Additional information to severe accidents and emergency preparedness on nuclear power plant Temelín

Compiled by State Office for Nuclear Safety, Praha as response to questions raised by the Austrian party during and after the public hearing under item V of the "Melk protocol" in Vienna on 26 June 2001

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Introduction

Most of the questions raised by Austrian representatives during and after the public hearing in Vienna on 26 June 2001 is to high extend specialised and thus exceeding the framework of public hearing covering the concerns of general public towards environmental impact assessment of nuclear power plant Temelín. Moreover, quite a lot of questions are raised repeatedly in spite the comprehensive answers provided to group of Austrian experts on special forum organised by the SÚJB on 4 of April 2001 in Prague.

Nevertheless, already during the public hearing in Vienna on 26 of June 2001 the representatives of the Czech Republic offered to Austrian party to continue the discussion of open questions on the expert level. We would see the solution in creation of common working group of experts of both countries to work out more concerted approach toward the emergency planning and response to radiological accident that could (even with very low probability) have transboundary impact. It could possibly provide more open and effective mode of communication than the exchange of correspondence. The overview we would like to offer this time is not thus structured in the form question-answer. It is a comprehensive packet of information aiming at recapitulation of results achieved in hypothetical severe accident analysis for nuclear power plant Temelín including the assessment of radiological consequences. The other purpose of this text is to provide once more in comprehensive way the description of background and approach applied in the Czech Republic for emergency preparedness and planning in general.

We hope that this overview can serve as an additional tool for our future common work and discussions of experts. We also hope that this information can be another contribution to good relationship of the two neighbours in Central Europe. It can be also the contribution to better awareness of general public in Austria concerning nuclear power plant Temelín and thus help in reducing anxiety and suspect toward the plant and state regulation of the use of nuclear energy in the Czech Republic in general.

Hypothetical severe accident analysis at nuclear power plant Temelín and the assessment of radiological consequences of such events.

During the licensing of the nuclear power plant Temelín the SÚJB kept in mind and carried out together with other aspects of nuclear safety and radiological protection also assessments of radiological consequences of:

- not only design basis accidents (called sometimes also reference accidents)
- but also beyond design basis and severe accidents normally not covered by Safety Analysis Report and other licensing documentation

According the Czech legislation in force applying also the IAEA recommendation SS-99, the following events were reviewed:

- Design Basis Accidents described in Chapter 15 of Pre-operation Safety Analysis Report (POSAR) as made available to Austrian experts by licensee, namely:
  - Steam pipe rupture spectrum (larger).
  - Feed-water pipe break.
  - Seizure of the rotor of the main circulating pump (stalled rotor).
  - Break of the shaft of the main circulating pump.
  - Spectrum of accidents with the shooting in of the control rod cluster.
  - Steam generator tube rupture.
  - LOCA (large rupture).
  - Faults on the inner side of the steam generator.
  - Design basis accidents when handling fuel inside the containment and in spent fuel storage buildings.

  The POSAR is obligatory licensing document submitted by the licensee before the active start-up of the plant. The consent of regulatory authority with POSAR is according the Atomic Act the indispensable prerequisition to first fuel loading permit.
- Beyond Design Basis Accident and Severe Accidents which influence the emergency planning zones extent (size). The consequences of such events could lead to releases into environment and subsequently to radiological impact exceeding the impact of releases occurring as a result of Design Basis Accidents described in POSAR. The results of the analysis of such events were presented by the licensee to regulatory authority outside the scope of standard licensing documentation.

