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EVALUATION OF CONSEQUENCES AND RISKS IN SLOVENIA

Janez Sušnik
"Jožef Stefan" Institute, Reactor Engineering Division
Jamova 39, 1111 Ljubljana, Slovenia

Abstract

The paper describes the evaluation of nuclear power plant accident consequences and risks using probabilistic safety codes during the last 12 years at the J.Stefan Institute. They cover classic individual and population risk studies due to assumed potential severe accident scenarios, prediction and estimation of Chernobyl accident consequences, the optimization of emergency countermeasures at the Krško site, where the 632 MWe Westinghouse PWR NPP went into commercial operation on January 1983, and the ranking of population risk within the public debate in connection with the civil initiative to close the NPP Krško.

We report on the initial use of the CRAC2 code in 1984 and later, when it was first applied for the study of population risk in the area of the second planned Slovenian-Croatian NPP for the Prevlaka site. The study was completed a few weeks before the Chernobyl accident in April 1986. Risk evaluation was also included in the analysis of nuclear safety at the NPP Krško during the war for Slovenia's independence in 1991.

We report on the (CRAC2) analyses of the Chernobyl accident: on initial estimation of the maximal potentially expected consequences in Slovenia, on the effect of the radioactive cloud rise on the consequences relatively close to the NPP; on the further research after the detailed information on the radioactivity release and on the air masses movement were published; then the cloud activity which moved towards Slovenia was assessed and the expected consequences along its path were calculated. As the calculated integral individual exposure to the I^{131} inhalation and the ground Cs^{137} contamination matched with the measurements in Ljubljana and with the UNSCEAR 1988 data, our reliance on the CRAC2 code and on its ancestors is high.

We report on the analyses, performed by the CRAC2 code and since 1993 also by the PC COSYMA code, related to the countermeasure effects. The consequences studied were extended to late health effects. We analyzed the relation of the evacuation scenario selection and the magnitude and extent of the accident consequences with the aim to prepare the optimal countermeasure strategies and scenarios. The studies also contributed the preliminary data for the comparison of existing risks.

Finally we report on the 1996 results on the recalculation of countermeasure effects and on the effect of the recommended post-accidental large scale stable iodine delivery to the population, using the new 2.01 error free version of the PC COSYMA code.

1. INTRODUCTION

Some 25 years ago we were faced with a need to quantify the NPP safety level, i.e. the efficiency and the reliability of engineered safeguards. We started to develop our own software, for verification of reactor containment behaviour in the loss of coolant accidents, which enabled us to assess the proposed designs in bids for the present 632 MW_e PWR NPP at the Krško site in Slovenia. In this process developed "reliability" codes, mostly based on Vesely's kinetic fault tree theory, enabled us to analyze and quantify the NPP safety systems inter dependencies.

Risk Studies. Later, after 1984, with the CRAC2 code [1], we were able to perform risk studies. The first CRAC2 application was devoted to the individual and population risk assessment in the region of the 1000 MWe nuclear power plant of the Krško type, planned for the Prevlaka site [2]. The study was completed a few weeks before the Chernobyl accident in April 1986. Risk evaluation was also included in the analysis of nuclear safety at the NPP Krško during the war for Slovenia's independence [3].

During NPP operation the dominant risk comes from potential severe accidents with serious consequences though their probability is small. This was shown in the RSS [1] and also confirmed in our risk study for the planned NPP on the Prevlaka site [2].

Activities related to the Chernobyl catastrophic accident. After the Chernobyl accident we quickly responded by conservative calculation of potential doses for the acute phase after the accident. We assumed that release of radioactive material was as in the PWR-1A scenario. We also performed a study of the consequences as a function of the radioactive cloud rise at the reactor site. After publication of the UNSCEAR 1988 report we estimated the fraction of the radioactive material that entered the cloud which travelled towards Slovenia and a comparison of the UNSCEAR and our values of the calculated and of the measured contamination was performed. The agreement was surprisingly good. This confirmed the credibility of the consequence predictions using the CRAC2 code

The evacuation scenario influence on post-accidental consequences. In case of a severe accident in a Nuclear Power Plant (NPP), the ultimate measure for lowering public risk are planned emergency procedures. The possibility of their enforcement, when the severe accident is already in progress, depends on the detailed advanced studies and preparations. Evaluation of sets of detailed evacuation scenarios are necessary to prepare the optimal strategies and scenarios.

