NUCLEAR POWER GENERATION ALTERNATIVE FOR A CLEAN ENERGY FUTURE

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ABSTRACT

World Energy Council stated that is huge scope to raise the efficiency in which energy is provided. Over 60% of primary energy is, in effect, wasted. At present 63% of the world's electricity comes from thermal power (coal, oil and gas) 19% from hydro, 17% from nuclear, 0.5% from geothermal and 0.1% from solar, wind and biomass. Nuclear power almost completely avoids all the problems associated with fossil fuels: no greenhouse effect, no acid rain, no air pollution with sulfur dioxide, nitrogen oxides, no oil spills etc. Its impact on health and environment is related to radiation and is relatively minor. Without pretending a high accuracy of numbers, if the Romanian nuclear power reactors will be replaced by a coal plant of equivalent capacity, about 10 millions tons of CO_2 and large quantities of associated sulfur and nitrous oxides, would be discharged to the atmosphere each year. However the acceptance of nuclear power is largely and emotional issue. In all activities in which nuclear industry is involved, it takes care of the environment. Nuclear energy can have an important contribution for the future of mankind regarding the sustainable supply of energy. Security problems are universal nuclear technology management is not risk free. The nuclear industry acknowledges responsibilities and has a unique security culture. Security is not only a technical problem, but also an emotional one.

Based on the environmental monitoring program this paper tries to demonstrate that the routine radioactive emissions of Cernavoda NPP, which are limited by National Competent Authority, gives an insignificant risk increase. For assessing the environmental impacts and damage costs from exposure, IAEA's Model SIMPACTS. SIMPACT is powerful and convenient tool for evaluating external costs of human health and environmental impacts for nuclear power and other energy sources.

KEYWORDS: *nuclear energy alternative.*

NUCLEAR ENERGY FROM THE SUSTAINABLE DEVELOPMENT PERSPECTIVE

The concept of sustainable development was elaborated in the late 1980s and defined as a development that fulfill the needs of the present without compromising the ability of future generations to meet their own needs. Sustainable development incorporates equity within and across countries as well as across generations, and integrates economic growth, environmental protection and social

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welfare. [1] To analyze nuclear energy from a sustainable development perspective it is necessary to consider its economic, environmental and social impacts characteristics, both positive and negative. It is obvious that the development of nuclear energy broadens the natural resource base useable for energy production, and increases human and man-made capital. There are also many arguments in favor of nuclear energy as a reliable source such as the large size of the plants, their long periods of operation and the expertise with which they are run.

The risks associated with radiation are among the most extensively studied hazards known to man but several factors make preserving public anxiety about radiation. Radiation is inaccessible to human senses, difficult to understand, and probabilistic in its effects, which to the public means uncertain. In consequence radiological protection is essential to ensure that nuclear energy is compatible with sustainable development. Nuclear energy has, in normal operation, a low impact on health and the environment. In order to meet the sustainable development goals, it is necessary to maintain its high standards of safety in spite of increasing competition in the electricity sector and reactors ageing in order to achieve a higher level of public acceptance.

The complex technologies used by nuclear fuel cycle facilities are controlled and regulated by international and national institutions. A framework of regulatory, institutional and technical measures is already in place ensuring that the use of nuclear energy does not significantly modify natural environment. The principles that support the radiation protection approach and system are consistent with the goals of sustainable development. The effectiveness of these systems may be measured by the status and trends in radioactive emissions from nuclear facilities and the exposure of the public and workers to radiation. Maintaining this framework is essential to address social and environmental concerns. To the extent that these concerns are addressed successfully, the nuclear industry, and the scientific knowledge and institutional infrastructure supporting it, can represent an asset for present and future generations. The governments have an important role in making the public to understand social, ethical and political issues related to nuclear energy into perspective with the issues raised by alternatives.

