Notes Webinar Leendert Bevaart

Slide 1
Good evening. I would like to spent some more introductory remarks to also explain how it happened that I came to address this illustrious company. As mentioned I worked for almost 30 years with the IAEA in various functions, always in the area of Nuclear Material Safeguards. It is the first time I am giving presentation that by talking to a computer screen. So please have some mercy with me. After my retirement I started writing what became later a booklet. I started this because I wanted to practise my mother tongue (I left the Netherlands in 1978), and because I am of the opinion that the information about nuclear energy presented to the public could at least be considered as incomplete. Jan Botman became aware of the book and asked me whether I could give a presentation about the book. That is how it came.

Slide 2
This is the book, please note that I used a pen name.

Slide 3
And this is the content.
Peaceful: with the emphasis on electricity production.
Sa and se are the responsibility of each state (not in the EU, Euratom plays a role)
IAEA advice, safg is the responsibility of the IAEA and is obligatory for states that are party to the NPT.
Many people heard about the Non-Proliferation Treaty, but there are many treaties, and agreements that try channelling the use nuclear energy and to reduce nuclear weapons.
Incidents: Majak (1957), Chernobyl (1986), Fukushima (2011).
This is too much to cover in one hour. Therefore I picked the following subjects for this presentation, of course after consultation with Jan.

Slide 4
Specifically in the light of the energy transition that is needed for the decarbonisation project to keep the global warming to a minimum. Radiation and LTS, two subjects that are frequently mentioned during discussions
about nuclear energy (among others of course, e.g. costs, long construction times)
I will pay special attention to the effects of radiation to the human body, not about economical effects.

Slide 5
The content of this talk is for a big part based on information in these references.

Most of them international institutions related in one way or the other to the UN. The last two are critical articles, concerning the practical implementation and financing of the recommendations made by the 26th COP of the UNFConvenCC 94 recently in Glasgow.
IEA was founded in 1974 within the OECD by oil importing countries (energy crisis)

Slide 6

Important to focus on the relative figures. Electricity is about 15% of the energy. Total energy production is the sum of what the end-users get and what the energy sector needs to provide that. 80% energy fossil, 65% electricity fossil.
Renewables are hydro, solar and wind.
Nuclear and renewables are low CO2 emitters.

Slide 7

Compared with 2020 energy will increase by 50% and electricity by 100%, that means that the electricity share will be about 20%. Renewables count for roughly half of the electricity, but still about 40 % fossil. Emission of CO2 will go down because of improved installations and because of CO2 Capture and Storage Facilities. Still being developed, little known about costs, but probably expensive. As I indicated the 26th COP of the United Nations Framework Convention on Climate Change (UNFCCC)1994 in Glasgow aims to have a net zero CO2 emission in 2050. That is probably not going to happen because: Coal: India 2070, Russia and China 2060. US did not make a firm commitment. These are the 4 biggest polluters 65%. Some experts say the figures are a bit optimistic while the energy needs will be much higher (savings will be less than predicted e.g. in Europe because it will take quite a lot of energy to bring the east up to speed, developing countries will need more than predicted, and probably also the emerging economies). Also there will probably be an increase in population of 2 or 3 billion people and climate change will for the time being continue. (More air conditioners and more drinking water and more hydrogen production). Billions of electric cars and batteries, etc. 100 trillion dollar from private institutions investments in the next decade to reach nze in 2050. On top of that Wastes (eg. Batteries). I don’t think the goal will be achieved, but the international community should do it utmost to come as close as possible. But what is needed is an integrated international approach. At the moment this is subject to improvement. More energy, but in particular more electricity, and more nuclear (in relative terms, could reach 25% of total electricity). Before we continue discuss how this could be done, I would like to in short explain how a nuclear reactor works.

Slide 8

Natural uranium contains 99.27% U238 and 0,71% of U235. The U235 isotope undergoes fission when it is hit by a neutron. It splits into two so-called fission

products and 2 or 3 other neutrons with high speed *(Kr, Ba 3n, or Cs144 Rb90 2n).* Since the total mass of the two fission products and the neutrons is somewhat less than the mass of U236, a lot of energy in the form of heat is released (E=Mc2). This heat will produce steam, which powers a turbine, which in turn drives a generator to produce electricity.
The released neutrons can cause other fissions, but we need only one to maintain a so-called controlled chain reaction. Therefore we need an absorber which is either B or Cd. Furthermore, the fission occurs the most frequently when the neutron speed is thermal, eg ~2 km per second, which means that the neutrons need to be slowed down. That means we need a moderator. Water is the most used for this purpose, but also heavy water, or graphite. And of course we need a cooling medium. Here water, either light or heavy are the most frequently used ones, but also gasses or liquids. So various combinations are possible. Since water can be used for both moderation of the neutrons as well as for cooling the so-called light water reactors are the most popular, but also others play an important role. E.g. heavy water is used as moderator as well as coolant in the CANDU reactor, or graphite as a moderator and light water as coolant as in the RBMK reactor in Tsjernobyl. The LWRs will be discussed briefly.
But before we do that I would like to mention that the fission products are highly radioactive and form the most radioactive part of the waste.

