DUST CONTROL INSIDE THE CHERNOBYL NUCLEAR POWER PLANT SHELTER DURING EMERGENCY CONDITIONS

Alain L'Hour, Maurice Giorgio (SGN, St-Quentin-en-Yvelines, France)
Mark Ball (AEA Technology, United Kingdom)
Arthur Korneev (Energoatom, Ukraine)

ABSTRACT

On 26 April 1986, the worst accident in the history of the nuclear industry occurred at Unit 4 of the Chernobyl Nuclear Power Plant (ChNPP), in Ukraine, which was then a republic of the former USSR. During the following days more than 17,000 tonnes of various materials were dropped into Unit 4 to stop the fire and minimise atmospheric pollution. The main components were boron carbide, lead, sand, zeolite, clay, calcite and dolomite, as well as concrete. A shelter to provide temporary shielding was rapidly built after the accident and completed in November 1986. Subsequently, following extensive studies undertaken by a number of scientific research institutes, it was estimated that the shelter contains at least 95% of the irradiated nuclear fuel that was located in Unit 4 prior to the accident. The quantity of hazardous fissile material therefore totals around 180 tonnes and the total radioactivity of materials inside the shelter exceeds 20 million Ci, of which a proportion is in the form of dust. Experience gained over the last 13 years shows that more than 90% of aerosol activity, which is determinant for radionuclide intake by the personnel, is related to fine fuel dust also known as hot fuel particles.

Damage has been identified on many structures of the shelter, mainly on the supporting elements. Destruction and displacement of civil engineering structures are possible due to atmospheric and temperature factors, as well as to forces induced by non-uniform precipitation, hurricanes, blast wave, earthquakes and so on.

Currently, the release of radioactive dust outside the shelter and personnel exposure in the event of an accident are among the major potential hazards.

Between May and November 1996, an international team of experts sponsored by the European Commission TACIS fund evaluated five major technical scenarios and a number of subsidiary options to produce a long-term environmentally safe solution for the shelter. This work was supported by the G7 Nuclear Safety Group and served as a basis for the further development of the Shelter Implementation Plan (SIP).

The European Bank for Reconstruction and Development (EBRD) and Ukraine entered into an agreement for the provision of grant funding to ChNPP for the purpose of implementing the SIP. Among the 22 tasks of the SIP, Task 11 concerns to the Emergency Dust Suppression System (EDSS). This paper presents:

- the basic data regarding the characteristics and quantities of dust contained in the shelter;
- the analyses of the different dust release accident scenarios;

- the basic ALARA cost-benefit analysis;
- a description of the main objectives for an EDSS;
- an overall view of alternative solutions.

DUST DATA

Total Dust Quantity

Knowledge of dust characteristics and dust inventory is the basis for any consideration regarding release and the subsequent radiological consequences. The total radioactivity of the dust is mainly concentrated in dust deposits on various shelter structures, but a proportion also exists suspended in the airborne phase (aerosols). The deposited dust particles form a layer on the surface of the debris of the destroyed reactor, equipment and walls. Tentative calculations have been performed, based on smear sample measurements to assess the quantity of radioactive dust. Considering the hot fuel particle density, the total area of the Unit 4 Central Hall and a corrective factor to allow for the non-flatness of the surface, the quantity of finely dispersed fuel dust is estimated at 500 kg. Moreover, experimental data from dust sampling has shown that the ratio of radioactive dust (hot fuel particles) to non radioactive dust is in the range of 1:100. Therefore, the total quantity of radioactive and non radioactive dust on the surface of the Central Hall debris and on other open surfaces under the roof of the shelter can be estimated at around 50 tonnes.

Radionuclide Distribution

During a dust release accident, radioactive dust deposited inside the former Central Hall is resuspended and released to the environment. It is important to know the size distribution of the radioactive dust because processes like dust resuspension and airborne transport efficiencies depend on particle size. Furthermore, if the particle size distribution is known, the fraction of the dust that is inhalable can be calculated in order to estimate the radiological impact on personnel. Figure 1 shows the normalised distributions of the main radionuclides plotted as a function of dust particle size.
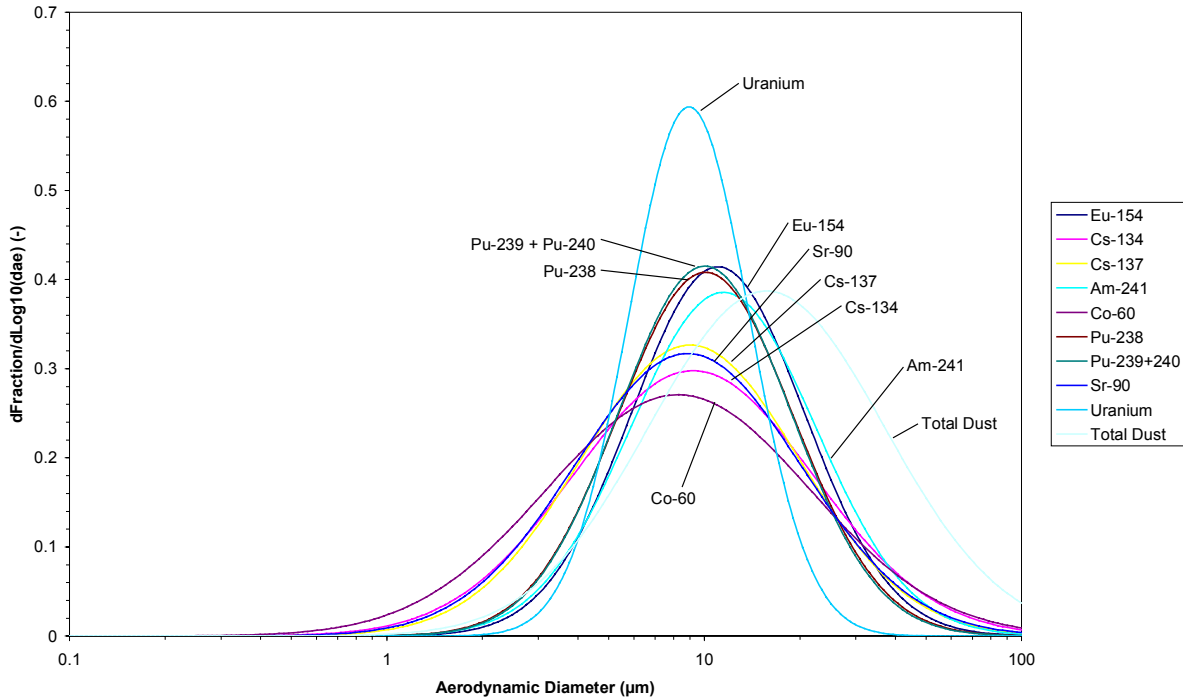
Figure 1 - Distributions of radionuclides as a function of aerodynamic diameter.