NUCLEAR ENERGY IN ROMANIA

Cernavoda Nuclear Power Plant in Romania was designed for 5 Units of 700 Mwe to be powered with CANDU 6 PHW reactors. The first Unit was commissioned in Cernavoda on December, 2th, 1996 and since then it has been successfully operating becoming an important component of the energetic sector. The second unit was commissioned in may 2007 and become operational in November 2007. As can be seen from Figure 1 Cernavoda NPP with 2 units provided 17 % from the energy produced in 2008 with a very good capacity factor as presented in Figure 2. The total power generation in 2008 produced by Romania's sources of domestic primary energy: lignite, hydrocarbons (oil and natural gas), hard coal, hydro, nuclear and renewables (hydro and wind) was of 64.772 GWh.

In 2008, the share of fossil fuel in power generation was around 57% (based mainly on coal - 44%) and renewable output was 26,02% (total hydro production - 26 % and wind - 0,02%).

Romanian government has decided to allot the necessary fund for the continuation of work at Cernavoda Unit 3 and 4. First of all the investment is justified by the price of electricity generated by the NPP, its updated unitary cost being of $ 13-15 per MWh. The specific investment for the value that remained to be achieved is estimated at $ 1000 per each installed kW, which represent a very attractive value.

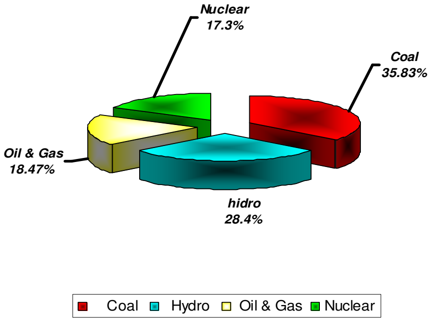


Figure 1. Electricity Output in Romania, 2008

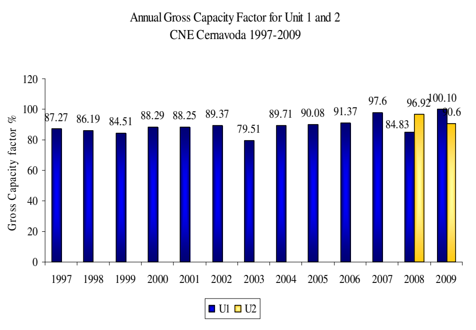


Figure 2. Cernavoda NPP Capacity Factor

ENVIRONMENTAL PROBLEMS WITH FOSSIL FUELS

A significant part of the energy is produced in present by burning fossil fuels: coal, oil, and gas. The associated environmental problems exceeds those of any other human activity: *greenhouse effect* which is supposed to change Earth's climate, *acid rain* which is burning forests and killing fish and *air pollution* which make suffer a lot of people.

Human activities have been substantially increasing the atmospheric concentrations of greenhouse gases. These increases enhance the natural greenhouse effect, and this will result on average in an additional warming of the Earth's surface and atmosphere and may adversely affect natural ecosystems and humankind.[2] Nuclear power almost completely avoids all the problems related to fossil fuels. When signing the Kyoto protocol Romania committed itself to decrease the greenhouse CO_2 emissions by a factor of 8, compared to 1989 situation. Due to Cernavoda NPP energy production a significant reduction of about 4.9 million tones of CO_2 emissions per one unit, Figure 3.

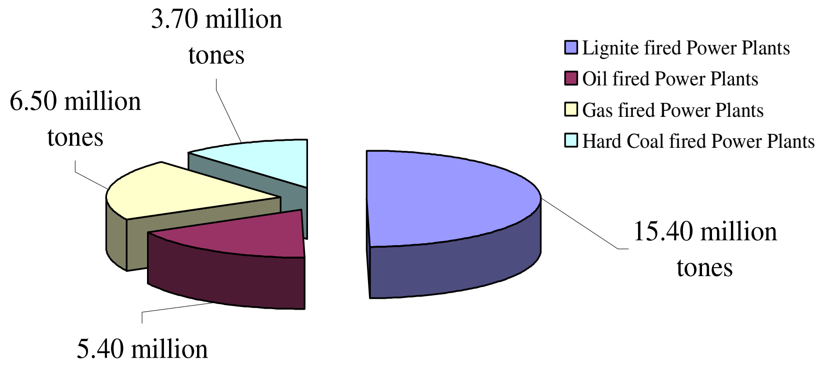


Figure 3. 1 CO_2 emissions in Romania

UNDERSTANDING RISKS – RADIOLOGICAL PROTECTION

Regardless of many favorable arguments the acceptance of nuclear power is largely an emotional issue. Scientific community has always been firmly supportive to nuclear power development but the public opinion was negatively influenced when several groups opposed to nuclear power formed and gained support from the media to depict it as a dangerous technology operated by incompetents.[3]

