the status that nuclear power enjoys as a renewable energy resource. Thus, risk assessments pertaining to recycling and disposal of spent nuclear fuels, comparison of CO\textsubscript{2} emissions, radiological risk assessments and other economic assumptions necessary for a complete evaluation of nuclear energy risk factors needs to be developed for the implementation of sound energy policies.

The ExternE (External costs of Energy) European Research Network (The ExternE) has been involved in compiling and estimating the factors that impact economic considerations of fossil fuel technology and renewable resources besides energy-related activities such as fuel cycles, and other production processes. The ExternE project\textsuperscript{59} has developed a cost-benefit analysis wherein the costs to implement measures to reduce a specific environmental impact (burden) is compared with its benefits. An illustration of the main steps of the impact-pathway approach for the consequences of pollutant emissions is shown in Table 10. A bottom-up approach calculates the environmental costs and benefits by following the source emissions to physical impacts.

\textsuperscript{58} In scientific terms, a “busbar” is an electrical conductor that serves as a common connection for two or more electrical circuits. A busbar may be in the form of a rigid bar, strands or cables and acts as a power conduit of an electrical power plant. Hence, “busbar” cost implies cost of producing electricity up to the point of the power plant busbar.

\textsuperscript{59} Over the past 20 years the multidiscipline ExternE Project series started in early 1990, is aimed at developing a consistent methodology to assess the externalities of electricity generation technologies. It uses a bottom-up impact pathway approach coupled with “EcoSense” model- an analytical software tool, for environmental impact pathway assessments. More detailed description of the ExternE methodologies can be found in the ExternE Project series (The ExternE). A decade of research has led to compilation of data on impacts from a wide range of fuels (coal and oil technologies, nuclear onshore and off shore wind, hydro and biomass) and transport externalities (road, rail, aircraft and navigation). For more details on environmental impacts see Appendix.
Table 10: Impact pathway approach developed by ExternE Project\textsuperscript{60}

\begin{center}
\begin{tabular}{|c|}
\hline
\textbf{SOURCE} \\
(specification of site and technology) \\
\hline
\textbf{Emission} \\
(e.g. kg/yr of particulates) \\
\hline
\textbf{DISPERSION} \\
(e.g. atmospheric dispersion model) \\
\hline
\textbf{Increase in concentration} \\
at receptor sites \\
(e.g. kg/yr of particulates) \\
\hline
\textbf{DOSE-RESPONSE FUNCTION} \\
(or concentration-response function) \\
\hline
\textbf{Impact} \\
(e.g. cases of asthma due to ambient concentration of particulates) \\
\hline
\textbf{MONETARY VALUATION} \\
\hline
\textbf{Cost} \\
(e.g. cost of asthma) \\
\hline
\end{tabular}
\end{center}

Figure 7: The results of the ExternE Project as applied to different power generating technologies

An important tool in assessing environmental risk factors involving nuclear power (or any other energy resource) is nuclear power life cycle cost assessment. Life cycle cost assessment (LCA) is the decision support tool that is currently widely accepted for impact analysis. LCA evaluates the entire life cycle of the product from raw material extraction, acquisition and waste disposal. In the impact assessment step, environmental burdens (impacts) are identified and subjected to elaborate quantitative analysis. Regardless of their varied nature (due to different energy sources), burdens are subsequently classified

\textsuperscript{60} ExternE. Externalities of Energy. A research project of the European Commission. Methodology 2005 update.
independent of their type, number or size, and then reported. For the final analysis, only some of the impacts considered by arbitrary criteria to be most important are chosen and their effects calculated using an exposure-response model before being evaluated in monetary terms. In this manner, society would be not only aware of the actual cost of electricity but would also be informed that the said utility was produced from a power plant with better environmental performances.

The data in Figure 7 (ExternE: External Costs Study) illustrate that external costs of electricity generation are largely dependent on the choice of fuel, technology and location, although assumptions underlying specific technologies studied cannot be generalized. In the case of nuclear energy, the impact assessment will need to include the risk of severe radiation accidents as the major environmental burden. It is largely perceived that the weakest areas of nuclear power externality studies are the assumptions that: 1) nuclear fuel cycle wastes and other hazardous impacts are well managed. 2) The probability of nuclear accidents and its deleterious effects on society and environment, which are either ignored or neglected. Factors that might also affect nuclear externality studies are resource depletion, the extent of risk perception and capital invested in research and development.

An externality study of a 1000 MW(e) nuclear plant operation for a year in France indicated that the impact of radioactive wastes was negligible and occupational hazards were reduced owing to small mining requirements (Sustainable development and nuclear power: IEA publication). Less than one equivalent life lost (0.1 public and 0.02 occupational) in a 300 million European population was attributed to the yearly operation of the plant. This was calculated by incorporating the impact of severe accidents using a probability methodology since human mortality rate has a considerable effect on externalities. However, an infrequent event has only a small impact on the unit of energy generated since its impacts are compared to the total amount of energy generated over a period with no accidents.61

Table 11: External Costs study of power technologies in Belgium (mecum/kWh). Please see External Costs, http://externe.jrc.es/infos/Belgium, for more information.

<table>
<thead>
<tr>
<th>Damages</th>
<th>Coal (no FGD, SCR)</th>
<th>Coal (with FGD, SCR)</th>
<th>Gas</th>
<th>Nuclear (3%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality (years of life lost)</td>
<td>87.8</td>
<td>15.3</td>
<td>2.54</td>
<td>0.2 + 3.3 (mill tailings)</td>
</tr>
<tr>
<td>Morbidity</td>
<td>13.4</td>
<td>2.4</td>
<td>0.48</td>
<td>0.17</td>
</tr>
<tr>
<td>Accidents Occupational health</td>
<td>n.g</td>
<td>n.g</td>
<td>N.Q</td>
<td></td>
</tr>
<tr>
<td>Major accidents</td>
<td>0.067 + 0.37</td>
<td>0.067 + 0.37</td>
<td>0.081</td>
<td>0.19</td>
</tr>
<tr>
<td>Materials</td>
<td>2.2</td>
<td>0.04</td>
<td>~ 0</td>
<td>0.00084 - 0.35</td>
</tr>
<tr>
<td>Crops</td>
<td>1.3</td>
<td>0.28</td>
<td>0.08</td>
<td>-</td>
</tr>
<tr>
<td>Noise, others</td>
<td>0.27</td>
<td>0.27</td>
<td>0.03</td>
<td>-</td>
</tr>
<tr>
<td>Global warming (mid 3%)</td>
<td>17.4</td>
<td>18</td>
<td>7</td>
<td>0.09</td>
</tr>
<tr>
<td>Total</td>
<td>122.8</td>
<td>36.7</td>
<td>10.58</td>
<td>4.027 - 4.4</td>
</tr>
</tbody>
</table>

FGD: flue gas desulphurization SCR: selective catalytic reduction mECU = European Currency Unit. Euro now replaces ECU.

61 Likewise, another ExternE study of new energy power plants in six different regions in China based on different technologies can be found in “External costs of electricity generation in China”.
The externalities of power generating plants in Belgium are shown in Table 11 (External Costs, http://externe.jrc.es/infos/Belgium). The study considered both open and closed fuel cycles of nuclear plants but the differences were negligible. Three assumptions common to all countries in the ExternE project were considered for global warming: low, mid and high impact. For mid assumptions, discount rates of 1% and 3% were chosen and long-term effects due to radon from uranium mine tailings were not discounted in the case of nuclear energy. One can see that the external cost including accidents is lower for nuclear energy than that for coal.

Striking a balance between economically feasible energy technologies, which is also environmentally friendly, is a challenge faced by some countries in South-Asia. An economic feasibility study of rural South-Asia by USAID in 2006-07, indicated that while there was an immediate need for “clean” power, the true costs of existing power technologies like fossil fuel and nuclear power were not being assessed. While providing cheap power to the rural areas seems to be politically motivated, the by-products of the energy source, which cause damage to health and environment, are not internalized in the electricity costs. Thus, the figures that show rapid growth in the power sector for Asia in recent times, actually omit certain social costs incurred at the expense of the said utility. Deterioration of buildings, respiratory problems, contamination of natural water bodies, displacement of farmers from villages and a consequent drop in agricultural produce are some of the many “unseen” problems. A pertinent question that one can ask is whether these pressing issues have been ignored by local governments in the race for economic competence while the community at large bears the brunt of such a progress. While externality assessments for various power technologies can be complicated, socio-ecological factors need to be incorporated into the accounting framework such that a variety of power technologies can be studied to provide a clean, dependable power supply for the future. That many Asian countries aim for nuclear competence with the West is evident from the India-US civil nuclear accord of 2005. While nuclear technology is a viable option for India, this treaty essentially extends technology transfer for nuclear growth in India only for civilian use, notwithstanding the opposition from some political parties. Although nuclear technology is relatively carbon-free, nuclear accidents can be catastrophic if they were to occur due to which compensatory measures for civilians need to be specified. Damages to the environment caused by nuclear wastes have to be translated in terms of monetary expenses. Thus, to pave the way for a clean and safe technology transfer, the Indian government stressed the need for a civil liability protection by prospective US investors. A more detailed description of the nuclear liability measures in different countries can be found in the Appendix.

