MODELLING THE IMPACT OF CERNAVODA NPP ON THE ENVIRONMENT

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ABSTRACT

In connection with a stay as a visiting researcher at VTT Energy (Technical Research Center of Finland), a study was conducted related to the atmospheric dispersion and dose assessment for radioactive releases from nuclear power plants. The most important aspects of this study are described in this paper. These include: the application of the TRADOS dispersion and dose assessment model in the case of the Cernavoda NPP and the development of a special program INTEGRATION for the calculation of cloud gamma dose rate of 72 nuclides.

INTRODUCTION

The Cernavoda NPP has been given in commercial exploitation in 1996 December 2nd and was constructed in cooperation with Canadian, Italian and American specialists. This is the first nuclear unit in Romania that covers 10 – 15 % of the electric energy necessities of the country and contributes to the reduction of the hydrocarbon import and atmospheric pollution in my country. With the occasion of the definitive reception of the first unit of the Cernavoda NPP it has been established that the young nuclear power plant obtained great results, greater than those guaranteed by the producing firms AECL and General Electric and than many other units from the same CANDU-6 series.

The production costs of energy delivered from the first unit of Cernavoda are much lower (13 $ / MWh) than that realized by the thermo-electric power stations from my country. This fact determines Cernavoda NPP to work in base regime in national power system. The values of the LOAD factor realized in the years 1997-1998 in comparison with the other units indicate a value of 86.19 %, greater than that of Point Lepreau NPP and Gentilly from Canada and Wolsung 1 and 2 from South Coreea.

If we make a comparison between the performance level established at Cernavoda NPP and the values obtained in the world results special successes, proved by the WANO (World Association of Nuclear Operators) report which specified that the values realized by the first unit of Cernavoda NPP are better than the average values in the world.

The permanent preoccupation for the radiation protections has been proved by the low individual radiation doses registered in 1998 for the atomic radiation workers (ARW) (0.77 mSv/year, in comparison with the legal limit of 20 mSv/year) and by the critic population group doses due to radioactive emissions of the nuclear power plant (5.58 µSv/year in comparison with 2200 µSv/year, the natural environmental dose).

THE ATMOSPHERIC DISPERSION MODEL ARANO AND TRAJECTORY DOSE MODEL TRADOS

The code used in this study, TRADOS (TRAjectory DOse model), is partially based on ARANO and became operational in 1983 in Finland. Both programs have been developed in cooperation between VTT and the Finnish Meteorological Institute (FMI) and have been continuously refined ever since their first use (Ilvonen, 1994).

With the computer code ARANO it is possible to calculate environmental radiological consequences caused by radioactive materials released into the atmosphere. Results can be individual doses for different organs at given distances from the release point, collective doses, numbers of casualties, areas polluted by deposited activity and losses of investments or production due to radioactive contamination (Savolainen, 1980).

If the radioactive releases and the dispersion conditions are described by probability distributions, the program assesses the magnitudes of specified effects in all combinations of the release and dispersion situations and then calculates the expectation values and the cumulative probability distributions of effects.

TRADOS determines the air parcel trajectories and the dispersion conditions along them. The program TRADOS-DD evaluates the consequences and it has been developed to simulate the transport of the radioactive cloud, and to estimate the doses it causes via several dose pathways due to long range transport of airborne radioactive material (Nordlund, 1979 and Rossi, 1985).

In the horizontal direction the dispersion of radioactive material in TRADOS model is described by three-dimensional air-parcel trajectories. The vertical concentration profile is described with the gradient-transfer (K_z) approach. The trajectory model needs to be run separately and it forms the necessary trajectory database for the consequence assessment part of TRADOS.

For advection of the three-dimensional trajectories an iterative method developed for the FMI's (Finnish Meteorological Institute) meteorological workstation environment (Eerola, 1990) was adopted.

Figure 1 presents the main steps of dose assessment and their relations in TRADOS. In this figure, rectangles represent subprograms (or sets of subprograms), whereas ellipses represent input files. However, the flowchart of Figure 1 does not strictly follow the actual flow of the program, as some quantities are calculated in a different order. TRADOS is a Lagrange-type atmospheric dispersion model. Air transport of successive periods of the release is described by 3D trajectories, which are usually based on data from the Nordic HIRLAM weather prediction model. Dispersion of the cloud around its center point is computed separately. In the vertical direction, the K theory of turbulent diffusion is used, and the cloud is divided into three layers according to the possible values of the mixing height. In the horizontal, a uniform distribution together with some turbulence-based corrections is assumed.