The long term role of the nuclear industry should be defined this century, as fossil fuel dominance eventually erodes and as the environmental and economic costs of energy alternatives are explored in larger scale deployments, and as the research in advanced fission and fusion energy provides more attractive commercial products. [4]

One of the main obstacles in gaining widespread public acceptance of nuclear power is that the great majority of people does not understand and quantify the risk. Every human activity involves risks. The International Commission on Radiological Protection (ICRP), a non-governmental body of experts, made recommendations for the protection of people from the harmful effects of ionizing radiation. The latest ICRP recommendations are reflected in Romanian national regulations. The primary aim of radiological protection, as stated by the ICRP, is to provide an appropriate standard of protection for mankind without unduly limiting the beneficial practices giving rise to the radiation exposure. Standards and recommendations are based on limiting by all reasonable means the risk of health effects, adopting a precautionary approach, but not on eliminating that risk entirely.

Three principles form the framework for protection concerning practices that involve exposure: justification of the activity; limitation (i.e. keeping individual doses within regulatory limits); and optimization (i.e. keeping doses as low as reasonably achievable – ALARA – economic and social factors being taken into account).

Table 1. Summary of annual dosimetric data at Cernavoda NPP

Year	*Internal* (man-mSv)	External (man-mSv)	Total (man-mSv)	No. of Exposed Workers	No. of individual doses between 5 and 10 mSv	Average Individual Dose by Exposed Workers (mSv)
1996	0.60	31.70	32.30	74	0	0.40
1997	3.81	244.48	248.29	251	3	0.99
1998	54.37	203.35	257.72	339	2	0.76
1999	85.42	371.11	456.53	355	3	1.29
2000	110.81	355.39	466.2	372	6	1.25
2001	141.42	433.44	574.86	434	16	1.12
2002	206.43	344.04	550.48	488	14	1.26
2003	298.02	520.27	818.28	648	22	1.17
2004	398.26	258.45	656.71	554	16	1.42
2005	389.3	342.29	731.59	508	20	1.15
2006	302.27	258.79	561.06	481	14	0.74
2007	83.34	187.49	270.83	353	6	0.77
2008	209.3	474.3	683.5	884	19	0.57
2009	67.59	417.66	485.25	837	13	1.12

Regulatory standards for radiation apply to those human activities which cause public or worker exposure. The dose limits recommended for these activities are 1 mSv per year for exposure of the public, and 20 mSv per year for exposure of workers.

Table 1 presents the summary of dosimetric data registered at Cernavoda NPP between 1996 and 2009. All individual doses were below 10mSv and, as can be seen from this table very few workers received doses between 5 and 10mSv per year.

ENVIRONMENTAL PROTECTION AT NUCLEAR POWER PLANTS

Natural ionizing radiation arises in outer space, where cosmic rays are formed but also in and on the earth, where radionuclides normally present in soil, air, water, food and the human body undergo radioactive decay. The assessment of radiation doses in humans from natural sources is important because natural ionizing radiation is the largest contributor to collective effective dose received by the world's population. Dose limits recommended by ICRP can be compared with the average doses from natural background radiation of about 3 mSv per year, noting that actual figures vary widely with location.

The operational system for environmental protection at Cernavoda NPP refers to the main factors that ensure the public health and environmental preservation, i.e. source control effluent control, effluent monitoring, environ-mental monitoring. ICRP principles and IAEA recommendations for design and operation have been applied and are in force: now for the environmental protection system. Derived Emission Limits (DELs) were approved by CNCAN, the Romanian Authority in Nuclear Activities.

