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Comparison of MACCS Users Calculations for the International Comparison Exercise on Probabilistic Accident Consequence Assessment Codes

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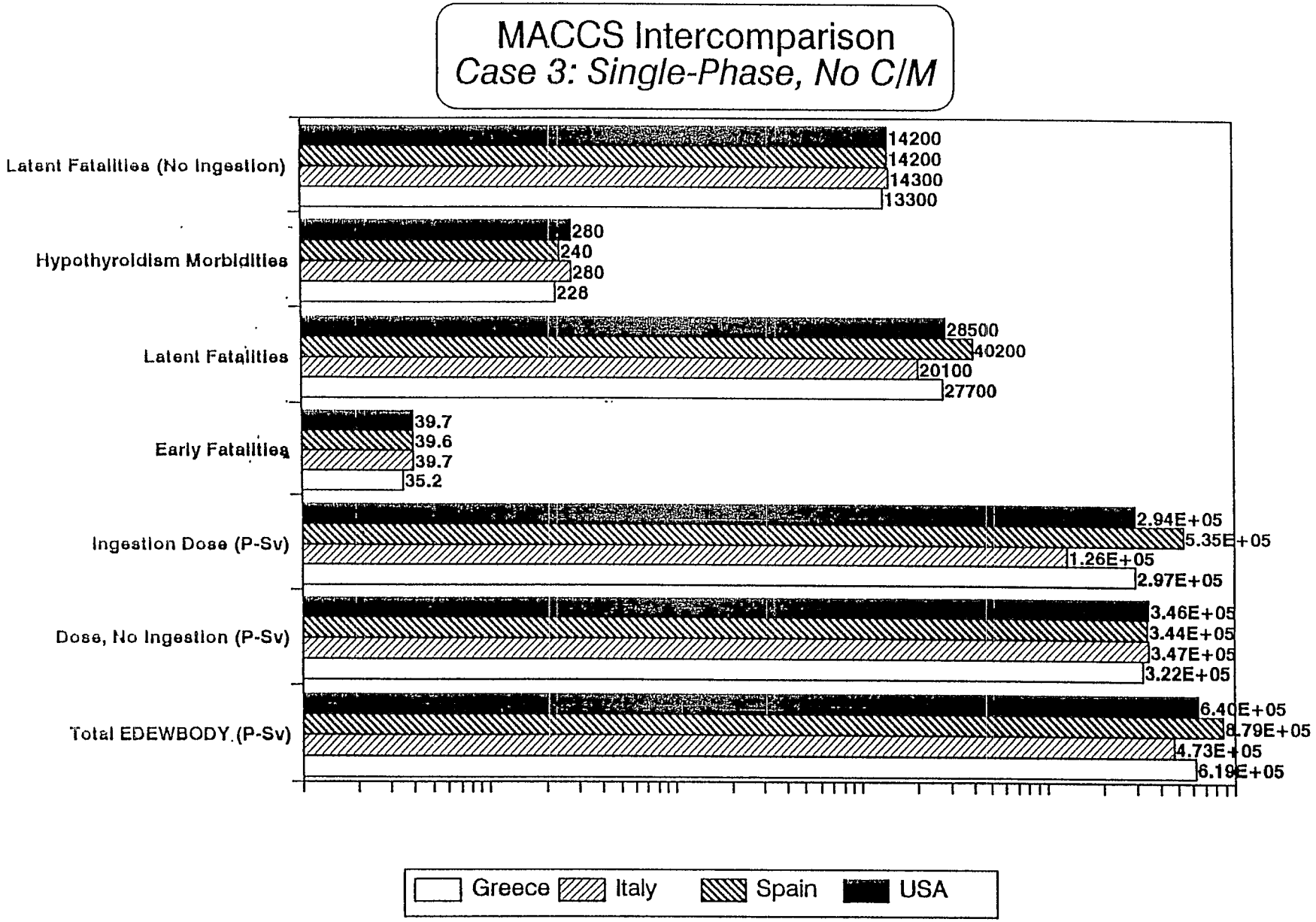


Figure 3.3 Single-Phase, No Counter Measures Prediction (Case 3): Mean Values Comparison