Besides doses, the output quantities of TRADOS are concentrations at breathing height, deposited amounts and external dose rates from fallout and the cloud itself. The calculation of cloud gamma dose is based on the actual distribution of material according to the K-theory.

The trajectory model can be run either on HIRLAM data or on that from the European Center for Medium Range Weather Forecasts (ECMWF). There are almost always some differences between trajectories computed from ECMWF and HIRLAM data. Three-dimensional trajectories are subject to errors generated by the numerical wind fields, especially when there is a strong isobaric curvature. These areas are typically related to the low-pressure centers. The capability of the trajectory model to follow the ascending air currents associated to the weather fronts is highly dependent on the resolution of a meteorological model and also on the method of interpolation. In TRADOS, the horizontal spatial interpolation can be chosen from four options; (1) bi-linear, (2) bi-quadratic, (3) bi-cubic or (4) no interpolation (=nearest grid point value). The temporal and the vertical spatial interpolations are always linear.

The mentioned programs ARANO and TRADOS rely on relatively sparse spatial and temporal discretizations of concentration in the air, which directly affects dose assessment. Therefore the development of an advanced real-time multi-scale atmospheric dispersion and dose prediction model (SILJA) has been commenced in mid 1990's in co-operation between the Finnish Meteorological Institute (FMI) and VTT Energy. The new model takes into account the state-of-the-art in atmospheric dispersion modeling. The SILJA model is based on fine-grid HIRLAM and application of several optional dispersion models is planned. One detail of the SILJA model system worth to be mentioned related to this paper is the totally new method for calculation of cloud gamma dose: the algorithm is fast and accurate and applicable for arbitrary vertical profiles. The new model system has already been applied in practice in the connection of the international INEX-2-FIN exercise on April 17, 1997, where the accident was supposed to take place at the Loviisa NPP in Finland. Two tasks were then accomplished by employing the SILJA model: (1) producing simulated radioactivity measurements prior to the start of the exercise employing real time weather data and (2) predicting dispersion and radiation doses during the exercise.

In TRADOS model, we must input either released amounts as percentages of reactor core radioactive inventory or released radionuclide activities. The first alternative requires a core inventory specific for CANDU 600- Cernavoda Nuclear Power Plant.

We present now the data that we introduced in TRADOS to make the calculation for Cernavoda NPP.

TABLE 1: This table presents released amounts of reactor core radioactive inventory

Nuclide	Inventory (whole core) [10^7 Curies]	Release > 800 °C [10^6 Curies]	Release < 800 °C [10^5 Curies]
I-131	6,3	1,015	2,5375
Xe + Kr	50,3	1,5024	15,024
Ru-106	1,09	0,0109	0,0242
Cs-137	0,1211	0,013300	0,0665
Sr 89	4,3425	0,043440	0,1448
Sr 90	0,084336	0,000847	0,0028

We could choose set grid to make the grid representation for the country that we'll have to make maps and the geographical coordinates that bound the target area and give number of grid elements in x and y directions (≤ 100). After this, we start calculation and draw a map with the coordinates that we have given. For example, for the Romania map, we input 49 northmost latitude; 18 westmost longitude; 32 eastmost longitude; 42 southmost latitude. We can draw the map according to trajectories or current target area and if we choose the second alternative, we can obtain Romania map with vicinity of the NPP. If we want to draw the map, we can choose continents (shorelines), countries (borders), trajectories, grid representation, isocurve representation and if we want to show on the map the cities and the nearest localities, we choose the command *sampling stations.* For a much closer image of the vicinity of Cernavoda NPP, we can change the coordinates into: 45.5 northmost latitude; 26 westmost longitude; 30 eastmost longitude; 43.5 southmost latitude. For a 30 km image around the Cernavoda NPP, we can choose the following coordinates: 44.468 northmost latitude; 27.80 westmost longitude; 28.35 eastmost longitude; 44.198 southmost latitude. For each picture, we can add a legend and threshold values. We can put 4 pictures on the same paper, dividing the screen in 4 pieces: left upper, right upper (upper part), left lower, right lower (lower part).