A detailed nuclear impact assessment (both environmental and societal) of nuclear power plants that include risk analysis of nuclear radiations, safety procedures employed at every stage of the nuclear power plant to its eminent final decommissioning is now a prerequisite for all potential licensees and existing nuclear facilities in the UK. The Nuclear Installations Act (NIA, 1965, as amended) that is enforced through the Health and Safety Executive (HSE, 1974) stipulates that a site cannot have a nuclear facility unless the HSE grants a license after all necessary, precautionary measures have been taken to deal with possible risks at the nuclear facility. Under the framework of the Technical Assessment

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62 An estimate of the subsidy requirements in the USAID study indicated that Bangladesh was only 33% electrified with a subsidy loss of 125 million US dollars. Sri Lanka is 54% electrified (subsidy losses of 150 million USD), Pakistan is 40% electrified (126 million USD) and India is 56% electrified (subsidy losses of 7 million USD).

63 Due to previous experiences with Union Carbide, a “Civil Liability for Nuclear Damage” bill (2010) holds the supplier and the operator liable to any nuclear accidents as a result of sub-standard services, patent or latent defects in equipment and material.
Guide (TAG), the HSE’s risk management philosophy directs Licensees or employers to comply in numerous ways such as adopt measures to safeguard workers against ionizing radiation, on-site accidents, implement safety standards at every stage of a plant’s life and provide guidance on safety assessment principles for plant workers as well as to the public. The employer is expected to make sure that these considerations are met “so far as is reasonably practical” (ALARP). The Tolerability of Risks from Nuclear Stations (TOR, 1992) defines risks which are so high that they are unacceptable unless there are special circumstances and risks, which are so low that they are considered broadly acceptable. Between these two boundaries, Regulators and Licensees have to make sure that the risks have been reduced to ALARP. More information on the HSE-ALARP guidelines for safety standards in nuclear facilities can be found in the HSE manual (http://www.hse.gov.uk/index.htm).

A detailed impact analysis of the Pebble-bed modular reactor-Demonstration Power Plant (PBMR-DPP) nuclear facility in South Africa covering environmental and newly identified risk factors have been carried out through specialist studies. These studies can potentially be universally applied to any power plant site since externalities are an inherent part of power technology. The impacts were classified as effects on biophysical environment and effects on socio-economic environment. Moreover, depending on the stage of development of the power plant in which these impacts were likely to occur, impacts were further classified as i) Construction phase, ii) Commissioning phase, iii) Operational phase and, iv) Decommissioning phase. The studies also considered the impact analysis both before and after mitigation procedures were suggested. The potential construction phase impacts for a nuclear power site are as described in Table 12 (Environmental Impact Report, Sept. 2008).

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64 ALARP is the term coined under UK law and is different from ALARA. While ALARP suggests a balance between risk and benefit, ALARA takes into account socio-economic factors.

65 A PBMR is a new generation high temperature helium gas-cooled reactor designed to produce 1100MW of power. Its inherent safety features and robust design make it a popular choice in countries like South Africa. At least 30,000 homes can be powered by one PBMR and a more than one PBMR’s can be located in one facility to form an energy park. These relatively small power stations would be versatile and can be built anywhere provided there is a steady source of water. Their load can be adjusted depending on the need (base-load stations) or the communities they serve.
Table 12: Examples of potential bio-physical and socio-economic impacts during Construction Phase of a nuclear power plant (Adapted from Environmental Impact Report, Sept. 2008).

<table>
<thead>
<tr>
<th>Construction phase Impacts</th>
<th>Description of effects and ethical issues</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bio-physical Impacts - examples</strong></td>
<td></td>
</tr>
<tr>
<td>Wetlands</td>
<td>All wetland patches within the laydown area (laydown area 1 - second section) would be completely destroyed by its use as a laydown area.</td>
</tr>
<tr>
<td>Loss of <em>Ficinia nodosa</em> wetlands</td>
<td></td>
</tr>
<tr>
<td>Significance: Mitigation not possible</td>
<td></td>
</tr>
<tr>
<td>Surface water</td>
<td>Surface soils are non-cohesive and erosion related to rain events would be a concern. It is likely that such erosion may not produce significant scars in surface soils, but the normal functioning of storm water management infrastructure could be severely impeded by siltation resulting from surface soil erosion.</td>
</tr>
<tr>
<td>Erosion of surface soil and contamination of surface run-off. Significance: Mitigation possible</td>
<td></td>
</tr>
<tr>
<td>Ground water</td>
<td>Flooding will occur immediately when excavations commence due to the fact that natural ground water level is approximately 4mgbf</td>
</tr>
<tr>
<td>Flooding of the excavated areas by groundwater. Significance: Mitigation results in low intensity of the impact.</td>
<td></td>
</tr>
<tr>
<td>Lowering of the water table due to watering and pumping of groundwater for construction use. Significance: Mitigation results in low intensity of the impact.</td>
<td></td>
</tr>
<tr>
<td>Drying up of wetlands due to dewatering and pumping of groundwater for construction use Significance: Mitigation results in a low intensity of the impact</td>
<td></td>
</tr>
<tr>
<td>Fauna</td>
<td>Natural habitats on construction site will be permanently destroyed. Intensity low because habitats already degraded. Dust generated by construction activity will drift into neighbouring habitats and degrade them. Intensity medium because impacts are partial and temporary.</td>
</tr>
<tr>
<td>PBMR DPP - habitat destruction</td>
<td>Natural habitats on construction site will be permanently destroyed. Intensity low because habitats already degraded.</td>
</tr>
<tr>
<td>PBMR DPP - Dust pollution off site</td>
<td>Dust generated by construction activity will drift into neighbouring habitats and degrade them. Intensity medium because impacts are partial and temporary.</td>
</tr>
<tr>
<td>Significance: with and without mitigation are low</td>
<td></td>
</tr>
<tr>
<td>Marine flora and fauna</td>
<td>Ground water will be pumped from the site for 2 years and released into the sea via existing outfall pipe. Due to the high salinity of the released water and the dynamic nature of the coastline, the intensity will be low and local in extent. As groundwater discharges from the site of the proposed development into the sea, organic and bacterial contamination of groundwater due to leaks and spillages from on-site sanitation facilities may ultimately result in contamination of the marine environment. Due to the exposed nature of the coastline, contamination is likely to dissipate quickly and is unlikely to have a significant effect on marine organisms</td>
</tr>
<tr>
<td>Release of saline groundwater during dewatering of the proposed site. Organic and Bacterial contamination resulting from discharge of contaminated groundwater</td>
<td></td>
</tr>
<tr>
<td>Significance: low intensity with and without mitigation.</td>
<td></td>
</tr>
<tr>
<td>Air quality</td>
<td>The significance rating for possible impacts to air quality by the proposed PBMR DPP.</td>
</tr>
<tr>
<td>PM10 Significance: Intensity with and without mitigation is low</td>
<td></td>
</tr>
</tbody>
</table>
From the above table we can see that the parameters for measuring the effects of the various biophysical impacts change with and without mitigation procedures. For some impacts, mitigation procedures have no effect on certain impacts, either due to their low probability of occurrence or due to significantly low impact coupled with short-term effect on the surrounding area. On the other hand, mitigation procedures are effective in lowering the intensity of the said impact to a low significance thereby alleviating some of the effects on the environment. More detailed information on the potential impacts during the commissioning, operational and the decommissioning phases can be found in the Impact Analysis data of PBMR’s (ESKOM Holdings Limited).

While mitigation procedures will alleviate many of the environmental problems arising due to the construction of a nuclear facility, the ethical question that can be raised is whether “harm” caused to the environment by humans by overlooking seemingly low intensity environmental impacts is morally acceptable. In this context, an anthropocentric viewpoint, would tolerate such minor aberrations thereby upholding the betterment of mankind, while certain species of flora and fauna and other water bodies equally important to the local ecosystem are actually driven to extinction. Ecosystem functioning depends on the

<table>
<thead>
<tr>
<th>Social Environment</th>
<th>Description of Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction of people dissimilar in demographic profile</td>
<td>Introduction of people dissimilar in demographic profile. Significance: low intensity with and without mitigation.</td>
</tr>
<tr>
<td>Impact commensurate with in flow of temporary workers.</td>
<td>Potential negative increase in antisocial behaviour due to influx of workers and jobseekers into the area. Significance: mitigation reduces the intensity from high to low.</td>
</tr>
<tr>
<td>Local /Metropolitan Government Impact</td>
<td>Additional pressure on service delivery. Significance: mitigation has no effect on intensity (low to medium)</td>
</tr>
<tr>
<td>Impact on daily movement patterns</td>
<td>Increased vehicle movement will contribute to existing serious traffic congestion problems and routine daily movement patterns. Significance: mitigation lowers the intensity from medium to low-medium</td>
</tr>
<tr>
<td>Public Health and safety</td>
<td>Potential negative nuclear-related health impacts and other safety risks related to construction projects. Significance: low intensity with or without mitigation</td>
</tr>
<tr>
<td>Economic Environment: Employment Creation</td>
<td>Limited employment opportunities created for local communities.</td>
</tr>
<tr>
<td>Employment Equity and Inequity</td>
<td>Specific disadvantaged individuals and groups are prevented from equal opportunities (Those with skills that are not in keeping with the requirements of construction firms and the project proponent).</td>
</tr>
<tr>
<td>Property Values and Tourism</td>
<td>Impacts that the development may have on property values for homeowners in the immediate area. Reduction in tourism activities and visitors Significance: low</td>
</tr>
</tbody>
</table>
interaction (physical and chemical) of different species (including humans) with their environment due to which costs of preserving ecosystems and the environment has to be borne by the very people who generate them. Based on the Principles of the Convention on Biological Diversity, conservation of ecosystem should be one of the main targets of the mitigation procedures adopted during the construction phase of a nuclear site. The interdependence of biosphere on human lives stresses the need to better understand the functioning of ecosystems. Hence, in the context of preserving the biodiversity, a critical step would be to consider and share all relevant information with the stakeholders in order to arrive at effective management strategies.