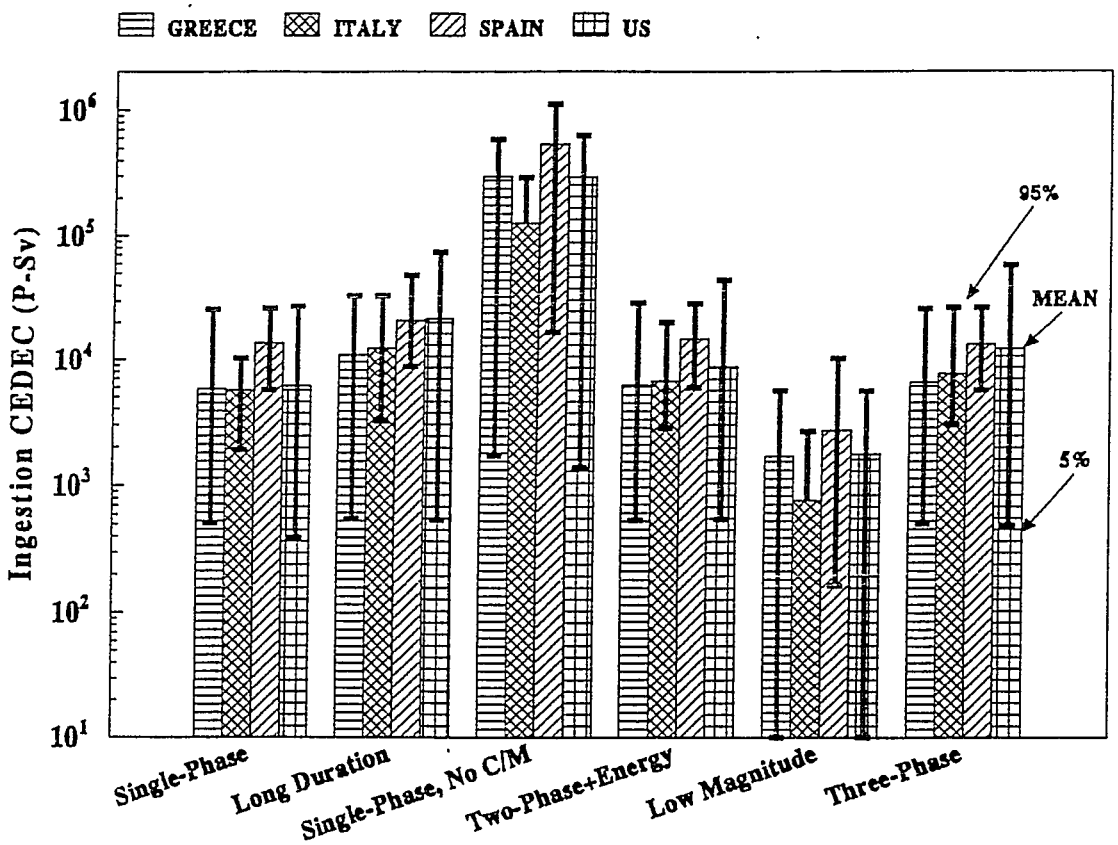


Figure 3.9 Ingestion Pathway CEDEC Prediction: Mean, 5th, and 95th Percentiles Results Comparison