The situation in the region of the Nuclear Power Plant Krško was considered. The calculations were initially performed by the CRAC2 code. Several health effects were considered. In the conclusion we recommended "the living emergency preparedness" to implement the optimal evacuation scenarios (for different prevailing situations) to keep the population risk level low.

However, to optimize the evacuation, very detailed studies have to be performed in advance. At present, the available software includes the PC-COSYMA code [4], which we obtained thanks to the CEC. First, evaluations of evacuation scenarios were performed with the help of the CRAC2 code [5, 6]. Now, when it became possible to independently evaluate accident consequences we started to perform risk calculations using also the PC-COSYMA code package [7].

Our Public Information activities are related to the Initiatives to close the NPP Krško. On the basis of the performed severe accident studies, we were able to present to the public the information on the expected long term consequences and put it in the perspective of the number of road traffic accidents we experience in Slovenia annually.

Large Scale Stable Iodine Tablets Application. The reported post Chernobyl status of health effects, [17], stimulated us in performing a study on the post accident effect of large scale stable iodine intake.

2. EXPERIENCE

2.1 Risk Study for the NPP at the Prevlaka Site

In [2] the expected additional population risk due to the 1000 MWe Krško type NPP operation was obtained, using the CRAC2 code and the WASH-1400 Reactor Safety Study. The Prevlaka site-specific meteorology data and population distribution data were incorporated. The plant risk profile included the risk of early fatality, risk of latent cancer fatalities, and the whole body effective equivalent dose. No credit was taken for the population evacuation. The analysis covered the population within the 80 km radius. Figures 1 and 2 show some of the risk results.

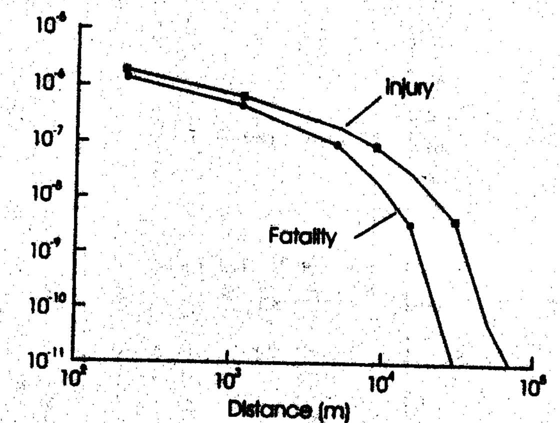


Figure 1: Individual risk per year due to nuclear power plant accidents; no evacuation.

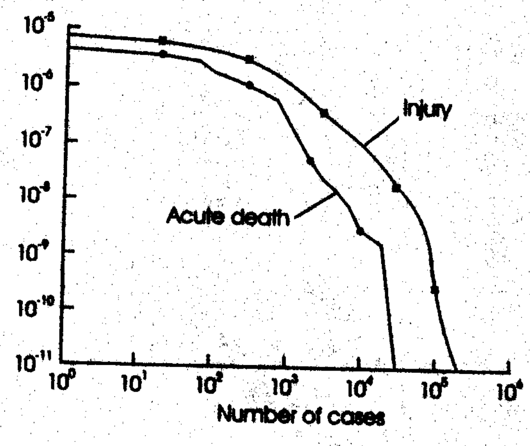


Figure 2: Population risk per year from the Prevlaka nuclear power plant; no evacuation.

2.2 Radiological Consequences of the Chernobyl Accident

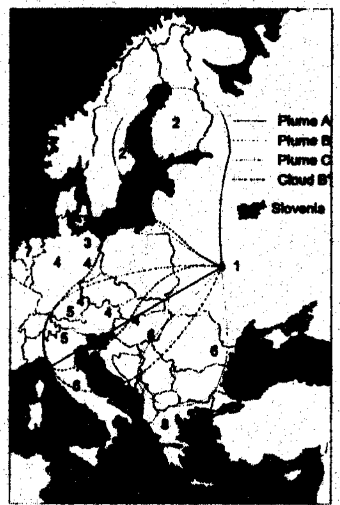
The Chernobyl accident started on April 26, 1986, approximately 1300 km from Slovenia. In [8] we presented our efforts to estimate the status and the potential consequences immediately after the accident, during the 1986, and after the UNSCEAR report in 1988, when it became possible to determine more precisely the radioactive source in the cloud which passed our country, to estimate the expected radiological consequences, to compare predicted values and measured data, to assess the suitability of the tools we used and the effectiveness of the countermeasures. See Figures 3 and 4 [8]. The main emphasis was put on the dominant radiological contaminants iodine-131 and cesium-137.