Table 13: Examples of potential societal impacts of nuclear reactors in the Operation phase (Adapted from Environmental Impact Report, Sept. 2008).

<table>
<thead>
<tr>
<th>Potential Biophysical Impacts</th>
<th>Description</th>
<th>Concern</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oceanography:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flooding due to tsunamis</td>
<td>Although the region has a moderate climate, the main meteorological concern is wind speed.</td>
<td>Close proximity of the ocean drives a large percentage of the wind onshore thus depositing salt particles on the structure. This can have a major corrosive effect on the infrastructure. Not much is known about tsunamis in the coast. Undertake studies to ascertain the reasonable expected maximum tsunami effect. Reactor to be situated above the expected tsunami level during its lifetime. Spent fuel to be stored such that it is not swept away by receding waters.</td>
</tr>
<tr>
<td>Exposure of cooling water intake pipes under tsunami conditions</td>
<td>Low significance. Maximum credible tsunami for the sit is predicted to be 4m above still water. Low probability; will not flood the PBMR-DPP if it is built 8m above MSL*.</td>
<td></td>
</tr>
<tr>
<td><strong>Seismic Environment:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short period tectonic changes in the existing geology either from rock fall or rock movement within a radius of 230 km. Movements along any of the known faults or a new fault within a radius of 320 km.</td>
<td>Movement along unknown faults sometimes causes small earthquakes, but larger rock falls and movement of large volumes of sediment in the ocean may result in after shocks being transmitted. Pushing of the mid Atlantic Range against the African Plate can cause stress build-up of the African Plate leading to possible rock faults. Travelling seismic waves can also cause severe ground movement. These are impossible to predict.</td>
<td>High significance but probability of occurrence is negligible. Foundations of the facility need to be sunk into the bedrock. Completed project will have to withstand tectonic/seismic changes.</td>
</tr>
<tr>
<td>Wetlands</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*MSL: mean sea level
3.6. Nuclear waste and decommissioning

The final stage of a reactor’s life cycle is characterized by nuclear waste and dismantling of the plant. Nuclear waste management has been an on-going cause for concern by countries with an active nuclear program and more recently become a global issue due to increasing environmental pollution. A nuclear reactor cycle is associated with several stages - starting from fuel mining to final waste disposal as described already in chapter 2 of this document. The life cycle of the fuel depends on reactor design and type as well as whether or not spent-fuel is reprocessed. The nature of nuclear wastes produced during various stages of the fuel cycle and their impact on society and environment have been discussed in section 2.4; as are ethical issues concerning nuclear energy technology in sections 2.3 – 2.5.

The decommissioning or dismantling of a power plant at the end of its life cycle remains an important ethical dilemma in terms of both cost and public safety. Three dismantling options proposed by the IAEA and adopted by some countries, are as follows:

- Immediate dismantling or early site release, which allows for a nuclear facility to be removed from any regulatory control within a few months of cessation of plant activities. Subsequently, the plant-site becomes available for re-use.
- Safety Enclosure option postpones the removal of reactor controls for a longer period of 40 – 60 years. The nuclear facility is placed in a safe storage configuration until further dismantling.
- Entombment involves placing the plant within a concrete structure or ‘sarcophagus’ so as to contain all radioactivity within itself.

Nuclear waste disposal and progressive plant dismantling are associated with a number of significant negative externalities arising due to radiation damage to life and property. The management of high-level nuclear waste, which is mostly, spent liquid waste, after the recovery of uranium and plutonium poses a considerable challenge. For example, the volume of high-level waste from reprocessing 30 tonnes of spent fuel released annually from a 1000MW(e) plant, containing more than 99% radioactivity, is about 10 cubic metres. This compares with 400,000 tonnes of ash produced from a coal-fired plant of the same operating capacity. It is estimated that the back-end of the fuel cycle (waste disposal and dismantling) contributes to an additional 10% to the overall costs per kWh (WNA April 2010). Regardless of the fact that the nuclear industry enjoys subsidies for operation, in most countries power operators are responsible for decommissioning costs, which are internalized and passed onto the consumers in the net cost.

There are ethical issues regarding this approach by the nuclear industry, owing to its reluctance to adopt a “level playing field”, despite improved cost estimates established in 1986 that now allow for a better understanding of the monetary implications of dismantling a nuclear plant. Long-term disposal of high-level nuclear waste poses a serious dilemma in countries with an active nuclear program, which is further exacerbated by the growing stockpile of both spent and new nuclear weapons. Hence, countries that wish to pursue nuclear programs for peaceful purposes need to consider the looming problem of nuclear waste disposal before embarking on costly power programs. Lawmakers need to examine the ethical implications of waste disposal policies on both human life and the environment as an overriding factor in all their decisions. As waste disposal and dismantling increase, decommissioning costs can no longer be embedded as part of construction costs but need to be evaluated separately. The total cost of decommissioning is dependent mostly on the sequence and timing of the various dismantling stages. While deferment of a stage tends to reduce its cost due to radioactive decay, it is hugely offset by the costs involved in the storage and surveillance of the said radioactive waste. Existing laws and financing nuclear plant dismantling have to incorporate “polluter pays principle” (Article 16 of the 1992 Rio
Declaration on Environment and Development) with the aim of preserving the safety of present and future society members as well as to prevent environmental burdens of nuclear wastes. Many other international organizations have issued directives regarding ethical issues with respect to dismantling of a nuclear facility, however, the underlying concerns of costs and externality assessment have not been addressed.

Vitrification of liquid wastes and underground geological repositories are two of the proposed choices for the maintenance of high-level waste, which still await political consent in some countries. Deep multiple barrier geological repositories at depths ranging from 250m to 1000 m are said to ensure that there is no radiation leakage into the biosphere. Thus, countries like Finland and Sweden have already approved sites for geological burial while the Waste Isolation Pilot Plant in New Mexico is the only geological repository in the US, operational since 1999. The proposed site at Yucca Mountain is still awaiting approval from the NRC and environmental protection Agency (EPA) after some decades as there are some concerns regarding its suitability. Although many nations favour the idea of deep disposal, the apparent delay in pursuing such a program stems from the lack of communication between decision makers and regulators, lack of advocacy regarding nuclear waste disposal coupled with the failure to educate people on the effect of such programs on human life and bio-diversity. Hence, while public reluctance to co-operate with authorities in decision-making is also fueled to a large extent by incidents of nuclear accidents and their after-effects, it does little to boost public confidence in law makers.

Yet another case of lack of public involvement and improper ethical principles by political parties concerns the nuclear power project in the Philippines. The growing power crisis in the country has led to hasty decisions made by changing political parties thereby affecting both the country’s economy and the people of South Luzon. The nuclear facility at Bataan peninsula (Karl Wilson, Energy Bulletin) that was built at a cost of 2.3 billion US dollars, has not produced a single watt of electricity while tax-payers are paying $155,000 US dollars a day in interest. The nuclear plant, upon inspection by an international team of experts, was deemed unfit for operation since it was built in a geologically restive area prone to earthquakes, as well as in close proximity to Mount Pinatubo, at present a dormant volcano. After being mothballed for several years, the government’s decision to decommission the nuclear plant was met with strong public resistance as dismantling would cost at least another billion dollars of taxpayers money. The hasty decisions of subsequent governments has eventually led to a collaboration with foreign investors with an intention to convert the nuclear facility to a fossil fuel plant. Likewise, proposals for small-scale wind and flow-through mini-hydro power plants as cheaper and safe sources of electricity have also

Refer to a discussion of the Polluter Pays Principle in ECCAP WG7 report.

Nearly a quarter of a century after the Chernobyl meltdown, large numbers of wild boars are fairly radioactive. The Environment Ministry has paid out 555,000 USD as compensation to hunters for wild boar meat that was contaminated by radiation and hence unfit for consumption. The amount paid off has nearly quadrupled since 2007 due to the rising levels of radioactivity. The animals showed an average of 7000 becquerel per kilogram of radioactive cesium (Cs-137); well above the specified limit of 600 becquerel. There is considerable cause for alarm since wild pigs with considerably high levels of contamination are frequently killed by hunters in the forests bordering Germany and The Czech republic. Bavarian hunters have been feeding the pigs with Giese salt, which when ingested is known to accelerate the excretion of the radioactive substance. A pilot program that was started about a year ago to reduce contamination levels in these animals, has brought down the numbers have significantly. However, according to the Environment Ministry, the problem is expected to last for another 50 years atleast.

The construction of the nuclear reactor was started in 1976 and completed in 1984 at a cost of $2.3 billion. It houses a Westinghouse light water reactor (PWR) designed to produce 621 Megawatts of electricity.
been suggested by experts at the behest of the Philippine government. However, the people of Central Luzon have expressed resentment as they feel that it is not them but foreign investors and the government who will benefit from such endeavours (see Ronalyn V. Olea).