For the emergency planning zone size determination first two maximal hypothetical sequences were analysed as the worst case approximation. Both of them have probability of occurrence of the order 10^{-10}/year (e.g. once in 10 000 000 000 years of plant operation). Further step took into consideration more realistic scenarios and their radiological consequences. According to Government Ordinance No. 11/1999 applicant (licensee – operator of the plant) must provide as an input for SÚJB decision a list of possible radiation accidents with the probability of occurrence for the particular nuclear facility higher or equal 10^{-7}/year (e.g. occurrence higher than once in 10 000 000 years of plant operation) and to evaluate their consequences. These scenarios were for the nuclear power plant Temelín chosen on the basis of PSA level 1and level 2 results. The probability stated in the Government Ordinance No. 11/1999 results in the duty to analyse the radiological consequences for event with probability of occurrence of one order magnitude lower than recommended in IAEA SS – 99 (see Tab.1 – severe accidents). Here is to be stress out that in the Czech Republic naturally the same principles are and will be applied as in the EU countries. According to the screening process results the relevant Czech legislation is practically fully harmonised with radiation protection acquis commmunitaire. The same principles of intervention and countermeasures introduction would be used in case of radiation accident including optimisation. The same intervention levels in term of incurred or averted dose will be applied. Our approach is consistent for instance with the approach described in „Compendium of Measures to reduce radiation exposure following events with not insignificant radiological consequences“ (Federal Republic of Germany, BMU, 2000) and Assessment of the radiological consequences of releases from degraded core accident for a proposed PWR at Hinkley point“ (UK, NRPB, 1988).

Table 1: IAEA (SS/99) requirements for grouping of initiating events by frequency of occurrence and radiological consequences

Probability of occurrence (1/reactor year)	Terminology used	Adequate acceptance criteria
10^{-2} - 1 (expected in the life of the plant)	Anticipated Operational Occurrence	No additional fuel damage
10^{-4} - 10^{-2} (chance greater than 1% over the life of the plant)	Design Basis Accidents	No radiological impact at all or no radiological impact outside exclusion area
10^{-6} - 10^{-4} (chance lower than 1% over the life of the plant)	Beyond Design Basis Accidents	Radiological consequence outside exclusion area within limits
$< 10^{-6}$ (very unlikely to occur)	Severe Accidents	Emergency response required

According to the Czech legislation there is no advance planning of response and countermeasures introduction for events with the probability of occurrence lower than 10^{-7}/year. Nevertheless there is the general emergency response system established in the Czech Republic which has to be able to cope with even less probable disasters with more severe consequences ad hoc depending on the extent, development and actual and predicted consequences. The response to radiation accidents is included into this system. The basic technical and organisational tools for such hypothetical cases are the nation-wide radiation monitoring network and off-site and national emergency response plan (on the level of region and the whole country).

The selection of severe accident scenarios meeting the probabilistic target given in the Government Ordinance 11/1999 (the probability of occurrence for the particular nuclear facility higher or equal 10^{-7}/year) was based on the following criteria:

- sequence with the highest frequencies, *i.e. with the highest probability of occurrence*
- sequence with the highest significance's, *i.e. with the highest source term related to frequency*

It was determined after application of these criteria that mainly two sequences would contribute to the considerable radiological consequences, both meeting high frequency and high significance criteria:

- Major leak from primary to secondary circuit (T9S02)
- Large LOCA (S2S02)

The first sequence is defined as a major leak from primary to secondary circuit when the operator fails to cool down and depressurize the primary circuit. Damage of the core and significant leak of radionuclides will occur after the loss of inventory to cool the core. Similar initiating event together with simultaneous complete loss of electric power was defined by deterministic approach as a sequence V, having probability of occurrence of about three magnitudes lower, i.e. 10^{-10}/year), that T9S02.

The second sequence is defined as large LOCA with the failure of low-pressure emergency make up system. Other emergency systems remain available. Due to insufficient capacity of these systems, there is a severe damage to the core with subsequent damage to reactor vessel. As a consequence of the spray system in operation, the containment is not challenged due to overpressure. Again, similar initiating event with the simultaneous loss of electric power (having again probability of the occurrence 10^{-10}/year), was analysed as the sequence AB for the purpose of determination of the EPZ.

