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A brief History of Nuclear Disasters: Prevention, Consequences and Re-coverage

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Abstract – After an introduction on the discovery of nuclear fission in the 1930s and the applications of this then unknown new energy source, the possible consequences of nuclear accidents and disasters on man and the environment are discussed. The paper focusses in particular on the question how to avoid such accidents, and how their impact on human health and environment could be limited or reduced. Special emphasis is made on the need for improvement of nuclear safety and security and the importance of the human factor, as most of technological accidents are due to human failure.

Keywords – *nuclear weapons, nuclear energy, nuclear disasters*

1. Introduction: Nuclear Fission

1.1. The Discovery

Nuclear fission was first observed on December 17th 1938 by the German Scientists OTTO HAHN and FRITZ STRASSMANN at the «Kaiser Willhelm Institut für Chemie» in Berlin-Dalem. After irradiating Uranium atoms with neutrons, the two scientists discovered a new element suddenly present in the residue: Barium. A year later, LISE MEITNER, an Austrian Physicist of Jewish origin, finally published in «Nature» the scientific explanation of what happened: the uranium nucleus broke into two parts, one of atomic mass around 90 and the other of around 140, thereby producing Barium as well as releasing a great quantity of energy. HAHN and STRASSMANN were awarded the Nobel Prize in 1944 for their work. Regrettably, Mrs. MEITNER was all but «forgotten», earning only a mention in the Nobel Prize presentation speech given by Professor ARNE F. WESTGREN.

These findings stimulated optimistic scientists on both sides of the Atlantic to speculate on a new type of weapon and new possibilities to produce (electric) energy based on nuclear fission. More pessimistic ones, however, spoke of nuclear science and nuclear fission as a sort of Pandora's Box and as a threat to humanity and the environment.

Already in 1942, the first nuclear reactor «Chigaco Pile-1» had been constructed in Chicago by ENRICO FERMI, in cooperation with LEO SZILARD and other scientists. In contrast to the atomic bomb, where all of the energy is released in a fraction of a second, in a reactor, the nuclear chain reaction is under control and can be stopped at any moment. The reaction's energy is then harnessed and used for electricity generation.

1.2. Development and Testing of Nuclear Weapons

As there is no way to stop human curiosity and scientific progress, all of the potential uses of nuclear energy were quickly exploited. Following the famous letter written by ALBERT EINSTEIN and LEO SZILARD in August 1939 to President FRANKLIN D. ROOSEVELT, the American government launched the so called «Manhattan Project». Under the military direction of General L. R. GROVES and the scientific direction of J. R. OPPENHEIMER, the project's objective was to develop the atomic bomb. The scientists who suggested this venture had gained word that the Nazi Regime had already begun a nuclear weapons research program and encouraged the US to develop its own before it was too late. It was only after WWII that it came out that the supposed German nuclear program was not nearly as advanced as previously believed. In the US, numerous European scientists who had immigrated to the US during the war were implicated in the Manhattan Project. Many of them, for secrecy, worked under a code name, such as for example HENRY FARMER, for the famous Italian physicist ENRICO FERMI. The first nuclear bomb test was successfully conducted at New Mexico's Alamogordo Bombing and Gunnery Range on 16 July, 1945. Soon after in the same year, the new US President HARRY S. TRUMAN decided to use this new weapon to force Japan to capitulation by bombing the Japanese cities of Hiroshima and Nagasaki on August 6 and 9, respectively.

Post WWII, the world witnessed a period of nuclear euphoria with atomic bombs of the equivalent force of several thousand tons of TNT (Trinitrotoluene, a classical explosive material) being not enough to satisfy geopolitically ambitious governments. With EDWARD TELLER as its driving force, the next step was the development of the Hydrogen Bomb, touting an explosive power corresponding to some Megatons of TNT. The most powerful Russian bomb, dubbed «Tsar», had a force corresponding to nearly 60 Megatons of conventional explosives. To put this figure in perspective, a railway train carrying 60 million tons of TNT would be so long that it would reach around the earth along the equator. This era was defined by an unprecedented arms race between the US, the UK, and the former Soviet Union and later China, France, India, Pakistan, perhaps Israel, South Africa, and, recently North Korea. More than 2000 nuclear test explosions, 622 of them in the atmosphere, were conducted during the period. Only after 1963 were atmospheric tests banned by a Partial Test Ban Treaty (PTBT). Then in 1974, tests were limited to 150 kT TNT equivalent by a Threshold Test Ban Treaty (TTBT). Nevertheless, a significant increase of artificial radioactivity, in particular in the northern hemisphere, came as a consequence of the careless testing, with the highest contamination observed from 1958 to 63. In the 1960s, many countries started regular radioactivity monitoring of the environment and finally, in 1996, a Comprehensive Test Ban Treaty (CTPB) banned all nuclear weapon tests. A worldwide organization (CTBTO, with its headquarters in Vienna) was even established to verify the fulfillment of this treaty.