Although there are differences between the distributions of the radionuclides measured, they are small. The median sizes of the distributions are all close to 10 µm aerodynamic diameter and therefore have a respirable fraction that cannot be ignored. ISO standard 7708 (ISO, 1995) defines three conventions for the fraction of aerosol that can be breathed (inhalable, thoracic, respirable). The percentage of airborne dust for each radionuclide is shown in Table I.

Radionuclides	Inhalable (ISO, 1995)	Thoracic (ISO, 1995)	Respirable (ISO, 1995)
Eu-154	74.98	42.87	8.78
Cs-134	77.04	50.21	18.67
Cs-137	77.54	51.43	17.75
Am-241	74.34	41.29	9.08
Co-60	78.15	53.51	23.01
Pu-238	76.33	47.15	11.12
Pu-239 + 240	76.42	47.41	10.98
Sr-90	77.69	51.94	18.77
Uranium	78.61	54.50	9.16
Total dust	69.98	30.98	7.49

Table I - Fraction of inhaled dust for each radionuclide in percentage

Table 1 shows that approximately 75% of transuranium dust and about 70% of total dust are inhalable and contribute to the radiological impact.

ANALYSES OF VARIOUS DUST RELEASE ACCIDENT SCENARIOS

Roof Collapse

Radiological Impact of a Roof Collapse Accident on Workers and the Environment Assessed by Various Organizations.

In pessimistic accident scenarios involving roof destruction (part of the external protective barrier), roof elements fall on materials covered with fuel dust and rupture any dust fixating film. A dust cloud is formed and radioactive materials are released to the environment outside the shelter. The magnitude of the accident consequences will depend on the total activity in the dust cloud, release height and weather conditions. This type of accident scenario and possible consequences of environmental contamination and dose burdens have been modelled by organisations in a number of countries, including Russia (R.R.C. Kurchatov), Germany (GRS), Belarus (IREP-ASB) and Ukraine (Iyai Nanu). The synopsis of the main results for the modelling of fuel dust removal in case of Shelter roof collapse implemented by these organisations shows that:

- The quantity of dust raised is in the range of 10 to 100 kg of hot fuel particles released in a cloud during the roof collapse accident. These values are determined by dust resuspension mechanisms used in the different models.
- The time of cloud existence in all models is evaluated at 1 hour.
- The choice of the accident time regarding the doses is not important because inhalation doses are determined by long-lived transuranic elements and doses from ground contamination are determined mostly by long-lived ^{137}Cs. Radiation doses from the contaminated ground surface are one order of magnitude lower compared with inhalation doses during the accident phase (at residence time of 30 working days).
- The main results determined by each organisation regarding the radiological impact are:
  - One of the main features of the Kurchatov Institute and Iyai Nanu models is to account for the effect of the aerodynamic shadow, since the height and diameter of the cloud are comparable with the shelter size. Studies by the Kurchatov Institute and Iyai Nanu show that volumetric concentration of transuranium radionuclides in the shadow exceeds the MPCa in rates of the order of 10^7. The concentration of transuranic elements in the aerodynamic shadow has been estimated as follows:

    ^{238}Pu ~ 10^{-9} Ci/l, ^{240}Pu ~ 1.2 x 10^{-9} Ci/l and ^{241}Am ~ 2.2 x 10^{-9} Ci/l

    These very high concentrations of transuranic elements generate extremely high inhalation doses in the range of 1 Sv/h to personnel present near the shelter after the roof collapse.

- Maximum equivalent dose rate (IREP) is about 600 to 700 mSv/h at a distance of 200 to 300 m from the source.

- Surface ground contamination (Kurchatov Institute and Iyai Nanu is 100 to 200 Ci/km^2 at a distance of 5 km from the source, which is in the range of magnitude of the present ground surface contamination.

Assessment of conservative assumptions used in past work
A tentative estimate has been made to assess some of the conservative assumptions used in the previous studies.

- Quantity of dust in the cloud formation resulting from roof collapse
  The quantity of hot fuel particles released in the cloud as a result of the roof collapse has been estimated at around 10 to 100 kg, with an actual average value of 50 kg. This value does not result from an actual scientific assessment. The dust resuspension mechanism as a result of roof collapse is difficult to analyse because the processes engaged are very complex and cannot be assessed with a simple analytical model. A tentative evaluation of the dust released in the cloud is proposed below on the basis of the Mishima model. According to this model, the limit for dust concentration in air is approximately 10 g/m^3 under high energy conditions (e.g. chemical explosion) and up to 0.1 g/m^3 under low energy conditions. In the case of roof collapse, we may assume a dust concentration of 1 g/m^3. The initial displaced air volume resulting from roof collapse can be estimated at 55,000 m^3. The total displaced air volume is then assumed to be 550,000 m^3 using a 10-fold correction by analogy with equipment like an ejector, where the driving gas can drag up to 30 times its own flow. Under these conditions, according to the Mishima model, the maximum dust quantity in the cloud is 550 kg (1 g/m^3 x 550,000 m^3). Taking into consideration the 1:100 ratio of hot fuel particles to non-radioactive dust, a figure of 5.5 kg is derived for hot fuel particles in the cloud.

- Inhalable dust particle fraction
  The percentage of inhalable dust has been conservatively considered in the models to be 100%. Calculations shown in Table 1 have reduced this conservative estimate to 76% for transuranium dust. In addition, such high concentrations of dust (~ 1 g/m^3) are visible to the naked eye and sufficiently offensive to cause an aversion reflex such as covering the face. Aversion is likely to reduce the inhaled particles by a factor of 2.