Many sensitivity cases and variations of both above determined scenarios described further were analyzed by MELCOR[1] code, with the aim to study various phenomena influencing Temelin containment behaviour during progression of severe accident (indicated as bold in the followig text):

1. **Large primary to secondary leaks with containment bypass without any operator actions with and without thermal creep of the hot leg piping**

Large opening of d_{ekv} = 40 mm causing the leak from primary to the secondary circuit. The operating personnel fails to intervene and containment bypass occurs. **Thermal creep** of the hot leg was assumed in the first analysed case. In the other case the assumption was made that primary circuit will remain hermetically tight and that the sequence will develop as **a high-pressure scenario**. Following phenomenon was studied in this analysis: **direct containment heating** after failure of the reactor vessel bottom. For both cases the time course of the radionuclides leaking from the containment (source terms) were determined (source terms ST1* and ST1**).

We must stress out here that the operational personnel at nuclear power plant Temelín is carefully trained to have the capacity to operate skilfully and made the correct judgements in unprecedented situations; precisely those which may not be wholly foreseen when the particular facility is designed. The human factor is in our philosophy an advantage much more than the opposite and the important aim of the safety rules applied in the Czech Republic is to preserve the human capacity to intervene positively while deliberately making harmful intervention as difficult as possible. The great attention is paid to the instrumentation available to an operator, to his controls and unambiguous information on which he makes his judgement. The SÚJB regards the scrutiny of operating procedures and contingency planning of all kinds as as much a part of its business as attention to design or to actual operations record; and the need to specify procedures and follow them is a part of the licensing conditions. Procedures are regularly reviewed in the light of any event that occur. Training and practice support procedures. Therefore the assumption that the operators completely fail to intervene and introduce any measures to prevent the core degradation is totally unrealistic. Initiation events are manageable without the fuel integrity damage using the symptom based emergency operation procedures, regularly practised by the operators even at full scope simulator. Operator who fails to prove ability to cope with initiating event properly is not licensed to work in shift. The basic aim of EOP is to end the initiation event with design basis accident in the worst case. The design basis accident can not have the detrimental consequences in neighbouring countries (as described and documented in POSAR).

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[1] A number of calculation codes were used upon assessment of the dispersion characteristics of radionuclides and their radiological consequences (especially for the needs of comparison of results), from relatively simple codes provided by IAEA such as InterRASS /described in IAEA documentation TECDOC-955) to RTARC, HAVAR (standardised by SÚJB), for several calculations the COSYMA code was used as well. Evaluation of source term was made by means of computer code STCP (Source Term Code Package) provided by IAEA to the member countries and modified for VVER reactors and used especially at VUJE, Source Term Analysis was in Nuclear Research Institute Řež conducted by means of MELCOR 1.8.3 program.

2. Large LOCA on the PRZR surge line without ECCS

Opening (d_{ekv} = 200 mm) on the PRZR surge line as the initiating event was modelled, causing large LOCA to the containment. Further it was conservatively assumed, that all active emergency core-cooling systems are not available from the beginning of the event. In one case the permanent loss of ECCS was assumed. The source term ST 2 corresponds with this scenario leading to the severe core damage. Spray system in operation was modelled enabling to analyse the effects of hydrogen combustion and deflagration. Another analysed case assumed restoration of one high-pressure emergency core-cooling pump to proof that core integrity can be maintained was performed also. Following phenomena were studied with respect to the containment behaviour in the first analysed case: **hydrogen deflagration in containment during severe accident progression and molten core concrete interaction** (MCCI) after the failure of the reactor vessel bottom with the corium pool surface of approx. 100 m^2.

As in previous case the operating personnel is systematically prepared to cope with this initiating event. Moreover the probability of having no mean for compensation of loss of coolant is extremely low (there are 12 independent pumps available).