1.3. The Geneva Conference «Atoms for Peace»

In 1953, following the period of high secrecy surrounding the US nuclear program during the Manhattan Project, US president DWIGHT D. EISENHOWER opened up nuclear energy to the masses for peaceful use. An international conference called «Atoms for peace» was organized in 1955, in Geneva with an operating nuclear reactor exposed to the public for the first time in one of the UN buildings. In the following years many industrialized countries, mainly in the northern hemisphere, started using nuclear reactors for electricity generation and research on applications of nuclear in many fields was markedly stimulated.

2. Consequences of Nuclear Disasters

2.1. Hiroshima and Nagasaki

The bombing of the Japanese cities of Hiroshima and Nagasaki was by far the worst nuclear catastrophe the world has ever seen. Between 90000 and 166000 people died in Hiroshima and between 60000 to 80000 in Nagasaki in the first two months after the explosions. The health effects of the event on the survivors were monitored by a common research program between US and Japan under the name of «Live-Span Study» under the responsibility of the Radiation Effects Research Foundation (RERF). By the year 1977, among the 120000 survivors, a total of 9336 persons had died from solid cancers and 582 from Leukemia. Of these, 440 cancer deaths and 100 Leukemia deaths can be attributed to the radiation from the bombing. «For a person aged 70 who was exposed to the radiations from the bomb at the age of 30, the excess relative risk (ERR) per Gy[1] was 0.47 for all cancer combined.» (IAEA, 2012, Radiation Biology, p. 46). This means that the cancer risk for an exposed person was 47 % higher than the average risk of the non-exposed public. The current ICRP (ICRP, 2007, p. 53) risk factors are mainly based on the outcome of this Life-Span Study as well as a handful of studies of some other highly radiation exposed collectives. «The Commission (i.e. the ICRP) proposes nominal probability coefficients for detriment-adjusted cancer risk as 5.5 % per Sv[2] for the whole population and 4.1 % per Sv for adult workers. For heritable effects, the detriment-adjusted nominal risk in the whole population is estimated as 0.2 % per Sv and in adult workers as 0.1 % per Sv.» (ICRP, 2007, p. 55). In other words; among 1000 adult persons irradiation by 1 Sv, 41 will die from a radiation induced cancer and one severe hereditary malformation will occur in the offspring of these persons.

2.2. Nuclear Test Sites

Many people living near nuclear test sites were subsequently affected by radioactivity and some regions in the vicinity of these test sides were, years later, still heavily contaminated. For example:

- Some Pacific islands (by US nuclear tests mainly Eniwetok Atoll and Marshall Island), Christmas Island in the North Pacific and at Maralinga, Emu and Monte Bello in South Australia (by UK nuclear tests),
- South Sahara's Hoggar Mountains in Algeria - at that time Algeria was a French Department - where France performed its first nuclear test on February 1960,
- Some islands of French Polynesia (the Mururoa and Fangataufa atolls) in the South Pacific Ocean,
- Nuclear weapon test of China were performed at a place called Lop Nor, some 600 km south of the borders to Mongolia and Kazakhstan, whilst India and Pakistan conducted underground nuclear tests at, respectively, Pokharan (North-Western part of the country) and Chagai Hills (Western Part of the country).

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[1] Gray (Gy) is the SI Unit for the absorbed radiation dose (D) with 1 Gy = 1 Joule per kg organ or tissue

[2] Sievert (Sv) is the SI Unit for he effective dose (E) by ionizing radiation with 1 Sv ≈ 1 Joule per kg or organ or tissue. It is obtained as sum of the dose equivalent (H_T) (the absorbed dose weighted by the radiation weighting factor w_R) of the most important organs or tissues of the human body, weighted by the tissue weighting factor w_T.

Additionally (all in the former Soviet Union):

- Near Kyshtym (next to the Russian Mayak plutonium production plant), a town in Chelyabinsk Oblast, in the Southern Ural Mountains, Russia,
- Along the Techa River, a river on the eastern flank of the southern Ural Mountains,
- Near the Lake Karachay, a small lake in the southern Ural mountains in western Russia,
- In the Semipalatinsk Region: the Semipalatinsk Test Site is known as «The Polygon» and was the region, where for the Soviet Union made many nuclear weapons tests. From 1949 until 1989 some 456 nuclear tests were conducted at Semipalatinsk with little regard for their effect on the local people or environment. Today this region belongs to Kazakhstan,
- On the island Nowaya Zemlya, an archipelago in the Arctic Ocean in the North of Russia and the extreme Northeast of Europe. Over its history as a nuclear test site, 224 nuclear tests with a total explosive energy equivalent to 265 megatons of TNT were performed there.