There are also different views among nations as to whether buried nuclear wastes should be made retrievable from repositories. From an ethical standpoint, while future generations might consider this as a valuable resource, a permanent disposal leads to security concerns. However, after about 1000 years, the buried radioactive material will probably be similar to naturally occurring uranium ore from which it originated. Hence societal implications are of utmost importance for planning and implementation of large-scale nuclear waste disposal.

3.7 New generation nuclear reactor technology - Generation IV nuclear reactors.

The nuclear era that started in the early 1950’s, has spawned three generations of nuclear reactors: early prototype reactors, commercial power reactors and advanced light water reactors. The present population of nuclear reactors being used worldwide is designated as generation II and III reactors, and currently supplies 16% of the global energy demand. However, in the coming years it is anticipated that an increase in the world’s population by 60% (6 billion to 10 billion) would lead to a rise in the global energy demands making it imperative to adopt alternate, clean sources of energy like nuclear and hydro-power. It is also expected that nations that have not been using nuclear power might eventually do so in the interest of minimizing GHG to protect their environment. At present 40 reactors are in operation worldwide and 60 more being constructed to satisfy the needs for clean energy and a consequent reduction in carbon emissions (European Nuclear Society).

While nuclear energy is utilized by many countries as the first choice of power, the underlying challenges faced by the nuclear industry in the form of nuclear plant accidents, high costs of construction and the need for proper waste disposal pathways from uranium mining to spent nuclear fuel cannot be ignored. The use of nuclear material for subversive activities is presently an ongoing cause of debate by the international community as they strive to advocate nuclear non-proliferation via the peaceful use of nuclear power. The fact that nuclear power is a major negative externality and the long-term effects of radiation damage on all life forms and the environment is also a major cause for concern. Nevertheless, both developed and developing countries remain unfazed in the light of all these impediments and are going ahead with renewed vigour to adopt nuclear technology as one of the preferred choices to meet the energy needs of their country. Developing nations have incorporated nuclear technology as one their choices among a portfolio of other green renewable resources like wind, bio-mass and hydro power either through foreign collaborations or through indigenous, government funded technologies.

While there are many drawbacks to harnessing nuclear energy, nuclear technology has also made advances in recent years. Countries like the USA and Japan have invested heavily into basic research for developing new and robust reactor designs using alternate fuels and modified reaction pathways (WNA Feb 2010, WNA June 2010, US DOE). While generation II reactors are still safe and reliable to use, new reactors with improved cost effective designs and fuel efficiency now supersede them. These are the generation III and III-plus reactors that are now either under construction in Japan or ready to be ordered. Generation IV nuclear reactors are still being designed and are expected to be available by 2030. Most of these ventures are largely through international collaborations. Some of the improved features of third and fourth generation reactors are as follows:

1. Simpler, more rugged design making it easier to operate and less prone to operational errors.
2. Higher availability and longer operating life of about 60 years.
3. Standardized design for each type of reactor makes it easier to obtain licensing, reduce construction time (2-3 years) as well as capital costs.
4. Reduced possibility of core melt accidents, resistance to radiological release due to aircraft impacts.
5. Higher burn-up to reduce fuel use and hence the amount of waste.
7. Incorporates passive safety features that do not require active controls in the event of a malfunction.

Westinghouse AP600 is a generation III reactor that obtained certification in the USA in 1999. It is a 600Mwe reactor and has passive safety features. The AP1000 scaled up from AP600 is the first generation IIIplus design to receive final certification. The System 80+ is an advanced APR and with improved design features is expected to be marketed in South Korea as APR 1400 by 2013. Likewise, the IAEA’s international project on Innovative Fuel Reactors and Fuel Cycles (INPRO) is focused mainly on the needs of developing countries through a joint collaboration with USA and Russia. GE Hitachi Nuclear Energy’s ESWBR is another Generation IIIplus technology product that will produce 1520 Mwe of power and has a life of 60 years. Small-scale reactors with capacities of 600 – 1700 Mwe have been designed by Hitachi-GE that will further reduce costs. More detailed information on Generation III and IIIplus nuclear reactors developed through international collaborations can be obtained from World Nuclear Agency report (WNA June 2010).

<table>
<thead>
<tr>
<th>Coolant</th>
<th>Temperature (°C)</th>
<th>Pressure</th>
<th>Fuel</th>
<th>Fuel cycle</th>
<th>Size (Mwe)</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas-cooled fast reactors (GFR)</td>
<td>He(^a)</td>
<td>850</td>
<td>high</td>
<td>U-238(^+)</td>
<td>Closed</td>
<td>1200</td>
</tr>
<tr>
<td>Lead-cooled fast reactors (LFR)</td>
<td>Pb or Pb-Bi(^b)</td>
<td>480-800</td>
<td>low</td>
<td>U-238(^+)</td>
<td>Closed, regional</td>
<td>300-1200</td>
</tr>
<tr>
<td>Molten salt fast reactors (MSR)</td>
<td>Fluoride salts</td>
<td>700-800</td>
<td>low</td>
<td>UF(_4) in salt</td>
<td>Closed</td>
<td>1000</td>
</tr>
<tr>
<td>Molten salt reactor-Advanced High-temperature reactors (MSR-ATR)</td>
<td>Fluoride salts</td>
<td>750-1000</td>
<td>low</td>
<td>UO(_2) particles in prism</td>
<td>Open</td>
<td>1000-1500 30-150</td>
</tr>
<tr>
<td>Sodium fast-cooled reactors (SFR)</td>
<td>Sodium</td>
<td>550</td>
<td>low</td>
<td>U-238 &amp; MOX</td>
<td>Closed</td>
<td>300-1500 1000-2000</td>
</tr>
<tr>
<td>Supercritical water-cooled reactors (SCWR)</td>
<td>Water</td>
<td>510-625</td>
<td>Very high</td>
<td>UO(_2)</td>
<td>Open (thermal) Closed (fast)</td>
<td>1000-1500</td>
</tr>
<tr>
<td>Very high temperature gas reactors (VHTR)</td>
<td>Helium</td>
<td>900-1000</td>
<td>High</td>
<td>UO(_2) particles in prism or pebbles</td>
<td>Open</td>
<td>250-300</td>
</tr>
</tbody>
</table>

\(^a\)Helium gas, \(^b\)Lead-Bismuth, \(^+\)with some U-235 or Pu-239, \(\text{Uranyl fluoride}\)

The generation IV international forum (GIF) was set-up in the year 2000 and represents 10 countries including the USA, France, Brazil, Argentina, UK, Russia among others (WNA June 2010) that are committed to developing advanced reactor technologies for
In 2002, six reactor technologies were selected on the basis of being cost-effective, providing a safe and sustainable source of energy and resistant to proliferation. The estimated budget for this project is about $6 million USD over 15 years. Six technologies utilizing a closed fuel system were selected as the basis of constructing the most advanced, efficient and safe nuclear power reactors to combat the global challenges of energy requirements and are shown in Table 12 (WNA June 2010). The reactor design of each technology is shown in Figure 8 (Idaho National Engineering and Environmental Laboratory, INEEL) of the Appendix.

India is not part of the GIF but is developing a FBR (KAMINI) that will exploit the country’s rich thorium reserves. Its ambitious three stage nuclear program involves utilising PHWR’s (CANDU) followed by 500 Mwe FBR’s to breed U-233 from thorium. In the final stage, advanced nuclear power systems will process U-233. The FBR’s are fuelled by uranium-plutonium carbide with a thorium blanket to breed fissile uranium. Spent fuel will be reprocessed to recover any fissile material for reuse. The two options for the third stage are an Advanced heavy water reactor and subcritical Accelerator-Driven Systems. The project is expected to be operational in 2011 and is designed for a life span of 100 years with 65% fuel utilisation of thorium via U-233.
Ethics of Nuclear Energy Technology (ECCAP WG12 Report, draft)

4. Ethical Aspects of Nuclear Energy

4.1. Nuclear justice and equity

One of the unique and particular issues of nuclear energy technology ethics concerns equity and justice issues. Developing countries are spending considerable sums on nuclear energy as compared to developed countries, as mentioned before. When a significant proportion of the population suffers from the lack of basic needs this may represent an injustice to the poor and the marginalized of a given society. This runs contrary to the principle of justice.

This is particularly true with respect to nuclear weapons spending. Renner (2007) notes that the number of nuclear warheads held in 2006 by five of the world’s nuclear powers—the United States, Russia, the United Kingdom, France, and China—was estimated at about 27,000, down from a peak of about 70,000 in 1986. The US and Russia stockpiles account for over 97% of the warheads. Renner also provides estimates that around 2500 nuclear warheads remain on high alert status. Examples of costs of maintaining nuclear weapons are given below:

- The 1972 Strategic Arms Limitation Treaty I (SALT I) led to a sharp curtailment of any further anti-ballistic missile (ABM) development efforts. In 1974, a treaty revision allowed the U.S and the Soviet Union to retain only one ABM site each. The American site became operational in 1975 but Congress ordered its termination within four months. Before site shutdown, the cost was 21.3 billion USD (Garrison, 2006).

- The total incurred costs of the U.S. nuclear weapons program exceed 5.8 trillion USD in the period between 1940 and 1996. This includes 320 billion USD in estimated future-year costs for storing and disposing of more than five decades' worth of accumulated toxic and radioactive wastes, and 20 billion USD for dismantling nuclear weapons systems and disposing of surplus nuclear materials (Schwartz, 2008).