3. CTMT integrity challenge after hydrogen detonation during LOCA without ECCS

The same initiating event and assumptions as for the previous scenario but the function of catalytic recombiners and hydrogen deflagration was not considered. Hydrogen deflagration can be prevented if sprays are not in operation such causing sufficient humidity inside the containment which inert the atmosphere. Hydrogen accumulation in the containment was modeled and when the concentration exceeded the value for detonation (in the late phase of sequence progression, the failure of accident management measures (improper spraying) was assumed, causing a detonation wave with the supersonic velocity in the containment. Two source terms ST 3* and ST 3** corresponds with analysed cases both considering breach of the containment integrity after hydrogen detonation. So, in this case the phenomenon of **hydrogen detonation** with respect to the containment challenge was studied.
The hydrogen detonation can be easily excluded by rigorous adherence to severe accident management measures. Only complete failure of operational personnel, which is, however, trained for coping with such situations, could lead to conditions enabling the hydrogen detonation in the containment. The unreality of such an assumption is more than evident.

4. Station blackout with permanent loss of all active safety systems

Analysed case was commenced by station blackout (no AC power available) and scenario was further analysed as a high pressure one. It was selected because the selection criteria (probability and significance) were met for this scenario also. Following phenomena were studied in this case: **containment slow overpressure** due to the loss of heat sink, **direct containment heating** after the failure of the reactor vessel bottom, **molten core concrete interaction** in the reactor cavity and in vertical neutron measurement channels with the corium pool surface of approx. 25 m^2. Source terms ST 4 corresponds with this analysed case.

When comparing the probability of occurrence of station blackout for nuclear power plant Temelín with western power plants the results are favourable for Temelín because there are more independent AC sources available.

5. **Large LOCA on PRZR surge line (equiv. diam. 200 mm) with ECCS reinitiated after reactor vessel failure**

The progress of molten core concrete interaction when the water layer covers the corium pool was studied in this case.
The event was analysed in principle only for confirmation of possibility to stop the molten core penetration through concrete of the containment basement plate by flooding the melt in the late phase of severe accident progression. The analysis results in source term ST5.

From the results of submitted analyses it can be concluded:

- radiological consequences of events analysed in POSAR (publicly available) will not influence neighbouring countries
- analysed beyond design basis and severe accidents scenarios (AB and V sequences as well as other sequences meeting probabilistic target given in the Government Ordinance 11/1999 (the probability of occurrence for the particular nuclear facility higher or equal 10^{-7}/year) would lead to exceeding of selected dose levels (intervention levels) at distances summarised in Tab. 2. The worst case – conservative assumption of weather category F was used for dispersion model.

Table 2: Results of the calculation of radiological consequences for selected accidents

Stability class F						
Sequence	2 days			7 days		
	Intervention Level			Intervention Level		
	5 mSv	10 mSv	50 mSv	50 mSv	100 mSv	500 mSv
AB_01	8 km	5 km	<1 km	1 km	<1 km	<1 km
AB_02	14 km	8 km	2 km	2 km	1 km	<1 km
AB_03	18 km	11 km	3 km	4 km	2 km	<1 km
AB_04	16 km	9 km	1 km	2 km	<1 km	<1 km
ST_V	>40 km	>40 km	<1 km	<1 km	<1 km	<1 km
ST 1*	35 km	23 km	2 km	3 km	2 km	2 km
ST 1**	35 km	17 km	5 km	5 km	3 km	2 km
ST 2	<1 km	<1 km	<1 km	<1 km	<1 km	<1 km
ST 3*	27 km	19 km	2 km	2 km	2 km	<1 km
ST 3**	21 km	14 km	2 km	3 km	2 km	<1 km
ST 4	<1 km	<1 km	<1 km	<1 km	<1 km	<1 km
ST 5	5 km	2 km	<1 km	<1 km	<1 km	<1 km