Unfortunately, for most of these contaminations and incidents, little to no data has been published on the number of affected persons and the health and environmental implications. Only in 2009, did the French government decide that people living near French nuclear test sites on French islands in the South Pacific Ocean affected by nuclear tests should receive indemnity payments. (see: MINISTERE DE LA DEFENCE, REPUBLIQUE FRANÇAISE: La dimension radiologique des essais nucléaires Français en Polynésie, 2006). According to several sources cited by the UNSCEAR (UNSCEAR, 2000, pp. 159f) reports, the most exposed people living near these nuclear test sites could have accumulated radiation doses up to several hundred mSv (milli-Sievert[3]). In comparison, UNSCEAR (UNSCERAR, 2000, pp. 159f) estimates an average accumulated dose of the World population due to nuclear weapon tests of 3.5 mSv, with 3.6 mSv in the Northern Hemisphere and 2.7 mSv in the Southern Hemisphere. These values have to be compared to the overall average annual radiation doses by all natural and artificial sources. For example, the Swiss population, as published regularly by the Swiss Federal Office of Public Health (for example, in the annual report for 2012, page 30) receives some 5 mSv every year.

2.3. *Other Incidents with Radioactivity*

Further events, among others, but with minor impact on men and environment were:

- The crash of an American satellite powered by an radioisotope thermoelectric generator (SNAP 9a[4]) containing the radioisotope ^{238}Pu (Half-life 86.4 years), that in 1964 failed to achieve orbit and disintegrated in the atmosphere dispersing roughly 1 kg of plutonium,
- The crash over Canada of a Russian satellite (Kosmos 954) in 1978 powered by a nuclear reactor, scattered radioactive debris all over Northern Canada,
- Two US military aircraft carrying nuclear weapons, crashed, one of them near Palomares in Spain (1966) and the other near Thule in Greenland (1968); the bombs didn't explode, but a major regional contamination came as a consequence of the crash.
- A medical instrument containing a ^{137}Cs source put away on scrap near Goiânia in Brazil (1987) where the radiation source was not dispose safely, causing an important contamination of the scrap dump, four deaths and some 50 injured.

And finally three heavy reactor accidents with severe damage to the installations:

- At the (underground) Experimental Nuclear Power Plant (CNL) near Lucens/VD in Switzerland (1969), fortunately with no environmental consequences, as the report to the Swiss Authorities concluded: «Soon after the initial start up, an undetected blockage in one of the cooling pipes led to a partial fuel meltdown and massive radioactive contamination of the underground site. Following the accident, the reactor was decommissioned and the cavern was then sealed. No humans were irradiated in the accident».
- At the Windscale Nuclear Reactor in Cumberland (now Sellafield), Cumbria, UK (1957),
- At the nuclear power plant of TMI[5] near Harrisburg, Pennsylvania in the US (1979).

2.4. *The Chernobyl and Fukushima Accidents*

The most severe reactor accidents have occurred in Chernobyl, Ukraine (April 26th, 1986) and Fukushima (March 11th, 2011), Japan. The former due to an un-appropriated reactor design and several human errors and the latter to a large Tsunami following the Tohuku Earthquake (magnitude 9) in the Pacific Ocean east of the Japanese main island. It is worth noting that the Japanese incident was also heavily aggravated by severe safety and security lack of the company running this nuclear power plants TEPCO[6]. Both of these accidents were classified as Level 7, the highest level on the International Nuclear Event Scale (INES) of the IAEA. According to many nuclear experts, and in the case of Fukushima by the Report by an Expert team to the Japanese Government, these two tragedies could both have been avoided had safety culture been on a level that is state of the art in many - but unfortunately not all - industrialized countries. In both cases, the most contaminated areas (around Chernobyl up to a radius of 30 km and at a similar level around the Fukushima-Daiichi Nuclear Power Station) had to be evacuated and will most likely

[3] 1 mSv = 1/1000 Sv
[4] System for Nuclear Auxiliary power
[5] Three Mile Island Nuclear Generation Station in Pennsylvania, US
[6] Tokyo Electric Power Company

remain so for several years, if not decades. In both cases more than 100000 people permanently lost their homes, farms, jobs, social network and security, independence and capability of self-determination. Surprisingly indemnity payments by the Soviet government did not markedly improve the situation of the Chernobyl evacuees.