Initially we obtained an upper limit estimate of the potential consequences for people far away from the destroyed 1000 MW unit. Because the source term and other relevant data were not known, we had to make several assumptions: the worst WASH-1400 study accidental scenario PWR-1A and the wind direction towards Slovenia with a constant velocity of $7 ms^{-1}$ at the C category for the atmospheric stability. According to national weather forecasts these assumptions were realistic, after the wind changed its direction from blowing northwest to southwest. We assumed that Slovenia was passed by the cloud which had taken its radioactive material for 3 days, from the 2[nd] to the 5[th] day after the accident and release initiation.

Doses, contamination and the integral exposure to Iodine-131 in the air. We compared the UNSCEAR and computer predicted consequences with the post accidental measurements and the respective calculations performed at the J.Stefan Institute, especially the contributions of the radiologically dominant isotopes I-131 and Cs-137, the I-131 inhalation dose and the Cs-137 ground contamination, and the rain washout factors [9-10].

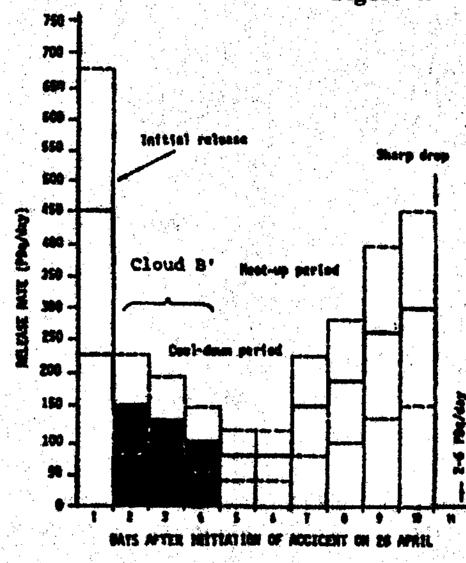
Comparison of the measured integral I-131 inhalation exposure with the UNSCEAR data and the CRAC2 code predicted values, where the realistic source term for the cloud contamination was used, showed that the values match surprisingly well, see **Table 1**, [8]. On this basis we concluded that the CRAC2 code is adequate for further studies.

Figure 3:



The plumes behaviour and the reported initial contaminated air arrival times, [8].

Figure 4:



Daily release rate to the atmosphere, excluding noble gases,[8].

The numbers 1 to 8 indicate initial arrival times:
1 (26 April), 2 (27 April), 3 (28 April), 4 (29 April),
5 (30 April), 6 (1 May), 7 (2 May), 8 (3 May).

Table 1: Integral exposure to contaminated air and the ratios of the (CRAC2) calculated to the (IJS) measured and to the UNSCEAR given concentration for Slovenia.

\# [10], Tab. III.3.1, 30.4.-9.5.
* CRAC2 with the realistic source term
x An estimation based on Slovenian newspaper reports.

Isotope	Exposure			Ratio		
	CRAC2	Measurem.	UNSCEAR (SLO)	CRAC2/Measure.	CRAC2/UNSCEAR	Average
	Bq. days/(cubic meter)					
Cs-137	8.1 *	9.03 #	7.4	0.90	1.094	0.995
I-131	84.6 *	77.5 # 64-101 X	72	1.09 1.39-0.84	1.175	0.983

The influence of potential countermeasures. Finally we estimated the potential dose reductions after introducing certain countermeasures: to increase the time of staying indoors from 80% to 90% and to use the special diet (no fresh milk, no leafy vegetable during the first month after the accident). The doses are given for a typical adult and for a 10 year old child, [10-11]. The results for the first year after the accident, which dominates in the total committed dose, are presented in the **Table 2.**

Table 2. The contributions to the individual May 1986 and 1986 effective equivalent doses for adults and 10 years old children due to Chernobyl accident, in microsieverts (μSv), [11]. *Values in brackets represent potential doses where certain countermeasures were introduced during the first month.*