Results in Tab. 2 are relevant for urgent (short term) countermeasures (sheltering, iodine prophylaxis – 2 days and evacuation – 7 days). The countermeasures need not be introduced at distances at which the doses does not exceed upper bounds of intervention levels interval, i.e. at distances where the dose is lower than 50 mSv for sheltering and iodine prophylaxis and lower than 500 mSv for evacuation. For all urgent countermeasures the upper bound of intervention levels interval is not exceeded at distances greater than 5 km from the plant. It dos not imply necessarily the countermeasures can not be introduced for lower values of intervention levels. In any case, however, it is not justified to introduce countermeasures for doses below the lower bound of intervention levels interval presented in Decree 184/1999

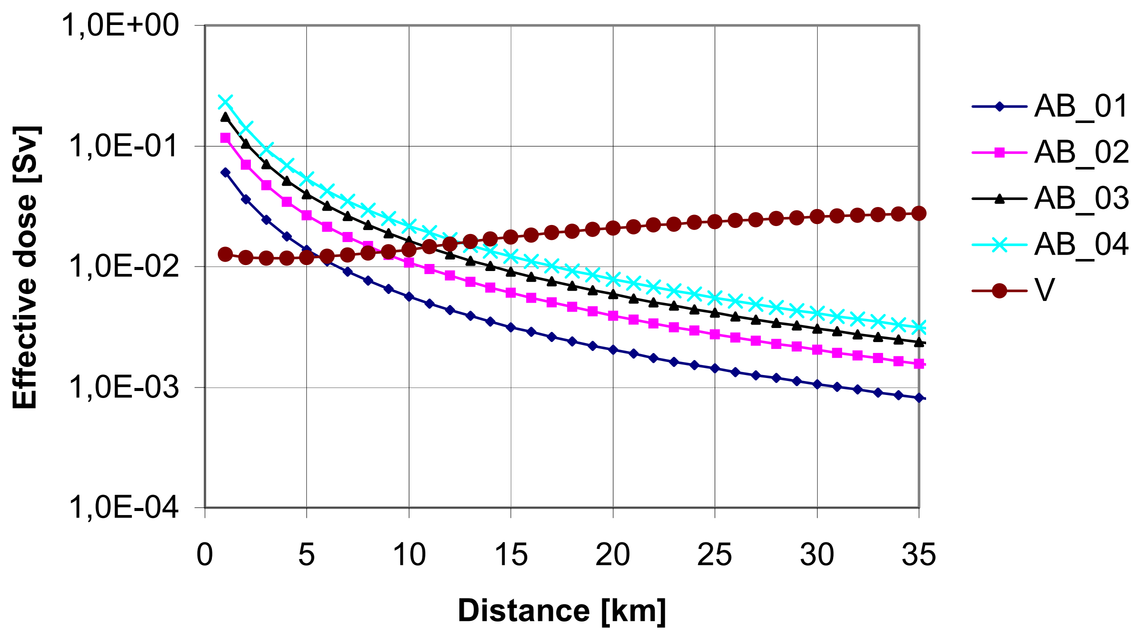
Coll., i.e. doses lower than 5 mSv for sheltering and iodine prophylaxis and 50 mSv for evacuation. From Tab. 2 it is obvious that these values will not be exceeded at the distance greater than 35 km from the plant (with the exception of V sequence) for sheltering and iodine prophylaxis and 5 km for evacuation. Thus for the sequences meeting above mentioned probabilistic criteria and requirements of the Czech legislation the radiological consequences requiring introduction of urgent countermeasures will not exceed the border of the Czech Republic. It should be stressed again that the principle of optimisation of intervention is strictly followed according the international practice and the Czech legislation requirements. There is stated in Decree 184/1999 Coll. the following:

> "The reasonable achievable level of radiation protection is possible to prove by the procedure during which there are compared the costs for the alternative measures for the upgrade of radiation protection (e.g. by the construction of additional barriers) with the financial assessment of expected reduction of exposure (further only “the contribution of measure”). The reasonably achievable level of radiation protection is considered as proved and the measures shall not be carried on, as far as costs would be higher than the contribution of measure. The contributions of measure is numerically expressed at this procedure so, that the reduction of collective effective dose in the case of exposed collective of workers with sources or in the case of population is multiplied by the coefficient 5 million Czech Crown/Sv for the exposure during the radiation accidents."