2.5. The Radiological Consequences of Chernobyl

What about the radiological consequences of these two severe nuclear disasters? The number of reports, of (more or less scientific) publications, books, and newspaper articles on the Chernobyl catastrophe is endless. This makes the search for the truth extremely difficult. To begin, one of the best and mostly impartial publications on the consequences of this accident is the book by JIM SMITH and NICHOLAS A. BERESFORD (Smith, 2005). The same situation is sure to arise in a few years' time following the wake of the Fukushima Daiichi nuclear accident. In the case of Chernobyl, in particular, the number of expected radiation induced cancer deaths among the population in the three most affected countries: Ukraine, Belarus and the Russian Federation, varies over some orders of magnitude from publication to publication and is still hotly contested. Therefore, it may seem slightly arbitrary to cite only two publications. In any case, it is not the exact numbers that count but the overall impression of the magnitude of the disaster. The International Agency for Research in Cancer (IARC[7]) based in Lyon, France under the director ELISABETH CARDIS (Cardis, 2006, pp. 1224-1235) has estimated using mathematical models that for the population of all Europe (570 million) until the year 2065, some 16000 additional thyroid cancer cases (with a 95% confidence interval from 3400 to 72000) will arise with an overall morbidity from other cancers of 25000 (with a 95% confidence interval from 11000 to 59000) cases. This represents an increase of about 0.01 % of all incident cancers in Europe. Concerning the increase of non-thyroid solid cancers among the population of the most exposed countries, the large number of epidemiological studies conducted so far «showed a lack of evidence for the growth of solid cancer incidence among the population.» (Smith, 2005, p. 231). This may be due - according to the author - to the relatively low dose level, the latency period, and a lack of good data. «There are some doubts whether such an increase can be determined since predictive models estimate that the increase of incidence (mortality) will not exceed a few percent for the lifetime of the exposed population.» (Smith, 2005, p. 231).

Due to lack of cancer registries, health follow-ups, and other health data in many countries, it will be impossible to verify theses prognoses, leaving these numbers as pure speculations. Due to the lack of information and access to KI tablets in the vicinity of Chernobyl, a massive increase of thyroid diseases and thyroid cancer caused by uptake of large amounts of ^{131}I was observed among the most vulnerable communities. According to CARDIS, between 1986 and 2002, in the three most affected countries; Belarus, the Russian Federation (4 most contaminated regions) and the Ukraine, 2010, 483 and 2344 cases of thyroid cancer were diagnosed among children up 17 years old at the time of exposure, respectively. «Since the accident, the number of patients having thyroid cancer (exposed as children and adolescents in 1986) in Belarus, Russia and the Ukraine has reached 4000.» (Smith, 2005, p. 229). Except for the Liquidators, epidemiological studies on Leukemia «... did not find evidence of increased leukemia incidence among children and adults subjected to exposure due the Chernobyl accident.» (Smith, 2005, p. 221). The most exposed people to the Chernobyl accident were the 192000 Russian emergency workers, commonly called «Liquidators»:

«The mean dose (of these «Liquidators») was approximately 0.1 Gy (roughly equivalent to 0.1 Sv) from external irradiation, and internal radiation doses are assumed not to contribute much to the total dose.» ... «The latest estimate of WHO in 2006 suggested that 4.6 % of all fatalities that occurred during 1 year after the accident can be attributed, either directly or indirectly, to radiation exposure associated diseases, among them 2.3 % to radiation-induced cancer, 2 % cardiovascular diseases and 0.3 % to radiation-induced leukemia. The liquidator studies are certain to provide much important information in the future on radiation risks from low dose rate radiation exposure.» (IAEA, 2010, p. 132).

2.6. The Radiological Consequences of Fukushima

The situation seen at Chernobyl is quite similar to that of the Fukushima nuclear accident. The International Commission on Radiological Protection (ICRP, 2007) advises against any calculation of hypothetical cancer death in the dose domain below 200 mSv (milli-Sievert) using ICRP's risk factors for dose-to-risk conversion (ICRP, 2007, p. 53). Nevertheless, such calculations have been made and published. John E. TEN HOEVE und MARK Z. JACOBSON of the highly reputed Stanford University «Worldwide health effects of the Fukushima nuclear accident» (Hoeve, 2012, p. 8743) conducted such a study. The authors estimate a worldwide increase of cancer mortality due to the Fukushima Daiichi accident of only 130 cases with a 95 % confidence interval of 15 to 1100 and an additional number of 600 deaths due to non-radiological consequences such as stress, anxiety, hopelessness, and consequences of the evacuation, etc. (these effects are commonly grouped under the title Post-Traumatic Stress Disorders (PTSD)). As radiation itself induces morbidity, the same authors predict 180 additional cases of radiation induced cancers worldwide with a 95 % confidence interval from 24 to 1800. Two reports from the WHO (WHO, 2011 and WHO, 2012) as well as one from the «United Nations Scientific Committee of the Effects of atomic Radiation» (UNSCEAR) (UNSCEAR, 2013, pp. 159f) all put forth numbers on the same order of magnitude. The radiation doses of the most exposed population around the Fukushima Nuclear Power plant are given by UNSCEAR

[7] Internet source: `http://www.iarc.fr/`

(UNSCEAR, 2013, pp. 159f) to be less than 10 mSv in the first year and, integrated over a life time period of 80 years, less than 20 mSv. So, in fact - one can believe it or not - the radiological consequences of this nuclear disaster are not nearly as dramatic as one might expect. In comparison, the official number of people killed by the Tsunami wave itself, having nothing to do with the reactor accident, has been announced by the Japanese authorities as 18784[8].