Slide 9

Here we see a schematic picture of a so-called Pressurised Water Reactor, which is one of the two types of reactors that use normal (light) water as a moderator and a coolant. These reactors are called Light Water Reactors. Reactor vessel, reactor core, fuel rods and control rods. The pressure in the vessel is 160 bar and the temperature about 350 degrees Celsius. In a PWR there are three loops. The first is a closed one in which the water from the reactor core is circulated through a steam generator. Containment, where the heat is transferred to a second closed loop. Here originates saturated steam (60 bar, 270 °C), that goes through the turbine, generator, electricity. The steam is then transformed to liquid in a condenser, by using surface water in an open loop. River, cooling towers. About 290 in operation. Borssele.

Slide 10

The other type of LWR is a so-called BWR. It basically the same principle, but with one loop less. Here the steam is produced in the reactor vessel at a pressure of 80 bar and a temperature of about 300 °C. About 75 operational. Dodewaard and Fukushima (2011). Both have advantages and disadvantages. *A PWR is considered to be safer than a because the control rods in a BWR there has to be electricity. On the other hand PWR is more expensive because more sophisticated equipment due to high pressure. Contamination of turbine, more expensive maintenance.* In LWRs the

U235 part in the fuel need to be enhanced from 0.7 to 2-5%. So the natural uranium needs to undergo an enrichment process. The first LWRs were developed in the US shortly after the second world war. The reactors that are currently being constructed are mostly of the so-called Generation III type.

Slide11

Before we go on, I want to say something about the past. Gen. I are basically the prototype reactors that were developed shortly after the Second World War. Generation II were the first-generation commercial reactors. They form the majority of the reactors that are currently producing electricity. They were in the course of time gradually improved. This process culminated in the development of the Generation III reactors. 1. Standardised Licensing. 2. Some parts are modular (shorter time, less concrete) 3.More robust and passive safety features (e.g. several independent cooling systems, using temperature and pressure) 4. long life time 5. Core catchers 6. more economical. Most of the ~55 reactors under construction are Gen. III PWRs. E.g. APR 1400 Korea (e.g. UAE and South Korea); AP 1000 Westinghouse (e.g. China, US); EPR Europe (China, Finland, France, UK) 2019, 12 march, end 2022,?; AES Russian Federation (Russia, Turkey, Hungary, Bangladesh). NATO members. Barakh construction time 8-9 years is now normal, UAE and China
In addition Generation IV reactors are being developed.

Slide 12

Fuel not suitable for weapons, produces less waste. More economical, even longer life, more intrinsic safety features. Gen. IV high temperature, fast neutrons, in some types no moderator, burning long lived isotopes. This reactor type is a Very High Temperature Reactor, it uses so-called TRISO (tristructural-isotropic) fuel. That consists of little grains, with in the center the fuel surrounded by a layer of carbon, a layer of silicon and another layer of carbon. They are embedded in a graphite structure. Graphite moderated, He cooled. Temp close to 1000 C, so they could be used for other purposes than only for electricity production, e.g. hydrogen production.
Gen IV reactors not operational not before 2040.
Another example is the molten salts reactor.

Slide 13

Reactor core consists of molten salt, normally Chloride or Fluoride salts with the fissionable material in the solution. Temp. between 500 and 750. Loop1 fuel salt, heat exchanger loop 2 coolant salt, loop 3 power conversion system. The fuel could be U –Th. Breed U-233. Frozen plug.
Many concepts are being studied worldwide, and also The TU Delft is in involved in developing and assessing safety systems. Very recently (last week) the decision has

been made that the province Noord-Brabant will finance a project related to the development of a thorium molten salt reactor.
Now some words on the Small Modular reactors.

Slide 14

Small and modular, short construction time, flexible. Capacity between 30 and 300 MWe.
Good in remote areas away from the national grid. They can be extended. Some orders have already been placed for mines in remote areas. Multipurpose. Could be used for heat production and desalination.
Could be different types, e.g. PWR, Molten Salt Reactor.
The only one in operation in Russia, is PWR, based on designs of icebreaker; China testing also PWR.