- Exposure time for a ChNPP worker
  The exposure time has been estimated at 1 hour. Considering the personnel protection plan to be developed in the framework of SIP C Task 9 activities, protective measures addressed include the evacuation of personnel from working areas into areas of lower contamination. The average time for personnel to reach a protected area is estimated at around 20 minutes, reducing the exposure dose by an approximate factor of 2 (exposure dose is not a linear function of time).

Radiological Impact of a Roof Collapse Assessed by the Sirocco2 Calculation Code Using a Gaussian Model

The previous section presented studies performed by different organisations based on conservative assumptions. A tentative estimate to assess those conservative assumptions has also been performed. The radiological impact of a shelter roof collapse accident on the ChNPP workers is assessed by the Sirocco2 code for a discharge of about 5.5 kg of hot fuel particles. In case of such an accident, ChNPP workers are mainly affected by:

- external exposure due to plume crossing;
- external exposure due to the presence of deposits on the ground;
- internal exposure due to plume inhalation.

The meteorological conditions considered are the mean values of the site (wind speed of 4.2 m/s), with and without rain (1 and 5 mm/h). Two discharge heights are considered (70 m and 100 m). The activities of various radionuclides in the plume (around 5.5 kg of fuel from ChNPP Unit 4) are indicated in Table II.

Nuclide	Activity (Bq)
^{90}Sr	5.64 x 10^{12}
^{90}Y	5.64 x 10^{12}
^{137}Cs	7.15 x 10^{12}
^{147}Pm	2.75 x 10^{12}
^{238}Pu	3.03 x 10^{10}
^{239}Pu	2.48 x 10^{10}
^{240}Pu	3.44 x 10^{10}
^{241}Am	6.60 x 10^{10}
Total	2.13 x 10^{13}

Table II - Activities of various radionuclides

It should be noted that the Sirocco2 code does not take into account the aerodynamic shadow effect resulting from roof collapse. Table III only reports the maximum values of the radiological impact due to internal exposure from the plume because external exposure is negligible.

Discharge Height (m)	Value Considered	Rainfall rate (mm.h⁻¹)					
		0		1		5	
		Distance from the discharge point	Value	Distance from the discharge point	Value	Distance from the discharge point	Value
70	Conservative internal exposure due to the plume (Sv) *	1 km	6.57 E-2	1 km	6.42 E-2	1 km	5.84 E-2
	Realistic internal exposure due to the plume (Sv)	1 km	1.31 E-2	1 km	1.28 E-2	1 km	1.17 E-2
	Surface activity $(Bq.m^{-2})$ (Ci/km^2)	1 km	1.01 E6 27.3	500 m	7.87 E6 213	500 m	3.67 E7 992
100	Conservative internal exposure due to the plume (Sv) *	2 km	2.50 E-2	2 km	2.38 E-2	2 km	1.97 E-2
	Realistic internal exposure due to the plume (Sv)	2 km	5 E-3	2 km	4.8 E-3	2 km	3.9 E-3
	Surface activity $(Bq.m^{-2})$ (Ci/km^2)	2 km	3.83 E5 10.4	500 m	7.67 E6 207	500 m	3.66 E7 989

Table III - Maximum radiological impact due to plume exposure and maximum surface activities

The maximal inhalation dose for individuals without the rainfall condition reaches 1.31×10^{-2} Sv at 1 km from the point source. This dose is within the annual limit established by Ukrainian regulations (2.0×10^{-2} Sv). Ground surface contamination may reach a high level in the range of 990 Ci/km^2 in case of rainfall rate of 5 mm/h, which is about five times the average existing ground contamination within the exclusion zone.

Large Fire Occurrence

There are several ways that fire can generate to a radiation hazard:

- Combustion may produce radioactive dust, which is then entrained by smoke and hot air currents.
- Combustion will give rise to intense air movements within the shelter facility, far in excess of normal ventilation related air flows. This will cause contamination to be removed in the heated areas, even where current dust fixative products are used. Active products are then entrained elsewhere.

The main difference, compared to a roof collapse, is a lower contamination flow, but a longer duration if the fire is not extinguished. Another difference, compared to roof collapse, is the potential of a hot plume to transport contamination to a higher altitude and therefore lower

contamination at short distances (i.e. on the ChNPP site). Potential higher contamination outside the site has not yet been evaluated. The total mass of combustible material in the shelter is estimated at 2000 tonnes. Flammable material in the Central Hall is mainly in the form of organic materials remaining from routine dust suppression, electrical insulation on cables, wood and graphite. However, the quantity of flammable material is not known with certainty and it is therefore difficult to evaluate the actual intensity of a fire inside the Central Hall. The following hypothesis is considered regarding a potential large fire occurrence in the Central Hall:

- fire covered area considered is A = 500 m^2
- fire duration taken into account is t = 5 h

The quantity amount of discharged radioactive dust M can be assessed as follows:

M = A x D x 60 x 0.1 = 500 x 3.4 x 60 x 0.1 = 10,200 g of hot fuel particles

The fire will generate both complex chemical and thermal process effects involving the dust that are difficult to assess in a scientific way. Such analysis has not been performed. Nevertheless, only a fraction of the radioactive dust involved in the process is released to the environment, mainly because gaps in the shelter roof from which dust will escape only represent 130 m^2 and are composed of mazes which will stop some dust. The fraction of the dust released to the environment is estimated to represent 10% of the total dust. According to the dust data, the density of hot fuel particles in the Central Hall is D = 3.4 g/m^2 and the corrective factor due to the non-flatness area is 60.

Plume model calculation methods have been applied to evaluate the radiological impact of dust released due to the fire accident. The exposure rate has been assessed considering the inhalable dust particle fraction given in Table I, the exposure time of 20 minutes required for personnel to reach the protected area and the aversion effect. Table IV shows the results for different weather conditions (A: very unstable, B: unstable, C: slightly unstable, D: Neutral, E: slightly stable, F: stable).

	500 m	1 km	10 km	30 km
Stability A	17.3	3.28	4E-3	2E-4
Stability B	11.3	12.7	0.32	3E-2
Stability C	1.73	13.1	0.78	0.14
Stability D	1.8E-2	0.13	0.3	9.6E-2
Stability E	8E-4	0.954	3.28	0.92
Stability F	NL	NL	2.86	2.3

Table IV - Radiation exposure at various points (mSv)

As shown in Table IV, the maximum dose outside the 30 km exclusion zone will be in the same range as the natural radiation dose (Stability E). The expected maximum dose will be 17.3 mSv at 500 m from the discharge point. Accordingly, it can be said that no person will receive a radiation exposure higher than 20 mSv, which is the annual dose limit for Category A workers.