Pathway	Effective Equivalent Doses (μSv)			
	May 1986		Year 1986	
	Adult	Child	Adult	Child
Inhalation	30 (30)	48 (48)	30 (30)	48 (48)
Ground irradiation	93 (49)	93 (49)	254 (210)	254 (210)
Ingestion	336 (94)	588 (134)	468 (226)	796 (342)
Total dose	459 (173)	729 (231)	752 (466)	1098 (600)

2.3 Emergency Contermeasures and the Population Consequences and Risk

In planning the mitigation of emergency situations the corresponding dose evaluations are possible and they show the directions for the optimization of the evacuation scenarios.

An important group of environmental parameters which influence the magnitude of accident consequences are the wind speed and direction, atmospheric stability, rainfall, population distribution, daily population migration, time of a day, season of a year, etc. There is another group of several "dependent" parameters we can influence: the area, the angle width and the distance from the damaged NPP of the complete population evacuation, the evacuation speed, the time delay before starting the evacuation after the evacuation alarm has been announced, i.e. the planned evacuation procedures.

Use of the CRAC2 code [5,6]. The main intention was to illustrate the selected evacuation scenario effects. The calculation was limited to the following early consequences: deaths, injuries, total population dose. We intentionally assumed the worst possible accident, i.e. the PWR-1A scenario which represents a real catastrophe, so that the effects of certain accident mitigating measures are more transparent.

Population distribution was taken from the Krško NPP FSAR, for the year 1991 [12]. The wind was assumed to blow into the WNW sector, and for the atmosphere stability we assumed the Pasquill C category. The emergency response assumptions in the presented preliminary calculations for the Krško NPP, (Case 141), were:

The population located within 8 km of the site is evacuated radially at a speed of 4.47 ms^{-1}. The population within an angle of +/- 45 degrees along the wind direction is

evacuated within 16 km of the site. The evacuation begins one hour after the warning time and once the evacuees reach a radial distance of 16 km they are assumed not to receive additional dose. People who are not evacuated are shielded up to 32 km from the NPP.
In 1994 we reported on our initial use of the PC COSYMA code [7]. The short term post-accidental period (acute phase) was assumed to lasts for 7 days. The general conclusions on the emergency countermeasures presented in the previous analyses [8,9,10] were confirmed in this analysis as well. **Figure R2J** at the end is taken from this year analyses **[15]** and is an example of a COSYMA calculationfor a post accident relocation and resettlement and shows how complex this countermeasure can be.

2.4 Public Information and the Initiatives to close the NPP Krško

In Slovenia two serious initiatives were raised in a national referendum to abandon the nuclear energy option and close the NPP Krško at the latest in 10 years (on October 1995 the group of 37 members of the Slovenian Parliament from almost all parties, except Slovenian Christian Democrats, and then for the 10^{th} anniversary of the Chernobyl accident in 1996, by the ex green party leader).

Following the public debate and presentations of the professionals and experts in nuclear energy, economic and environmental problems, the first initiative was dropped and the second has not obtained the required support of 40 000 registered voters (approximately 2000 votes were collected). The opponents claimed that the NPP Krško is threatening the whole Slovenian nation (2 million people).

On the basis of the severe accident studies performed, that is with the use of the CRAC2 and especially the PC COSYMA code, we were able to present to the public the information on the expected long term consequences and put it into perspective. On the basis of the PC COSYMA results, from the references [13],[14], and ***Tables 1 and 4 from [15]***, we gathered information shown in **Table 3**. We can see that due to 50-year irradiation after severe NPP accident, the expected consequences (number of deaths and number of seriously injured persons) would be comparable to consequences of accidents or suicides, or to the number of road traffic accidents we experience in Slovenia. The road traffic accidents involve approximately 494 deaths and 2622 seriously injured persons per year, for the period of 1990-94 [16], (Statistical Yearbook of the Republic of Slovenia 1995, pp. 89 and 336).