3. Prevention of Nuclear Disasters

3.1. Nuclear Power Phase-out or not?

Is there any means to prevent nuclear disasters to happen, or at least – in case such an event cannot be avoided – what can be done to reduce as much as possible severe consequences for men and environment ? The easiest way, as some claim, could be to avoid any further use of nuclear technology. This is to say, no nuclear power plants, nuclear weapons, or any other applications of nuclear material and ionizing radiation in research, technology, medicine, etc. This, however, is not very realistic. No ethical discussions will stop scientific and technological progress. They could or should, on the contrary, contribute to improve safety and security of such technical applications of nuclear science and not simply forbid their further use. In the field of nuclear weapons, there has been some progress. At the end of the Apartheid regime, South Africa stopped their nuclear weapons program and dismantled (under close surveillance by experts of the IAEA) their nuclear warheads making the southern hemisphere is now a nuclear-weapon free zone. This is enforced by the Pelindaba Treaty, which entered in force on July 15th 2009. In addition, the Treaty on the Non-Proliferation of Nuclear Weapons (NPT[9]), that entered in force 1970 and was extended in 1995, gives some additional security for humanity.

Some European countries such Italy and Austria to name only a few, have already renounced nuclear energy and closed down their existing nuclear power plants. Others, like Germany and Switzerland have announced, following the Fukushima reactor catastrophe that they plan to abandon nuclear power in the near future: Germany by the year 2022 and Switzerland by the year 2034 or slightly later. The majority of nations worldwide, however, among them the US, UK, France, the BRICS[10] States and in the future some newcomers in Middle East, North Africa and elsewhere rest members of, or are thinking seriously of entering, the nuclear energy club. The nuclear threat, if there is such a thing, will therefore remain in many regions of the world. In light of this fact, it is apparent that in order to avoid any further severe accidents, nuclear safety and security has to be increase on a global scale.

3.2. Increasing safety of existing nuclear installations instead of Nuclear Phase-out?

The second possibility, that should seriously be taken into account and also put rapidly into practice, are international treaties and a transfer of technological know-how from countries experienced in nuclear energy, in order to increase global nuclear safety and security. Initiatives, for example from the Swiss nuclear regulator (the Swiss Federal Nuclear Safety Inspectorate ENSI) have triggered discussions among the contracting parties of the IAEA Convention on Nuclear Safety. And the Director General of the IAEA, YUKIYA AMANO then stated[11] « ... a number of challenges were identified for consideration by Contracting Parties. These included: how to achieve harmonized emergency plans and response measures; how to make better use of operating and regulatory experience and international peer review services; and how to strengthen regulators' independence, safety culture, transparency and openness.»

In addition, on October 1st new nuclear safety reference levels have been published by the «Western European Nuclear Regulators Association» (WENRA[12]) as part of its response to the Fukushima Daiichi accident. Also Sweden recently has announced its intention to take severe measures to increase safety of their nuclear power plants.

4. Nuclear Culture Needs to be Improved Worldwide

4.1. The Need for Safety Culture

Safety culture is essential in every field of modern technology, in particular in fields in which the consequences of an accident pose a severe threat to man and the environment. In many fields, for example civil aviation, international treaties with many adherents have been established; their fulfillment is regularly controlled by international and neutral expert teams. Every accident or incident in civil aviation, even those with no immediate consequences for men, environment, aircraft or other technical installations is analyzed in detail, in order to find out what happened, why it happened, and to define the appropriate measures needed to increase air traffic safety and to avoid that the same incident could happen again. Such rules and norms are essential and state of the art in such fields as international trade, IT, telecommunication, electricity distribution networks, transport of people and goods by air, rail, road and sea, and also for certification, accreditation and education at University levels in Europe, for example the European Bologna process on higher Education. It seems therefore obvious that the same level of safety, by regular inspections and controls by peers, assured by international treaties should be extended to nu-

[8]NISHIKAWA, Satoru: Vice-President, Japan Water Agency (UWA), Saitama, Japan: Incorporation science and technology for disaster reduction, the Japanese experience. Oral presentation at the IDRC Davos 2014 conference on «Integrative Risk Management – The role of science, technology & practice» of 24-28 August 2014

[9]Non Proliferation treaty for nuclear weapons

[10]The BRICS States: Brazil, Russian Federation, India, China and South Africa

[11]On the Sixth Review Meeting of April 4th 2014 at the IAEA in Vienna

[12]Internet source: `http://en.wikipedia.org/wiki/Western_European_Nuclear_Regulators'_Association`