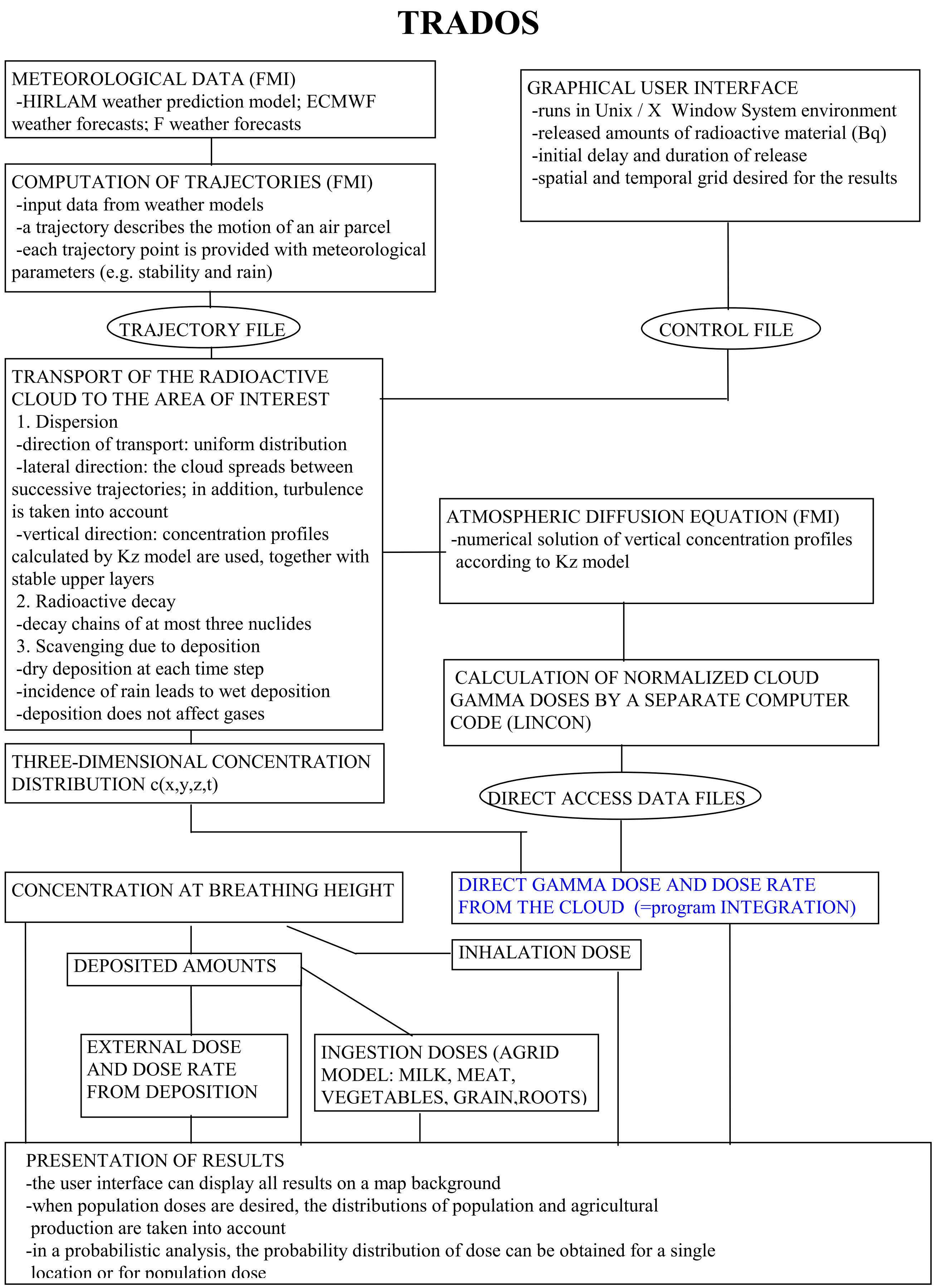

FIGURE 1. System modules and principles of dose assessment in TRADOS

Results of TRADOS application for Cernavoda NPP

In this project were made 35 pictures using TRADOS model. The first 5 pictures make a presentation of what kinds of trajectories and isocurves could be utilized during the dose assessment. Pictures made using 4 kinds of coordinates: for following the trajectories (a map with all Europe-picture A.1.); for all Romania country (picture A.2.); for 200 km around Cernavoda NPP (picture A.3.) and 30 km around nuclear plant (picture A.4.). All these types are found again in picture A.5. In the next 19 pictures (from A.6. to A.25.) we used a release of I-131 3.7555e+16 Bq in case of a big accident. For the next 10 pictures we used the mixed composition of I-131, Cs-137, Sr 89, Sr 90 and Ru 106.