2.5 Large Scale Stable Iodine Tablets Application

The reported post Chernobyl status of health effects, [17], stimulated us in performing a study on the effect of large scale stable iodine intake in the post-accidental phase. The incidence in childhood thyroid cancer has markedly increased in the areas surrounding the site of Chernobyl NPP, especially in the initial path of the radioactive plume. Children, in particular, received substantial doses to the thyroid gland. The total number of cases reported in Ukraine, Russion Federation and Belarus to the end of 1994 is 474.
The World Health Organization has advised European member states that stable iodine should be available for children, even at distances of several hundreds of kilometres from nuclear facilities.

Our study [15] assumed stable iodine tablets ingestion by all the people whose thyroid inhalation dose would exceed default COSYMA value (0.200 Sv during 50 years).
Some of the results are included in **Table 3**. It is seen that the effect on the population dose, *(man sieverts)* is obvious. The difference between zero stable iodine intake cases and cases with both stable iodine countermeasures is 20-35% (1.7E+3 man Sv). Scenarios (cases) from the **Table 3** show the calculated differences for the LATE HEALTH EFFECTS. For the iodine countermeasure cases we calculated: 41-67 % smaller total morbidity incidence (615-1616 cases less), and 15-57 % smaller total mortality numbers (58 to 348 less long term fatalities).

The preliminary results of a study like this support the WHO recommendation on large scale ingestion of stable iodine tablets, preferably to the young population below 15 years, and up to long distances from the nuclear accident.

4. CONCLUSION

Several examples of the application of the probabilistic consequence codes the CRAC2 and the PC COSYMA code, show a vast versatility of their potential application in evaluation of severe accident consequences as well as for risk assessment, for several very detailed analyses related to the Chernobyl accident and in the process of looking for the best emergency measures in the region of the operating NPP.

It is very important that the "Jožef Stefan" Institute, as a national research organization, is capable of preparing independent assessments on the nuclear safety issues, including on the severe nuclear power plant accident consequences and risks. The probabilistic consequence codes are beautiful stones in a mosaic that enable us to see the nuclear picture more clearly.

Nuclear power plant safety is of common concern. Our experience with the computer codes CRAC2 and PC COSYMA shows how important is the international cooperation and openess of institutions, and how important the friends are. It was Nobel who said that dissemination of knowledge is dissemination of property.

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Table 3: Grouping of countermeasure cases studied and some corresponding HEALTH EFFECTS. ***(by PC Cosyma v. 2.01)***

Case	COUNTERMEASURES				HEALTH EFFECTS				Mean collective dose to 50 years
	EVACUATION		SHELTERING		EARLY		LATE		
	Automatic after initial sheltering	Conditional on dose level	On dose level	Against late effects without evacuation	Mortality	Incidence	Mortality	Incidence	10^3 *man Sv*
AJ	No	No	No	No	2.5	48	490	1844	9.183
A	No	No	No	No	2.5	48	615	3093	12.71
CJ	Yes [2]	No	No	No	0	0	477	1783	8.923
C	Yes [2]	No	No	No	0	0	601	3025	12.43
EJ [1]	No	No	No	Yes	0	9	480	1828	8.974
E	No	No	No	Yes	0	9	615	3093	12.71
UrJ [1]	Yes [3]	Yes [4h]	Yes	No	0	0	464	961	8.604
Ur	Yes [3]	Yes [4h]	Yes	No	0	0	626	2576	13.17
R4rJ	No	Yes [4h]	Yes	No	0.0	1	464	961	8.602
R4r	No	Yes [4h]	Yes	No	0.0	1	626	2580	13.18
R3rJ [1]	No	Yes [3h]	Yes	No	0	0	344	730	6.596
R3r	No	Yes [3h]	Yes	No	0	0	427	1564	8.952
R1rJ [1]	No	Yes [1h]	Yes	No	0	0	329	748	6.466
R1r	No	Yes [1h]	Yes	No	0	0	387	1334	8.119
R2rJ	No	Yes [2h]	Yes	No	0	0	313	672	6.100
R2r	No	Yes [2h]	Yes	No	0	0	374	1285	7.838

Legend and comments:

Countermeasures accompany *2 hrs* initial delay. Sheltering on dose level: *24 hrs*.
Conditional evacuation on dose level: sheltering duration as stated.