This program fulfils several objectives, such as providing: an early indication of the appearance or accumulation of any radioactive material in the environment caused by the operation of the station, verifying the adequacy and proper functioning of station effluent controls and monitoring systems, providing an estimate of actual radiation exposure to the surrounding population, assurance to regulatory agencies and the public that the station's environmental impact is known and within operational targets, standby monitoring capability for rapid assessment of risk to the general public in the event of unanticipated or accidental releases of radioactive material, allowing an assessment of the Derived Emission Limits (DEL) calculations based upon empirical rather than theoretical data.

The annual reports for the period, 1996-2009, presenting the results of the monitoring programs illustrated a safe operation of Cernavoda NPP, with low quantities of radioactive effluents released in the environment, well below the approved limits.

The annual releases of radioactive materials are comparable with others' CANDU – 6 plants in operation.

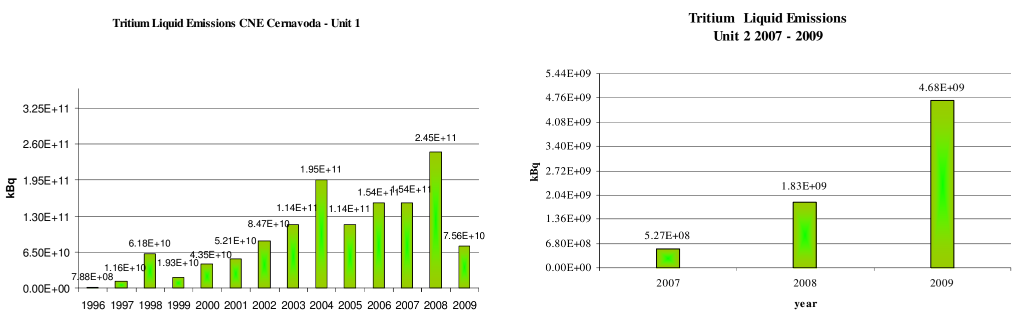


Figure 4. Liquid effluent emissions at Cernavoda NPP, 1996 – 2009

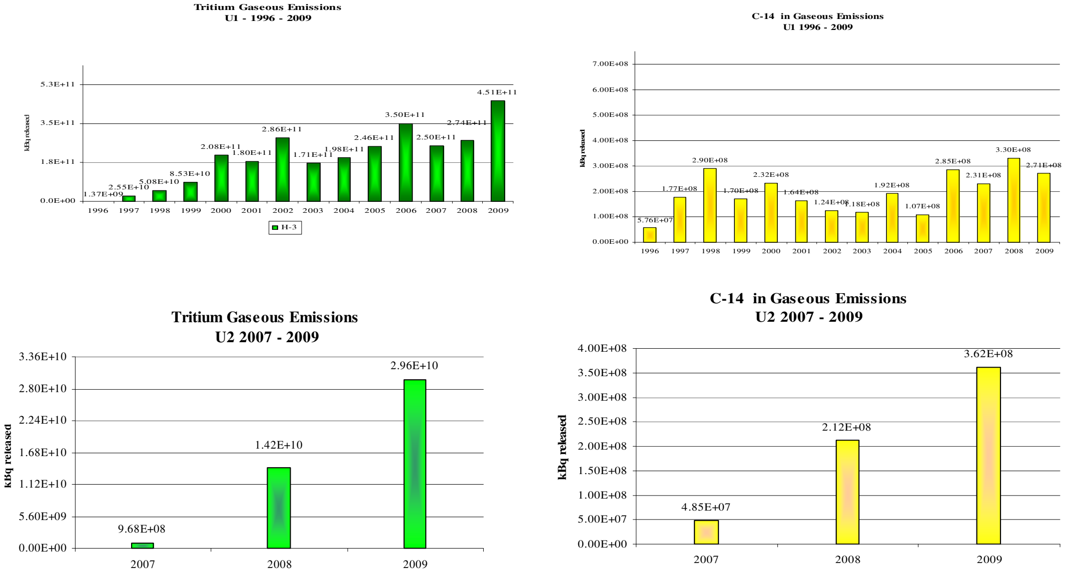


Figure 5. Gaseous effluent emissions at Cernavoda NPP, 1996 – 2009

The content of selected radionuclides in liquid and gaseous effluents is well bellow admissible limits ADELs approved by the national authorities. Figure 4 and 5 show the annual emissions expressed in kBq. The negligible impact of Cernavoda NPP operation could really contribute to public confidence.