Table 1: The International Nuclear Event Scale (INES) of the IAEA

	Level	Consequences for men, environment and installation	Examples
7	Major accident	- Impact on people and environment: Major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures	- Chernobyl, ex-S.U., 26.04.85 - Fukushima, Japan, 11.03.2011
6	Serious accident	- Impact on people and environment: Significant release of radioactive material likely to require implementation of planned countermeasures	- Kyshtym/Mayak, SU, 29.09.57
5	Accident With Wider consequences	- Impact on people and environment: Limited release of radioactive material likely to require implementation of some planned countermeasures. Several deaths from radiation. - Impact on radiological barriers and control: Severe damage to reactor core. Release of large quantities of radioactive material within an installation with a high probability of significant public exposure.	- Windscale, U.K., 10.10.57 - TMI, U.S., 28.03.79 - Chalk River, Canada, 12.12.52 - Lucens, Switzerland, 21.1.69 - Goiânia, Brazil, 13.9.87
4	Accident With Local consequences	- Impact on people and environment: Minor release of ra-dioactive material unlikely to result in implementation of planned countermeasures other than local food controls. At least one death from radiation. - Impact on radiological barriers and control: Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory. Release of significant quantities of radioactive material within an installation with a high probability of significant public exposure.	- Sellafield, U.K., 1955 to 1979 - SL-1, EPS, Idaho, U.S., 1961 - Saint-Laurent, France, 1969 - Buenos Aires, Argentina, 1983 - Jaslovské Bohunice, CZ, 1977 - Tokaimura, Japan, 1999
3	Serious incident	- Impact on people and environment: Exposure in excess of ten times the statutory annual limit for workers. Non-lethal deterministic health effect (e.g., burns) from radiation. - Impact on radiological barriers and control: Exposure rates of more than 1 Sv/h in an operating area. Severe contamination in an area not expected by design, with a low probability of significant public exposure. - Impact on defense in depth: Near accident at a nuclear power plant with no safety provisions remaining. Lost or stolen highly radioactive sealed source. Misdelivered highly radioactive sealed source without adequate procedures in place to handle it.	- THORP, Sellafield, U.K., 2005 - Paks, Hungary, 2003 - Vandellos, Spain, 1989 - Davis-Besse, U.S., 2002
2	Incident	- Impact on people and environment: Exposure of a member of the public in excess of 10 mSv. Exposure of a worker in excess of the statutory annual limits. - Impact on radiological barriers and control: Radiation levels in an operating area of more than 50 mSv/h. Significant contamination within the facility into an area not expected by design. - Impact on defense-in-depth: Significant failures in safety pro-visions but with no actual consequences. Found highly radioactive sealed orphan source, device or transport package with safety provisions intact. Inadequate packaging of a highly radioactive sealed source.	- Blayais, France, 1999 - Ascó, Spain, 2008 - Forsmark, Sweden, 2006 - Gundremmingen, Germ., 1977 - Shika, Japan, 1999
1	Anomaly	- Impact on defense-in-depth: Overexposure of a member of the public in excess of statutory annual limits. Minor problems with safety components with significant defense-in-depth remaining. Low activity lost or stolen radioactive source, device or transport package.	- various anomalies
0	Deviation	- No safety significance; no consequences on installation, man or environment	- various deviations

clear reactors. Unfortunately this is not yet the case everywhere.

Why is safety culture so important not only in nuclear technology but in every field of technology? Numerous analyses have shown evidence that some 80 % of technological incidents and accidents are due to human errors, human failure, violation of rules, and lack of education. These incidents occur on every level, from the conception and planning of nuclear installations to their construction and exploitation, to their surveillance, monitoring, and maintenance. Regular inspections are required at all levels and audits by external and neutral experts and in particular a «Blame-Free Error Management» is needed in order to learn from every incident and to allow a continuous improvement of safety and security without any delay in relation to scientific and technological progress.

The so called human factor includes not only the education and continuous training of staff members but also the organization of an enterprise, an optimal «working climate» and recognition, and positive feed-back from the superiors. In this way, everyone from the directors down to cleaning staff is conscious of their own responsibility for safety and security and their contribution to the good functioning of the whole plant.

4.2. The Services offered by the IAEA[13]

The IAEA offers several different services though it remains the decision of every country to use these services and to implement the recommendations they obtain in the inspection reports. Three of these services and their objectives are presented in following paragraph.