Other Hypothetical Accidents

Besides the fire and the roof collapse accidents, other emergency situations leading to dust release from the shelter may be induced by many other events, including earthquake, hurricane, tornado and airplane crash.

According to the Scientific Research Institute of Building Constructions, the probability of an earthquake of magnitude 7 (maximum earthquake) is once in 10,000 years (10E-4).

Hurricane probability with wind speed of 47.3 m/s is also once in 10,000 years (10E-4).

Annual probability of a tornado at the shelter is estimated to be 3E-6 per year with the following characteristics: maximum tornado wall rotation horizontal velocity is 72 m/s, tornado translational velocity is 18 m/s, tornado path width is 290 m.

Aircraft crash is considered critical when it causes roof collapse. Its probability is assessed at 1E-7 per year.

The common characteristics of all the above accidents are:

- The probability of these accidents is low in comparison with fire and roof collapse resulting from degradation;
- All of them generate extensive process of the shelter structures, including roof collapse. Although these events have not been thoroughly studied, they are all considered as potential initiating events for dust release to the environment. We also assume that radiological consequences for the ChNPP workers and for the ground surface would be in the same range as those for those of the roof collapse accident scenario.

ALARA APPROACH

Methodology

A cost-benefit analysis based on the ALARA principle was undertaken to determine if the radiological protection of operating personnel and population substantiates the construction of an EDSS. The fundamental difficulty in a cost-benefit analysis relating to radiological protection is to express the benefits and the health damages in the same units. The ICRP approach suggests expressing the value of the collective dose in monetary units so that the advantage of a reduction in collective dose can be compared directly with the cost of achieving this reduction. The only factors considered to be directly relevant for optimisation purposes are the financial costs of implementing protective measures and the associated levels of collective dose.

Under such conditions, the expenses of conversion of the shelter into an ecologically safe system can be substantiated by the intention to prevent further expenses. A comparison is made between the cost of the EDSS and the subsequent dose collected in the event of an accident and the dose collected during an accident without an EDSS system.

Application to Roof Collapse with Aerodynamic Shadow Effect

The ALARA cost-benefit methodology has been applied and the creation and installation of an EDSS has been justified from an economical point of view. Up to 4.5 MUSD could be spent for the creation of an EDSS. However, the uncertainties on the ALARA cost-benefit analysis are high and they are mainly governed by the uncertainties related to the radiological impact of dust release accident. This in turn depends on the source term, the transport model, the radiological model and the number of persons injured by the accident. Those uncertainties are developed below and are presented in Table V.

Amount of dust released (kg)		0.5		5.5		34		50	
Number of persons injured		Dust fraction inhaled (76%)	Dust fraction respirable (11%)	Dust fraction inhaled (76%)	Dust fraction respirable (11%)	Dust fraction inhaled (76%)	Dust fraction respirable (11%)	Dust fraction inhaled (76%)	Dust fraction respirable (11%)
1	S	4.9E-02	7.1E-03	5.4E-01	7.8E-02	3.3E+00	4.8E-01	4.9E+00	7.1E-01
	Y^b	9.1E-03	1.3E-03	1.0E-01	1.4E-02	6.2E-01	8.9E-02	9.1E-01	1.3E-01
	X^H	-5.0E-01	-5.0E-01	-4.0E-01	-4.9E-01	1.2E-01	-4.1E-01	4.1E-01	-3.7E-01
	S	1.5E-01	2.1E-02	1.6E+00	2.3E-01	1.0E+01	1.4E+00	1.5E+01	2.1E+00
3	Y^b	2.7E-02	3.9E-03	3.0E-01	4.3E-02	1.9E+00	2.7E-01	2.7E+00	3.9E-01
	X^H	-4.7E-01	-5.0E-01	-2.0E-01	-4.6E-01	1.4E+00	-2.3E-01	2.2E+00	-1.1E-01
	S	2.5E-01	3.6E-02	2.7E+00	3.9E-01	1.7E+01	2.4E+00	2.5E+01	3.6E+00
5	Y^b	4.5E-02	6.5E-03	5.0E-01	7.2E-02	3.1E+00	4.5E-01	4.5E+00	6.5E-01
	X^H	-4.5E-01	-5.0E-01	0.0E+00	-4.3E-01	2.6E+00	-5.0E-02	4.0E+00	1.5E-01
50	S	2.5E+00	3.6E-01	2.7E+01	3.9E+00	1.7E+02	2.4E+01	2.5E+02	3.6E+01
	Y^b	4.5E-01	6.5E-02	5.0E+00	7.2E-01	3.1E+01	4.5E+00	4.5E+01	6.5E+00
	X^H	-5.0E-01	-4.3E-01	4.5E+00	2.2E+00	3.0E+01	4.0E+00	4.4E+01	6.0E+00
100	S	4.9E+00	7.1E-01	5.4E+01	7.8E+00	3.3E+02	4.8E+01	4.9E+02	7.1E+01
	Y^b	9.1E-01	1.3E-01	1.0E+01	1.4E+00	6.2E+01	8.9E+00	9.1E+01	1.3E+01
	X^H	4.1E-01	-7.3E-01	9.9E+00	9.5E-01	6.2E+01	8.4E+00	9.1E+01	1.3E+01

Table V - Collective dose received (S, Man Sv) as a result of dust release during a roof collapse accident, expenses generated by personnel exposure if EDSS is not installed (Y^b, MUSD) and expenses for EDSS construction and installation

Application to a Large Fire

According to the above ALARA cost-benefit analysis methodology, the creation and instal-lation of an EDSS in the case of a large fire is not justified from an economical point of view.

Synopsis of the ALARA Approach

The main conclusions of the present ALARA cost-benefit analysis are:

- The construction of an EDSS is not justified for a large fire occurrence, assuming that no shelter destruction is associated with the fire.

- The uncertainty analysis made for the roof collapse accident shows that radiological protection starts to be justified when more than 5.5 kg of hot fuel particles are discharged to the environment and more than 50 persons are exposed to internal inhalation dose. Within these conditions, the expenses related to the creation of an EDSS should be up to approximately 4.5 MUSD. However, it should be noted that due to the uncertainties of the cost-benefit analysis and the cost of a man-Sv, which greatly depends on the standard used, the expenses related to the creation of an EDSS should be considered only as indicative.