- The average French nuclear defense budget per annum for 2003-2008 was planned to be 3.8 billion USD. For comparison purposes, the defense budget for 2006 was 49 billion USD (Tertrais, 2007).

Comparing nuclear defense spending and budgets with country’s budgets for education and development reveals that military intentions are often higher (GPF, 2009). The ethics of distributing societal financial resources for nuclear military expenditure versus developmental expenditure is a perpetual question in national governance. The governments involved, which are for the most part developed economies, may consider the opportunity cost to the impoverished when considering such spending.

An analysis of the data shown in paragraph 1.3 reveals that developing countries are spending a greater proportion of their National Income on nuclear energy compared to developed countries. Turning attention now to a developing country such as India, more than half of the population lives below the poverty line, and there have been many suicides by farmers in 2008 due to an inability to grow enough food (Lohan, 2009). While the immediate cost of generating energy from a nuclear power plant is higher than the thermal or hydroelectric methods of power generation, the justice principle would likely dictate that the relative cost of energy, whether nuclear or not, should be comparatively less, rather than more, in comparison to developed countries. To meet this ethical obligation of justice, developed countries may provide funding and development assistance or technology transfers and cooperation with developing countries.
However, even if such policies from developed countries are not forthcoming, or such policies are less than adequate, the justice principle still has further application. Since its independence, the issue of poverty within India has remained a prevalent concern. According to the common definition of poverty, when a person is unable to meet the minimum requirement of acceptable living standards, he or she is considered to be living in poverty. For example in India, millions of people are unable to meet the basic standard: according to Indian government estimates, in 2007 there were nearly 220.1 million people living in poverty. Poverty, in India or elsewhere, has dire downstream effects (World Bank, 2009; Mehta, 2003). If the cost of nuclear energy is relatively more for countries with high poverty rates, there will be less funding available to be spent on education, basic health and living.

Thus, in this further application of the justice principle, justice is relative for each country because it depends on the wealth of the given country. For example, nuclear technology development in India may not be justified if basic amenities of the people are not fulfilled. Basic amenities represent high value per dollar of investment, and if such money funds nuclear technology development, a large opportunity cost is imposed. However, in the case of developed countries such as France, nuclear technology development is more justifiable because basic amenities of a large proportion of the population are met.

4.2. A human-rights based approach

While the right to sustainable energy arguably deserves to be recognized as a fundamental human right, the current status on a generalized basis is that this right exists not as a substantive right by law/constitution but rather as procedural right (Wilson and Anderson 2005). However, a substantive emphasis is required to set objectives for energy policies and programmes.

Given the complexity of the technology, it then becomes necessary to examine the imperatives of international/national policies and treaties/programmes on nuclear energy in light of a human rights based approach. The United Nations Development Group (UNDG) Resolution adopted in 2003, said that

‘International policies and treaties on nuclear technologies need to take cognizance of the human rights principles of universality and inalienability; indivisibility; interdependence and inter-relatedness; non-discrimination and equality; participation and inclusion; accountability and the rule of law.’

A case for a right to a particular energy source such as nuclear energy remains ambiguous. For instance, while Article IV of the NPT states that signatories have a substantive and “inalienable right” to peaceful use of nuclear energy, it is subject to conditions. While this can be easily justified as a sovereign right, distributing this right down to the population can only, if at all, be achieved through relying on a human rights framework. Human rights are guaranteed by the sovereign to its people, in the interaction between the two. It is in this context that the UNDG Resolution of 2003 comes to life. State policy on nuclear energy should (presuming this right falls within the categorisation of economic, social and cultural rights) be progressively set to achieve full and affordable provision of sustainable energy for all, without discrimination. Unless understood in this way, the application of procedural rights to nuclear energy in particular is ambiguous. For example, the United Nations Framework on Climate Change (UNFCCC) excludes nuclear technologies in two of the three flexibility mechanisms under the Kyoto Protocol.

Given the complexity of applying the term “rights” to nuclear energy, it may be useful to examine the imperatives of policies, treaties, and programmes on nuclear energy in light of
a human rights based approach, which can be found among the countless documents and
understandings produced.

As an example which shows the human rights based approach at work, the outcome of
the Interagency Workshop on a Human Rights based Approach in the context of UN reform
3-5 May 2003 might be used. A common understanding was reached at the workshop
entitled, “The Human Rights Based Approach (HRBA) to Development Cooperation towards
a Common Understanding among UN Agencies” (HRBA, 2003). It outlined various
principles to be followed in all phases of programming, including: universality and
inalienability, indivisibility, interdependence and inter-relatedness, non-discrimination and
equality, participation and inclusion, accountability, and the rule of law.

Further, UN High Commission on Human Rights (UNHCHR) guidance (UNHCHR,
2006) can be adapted to HRBA in policies and programmes pertaining to nuclear
technologies. Such guidance is helpful because it provides additional ethical support for a
human rights based approach. The following are principles that may be derived from
including such guidance into the approach:

- The main objective of nuclear policies and programmes should be to fulfil human rights,
in particular the right to sustainable energy.
- Nuclear policies and programmes should identify the right-holders and their entitlements,
corresponding duty-bearers and their obligations, and work towards strengthening the
capacities of rights-holders to make their claims and of duty-bearers to meet their
obligations (the current emphasis in the nuclear context in many countries is on ‘stake-
holders’, not ‘right-holders’).
- Principles and standards derived from international human rights treaties should guide all
policies and programmes in the nuclear sector and in all phases.

As the above principles indicate, the right to sustainable energy is considered a fundamental
ethical right. The emphasis on the right to sustainable energy will not be productive unless it
is firmed up. Pinning it down would provide firm ground for a progressive framework of
energy management. Energy is essential for development. Just as food is a source of energy
for human development, so are renewable and non-renewable sources of energy essential for
economic growth and social well-being. If there is a right to development, then there exists a
right to sustainable energy.

The right to development (RtD) is an inalienable and indivisible human right ‘by virtue of
which every person and all peoples are entitled to participate in, and contribute to, and enjoy
economic, social, cultural and political development, in which all human rights and
fundamental freedoms can be fully realised’ (Art. 1, RtD Declaration). The right to
development is both, a substantive right, and a right to a process of development. The
process, which as expressed in the human rights based approaches to development (HRBA,
2003), should be universal and inalienable, indivisible, interdependent and inter-related,
non-discriminatory and equal, participatory and inclusive, accountable, and be situated in the rule
of law. The right itself then, as society progresses, includes not only food and shelter but also
energy. Humans, as hunter-gatherers, may not have dreamed of classifying food as a human
right, as food was a matter of reward for the fittest and ablest amongst them. However, as
society developed farming and became more settled, food became abundant and it became
abhorrent for anyone to go without food. Hence we arrive at today’s situation where food is
classified as a human right. So too should be the right to sustainable energy. It is rightly
arguable then, that the right to sustainable energy is a component of the right to development.
Such a right should be fulfilled in a manner that respects human rights. It is the duty of States
to ‘co-operate with each other in ensuring development and eliminating obstacles to
development’ (Article 3(3) RtD Declaration). Article 4 reinforces this duty by stipulating that
States should ‘take steps, individually and collectively, to formulate international development policies with a view to facilitating the full realization of the right to development’.

Ethical issues are encountered from experience. For instance, in the human rights based approach, individual and collective rights aspects also require special attention. Collective rights are called into question during various circumstances such as individual versus collective radiation doses, rights of the local community waste hosting repositories, and rights of the communities during transportation of nuclear material. Nuclear energy policies need to be explicit in addressing both individual and collective rights in human rights based approach.

Further declarations and sources of law and authority will need to be included. For instance, according to the 1997 declaration by the UNESCO Director-General, on the human right to peace, lasting peace is a prerequisite for the exercise of all human rights and duties (The Human Right to Peace: Declaration by the Director-General (SHS-97/WS/6)). The human right to peace, unlike the right to development, is a negative right. It restrains states from going to war and stipulates against the use of force. On the other hand, it can also be taken to mean that use of force is necessary in the face of unjustified aggression, in order to restore peace. The maintenance of balance of power through a stockpile of nuclear arms can be presented as a deterrent to disturb the peace. This right needs to be at the centre of all developmental and military research budgets that feed into nuclear technologies. This also requires a rights-based approach to international obligations arising out of treaties such as the Nuclear Non-Proliferation Treaty (NPT) and Strategic Arms Reduction Treaty (START).

The right to peace can be readily associated with the right to peaceful uses of nuclear technology, under the NPT. An escalation in peaceful use of nuclear technology will contribute quantitatively in securing development (Pg.5). Keeping in perspective the transformation that the NPT is undergoing in recent years, it comes as no surprise that the fundamental bargain of NPT – the institutionalisation of the ‘nuclear haves’ and ‘nuclear have-nots’, is coming under fire. The recent review of the Treaty produced fresh momentum towards the abolition of nuclear weapons, by proclaiming a world free of nuclear weapons as guiding light of nuclear diplomacy in the years to come. This is a step closer to ensuring that the right to peace can be realised without the possession of weapons of mass destruction.