4.2.1. The INES service is a classification system for all events or accident in the nuclear field, but also for all applications of radiation sources. It is described on the IAEA Web-Site as follows:

> «INES: is a tool for promptly and consistently communicating to the public the safety significance of events associated with sources of ionizing radiation. The primary purpose of INES is to facilitate communication and understanding between the technical community, the media and the public on the safety significance of events. The aim is to keep the public as well as nuclear authorities accurately informed on the occurrence and consequences of reported events. The INES scale applies to any event associated with the use, storage and transport of radioactive material and radiation sources, whether or not the event occurs at a facility; this includes events involving the loss or theft of radioactive sources or packages and the discovery of orphan sources, such as sources being discovered in scrap metal.»

4.2.2. Another service of the IAEA is the inspection of nuclear power stations by independent international expert teams, called OSART-Mission. The purpose is to give a neutral outside view and to document what is up to date, compared to the international level of state of the art and where there is room for improvement. Every member state of the IAEA can order such missions for their nuclear power stations.

It is then the responsibility of the national regulatory authorities to fix a term for the operators to implement these recommendations and finally to verify if these measures have been implemented correctly. The IAEA Website describes OSART as follows:

> OSART[14] «Nuclear Safety Peer Review Looks at Human Aspect of Plant Operations. Nuclear safety is a never ending quest for improvement, and one of the more prominent IAEA efforts that help countries achieve higher levels of safety is the Operational Safety Review Team (OSART) program. In OSART missions, the IAEA coordinates internationally-based teams of experts who conduct reviews of operational safety performance at nuclear power plants. The OSART review is a process that begins with a request from a country for a safety review, and can occur in three stages. Pre-OSART missions are conducted during the construction and commissioning phase of a plant´s life. These missions help ensure effective preparations for commissioning and operations. Safety review missions consist of a regular OSART mission, offering an in-depth examination of design features most closely related to safe and reliable operation. Human performance issues and recognized design weaknesses are assessed in an integrated way. These regular OSART missions are concluded by follow-up visits, which take place approximately 12-18 months after an OSART mission.»

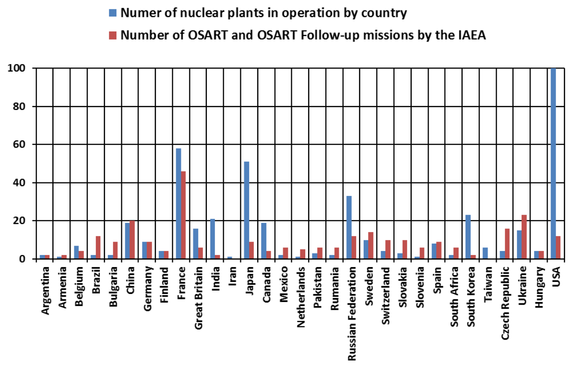

Figure 1: «Nuclear Safety Consciousness» in different countries worldwide, illustrated by the comparison of nuclear reactor to the OSART missions performed so far in each country.

The IAEA publishes regularly the number of OSART missions and OSART follow-up missions by country on his Web-Site. Figure 1 gives an overview of the number of such missions together with the number of nuclear power plants in operation by country. This graph foreshadows how important the safety of nuclear power plants is for these different countries. It seems obvious that regular inspections of every nuclear reactor worldwide would significantly increase the safety and security of these installations. It is the responsibility of every government to order such inspections and - as a follow up - to impose on the managements of these nuclear stations a prompt implementation of all suggestions and recommendations issued by the expert team in their reports.

4.2.3. The third service of the IAEA concern expertise of national regulatory authorities so called (IRRS Missions[15]) and is described as follow on the IAEA Web-Site:

> IRRS: Integrated Regulatory Review Service: «The IAEA Integrated Regulatory Review

[13] Internet source: `http://www.iaea.org/`
[14] Internet source: `http://www.iaea.org/newscenter/news/2010/osart.html`
[15] Internet source: `http://www-ns.iaea.org/reviews/rs-reviews.asp`

Service is designed to strengthen and enhance the effectiveness of the national regulatory infrastructure of States for nuclear, radiation, radioactive waste and transport safety and security of radioactive sources whilst recognizing the ultimate responsibility of each State to ensure safety in the above areas. This expressed purpose of the IRRS is to be accomplished through consideration of both regulatory technical and policy issues, with comparisons against IAEA safety standards and where appropriate, good practices elsewhere.»

5. Accident Preparedness

5.1. Safety of Nuclear Reactors alone is not sufficient

Safety can never be 100 %, therefore, in addition, measures have to be created on how protect workers, population, environment and installations from the consequences of a severe nuclear accident. This begins with rapid communication among authorities on a local, regional and national level, as well as among every organization concerned by such accidents. These may include national and regional authorities such as police, civil protection, hospitals, press, etc. Many countries have special regularly trained catastrophe organizations and have installed a rapid IT-based information network with partner organizations abroad. In a short paper it is impossible to list all the measures that are or should be taken in case of a severe nuclear accident, so we will provide only a few examples. It is, however, important that all these actions are trained and improved regularly by exercises and that they are harmonized with neighboring countries.