MAIN OBJECTIVES AND CRITERIA FOR EDSS DESIGN

General Safety Objectives

The release of radioactive dust and dispersion of airborne contamination to the environment could result from a shelter collapse or from any other release accident. The EDSS will be designed to limit the consequences of dust release only related to some accident scenarios. For this set of accident scenarios that generate dust release, the primary safety objective of the EDSS is to protect workers, the public and the environment against radiation.

Design Criteria
List of Initiating Events

Some initiating events on the shelter may generate radioactive dust release to the environment and may affect the workers. Among them, fire, roof collapse, earthquake, tornado and aircraft impact are the most significant and the probability of their occurrence has been estimated (Table VI).

Event No.	Initiating event	Expected probability yr^{-1} ***
1	Fire	0.4
2	Roof collapse due to degradation or SIP activities	0.1****
3	Earthquake magnitude 7	0.0001
4	Tornado	3E-6
5	Aircraft impact	1E-7

Table VI - List of dust release initiating events.

Design Criteria
In determining the design criteria for the EDSS, the list of accident scenarios to be considered is important. For each accident scenario, a separate set of design criteria can be defined.

Design Criteria Common to all the Accident Scenarios
Common criteria for all accident scenarios are described as follow:
- Referring to the ALARA approach, the EDSS should be the result of the better compromise regarding the dose benefit and the cost.

- Efficiency: The EDSS should ensure the suppression of dust resulting from a dust release accident in the shelter. Efficiency of the EDSS should be dictated by the criteria developed within the framework of safety objectives.
- Working area within the whole shelter: EDSS should operate over the whole shelter internal area, which is in the range of 7000 m^2.
- Automatic operating mode: The EDSS should operate in automatic mode. It should also be operated remotely from a control desk. The main EDSS parameters and EDSS working status should also be monitered.
- Minimise the requested time for project implementation: Due to the high probability of a dust release accident and the associated severe radiological consequences, the time required to implement an EDSS should be as short as possible.
- Maintenance: Considering radiological conditions in the vicinity of the shelter structure, technical and on-line operation of EDSS should be as low as possible.
- Dust suppression mixture: The dust suppression mixture, if any, should be fire-resistant, non-explosive and for all-season use.
- Amount of liquid used: The quantities of water used during operation shall be limited by the potential to create favourable conditions for a criticality event.
- Winter-summer temperatures: EDSS should perform its functions at temperatures in the range of -35 °C to +50 C°.
- High working temperature: EDSS elements located under the shelter roofing shall maintain their working characteristics under a temperature of up to +100 C°.
- Minimise forces exerted on shelter structures: The weight and the dynamic forces resulting from operation of the EDSS components supported by any existing shelter structure, should be compatible with the resistance of the present shelter structures.

Specific Design Criteria Related to Roof Collapse

- Time of EDSS response
  Taking into account the fast processes the roof collapse involves, the EDSS should include fast-acting devices. The response time of the emergency system from the moment of emergency signal transmission should also be compatible with the fast process of the roof collapse.

- Activation of the EDSS
  Sensors recording the stability of supporting structures combined with the radioactive airborne dust concentration in the Central Hall should serve as a signal for activating the system. Sensors will be installed on the surface of the supporting structures.

Specific Design Criteria Related to a Large Fire

- Long working process
  Taking into account the long process of a large fire, the EDSS should include a long period working device able to suppress the dust during the entire fire process.

Specific Design Criteria Related to an Earthquake of Magnitude 7,
Tornado and Aircraft Crash

- Taking into account the weakness of the Shelter structure, EDSS devices should not be implemented in the existing shelter structures in these conditions.

Selection of EDSS Criteria

It should be pointed out that each set of design criteria would correspond to a typical EDSS concept. Each will differ in technical complexity, dose budget to the workforce during the construction, dose reduction when the release accident occurs and cost. Either the EDSS design criteria could correspond to one separate set of design criteria mentioned above or it could be a combination of different sets of design criteria. Proceeding with a qualitative analysis approach, the selection of EDSS criteria has been established on the basis of the following factors:

- the probability of the accident scenario occurrence;
- the radiological consequences of the accident scenario;
- the radiological impact to the workforce during construction of the system;
- the cost of the EDSS;
- impact on the technical complexity of the system in relation with the difficulty to demonstrate its proper operation and the required time for project implementation.

As the result of the analysis, it is suggested that hypothetical accidents for the design of an EDSS should not be taken into consideration. Due to the high probability of occurrence and radiological impact (mainly due to the aerodynamic shadow effect), and to the ALARA analysis, only the roof collapse accident will be taken into consideration for the EDSS design. Concerning the large fire accident scenario, referring to the previous ALARA analysis, an EDSS is not justified from an economical point of view. To sum up, roof collapse and its associated set of criteria should be taken into consideration for the EDSS design.

OVERALL VIEW OF ALTERNATIVES

Risk Management Programme

The dust release accident risk can be managed through the following step-by-step activities:

- In the framework of EBP C Task 9, quickly develop the preventive measures part of the Emergency Preparedness Programme. The plan for personnel protection should address ways to protect workers from the airborne radioactive dust concentrations that would result from a shelter roof collapse. Sheltering and evacuation of personnel, provision of individual respiratory protection, medical evaluation and treatment, and training of personnel shall be addressed.
- The shelter structure shall also be protected by activities that limit collapse probability increases. Activities included in the scope of EBP A, concerning stabilisation and reinforcement of shelter structures, are in this scope.

- In the framework of EBP C Task 10, develop a dust suppression mixture capable of producing a protective fixative layer covering dust in the Central Hall. Reducing airborne dust concentration will reduce inhaled radioactive doses to ChNPP workers.
- In the framework of EBP B Task 16, develop a fire prevention programme to decrease the probability and consequences of a fire (see above section on large five occurrence).
- Start the EDSS design.