4.3. Application of Ethical Principles

As discussed in the introduction and the considerations above there are a number of principles and theories that can be applied to assist ethical policymaking in nuclear energy. A contrast in philosophical viewpoints can be found between the deontological and utilitarian approach. The deontological approach emphasises justice and the procedural aspects of decision-making, while utilitarianism focuses on the outcome of policies. The utilitarian approach also includes principles of justice, mainly distributive and retributive. Utilitarianism focuses more on the ends, deontology more on the means.

Further reflection on alternative sets of principles can be formulated, as discussed below. Further reflection on each principle in the light of each culture can be developed in the construction of policy analysis, taking into consideration the aspects mentioned in this report.

According to the principle of no acceptable risk a risk can never be an ‘acceptable’ risk, as a risk implies that there is a negative effect to be taken into consideration, in the hope of attaining a certain benefit. That negative effect can never be absolutely acceptable. When applied to nuclear energy, there are multiple aspects that can be considered a risk or a possible negative implication. The ones mentioned in this report are the negative effects of
mining, the risk of nuclear weapons proliferation and the safety risks of nuclear reactors. Although there is no absolute acceptable risk those negative effects should be weighed against the positive. This could make a negative effect more or less acceptable, but never completely acceptable.

In technology assessment, however, since all human activity has some risk, the relative risks of alternatives needs to be weighed against each other. The precautionary principle has been used to exercise precaution in applications where the risks are very difficult to calculate due to the novelty of the circumstance.

Resources used to address one negative aspect may leave no space to use those resources to mitigate other aspects. The principle of no free lunch could be stated in other words: 'you don't get anything for nothing'. Focusing on making one powerful reactor safer may not lead to an overall improved safety level of nuclear reactors worldwide unless the research is shared. Policy should promote general research on improving the safety level and efficiency of broad classes of reactors not just one. The no free lunch principle can also be applied to mining, where the commonly stated no GHG-emission of nuclear reactors needs to be calculate over total life cycle rather than just during operation of the plant, as construction, mining and decommissioning are often linked to negative effects upon the environment.

The principle of risk optimization means that if a benefit is achieved by sacrificing investment in other aspects, one should consider the consequences it has for the overall situation. Carefully examining all the risks and accordingly distributing the risk and potential benefits achieve the optimal results.

The principle that facts matters means that informed judgments are not based solely on good intentions but they need to be backed by scientific facts. One cannot take a sound decision if one has no idea about the true facts about the issue. Especially in projects of great expense and potential harm, scientific knowledge and data is quintessential, as one cannot afford to be ignorant about the true impact of certain measures and policies.

The principle of quantification where possible takes the facts one step further, calling for concrete data. Various nuclear monitoring institutions provide data. To rightly consider certain aspects and consider them in the decision-making process one needs a quantified assessment of every variable, including each risk and benefit.

In nuclear energy ethics a number of practical aspects must be considered including the issue of waste, the safety of the technology and nuclear weapons proliferation.

Is the development of nuclear energy as a renewable energy resource inevitable? As stated earlier in this report, the use of nuclear energy has become necessary in providing a sustainable energy resource in combating climate change. It produces little GHG emissions, although the other activities involved in the process towards maintaining a nuclear plant, such as the mining of the fuel, should be developed more so as to truly minimise the impact on climate change.

The nuclear waste resulting from the energy production processes creates a serious problem. Especially the fact that governments usually do not provide sufficient information means that the public is misinformed on the implications of a nuclear waste site in their direct environment. This prevents a well-informed decision and does not fulfil the criterion of adequate disclosure of information and therefore the freedom of choice. This is a crucial aspect of the theory of informed consent, which generally applies to ethics. Other criteria of informed consent are consideration of the rights and interests of all parties involved and often also to provide an objective timeframe for the decision-making. The theory of informed
consent is a consequence of recognizing autonomy, a principle that has been generally accepted in bioethics, and accepted in decisions regarding use of potentially dangerous substances such as pesticides and living modified organisms (under the Cartagena Protocol to the CBD).

Over the past decades many persons have objected to the general use of nuclear energy for fear of proliferation of nuclear arms and its catastrophic effects in case of armed conflict. Ethical theories have nonetheless rejected this argument in the light of increased safety and research in nuclear plants. Is developing nuclear energy worth possible global nuclear arms proliferation which would result in nuclear winter if they were used. Does the outcome outweigh the violation of human rights during even limited use? The issue remains that the recycling process of nuclear waste that is inherent to the production of nuclear energy, is difficult to monitor totally whereas an outbreak of a nuclear conflict could precede global-scale devastation. In this context the current status of climate change and technological developments should be considered. How reliable are the efforts of international organisations to monitor and hold inspections on site? Is it realistic to eventually subject nuclear plants on a global scale to international safeguards and prevent states from developing nuclear weapons with the enriched uranium or plutonium?

Overall, safety on nuclear sites is said by IAEA to be manageable. It is not said that nuclear sites are completely safe and any meltdown can be prevented, but technology has found ways of reducing a great part of the damage in unforeseen critical situations. Measures have been taken to improve the structure and internal system of the reactors, along with general procedural safety regulations. Thus far only two main nuclear accidents with environmental consequences have occurred. Each nation needs to answer the question whether the benefits of nuclear energy outweigh the consequences of any accidents.

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70 Refer to ECCAP WG4 report on Representation and Who Decides for issues related to community participation, including a case study on Olympic Dam Uranium Mine in Australia.

71 Three Mile Island, United States of America and Chernobyl, Ukraine. The former incident occurred due to a partial meltdown of the nuclear core and the latter incident was a miscalculation of the nuclear stability of the reactors during an experiment where the electrical energy supply was cut off.
5. Policy Options and Conclusions

The use of nuclear energy is associated with a complex set of issues requiring many ethical considerations. As nuclear energy technology becomes a more prominent issue, governments are urged to consider these issues and their attendant ethical considerations. To that end, the following policy options and conclusions are made. These options and conclusions are considered the most significant ones following the body of the report.

5.1. Reference to ethical principles in international relations

First, the ethical issues present in international relations should be tackled with greater ethical considerations in mind. It may benefit the international community to provide consideration for the perspectives of developing countries, which are not technologically advanced. These countries’ needs are often overshadowed by security concerns (for instance, in the GNEP), but greater measures to provide for equality may result in more stable international relationships.

5.2. More guidelines regarding the implementation of definitions

An improvement in the overall process of creating guidelines to implementing them is an option for creating more ethical and safe nuclear plants. Further explanation through detailed guidelines regarding definitions may be beneficial. The use of terms such as “as low as reasonably achievable” (ALARA), while undoubtedly context-sensitive, would benefit from greater detail and standardization. When several guidelines are available, these should be integrated into work cultures. As mentioned above, many ethical documents and guidelines exist for nuclear facility operators, but states may benefit from more integrated guidelines. These guidelines can in turn be integrated into nuclear safety cultures through mechanisms ranging from safety guidelines to employee performance appraisals.

5.3. Consider nuclear ethics in the context of climate change

This report shows that there are other considerations concerning the use of nuclear power with regards to its effects on society and environment. Any thorough ethical or policy analysis of nuclear energy technology needs to consider the entire nuclear fuel cycle. While the nuclear reactor itself is not a source of GHG gas emissions, negative externalities associated with uranium extraction and the problem of toxic radioactive wastes and their disposal cannot be ignored.

There are factors that can have far reaching economic consequences if states do not work towards establishing a common ethical rule that will safeguard the energy policies of countries wishing to pursue an active nuclear program for civil purposes. Both, the front end and the back end of the fuel-cycle should be considered to avoid an incomplete cost-benefit analysis. If uranium mining is not considered when deciding nuclear energy technology policy, it can lead to states not considering the health and environmental effects on uranium-mining countries and their populations in, for instance, Kazakhstan.

5.4. More favourable alternatives to nuclear energy technology

States may consider “safer” options when using nuclear energy technology. With respect to nuclear reactor design, states may wish to provide consideration for meltdown-resistant designs. With respect to enrichment, states may wish to consider purchasing enriched uranium or having it enriched elsewhere. This is a difficult choice for states, as they may wish to increase energy security by developing their own enrichment capacities. Nevertheless, they are options. With respect to reprocessing, states may wish to consider not reprocessing fuel or taking extra security precautions when doing so. Alternatively, they may consider increasing funding for more proliferation-resistant reprocessing technologies and/or consulting groups such as GNEP. With respect to depleted uranium, states may wish to
consider restricting its use to civilian purposes and disallow military use. States may also wish to consider supporting the banning of depleted uranium weapons.

5.5. Greater transparency of nuclear information
Societies may benefit from greater exchange and transparency of nuclear information. It was mentioned in this report that the general public often feels that it does not have enough access to nuclear safety information, making it difficult for them to take part in policy and ethical debates. The public may further not feel comfortable with nuclear energy if there are suspicions that information is being hidden. To therefore increase the efficacy of public discourse and improve acceptability of nuclear decisions by policy-makers, it may benefit states if nuclear information is provided with greater transparency.

5.6. Alternative measures to safeguarding nuclear proliferation
While most states take concrete steps to curb nuclear proliferation, there are other steps that may be underemphasized. As mentioned in this report, a more integrated approach to countering this threat may be beneficial. Tactics may need to shift from a predominantly technology and fissile material stock monitoring approach to targeting terror financing and social capital. Moreover, states may benefit from designing a complex fabric of nuclear security on a socio-technical basis. This may involve educating citizens, politicians, and policy-makers to the security implications of nuclear technologies and implementing complex security measures without causing alarm.