****J cases: intake of stable iodine tablets included:**
geometric (up to 3.2 km, resp. 1.6 km in [1] cases) *and on dose.*

****r cases: relocation and resettlement option included.**

[2,3] **Evacuation size area:** [2] $r = 3.2$ km, $R = 8.0$ km, $\alpha = 60^0$;
[3] $r = 3.2$ km, $R = 8.0$ km, $\alpha = 90^0$.

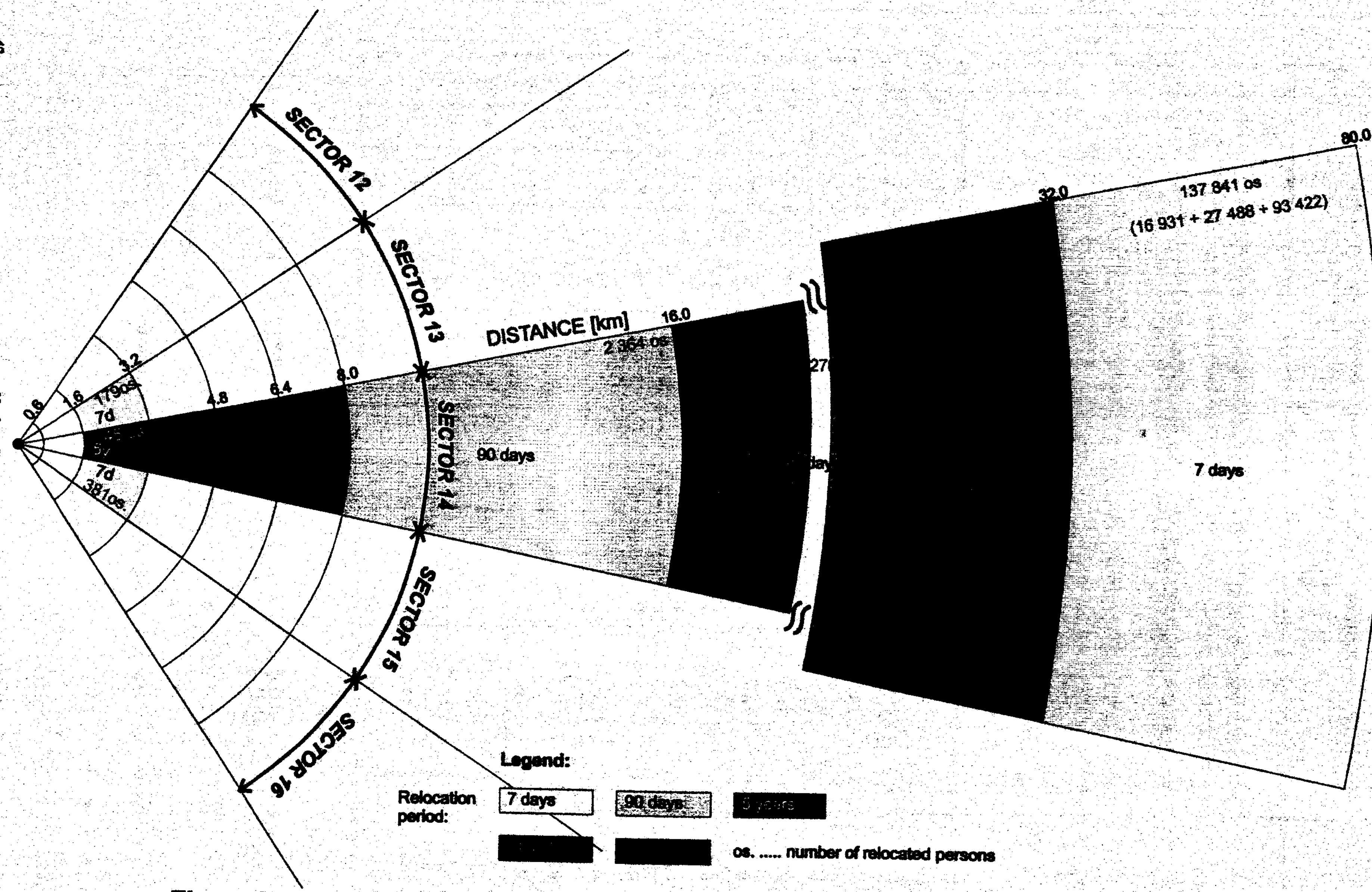

Figure R2rJ: PC COSYMA code suggested relocation countermeasure, R2rJ case.