5.2. Four levels of actions

5.2.1. On-Site measures in order to avoid overexposure of worker, major release of radioactivity to the environment (i.e. in air and water) and severe damages to the nuclear installation:

- Selection, education and regular training (by reactor simulators) of reactor operators,
- Multiple redundancy and diversity for all safety relevant systems such as reactor cooling and auxiliary power generators,
- Passive and inherent security of the reactor, in particular a negative void coefficient, so that in case of loss of coolant the reactivity decreases,
- Chose the best materials for all reactor components and regular quality control,
- systematic application of the multiple barrier principles in order to retain radioactivity as well as the rules of «Defense in Depth», based on «Probabilistic Safety Analyses»,
- a high level of automatic reactor control and monitoring systems, (this because some 80 percent of the accidents are du human error or human failure).

In the case of a loss of coolant or loss of control and an imminent danger of explosion or reactor core melt down, or a major release of radioactivity, the following prevention actions could help:

- catalytic hydrogen recombination devices,
- systems for filtered containment venting,
- auxiliary cooling systems and additional water reservoirs for reactor emergency cooling,
- Next generation reactors should have at the bottom a pan to catch and cool fused fuel in case of a core meltdown, etc.

5.2.2. Of-Site measures for an optimal protection of populations and environment:

- Computer modelling of radioactivity dispersion to estimate concentrations of radioactivity in the vicinity and of radiation exposure to the affected population,
- A rapid measurement program for radiation doses and trained teams for sampling and measurement in the vicinity,
- Radioactivity concentration measurements in air, rain, soil, food, drinking water, etc.

For the affected populations:

- Distribution of KI tablets to the population: By saturation of the thyroid by inactive iodine the accumulation of radioactive iodine (mainly ^{131}I) is avoided; this helps to prevent from thyroid cancer and other thyroid diseases in particular among children,
- A service for thyroid (^{131}I) and whole body measurements for the exposed population,
- Advice to the affected population on how they should behave: for example stay indoors, close windows and doors or, if necessary, sheltering, restriction on food and water consumption, etc.;
- Evacuation or resettlement of the populations of the most contaminated areas,
- Provide medical and psychological care, etc.

5.2.3. Information:

- Rapid and WEB-based information exchange with authorities and all bodies involved with such an accident on a national, a regional and a local level and also with the emergency organizations and authorities in neighboring countries,
- Information of the population (alerted in many countries by Siren alarm) and on how they should behave,
- Information of the mass media,
- Trans-boundary harmonization of protection measures and actions to take, etc.
- In the future social media could be an efficient and rapid means to communicate with the affected population.

5.2.4. Measures after an accident:

- Dismantling of the damaged nuclear installations; elimination and safe disposal of radioactive debris and waste; eventually construction of protection building (sarcophagus),
- Clean-up of contaminated surfaces and buildings,
- Rehabilitation measures in order to bring back the contaminated land to a normal radioactivity level so that evacuated populations can return to their houses, etc.
- On the rehabilitation of contaminated land after a severe nuclear accident and how to come back to a normal situation, great work is in progress at the CODIRPA (Codirpa, 2012) organization in France.

6. Outlook

Despite all the ethics discussions and militant anti-nuclear campaign going on in several, mostly European, countries, scientific and technological progress cannot be stopped. A few countries in Western Europe plan for various reasons to abandon or renounce nuclear power, have done so already, or have never been involved due to sufficient alternative energy sources. Many others, however, will continue in or intend to enter the nuclear country club. Due to increasing energy needs, the status of nuclear power as an almost Green House Gas-free energy source, and the ability to reduce CO2 emission by relieving dependence on fossil energy sources like coal, gas and oil, nuclear is an attractive option.

In my opinion environmental and ethics discussions should concentrate less on hindering scientific progress and technical evolution and more on how nuclear safety and safety culture could be increased as well as how accident preparedness could be improved on a worldwide scale. Experienced countries should transmit their knowledge to nuclear newcomers, for example in Middle East, Africa, and elsewhere in order to keep safety and security level as well as safety culture on the highest possible level around the world.

The evolution of safety and security in every field of technology should never remain behind the scientific evolution and technological progress. Therefore, international cooperation and treaties should help maintain safety and security of nuclear installations and the safety culture of the employees on the highest level possible in every part of the world. Some other fields of technology (as cited in 4.1.) could serve as successful examples.

7. Acknowledgements

The author thanks Liam Dizio, physics student at the University of Fribourg (Switzerland), for his help for reviewing this text.

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Citation

Völkle, H. (2015): A brief History of Nuclear Disasters: Prevention, Consequences and Re-coverage. In: Planet@Risk, 2(3): 271-280, Davos: Global Risk Forum GRF Davos.