The same or similar models and approaches would be used for accident scenarios with the radiological consequences requiring long term countermeasures (e.g. monitoring and regulation of foodchain) on the Austrian territory. To question now the amount of compensation caused by hypothetical accident of a Czech nuclear power plant in Austria is not relevant. All over the Europe as well as in other developed countries the approach based on international conventions is applied (The Vienna Convention on Civil Liability for Nuclear Damage and the Joint Protocol Relating to the Application of the Vienna and Paris Conventions, decreed under No. 133/1994 Coll.) The Czech Republic is party to these conventions. The amount of compensation in case of such an accident really requiring it would be assessed in concordance with above mentioned conventions and on the basis of real consequences of occurred event. This would have to be an ad hoc assessment evidently.

The course of effective dose in 7 days along the distance for the most important sequences is again for the worst case of weather category F is for illustration shown in Figure 1. Also from this figure it follows, that for the distances from the plant greater than 35 km the dose is lower than 5 mSv with the exception of V sequence.

Fig.1: Dose - distance dependency, stability class F, 7 days



For all sequences taken into consideration naturally the effective dose values were calculated not only for the 7 days but also for 30 days for one year and for 50 years. The results of calculation for the worst case (V sequence, weather category F) for 7 days and for one year and the contributions of individual exposition paths are summarised in Tab. 3 up to the 80 km.

Table 3a: Effective dose E (Sv); Sequence V, 7 days, weather Cat. F

X [km]	Plume	Deposit	Inhalation	Total
1.0	1.1 - 02	3.4 - 03	1.8 - 03	1.7 - 02
10.0	1.5 - 02	1.2 - 03	6.2 - 04	1.7 - 02
20.0	2.4 - 02	9.5 - 04	4.6 - 04	2.5 - 02
40.0	3.2 -02	8.6 - 04	4.1 - 04	3.3 - 02
60.0	2.8 -02	8.2 - 04	4.0 - 40	2.9 - 02
80.0	2.4 - 02	8.1 -04	3.9 -04	2.5 - 02

Table 3b: Effective dose E (Sv); Sequence V, 1 year, weather Cat. F

X [km]	Plume	Deposit	Inhalation	Total
1.0	1.1 - 02	2.9 - 02	2.3 - 03	4.2 - 02
10.0	1.5 - 02	1.1 - 02	7.3 - 04	2.7 - 02
20.0	2.4 - 02	8.5 - 03	5.3 - 04	3.3 - 02
40.0	3.2 -02	7.9 - 03	4.8 - 04	4.0 - 02
60.0	2.8 -02	7.7 - 03	4.5 - 40	3.6 - 02
80.0	2.4 - 02	7.7 - 03	4.5 -04	3.2 - 02

From the Tab.3 it follows:

- the doses change quite slightly with the distance. This is caused by the known conservatism in weather category and namely by the very conservative accident and scenario. In scenario extremely high thermal energy in the release must be taken into account leading to very high plume rise (above the mixing layer). It also assumes that radioactive substances will spread practically without dispersion. This unrealistic assumption leads to extremely narrow plume of radioactive substances irradiating very limited area bellow it. Much more probable is dispersion of radioactive substances from the plume leading to substantial decrease of dose with distance. When rain occurs there will be greater contribution from deposit on ground surface, but the dose will decrease with the distance again very substantially and even faster.
- Beyond the conservative approach in sequence selection, parameters of dispersion selection (worst weather category) there is another conservatism in technology parameters of the sequences. It can be illustrated namely on V sequence which is probably the most interesting one from the point of view of radiological consequences. The sequence tree is based on the assumption that any subsequent event in the tree will make the situation worse in principle in spite of means and measures available for prevention and mitigation. These assumptions based on complete failure of operational personnel to carry out any measures together with the simultaneous occurrence of total station blackout are maximally unrealistic. In direct combination with identified initiation event is the probability of occurrence of V sequence 10^{-10}/year.
- Comparison of exposure paths for 7 days and one year for V sequence indorse that more than 70% of total dose at the distances greater than 10 km comes from the plume. The effective dose in Z days by far does not reach 50 mSv i.e. lower bound of intervention level interval for evacuation and at the same time the upper bound for intervention levels interval for sheltering and iodine prophylaxis. Taking into account the above mentioned highly improbable parameters of release and dispersion (narrow non dispersing strip of radioactive substances) the neither the sheltering nor the iodine prophylaxis will be practically justified.
- One-year doses for the V sequence do not exceed 50 mSv either. So in case of the occurrence of the V sequence the only justified measure on the Austrian territory would probably be monitoring in delineated areas with lower probability of food regulation in limited parts of territory.

Conclusion

In conclusion we would like to propose again that all questions raised in the letter of H.E. minister Wilhelm Molterer to H.E. minister Jan Kavan dated from 20 July 2001 as well as other aspects of severe accidents and emergency planning and response in general can be discussed in more details and in more effective way during bilateral meetings of the Czech and Austrian experts. There is already preliminary agreement on proposal to interconnect more closely radiation monitoring networks, both sides agreed also on the need to tune up further the notification and information channels and procedures for case of radiation accident. It is important to mention also that that the Long Term Protection Zone (LPZ) is not set up in the Czech Republic. Our approach is based on the assumption that long term protective measures would be introduced only after the evaluation the monitoring results on the territory influenced (contaminated) by the radionuclides from occurred release (with strict application of optimisation principle). The Czech Republic similarly to Austria has in operation very sophisticated radiation monitoring network able to provide all necessary measurements. This network was described in detail during the workshop on 4 April 2001. This is the main reason for not setting up the LPZ. Thus the question concerning the size of LPZ on Austrian territory does not seem relevant in this context. Long term countermeasures would be according our philosophy introduced on the territory really requiring them according the actual situation. Known radioactive substances dispersion principles cannot of course exclude (and it was proven by Chernobyl experience) that the substantial contamination would occur at quite long distances from the source. The meteorological conditions play the main role here. For Temelín accident sequences analysed, however, even the worst meteorological conditions would not lead to levels of contamination preventing timely introduction (after evaluation of course and extent of the event and monitoring results) of necessary countermeasures (regulation of food chain). In this hypothetical situation the solution is (and basic steps in this direction were already taken):

- to set up and maintain the system of extensive mutual information exchange concerning the plant status
- interconnect the early warning systems of both countries
- based on expert discussions gradually build up the confidence concerning the reliability of emergency planning and response organisation and system.

However, we cannot achieve the positive results by insisting on complete elimination of all hypothetical accidents with consequences influencing Austrian territory as the necessary condition of nuclear power plant Temelín start up. This cannot be achieved at any power plant in any country. We can only repeat that severe accidents analysed for nuclear power plant Temelín in accordance with the Czech legislation i.e. meeting the probabilistic target given in the Government Ordinance 11/1999 (the probability of occurrence for the particular nuclear facility higher or equal 10^{-7}/year) would not require urgent countermeasures on the Austrian territory. We never put into question the results of Austrian experts, we only said that the presented results concerning the contamination of territory by ^{137}Cs seem to indorse our opinion on non-necessity of urgent countermeasures introduction on Austrian territory. Austrian experts are very well aware that for more thorough comparison of model calculation results the detailed exercise is needed with very detailed identical scenario and input parameters. We are willing to prepare such a common exercise if it is of interest for our Austrian colleagues.