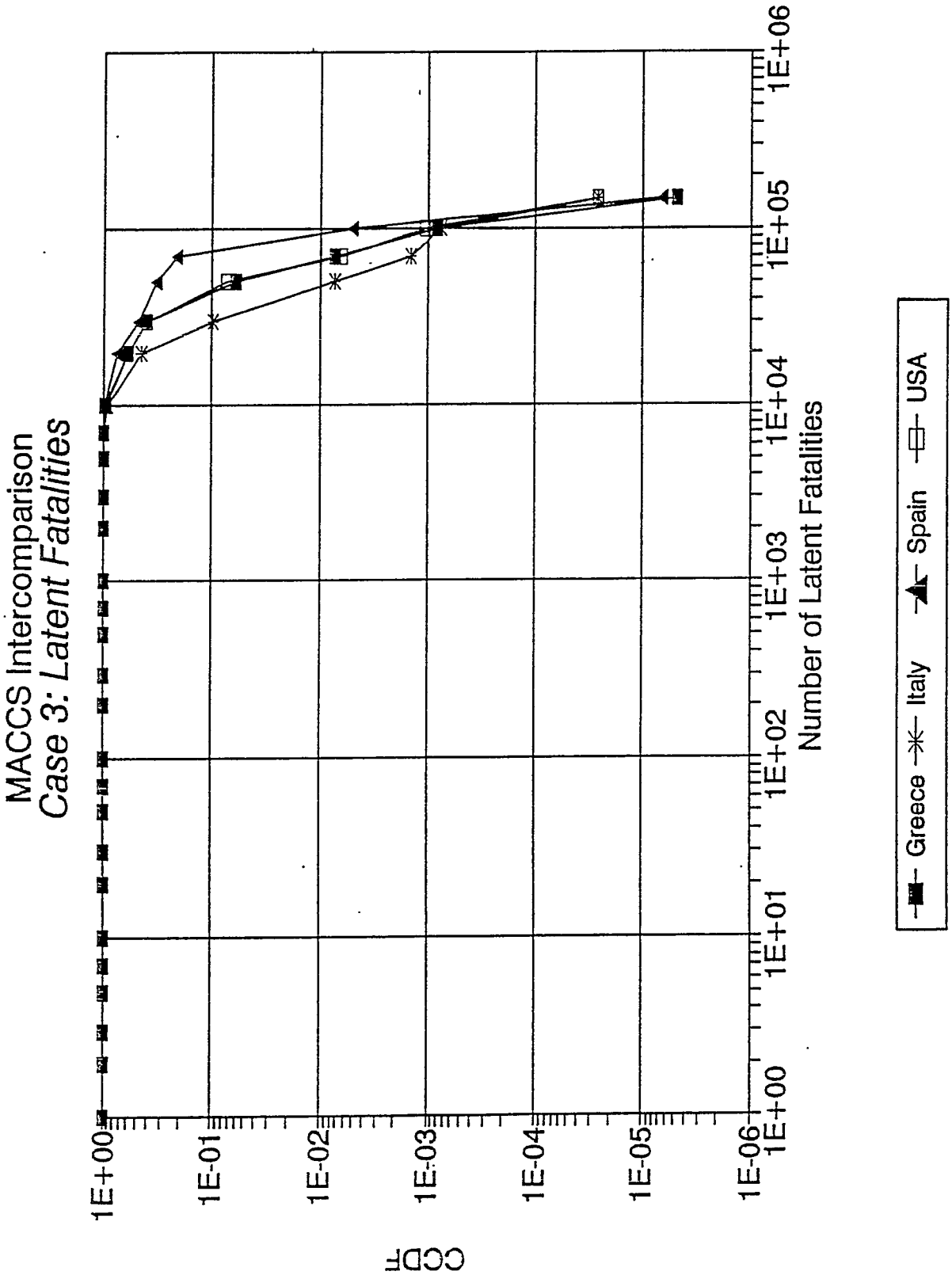


Figure 3.34 Latent Fatalities Prediction: CCDF Results Comparison, Case 3

IMUG MACCS Comparison Conclusions

The following major conclusions were drawn:

- The largest differences between predictions are found in the measures related to ingestion pathway modeling (largest spread in ingestion dose, crop disposal area, and cost of food bans)

- Reasons for the differences in the ingestion pathway:
    - annual human food basket
    - mapping of agricultural production
    - variation in values of retention and transfer factors for different crops

- Dispersion model options (straight line vs. wind shift both with rotation), weather data categorization

- The choices in the process of preparation of input data from the same specifications can result in noticeable differences between the predictions

ON THE ESTABLISHMENT OF PROTECTIVE LONG TERM MEASURES AFTER SEVERE NUCLEAR ACCIDENTS:

METHODOLOGY, APPLICATIONS, DECISION SUPPORT SYSTEM

Presentation at the IAEA Postgraduate Educational Course in Radiation Protection and the Safety of Radiation Sources
Aghia Paraskevi , Greece, June 2003

Objective:

Develop and demonstrate a methodology for supporting decisions on the establishment of medium and long range intervention levels following a severe nuclear accident.

Methodology:

Multicriteria decision analysis approach with the use of efficient frontiers to exclude all technically inferior solutions and with value tradeoffs postponed until the very last stage of the decision process

Application:

Demonstration based on the situation of the Chernobyl accident.

The intervention policy generating scheme proposed allows the recipients of the protective measures to be defined on the basis of the value of physical parameters (e.g. contamination levels) but additionally on the basis of geographic considerations (e.g. regions, towns, localities) resulting in a rich but discretized decision space.

Decision Support System:

A fast algorithm for determining the efficient subset in a discrete consequence space is employed.

A graphic user interface system has been developed allowing the decision maker to explore a multidimensional efficient frontier through 2-dimensional projections and at the same time observe on the screen the protection policy implied by each efficient consequence.