Selection of The Process for an EDSS

Overview

The original Task 11 main objectives have been exceeded and some alternative preventive measures have been investigated to include the analysis of other solutions. Those included in SIP activities like EBP A reinforcement and stabilisation, or EBP C Task 10 protective fixative layer as well as measures taken to limit the consequences of the accident in the framework of EBP C Task 9, are not discussed here. Other measures envisaged were to create:

- A physical barrier under the shelter roof all over the Central Hall area to contain the dust. Defining the type and characteristics of the physical barrier could result in a set of conceptual design features each considering a different type of material. It should be pointed out that the protective fixative layer developed in the framework of EBP C Task 10 may also be considered as a containment barrier.
- A physical barrier arranged above the present shelter roof. This equates to an overall cover of the shelter roof.
- A dust treatment system that reduces the total amount of radioactive dust inside the Central Hall during normal operating conditions. Within these conditions, no accident scenario would result in a sufficient quantity of dust released to generate high radiological impact to the environment. The dust treatment could be assessed by the implementation of air sampling systems.

The conclusion of the above analysis is that no reliable and credible alternative solutions to the wet suppression technique can reasonably be proposed for the implementation of the EDSS. Regarding the wet suppression technique, two main technologies can be taken into consideration.

Fire Fighting Technologies Using Water Jets

These technologies use high-pressure water jets. That can project water up to several hundred metres. However, the maximum elevations reach by water jets are around 60 to 70 m. This means that jets installed at ground level could not reach the top of the shelter (> 70 m high). Moreover, these water jets are not suitable for the required dust scrubbing. These kinds of processes use dispersed water drops with a given median diameter. Water jets would not produce the mist or rain needed to catch the radioactive dust particles.

Gas Washing Technologies Using Spray Nozzles

Gas washing technologies use a mist, or a rain, with a given median diameter of the drops, to catch the dust particles. A convenient way of getting water drops of a given diameter is to use spray nozzles. This technology is commonly used in industry with good results and is supported by a comprehensive theoretical approach. It is also used in off-gas washing columns in the nuclear industry. This technology is selected for the EDSS as it better complies with the dust suppression release generated by the roof collapse accident. Considering the gas washing technologies with spray nozzles, the technical solutions envisioned in the present conceptual design report are:

- Fast acting devices (Figure 2).
- Stationary system developed in the framework of the UK-72 project (Figure 3).
- Stationary system developed in the framework of the ALLIANCE programme (Figure 4).
- Stationary system developed by Nikimt in 1993 (Figure 5).
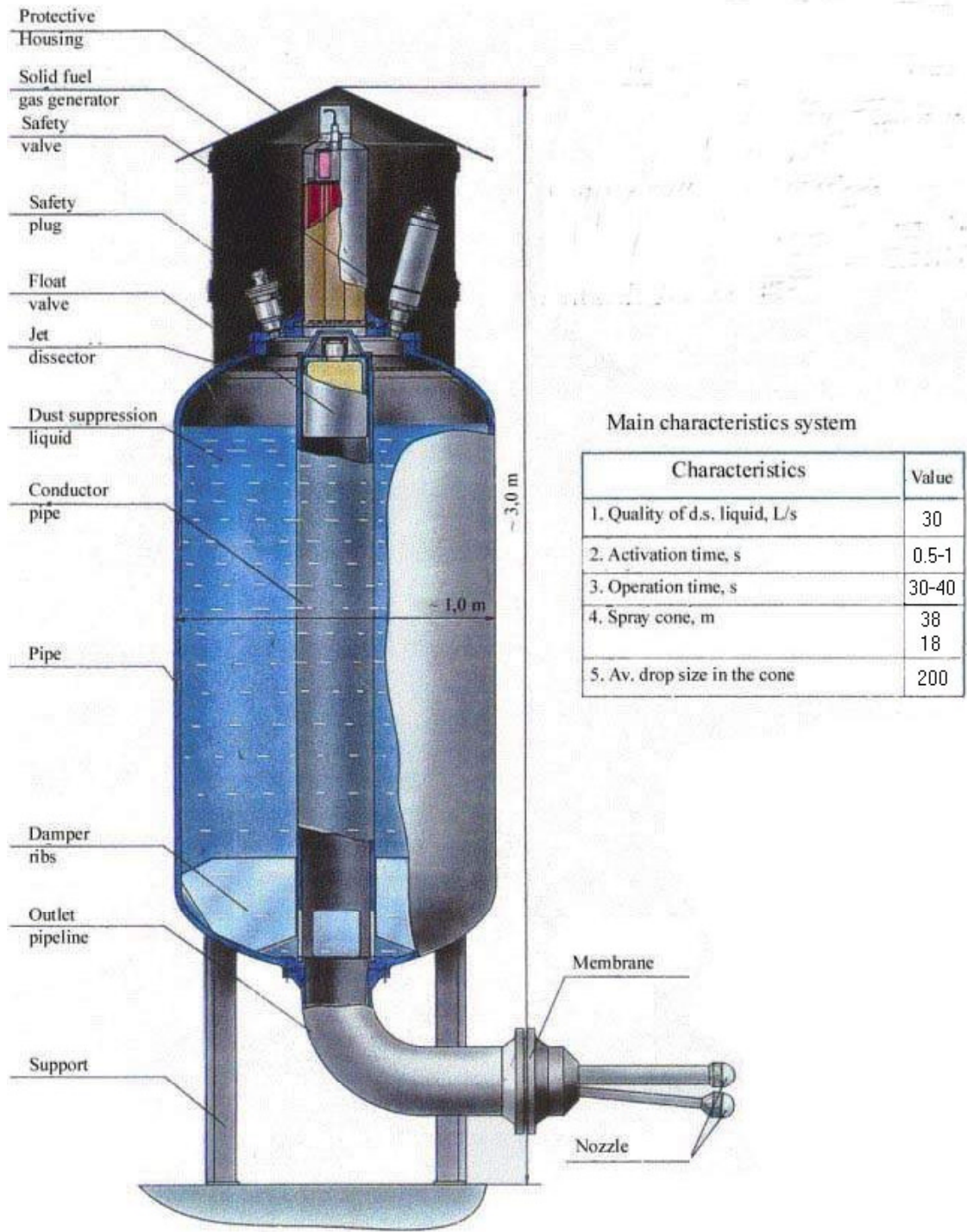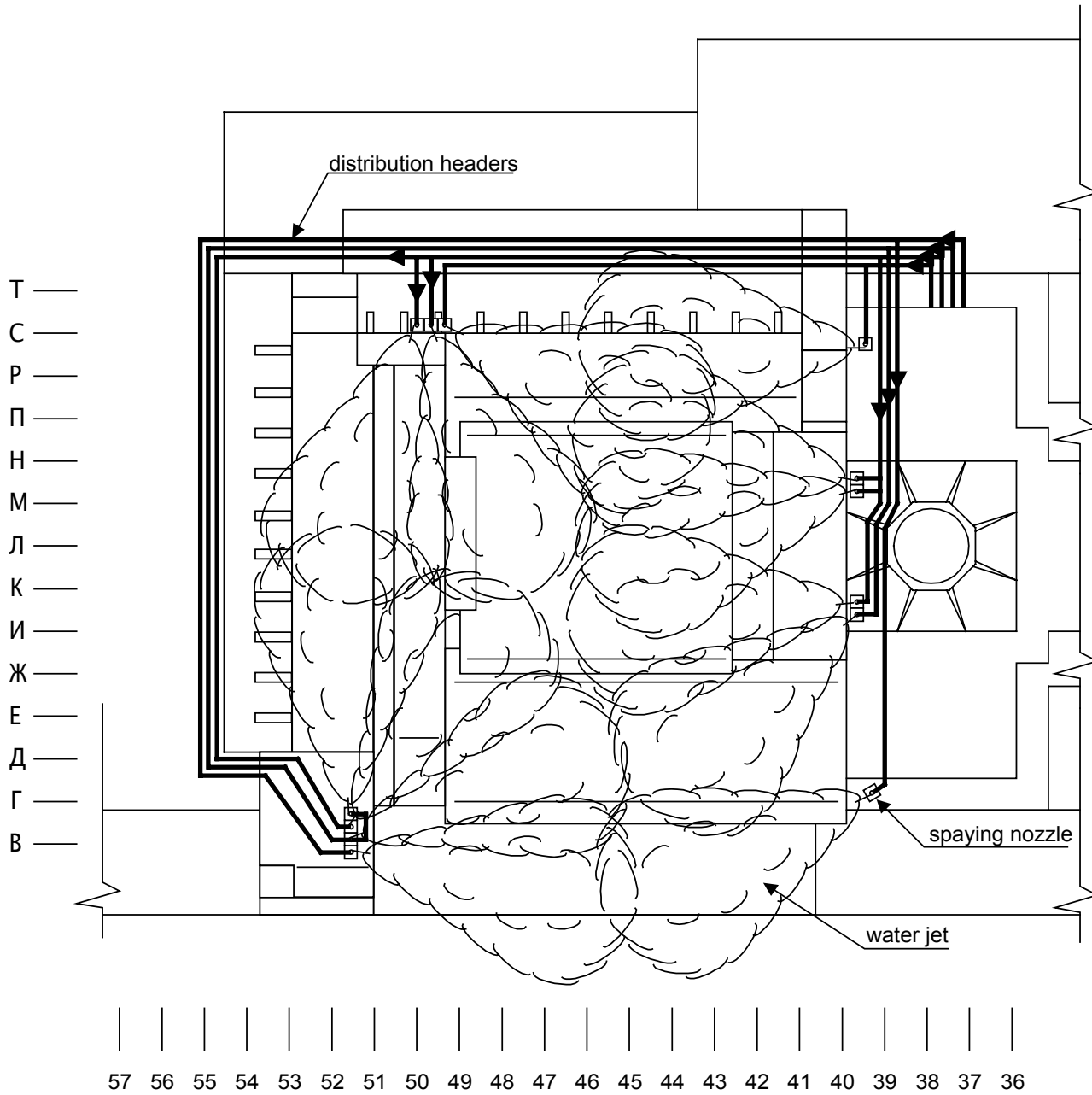
BASIC DESIGN OF FAST ACTING DEVICE