5.7. Realistic assessments of costs and implications
The cost of nuclear energy should be more completely assessed by taking into consideration the opportunity cost vis-à-vis other energy sources and all “hidden” costs. These were mentioned in this report, and include insurance guarantees, the cost of decommissioning plants, regulatory oversight, non-monetary “safety” costs, and environmental costs, among others. The total costs for other energy sources should also be considered.

5.8. Greater equality for developing countries
The ethical issues present in international relations should be tackled with greater ethical considerations in mind. It may benefit the international community to provide consideration for the perspectives of developing countries, which are not technologically advanced. These countries’ needs are often overshadowed by security concerns (for instance, in the GNEP), but greater measures to provide for equality may result in more stable international relationships.

5.9. More ethics in international agreements
Nuclear agreements should be analyzed with significant emphasis on ethical aspects. The ethical issues should be identified, common definitions developed and standardized, and various nuclear agreements can benefit from integration in a more cohesive and unified regime.

5.10. Increased importance of equity and justice
Greater application of ethical principles such as justice and equity may provide a reason to consider the opportunity cost to the impoverished when considering such spending. This may also prompt developing countries to spend comparatively less on nuclear technology and provide greater financial attention to the impoverished. Finally, to meet the ethical obligation

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72 Refer to ECCAP WG1 report which examines different ethical theories and principles used in international agreements.
of justice, developed countries may provide funding and development assistance or technology transfers and cooperation with developing countries.

5.11. A more human rights-based approach

Given the complexity of nuclear energy, it may be useful to examine the imperatives of policies, treaties, and programmes on nuclear energy in light of a human-rights based approach, which can be found among the countless documents and understandings produced. The right to sustainable energy is not yet recognised as a human right, but when placed within the right to development, it can be argued that in a society where progress is fundamental to its identity, the right to sustainable energy has a strong case as a human right. It would be unethical to not persistently explore ways and means to establish the human right to sustainable energy. The human rights-based approach is able to simplify some of complexity resulting from international politics as well as the procedural complexities involved in the implementation of myriad nuclear agreements and regulations. Nuclear energy development would be considered more ethical if the infringement on human rights would also be limited.

It is therefore in our interest to invest in improved safety regulations and technology, so as to prevent further violation of the human rights involved. Modern reactor designs can achieve a very low risk of serious accidents, but “best practices” in construction and operation are essential. The suppliers of nuclear materials should take up research in this area. It is within the theory of deontology to adhere to procedures and rules and eventually decide whether breaching the rules in a process is worth the outcome or result. Utilitarianism would consider that the infringement of certain rules or procedures is compensated by the outcome. Human rights are considered by some philosophers as an expression of those rules or procedures and therefore are generally most supported by the deontological school of ethics.

5.12. Provide effective measures against misuse of nuclear waste

Geological disposal is technically feasible but execution is yet to be demonstrated or certain. A convincing case has not been made that long-term waste management benefits of advanced, closed fuel cycles involving reprocessing of spent fuel are outweighed by the short-term risks and costs. Improvement in the open, once through fuel cycle may offer waste management benefits as large as those claimed for the more expensive closed fuel cycles. The company, which sells nuclear fuel, should take up the moral responsibility of disposing the nuclear waste also without any additional cost.
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7. Case studies of societal and environmental security in Asia: The use of nuclear technology as a “clean” source of power.

7.1 The development of nuclear power technology in Indonesia: Is it prudent?

Indonesia is situated between the Pacific and Indian Oceans between Asia and Australia. It consists of nearly 18,000 islands and is the fourth largest country in the world. A large portion of the country lies within the “Pacific Ring of Fire”, a 40,000 km zone that is seismically active due to subterranean faults arising from plate tectonics, movement and collision of the Indo-Australian, Indo-Chinese, Pacific and Philippine crustal plates. Thus, 90 percent of the earthquakes and volcanoes occur in the 7000 islands, which are inhabited, of which Java, Bali and Sumatra are highly prone to geological upheavals. Thus, a question that can be asked is whether such a country can undertake the risk of running nuclear power plants? Ethically speaking, should a nation hold back its struggle for “green” power to satisfy its energy crisis, against the backdrop of impending natural disasters? In September 2010, about 1,100 people died due to a 7.6 magnitude earthquake in west Sumatra. Another 81 people were killed, 350,000 buildings collapsed in Yogyakarta and 45,000 in west Java in an earlier earthquake. The country’s energy situation is of a serious concern in cities like Surabaya and Jakarta as it battles repeated blackouts due to earthquakes and volcanic activity. People living in remote parts of the islands are frequently deprived of power and live in darkness.

Indonesia has about 30 gigawatts (Gwe) of power in its national grid and needs an additional 5GW very year in the near future (see Richard Tranter-Asia pacific Journal). From 1980 to 2006, the last year for which figures are available, annual electricity consumption rose dramatically from 11.299 to 110.71 billion kWh according to IAEA, and continues to rise at an alarming rate. The country’s first “fast-track” power program in 2006 was designed to deliver 10,000 megawatts to the grid. However, it is years behind schedule and has been delayed due to low pricing of power, fluctuating coal prices, convincing Chinese export banks to provide loans against absence of state guarantees and additional problems like multi-ministry delays on permits, permissions and procedures coupled with the negative impact of corruption and inefficiency. Coal producers are facing the dilemma of selling to an energy-starved internal market in a country without efficient roadways, ports and pipelines versus exporting coal and gas to good profits abroad. The Asian Development Bank (ADB) has suggested that the country must invest 4 million US dollars in the power sector to make the economy more competitive.

In light of the above problems Indonesia strives to embrace nuclear technology as a solution to stave off its power crisis that affects its ever-increasing population. The Nuclear Energy Regulatory and National Atomic Energy Agencies (BATAN), which are jointly responsible for overseeing the country’s nuclear activity, in 2002-2003 proposed nuclear plant sites in the Muria peninsula on the north coast of central Java despite repeated protests from the public. However, the reasons cited by the BATAN experts in selecting the site at Muria besides its proximity to the sea, was low population density and good ground characteristics with low probability of seismic activity. However reports from the IAEA geologists and volcanologists suggest that the area is composed of several fault lines, as well as the presence of the Muria volcano complex 25 kms away that is capable of erupting in the expected life-time of the plant.

Despite political turmoil and a weak regulatory framework, the Indonesian government seems determined to go ahead with the project that will supposedly provide 4000 Mwe to alleviate problems arising due to green-house gas emissions from coal-fired plants, as well as
supply electricity to the industrialized region around Jakarta. An overruling reason for investing in this expensive energy option seems to be driven by the fact that nuclear power manufacturers (and their governments) in countries like Japan, China, Korea and France are looking at export markets like Indonesia to underwrite their cost of domestic production. Yet another deterrent to the Muria nuclear energy program is based on religious reasons. The local Islamic population, a major ethnic community in Indonesia, forbids such endeavours according to Islamic jurisprudence. The Islamic community with a strong support from the locals, has criticized the BATAN regarding the negative effects of the nuclear plant including long-term disposal and storage of radioactive waste, environmental effects of waste water from the nuclear plant on nearby fresh water lakes, financial clarity of the project and long-term dependence on fuel and foreign technology. In light of strong public resentment and opposition from scientific members, at present the Muria site has been stalled and other sites in Kalimantan (Borneo) and Java are being considered, as the government seems determined to put Indonesia on the nuclear map.

Nevertheless, the long term viability of such a project is questionable under the threat of natural calamities and protesting ethnic groups against leaders need to take on both biocentric and ecocentric viewpoints instead of adopting a purely anthropocentric approach. Awareness of the risks and benefits need to be debated so as to avoid the misuse of nuclear technology. Externalities associated at every stage of nuclear power production needs to be assessed to address issues of economic feasibility, environmental implications and the well being of the citizens. Under such circumstances it is necessary for the government to adopt a pluralistic approach to the issue of energy crisis by setting up dialogues between stakeholders namely, state representatives and a cross-cultural group of citizens to arrive at sound decisions that would benefit the country, globally and its people.

7.2 Case studies of the ethical issues concerning nuclear accidents in Japan
The following are three cases of nuclear accidents in Japan that address societal implications of unethical acts of engineers working in nuclear power plants.

7.2.1 Fire due to sodium coolant leak in a Fast Breeder Reactor at Monju.
On December 8, 1995, a prototype fast breeder reactor, Monju, located in Tsuruga City, 350km west of Tokyo, was operating at 40% power. The Power Reactor and Nuclear Fuel Development Corp (PNC), a government controlled organization, operated this reactor. At 7.47 pm high temperature liquid sodium coolant at one of the three secondary heat exchangers started leaking through a broken thermometer sheath on the piping and ignited on contact with air. Primary heat exchangers are designed to take heat out of the core of the reactor to the secondary heat exchangers, which then transfer the heat to steam generators for power. Because of this design, it was a simple fire caused by the leakage of chemically reactive but non-radioactive sodium coolant. However due to the delay in shutting down of the reactor, 640kg of the sodium leaked in 3 hours and caused some unexpected damage due to the fire and chemical reactions with the surrounding structure.

The sheath was found to have been broken by following design errors such as,

1. Stress concentration and breakage.
2. Mechanical faults
3. Failure to consider the fact that liquid sodium is 120 times more heat conductive than water.
4. Use better and simpler design of primary heat exchangers.