In general it was ascertained a big value of atmospheric concentration between 7.26E+01 Bq/m^3 and 1.42E+03 Bq/m^3 for immediate time in the vicinity of the place were it was produced the nuclear accident (in our case - Cernavoda site) and this concentration is painted on the maps with light red color (examples: pictures A.6., A.7., A.8). This is the predominant color of the first 18 h after the accident (for example pictures A.11. and A.12.). In the first hours after the releases, we can meet also an air concentration between 1.42e+03 Bq/m^3 and 2.78e+04 Bq/m^3 (corresponding with dark red color). For the next 6 h we can say that the predominant color is yellow corresponding with an atmospheric concentration between 3.71e+00 Bq/m^3 and 7.26e+01 Bq/m^3. The colors green and blue appear at 30 h and more, generally at long distance from the nuclear power plant place.

PROGRAM INTEGRATION

In connection of studies at VTT Energy, a computer program called INTEGRATION was developed. The code is intended for the calculation of external cloud gamma dose rates for different nuclides, atmospheric layers and 'rings' with constant distance to the target. Subsequently the model has been incorporated in a further developed for to the new SILJA model.

The old method is program LINCON that uses a Gaussian horizontal concentration profile. This Gaussian horizontal concentration profile is used in ARANO, but not in TRADOS which has a uniform horizontal distribution. Program LINCON uses various vertical concentration profiles, but only a finite number of different ones. The number of profiles is 180 and it comes from release heights (4), stability classes (3) and times (15). The new method is the program INTEGRATION and it uses a uniform horizontal concentration profile (or rings, which will be described later, if the ring results will be written to a file). Program INTEGRATION theoretically provides the basis for using an infinite number of possible vertical concentration profiles, because the dose rate from every possible profile can be decomposed into layers.

To calculate dose, one starts with the so-called energy fluence rate, which is defined as Ψ = energy fluence rate (J/(m^2 s)= the amount of energy per unit time that has entered an infinitesimally small sphere-shaped volume around a point divided by the area of a circle with the same radius as the sphere.

The Ψ-values obtained from equation:

$$\Psi(t)= \int_{x=-\infty}^{\infty}\int_{y=-\infty}^{\infty}\int_{z=-\infty}^{\infty} c(x, y, z, t)E_\gamma \frac{1}{(4\pi rrr)} Be^{-\mu r}\, dz\, dy\, dx$$

where: Ψ (t) = energy fluence rate (W/m^2)
= energy flux density
c(x,y,z,t)= activity concentration of nuclide (Bq/m^3)
E = egamma energy (J)
B = build-up factor
$\mu=\mu(E_\gamma)$ = linear attenuation coefficient (1/m)
$r^2 = x^2 + y^2 + z^2$

The program INTEGRATION is further elaborated for consideration of a finite cloud.

The finite cloud model involves simulating the plume by a series of small volume sources and integrating over these sources. There are two stages in the calculation, the evaluation of the photon flux at the point of interest and the conversion of the photon flux to absorbed dose in air. In general a number of photons of differing energy and intensity are associated with the decay of a particular radionuclide. The procedure for estimating the dose for photons with discrete decay energy is described; the evaluation of the dose from the decay of any radionuclide is obtained by summation over the photon decay energy spectrum. In program INTEGRATION, this is accomplished by the function *all_photons*.

The results show that the dose rate grows as height is decreased because at a lower height there is less air giving attenuation between the layer and the target, which is 1.0 m above ground surface (a standing person).

The program is written in FORTRAN 77 language and runs on operating system UNIX, on HP workstation.

In this study the potential radiological effects in Romania due to some hypothetical accidental airborne releases at the Cernavoda nuclear power plant site were analyzed. The trajectory-dose model TRADOS was employed. Trajectories are started at 3-hour time intervals and the consequence code utilizes the same time increment. This enables the consideration of long duration releases. Furthermore, it is possible to consider wind field variations as well as changing dispersion conditions. Dose conversion factors are based on data published by Kocher (Kocher, 1980).

On the basis of the specific Cernavoda nuclear power plant type of releases in mentioned table, two sets of maps were produced corresponding to two different release cases: (1) $3.76\cdot10^{16}$ Bq of I-131 in case of large accident (temperature >800 °C) and (2) for medium release with a composition of as follows:

I-131	$9,4\cdot10^{15}$ Bq;
Sr 90	$1,0\cdot10^{12}$ Bq;
Cs-137	$2,4\cdot10^{13}$ Bq;
Ru 106	$9,0\cdot10^{12}$ Bq.
Sr 89	$5,4\cdot10^{13}$ Bq;