Protective Housing

Solid fuel gas generator
Safety valve

Safety plug

Float valve

Jet dissector

Dust suppression liquid

Conductor pipe

Pipe

~ 3,0 m

~ 1,0 m

Damper ribs

Outlet pipeline

Support

Membrane

Nozzle

Main characteristics system

Characteristics	Value
1. Quality of d.s. liquid, L/s	30
2. Activation time, s	0.5-1
3. Operation time, s	30-40
4. Spray cone, m	38 18
5. Av. drop size in the cone	200

Figure 2 – Fast acting device

distribution headers

Т
С
Р
П
Н
М
Л
К
И
Ж
Е
Д
Г
В

spaying nozzle

water jet

57 56 55 54 53 52 51 50 49 48 47 46 45 44 43 42 41 40 39 38 37 36

Figure 3 – Stationary system developed in the framework of the UK-72 project

distribution headers
supporting trusses

feeding collector

feeding collector: ND 700

nozzle feeding pipe: ND 50

distribution header: ND 200

spraying nozzle

water jet

glycol tank

50 m³/h

pond

250 m³
glycol/water

5700 m³/h

5700 m³/h

concrete feeding pipe
ND 1100

2 feeding collectors

Figure 4 – Stationary system developed in the framework of the ALLIANCE programme