Enough about reactors, now some words about the effects of radiation and LTS of highly radioactive waste.

Slide 15

Mobile telephones or microwave oven (vibration).
The International Commission on Radiological Protection (ICRP) in cooperation with the United Nations Scientific Commission on the Effects of Atomic Radiation (UNSCEAR) have produced radiation protection guidelines.
In order to understand these guidelines one has to know a little bit about how radiation and its effects.

Slide 16

1 Kilo fertilizer (phosphate) 5000 Bq, an adult person 7000 Bq, medical radiation equipment 70 million, an atmospheric test 10^(20.) Bq.
The dose is a physical quantity whereas the equivalent dose is a biological effect.
The biological effect depends on the intensity (radioactivity), energy and type.
W is the radiation weighing factor.
Why is a person radioactive?

Slide 17

118 elements, more than 2000 isotopes, about 300 are stable, the rest is radioactive.
Many are in the surrounding nature.
In any case UNSCEAR advises to use the 20 mSv for regulatory purposes only.
The question is: how dangerous is radiation? A single equivalent dose of 10 Sv causes serious illness and is fatal within a month, 1 Sv causes serious radiation sickness but is not necessarily fatal. For the area below about 250 mSv, the situation is not very clear, because of a lack of trustworthy data. In Ramsar no more cancer

cases and no shorter life expectancy occurred. *Some divergencies in the blood values*. Above that figure of about 250 mSv per year the number of fatal illnesses (cancer) rises linearly with the equivalent dose. This Is reflected in the next slide.

Slide 18

Horizontale dose (rate), vertical fatal illnesses (cancer, on top of normal).
Interpolation is very difficult, because there are so many cancer death. In any case, if any risk then relatively small.
There are roughly four possibilities.
Line A depicts the so-called supralinearity. Here one assumes that the number of cancer cases is higher than would be expected based on a linear interpolation. This theory does not have many supporters.
Line B enjoys a lot of popularity. It is linear. The argument is: There is a linear dependency above 250 mSv, why shouldn't there be one below 250 mSv. This is the so-called linear no threshold theory and used by numerous institutions as a health safety measure.
Lines C and D represent the cases in which the risk is lower than the one predicted by the LNT theory. In case C the risk is low but still positive. For case D the risk becomes negative, that means that the probability for not getting cancer increases. This phenomenon is called Hormesis. It is being studied in, among others, France, China, Japan and Sweden. But for case D there are some real data: in Taipei, Taiwan, China. As was found out in 1992, during the construction of several buildings in the beginning of the 80ties recycled steel contaminated with Co-60 was used. This caused a radiation level that was well above background. It was afterwards found out that the relative number of cancer cases under 10000 people concerned was dramatically lower than in the rest from Taiwan, China (measured over a long enough period). Maybe beneficial.
After the catastrophe in Fukushima, the population was evacuated from an area that showed a level of 20 mSv or more contamination. This was done because one assumed that the 20 mSv was not only a regulatory limit, but also a health safety measure. The radiation level was well below 100 mSv (only about 200 persons got a dose of 100 mSv). So, in fact no evacuation would have been necessary. More than 1000 disaster related deaths, mostly as a result of the evacuation, but none from radiation. 18000 from the tsunami. Lesson for the future, the cure worse than the disease.
About 2000 disaster related deaths. LNT taken as a guide.
Let's now finish with some words about long-term storage of high-level radioactive Waste.

Slide 19

In the beginning low and intermediate waste in the ocean, also the Netherlands

from 1969 till 1982. Soviet Union even spent fuel in the arctic sea. Since 1994 waste in sea forbidden.
Types: nuclear waste management organisation.
Here we concentrate on high level waste, produces quite a lot of heat, and contains long lived isotopes. And specifically on the long term storage of this waste.
Belgium clay, Canada graphite, France Japan south Korea rock (marble graphite)
After about 40 years radioactivity 99% and heat 50%.

Slide 20

Fully approved and probably operational in 2023. South west of Finland. Olkiluoto. Concept developed by the Swedes.
Storage tunnels about 450 meter deep. Fuel elements encapsulated in copper canisters, then embedded in bentonite clay. Tunnel segment sealed.

Slide 21

For reasons of completeness the Swedish repository at Forsmark. It might take another 10 year to finish. 500-700 meter deep.

Remark: If mankind had treated its waste like it does with nuclear waste, then the world would be healthier (greenhouse gasses, particulate matter, plastics, etc. and maybe batteries, solar panels rare earths)

Slide 22