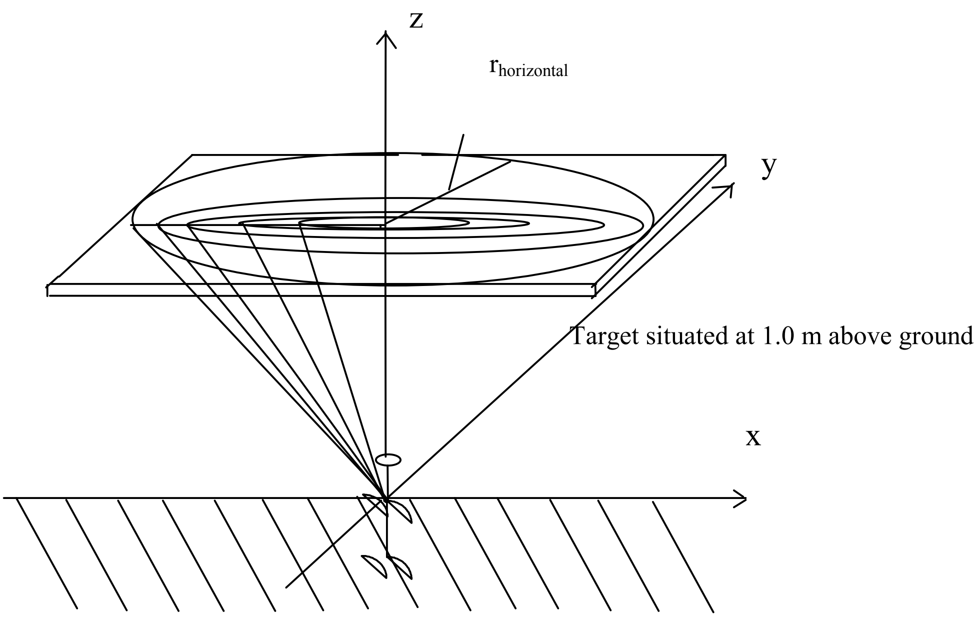

FIGURE 2. This figure presents the geometry of the program INTEGRATION

Results of program INTEGRATION

With the program INTEGRATION we were made 6 picture for a single nuclide (for example - I-131) and it was realized 2 pictures using this example and 4 pictures for all 72 nuclides from Kocher publication. Looking at these pictures we can see in graphic mode how was applied the dose rate calculation on 3D system. The biggest dose rate we can observe at the first nuclide ^{110}Ag, which has a value of the dose rate approximately *0.47634E-12* $\left[(Sv/s)/(Bq/m^3)\right]$. It was done a comparison between the values calculate with the program INTEGRATION and the values from Kocher data. Looking to the ratios mentioned on the fourth column at the program INTEGRATION results, it was constated that exists some errors like:

For *Pu 241* the error is *00000E++000INF* because we was not found the value of dose rate in the Kocher publication;

For *Sb 129* the error is *0.28944E+11* because we wrote a negative value for dose rate for this nuclide;

For *Ag110* the error is *0.33482E+03;*

For ^{85}Kr the error is *0.23945E+03*;

For ^{90}Y the error is *0.88729E+04*;

For ^{83}Kr the error is *0.44035E+04*;

For ^{127}Te the error is *0.58859E+00;*

For ^{85}Kr the error is *0.52203E-01;*

The results from the program INTEGRATION represent dose rates in air whereas the results of Kocher refer to dose rates applicable to the total human body and thus include attenuation within the human tissue.

CONCLUSIONS

The programs called INTEGRATION and TRADOS can be used as a computerized decision support for the Cernavoda NPP in case of a nuclear accident as well as a useful tool to estimate the environmental impact of airborne emissions in case of normal operation.

The continuous preoccupation for radioprotection has been proved at Cernavoda NPP by the lowest individual radiation doses registered in 1998 for the atomic radiation workers (ARW) (0.77 mSv/year, in comparison with the legal limit of 18 mSv/year) and by the collective doses to critical population group from the nuclear power plant radioactive emissions (5.58 μSv/year in comparison with 2200 μSv/year, the environmental dose).

The weight of the young specialists under the age 35 (which represents the young personnel who acquired the special results obtained at CERNAVODA NPP) is about 49.3 % of the plant staff (from the total number of workers -1633 at 12/31/1999 a number of 805 has age under 35). The average age is situated at age 37.16. The specialists' training is permanent and perfectible thanks to the real time Full Scope Simulator situated in the Training Center Building. The simulator provides the facilities to supply hands-on training in an environment which replicate the Main Control Room.

These positive results represent a convincing argument for the continuation and end of the work at the Cernavoda NPP second unit which will bring great benefits for my country power; the reduction of the organic fuel import; the essential reduction of atmospheric pollution of the thermo-electric power stations on the inferior coal, in present in majority; the cost reduction of electric energy; the possibility of a large number of work places and energy export in the neighboring countries.

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