spraying nozzle

water jet

distribution header supporting truss
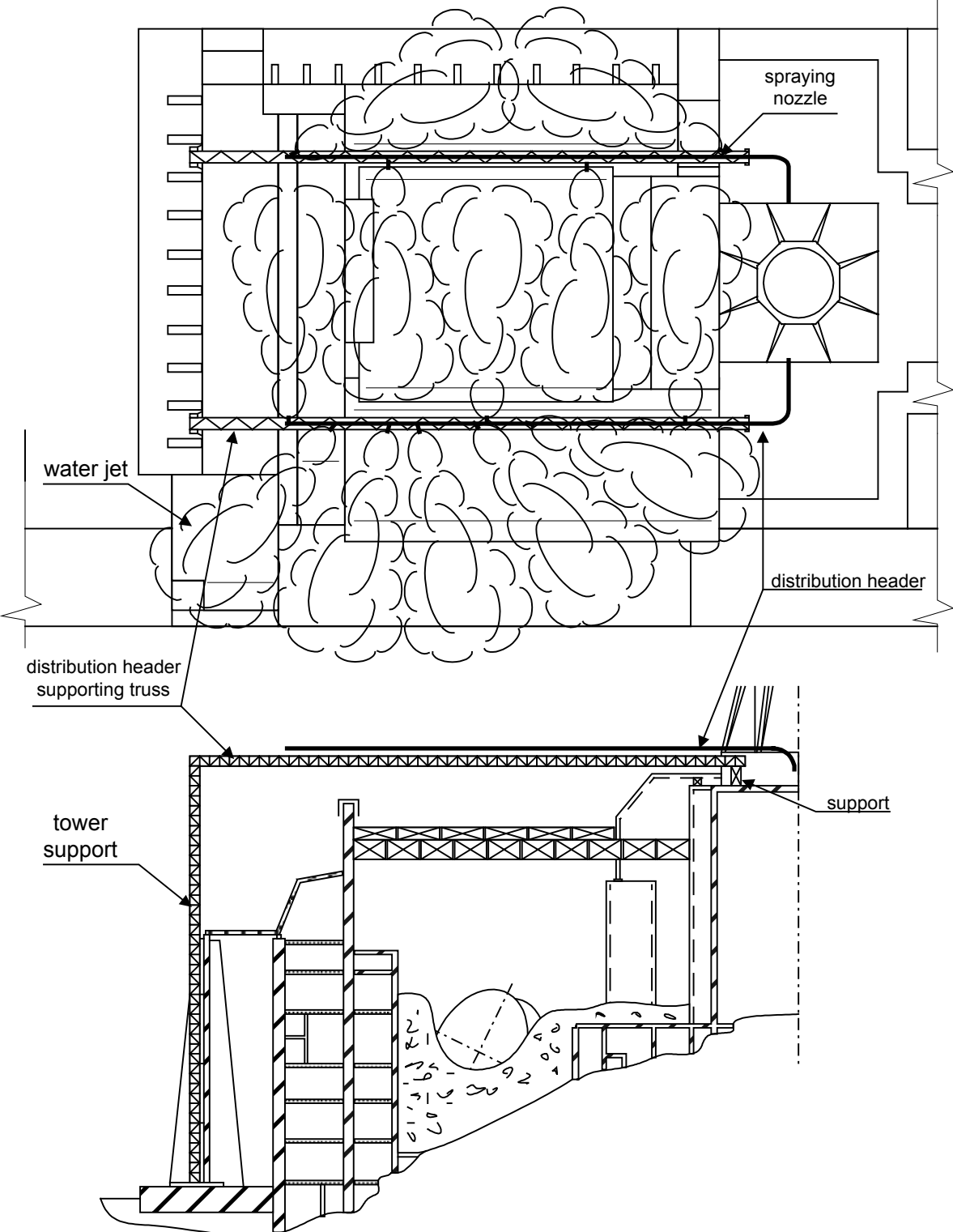
distribution header

tower support

support

Figure 5 – Stationary system developed by Nikimt in 1993.

Comparative Technical Analysis of Alternatives

Proceeding with a qualitative approach, the technology to be used in the framework of the present conceptual design is on the basis of a technical comparison regarding the design criteria presented above. Referring to the above analysis, based on a qualitative approach, it appears that the more convenient technology to be used for the EDSS regarding the list of criteria is the fast acting devices.

CONCLUSION

As a result of the Evaluation Report of Alternatives for an EDSS, the following conclusions are emphasised:

- There are a number of accident scenarios that may induce dust release to the environment. Among them, the roof collapse and a large fire are the potential hazards.
- The roof collapse accident scenario and possible consequences on territory surface contamination and dose burdens has been analysed by organisations in Russia (R.R.C. Kurchatov), Germany (GRS), Belarus (IREP-ASB), and Ukraine (Iyai Nanu). Radiological impact for individuals is usually high and exceeds the annual dose limit established by Ukrainian regulations (20 mSv). However, as a result of the accident scenario analysis, it has been deduced that the basic data combined with very complex processes generated during the accident scenarios contained a large number of uncertainties when used to assess the radiological impact. Basically, those uncertainties have caused organisations involved in these dust release accident scenarios to adopt very conservative assumptions. A tentative assessment of those commonly used conservative assumptions has been conducted and the analysis of a dust release accident has been determined accordingly. The main outcome of this analysis is that, considering the aerodynamic shadow effect during a roof collapse, the radiological impact for individuals is in a range of 0.5 Sv close to the shelter. This value greatly exceeds the annual dose limit established by Ukrainian regulations. Within these conditions, ALARA cost-benefit analysis shows that an EDSS is justified from an economical point of view.
- The analysis of the dust release accident resulting from a large fire accident performed with a plume model has shown that the maximum radiological consequences to the ChNPP workers (~ 17 mSv) do not exceed the maximum annual dose limit. The subsequent ALARA cost-benefit analysis has also concluded that an EDSS is not required in such circumstances.
- The dust release accidents should be managed according to a step-by-step risk management programme. The main activities included in this programme in order to prevent the accident and to limit the radiological impact are:
  - Reinforce the Protection Plan for Personnel in order to protect ChNPP workers in case of dust release accident within the framework of EBP C Task 9. To prevent dust inhalation, the wearing of a full-face mask is required. Considering that the roof collapse accident is a fast process, the protection of the ChNPP workers could only be ensured if the Protection Plan for Personnel is implemented very quickly. However, such a measure will not suppress the surface territory contamination.

- A shelter structures stabilisation and reinforcement programme within the
- framework of EBP A. However, the status of the shelter structures is such that even after this improvement, the probability of shelter collapse will still not be negligible.
- Apply a protective fixative layer covering dust inside the shelter area from the existing DSS or using additional devices within the frame of EBP C Task 10.
- Develop the fire prevention programme in order to decrease the probability and consequences of a fire in the framework of EBP B Task 16.

- Because the above measures described in the risk management programme cannot be considered as a guarantee against the roof collapse, in the framework of Task 11, it is recommended to implement an EDSS. The recommended EDSS will be composed of fast acting devices arranged above and below the perimeter of the shelter roof and will suppress the dust release at the source during emergency conditions generated by a roof collapse.

REFERENCES

[1]   Evaluation Report of Alternatives for an EDSS - Final Report - SIP-03/1/C01 - TN/00111 rev 4 dated September 7, 1999.

[2]   Dust Management, Dust Characterisation Plan and SIP - 03/1/C01 - TN/00101 rev 1 dated March 27, 1999.