In the area of the nuclear power plant the impact was estimated at a value of dose equivalent of about 10 μSv per year that is less than 0.3% of the natural background radiation. Figure 6, presents the values computed by using measured concentrations in effluents. There is no doubt that this value is about 100 times smaller than the authorized limit. Figure 7 presents the values computed based on tritium concentration measured in environmental samples.

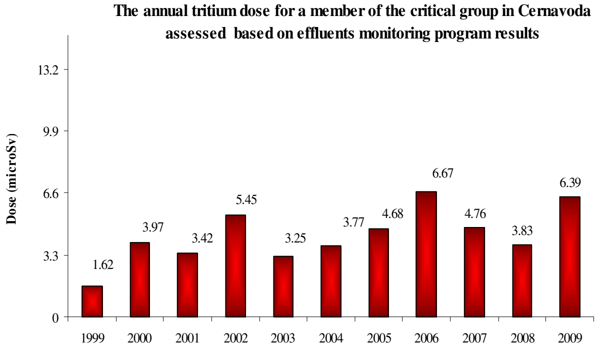


Figure 6. Estimated annual doses for a critical group member based on tritium concentration measured in effluents

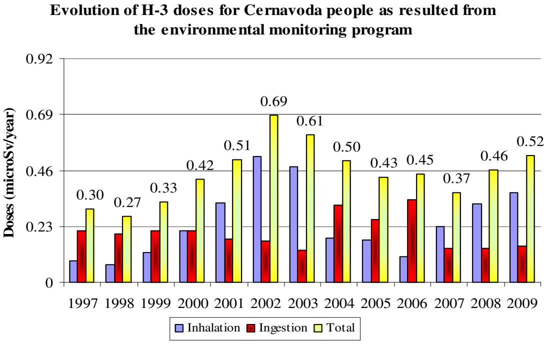


Figure 7. Estimated annual doses for a critical group member based on measured tritium in environmental samples

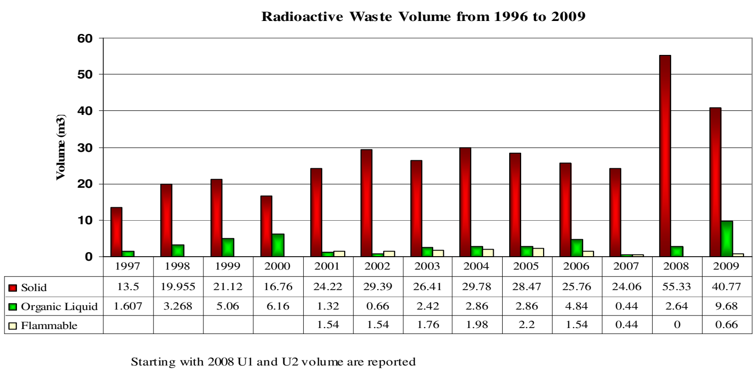
RADIOACTIVE WASTE FROM NUCLEAR POWER PLANTS

As many other human activities nuclear technology applications generate waste that requires adequate management to protect human health and the environment now and in the future without imposing burdens on future generations. An important reason for the public's concern about nuclear power is an unjustifiable fear to the hazards from radioactive wastes besides the systematic approach of all relevant parties involved in radioactive waste management.

Cernavoda NPP established a management concept for the collection, handling, conditioning and storage of radioactive waste to maintain acceptable levels of safety for workers, members of the public and the environment.

As can be seen from Figure 8 the volumes of radioactive waste produced at Cernavoda NPP are relatively low. Low-level waste are usually conditioned in special containers and stored in a temporary storage.

A national concept for disposal of conditioned low and intermediate level waste in shallow land burials is under development.