Despite repeated requests from neighbours and other anti-nuclear agencies, the PNC affirmed that the power plant was absolutely safe to operate. It was subsequently proved that videotapes taken at the site were allowed for public viewing after editing. The PNC’s delay
(of about one hour) in informing the neighbouring community and other agencies of the accident also sparked a fierce protest by the public.

7.2.2 Fire and Explosion at Bituminization Demonstration Facility in 1997
The second accident occurred 14 months after the first one at Tokai Works of PNC, located in Tokaimura, 140km north of Tokyo. The facility mixes low radioactive nuclear wastewater with molten bitumen and evaporates water in a steam-heated extruder and pours the molten mixture into steel drums (180 litres) to cool down. Since the waste contains a high percentage of sodium nitrate, a strong oxidation reagent, and bitumen and other organic chemicals, the mixture is likely to initiate oxidation reaction by itself at high temperature. Because of the risk, reagents to retard the oxidation reaction were investigated before the process started operation in 1982.

Engineers planned an experiment to reduce a flow rate by 10% then 20%. Operators from subcontractors observed lowering viscosity of the final mixture, an indication of higher temperature but the thermometer at the exit of the extruder was not working well for years. When they saw pillars of flame on the drums being cooled down, they splashed water from sprinklers for one minute just enough to extinguish the fire. They reported to the engineers who did not show up for an inspection before an explosion occurred 10 hours later due to which a small amount of radioactive material went out of the building. Several workers had been scheduled to enter the building 40 minutes after the explosion. Although there were no casualties, engineers could have foreseen the explosion if they had understood the cause of the original fire.

The above incidents show the importance of sound ethical practice by decision makers and engineers working in a nuclear plant facility. Design errors and cheap components arise from the lack of competence on the part of the engineers attributable to the cheap labour employed by power plant owners to save money. Secondly, the cover up of information and the obvious delay in reporting a nuclear accident, regardless of its magnitude goes against the basic ethical principle of moral theory and the obligation to fulfil one’s right to knowledge. The failure of the officials to raise alarm caused a loss of faith in the public due to which the projects were delayed for at least 6 years and led to a loss of several tens of billion dollars.

In response to the Depleted Uranium (DU) Resolution adopted at the United Nations General Assembly on 5 December, 2007, the participants of the Joint UNESCO-UNITAR Asia-Arab Interregional Philosophical Dialogues on the Roles of Philosophy in War and Peace, and the Joint UNESCO-UNITAR Workshop on the Ethics of Nuclear Energy Technologies, noted that they are deeply concerned about the DU issue especially because it is understood that children are most susceptible to toxic radioactive materials.

Thus, the participants considered it is urgent to:

1. To alert the peoples and children living particularly in the DU-affected areas to the dangers caused by DU weapons;
2. To give serious consideration to the harmful effects of DU weapons by setting up an expert committee on the DU issue as quickly as possible;
3. To place an international moratorium on the use of DU weapons to prevent further DU-caused harms on human health and contamination of the environment.
4. To establish a Body to transport DU polluted war machinery and ammunition away from populated areas, and to properly dispose of them in remote and safe locations.

Agreed in Hiroshima, Japan, 27 July, 2008
Appendix: Diagrams on Nuclear Power Plant Designs (This section is under development)

Figure 1. Nuclear Power Plants, energy availability factor 1991 - 2007 (IAEA 2008)

Figure 2: Worldwide distribution of nuclear power plants
Figure 4: Generation IV nuclear reactors based on 6 different technology designs- Gas-cooled Fast reactor
Figure 4a: Lead-cooled Fast Reactor
Figure 4b: Molten Salt Reactor
Figure 4c: Sodium-cooled Fast Reactor

Figure 4d: Very-high Temperature Reactor.
Figure 4e: Supercritical Water-cooled Reactor
Table: Impact pathways of health and environmental effects included in the externality studies of energy and transport in the ExternE Project.

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Pollutant / Burden</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Health – mortality</td>
<td>PM$<em>{10}^{a)}$, PM$</em>{2.5}^{b)}$, SO$_2$, O$_3$</td>
<td>Reduction in life expectancy due to short and long time exposure</td>
</tr>
<tr>
<td></td>
<td>Heavy Metal (HM), Benzene, Benzo-[a]-pyrene 1,3-butadiene Diesel particles, radionuclides</td>
<td>Reduction in life expectancy due to short and long time exposure</td>
</tr>
<tr>
<td></td>
<td>Accident risk</td>
<td>Fatality risk from traffic and workplace accidents</td>
</tr>
<tr>
<td></td>
<td>Noise</td>
<td>Reduction in life expectancy due to long time exposure</td>
</tr>
<tr>
<td>Human Health – morbidity</td>
<td>PM$<em>{10}$, PM$</em>{2.5}$, O$_3$, SO$_2$</td>
<td>Respiratory hospital admissions</td>
</tr>
<tr>
<td></td>
<td>PM$<em>{10}$, PM$</em>{2.5}$, O$_3$</td>
<td>Restricted activity days</td>
</tr>
<tr>
<td></td>
<td>PM$<em>{10}$, PM$</em>{2.5}$, CO</td>
<td>Congestive heart failure</td>
</tr>
<tr>
<td></td>
<td>Benzene, Benzo-[a]-pyrene 1,3-butadiene Diesel particles, radionuclides, Heavy Metal (HM)</td>
<td>Cancer risk (non-fatal) Osteoporosis, ataxia, renal dysfunction</td>
</tr>
<tr>
<td></td>
<td>PM$<em>{10}$, PM$</em>{2.5}$</td>
<td>Cerebrovascular hospital admissions, Cases of chronic bronchitis, Cases of chronic cough in children, Cough in asthmatics, Lower respiratory symptoms</td>
</tr>
<tr>
<td></td>
<td>Mercury</td>
<td>Loss of IQ of children</td>
</tr>
<tr>
<td></td>
<td>O$_3$</td>
<td>Asthma attacks Symptom days</td>
</tr>
<tr>
<td></td>
<td>Noise</td>
<td>Myocardial infarction, Angina pectoris, Hypertension, Sleep disturbance</td>
</tr>
<tr>
<td></td>
<td>Accident risk</td>
<td>Risk of injuries from traffic and workplace accidents</td>
</tr>
<tr>
<td>Building Material</td>
<td>SO$_2$, Acid deposition</td>
<td>Ageing of galvanized steel, limestone, mortar, sandstone, paint, rendering, and zinc for utilitarian buildings</td>
</tr>
<tr>
<td></td>
<td>Combustion particles</td>
<td>Soiling of buildings</td>
</tr>
<tr>
<td>Crops</td>
<td>NO$_x$, SO$_2$</td>
<td>Yield change for wheat, barley, rye, oats, potato, sugar beet</td>
</tr>
<tr>
<td></td>
<td>O$_3$</td>
<td>Yield change for wheat, barley, rye, oats, potato, rice, tobacco, sunflower seed</td>
</tr>
<tr>
<td></td>
<td>Acid deposition</td>
<td>Increased need for liming</td>
</tr>
<tr>
<td></td>
<td>N, S deposition</td>
<td>Fertilizing effects</td>
</tr>
</tbody>
</table>
Global Warming | CO₂, CH₄, N₂O | World-wide effects on mortality, morbidity, coastal impacts, agriculture, energy demand, and economic impacts due to temperature change and sea level rise

Amenity losses | Noise | Amenity losses due to noise exposure

Ecosystems | Acid deposition, nitrogen deposition, SO₂, NOₓ, NH₃ | Acidity and eutrophication, 'PDF' of species

Land use Change | 'PDF' of species

Table: Maximum liability of the Operator and the Government in the top 10 nuclear power generating countries and India. (Civil Liability for Nuclear Damage Bill 2010)

<table>
<thead>
<tr>
<th>Country</th>
<th>Total generation (MW(e))</th>
<th>Operator’s Liability (USD million)</th>
<th>State Compensation (USD million)</th>
<th>Total Liability* (USD million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>1,00,683</td>
<td>11,900</td>
<td>Unlimited</td>
<td>Unlimited</td>
</tr>
<tr>
<td>France</td>
<td>63,130</td>
<td>861</td>
<td>300</td>
<td>1,161</td>
</tr>
<tr>
<td>Japan</td>
<td>46,823</td>
<td>Unlimited</td>
<td>Unlimited</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Russia</td>
<td>22,693</td>
<td>No amount specified</td>
<td>Unlimited</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Germany</td>
<td>20,480</td>
<td>Unlimited</td>
<td>2,500</td>
<td>Unlimited</td>
</tr>
<tr>
<td>South Korea</td>
<td>17,705</td>
<td>474</td>
<td>Unlimited</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Ukraine</td>
<td>13,107</td>
<td>237</td>
<td>Unlimited</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Canada</td>
<td>12,569</td>
<td>71</td>
<td>Unlimited</td>
<td>Unlimited</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>10,137</td>
<td>228</td>
<td>50</td>
<td>278</td>
</tr>
<tr>
<td>Sweden</td>
<td>9,041</td>
<td>474</td>
<td>198</td>
<td>672</td>
</tr>
<tr>
<td>India**</td>
<td>4,189</td>
<td>109</td>
<td>345</td>
<td>454</td>
</tr>
</tbody>
</table>

Sources: Various Sources¹³; PRS.

* Values have been converted into USD in source document as of December 2009.

** The values for India have been taken from the Bill and calculated at current exchange rates.