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Solid	13.5	19.955	21.12	16.76	24.22	29.39	26.41	29.78	28.47	25.76	24.06	55.33	40.77
Organic Liquid	1.607	3.268	5.06	6.16	1.32	0.66	2.42	2.86	2.86	4.84	0.44	2.64	9.68
Flammable					1.54	1.54	1.76	1.98	2.2	1.54	0.44	0	0.66

Figure 8. Radioactive waste volume produced

SPENT FUEL

The fuel from a nuclear reactor is in the form of ceramic pellets of uranium oxide lined up and sealed inside metal tubes which are bound together to form a “fuel assembly”. A CANDU-6 reactor contains about a 100 tons of uranium which remain in reactor for about a year. Approximately 5500 fuel bundles are used every year, At the end of this period the fuel is spent and must be replaced by fresh fuel. After some years of storage in special water pools the radioactivity decrease considerably and the spent fuel can be stored in special dry facilities.

Cernavoda NPP will provide sufficient on-site storage capacity for their own spent fuel A "monitored retrievable storage" facility MACSTOR type is under construction. MACSTOR™ Modular Air-Cooled Storage was developed by AECL. Using its efficient heat-rejection and shielding capabilities, this advanced system can store spent fuel from any type of reactor. MACSTOR™ can save up to one-third of the space required by comparable systems while also reducing staffing, operating, and construction costs. In addition, MACSTOR™ permits easy fuel retrieval at the time of final disposal. At this moment 3 modules are constructed and filled with spent fuel bundle.

Evaluating External Costs of Human Health and Environmental Impacts Using IAEA's Model SIMPACTS

Using SIMPACTS Model we tried to compare the local and regional health impacts of Cernavoda NPP with a hypoteticale TPP based on coal and located in the same location Constanta – Cernavoda. The results are presented in Table 9, 10 , 11 and 12

TPP based on coal located in Cernavoda

Table 9. Health Impacts - Impact estimates in cases/year

Pollutant	Local	Regional	Total
PM10	2.33E+01	1.79E+02	2.03E+02
Nitrates	n/a	9.29E+02	9.29E+02
Sulfates	n/a	4.36E+03	4.36E+03
SO_2	6.13E-02	4.59E-01	5.20E-01

Table 10. Damage Cost Damage Costs in US $/year

Pollutant	Local	Regional	Total
PM10	1.60E+06	1.23E+07	1.39E+07
Nitrates	n/a	6.38E+07	6.38E+07
Sulfates	n/a	3.00E+08	3.00E+08
SO_2	3.35E+03	2.51E+04	2.84E+04

NPP Cernavoda (one Unit)

Table 11. Health Impacts - Impact estimates in cases/year

	Local	Regional	Total
Fatal cancer	7.68E-05	1.99E-05	9.68E-05
Non-fatal cancer	1.84E-04	4.78E-05	2.32E-04
Severe Hereditary Effects	1.54E-05	3.99E-06	1.94E-05

Table 12. Damage Cost per year of Health Effects in US $/year

	Local	Regional	Total
Fatal cancer	3.11E+01	8.07E+00	3.92E+01
Non-fatal cancer	1.39E+01	3.61E+00	1.75E+01
Severe Hereditary Effects	2.49E+01	6.46E+00	3.14E+01

CONCLUSIONS

Nuclear energy is consistent with the objectives of sustainable development related to the creation and effective use of natural resources and their preservation for future generations.

Nuclear power almost completely avoids all the problems related to fossil fuels contributing to significant reductions of CO_2 emissions.

The population dose contribution of a nuclear power plant is only a small fraction from the natural ionizing radiation which is the largest contributor to collective effective dose received by the world's population. Monitoring data from Cernavoda NPP sustain this conclusion. Improving the understanding of dose contribution of nuclear industry and the health effects of low level radiation is a condition for public acceptance of nuclear power generation. Using the SIMPACTS model in assessing the health effects and damage cost per year, the results shows that for Cernavoda site, the nuclear power plant has the lower health effects and damage cost comparing with other type of power plant.

By adequate management of nuclear safety and of radioactive waste nuclear power generation could remain a valid alternative for a clean energy future.

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