Principles for Protection from Radiation Harm

- *Initially* based on criteria concerning various forms of acceptable or unacceptable individual or collective dose limits

- *Later* based on optimization principles with upper and lower limits

- *Today* an intervention policy is based on three general principles:

    - Justification of the practice
    - Optimization of protection
    - Limitation of individual risk

Multiattribute decision analysis

Multiattribute decision analysis offers a comprehensive and self-consistent framework for making decisions in the presence of multiple criteria.

Preferences of the decision maker are assessed in the form of a value function $v(c_1,c_2, \ldots ,c_n)$ which gives a scalar measure of the value to the decision maker of a specific set of consequences $C(c_1,c_2, \ldots ,c_n)$.

Tradeoff assessments are not made explicitly and prior to the analysis of the alternatives. They are rather postponed for a later part of the analysis, when only a smaller part of the possible solutions has been retained following the rejection of the majority of the possible solutions.

Then the decision can be made without a formal assumption of a specific structure of a value function.

Basic operational steps of the methodology:

1. Determination of the alternatives,
2. Determination of the consequences,
3. Preference assessment, and
4. Determination of the optimum solution.

- The methodology provides a consistent framework for incorporating the issue of value tradeoffs into a complex problem

- However a formal assessment of the decision maker's preferences, a usually difficult task involving highly debated issues such as public health consequences, economic benefits, environmental degradation etc. is required

- To overcome these difficulties a great number of available alternatives is rejected by applying the concept of dominance

Efficient Frontier

An alternative I is said to dominate another alternative II if the following relationship is true: $c_j(I) \geq c_j(II)$ for all criteria j, with at least one inequality being strictly true.

It is assumed, without loss of generality, that more c_j is preferred to less c_j for all j.

In this case alternative II is called dominated or non-efficient. An alternative I is called *efficient* or non-dominated if it is not dominated by any other possible alternative.

The set of all the efficient alternatives constitutes the so called efficient set or efficient frontier.

Once the efficient frontier is established a decision might be possible by simple perusal of its elements and the corresponding consequences.

- Long term protective policies following a radiological accident aim at enabling the population at the affected areas to live safely. This can be achieved by reducing the radiation dose

- Maximum protection is limited by the financial costs associated with a protection policy, which increase with increasing degree of protection

- There might be also adverse effects associated with protective measures (e.g. inducing stress to the population that degrades life quality)

- It is therefore questionable whether protective actions can be only formed and evaluated on the basis of dose averted and financial cost

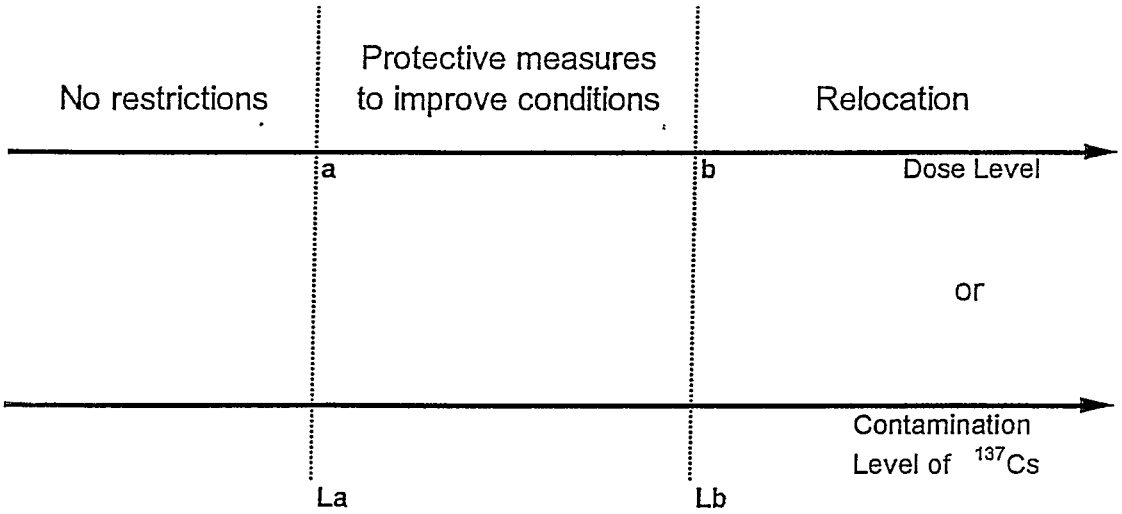


Fig. 1 Graphical illustration for protective strategy generation scheme

Figure 3.2(a). Desicion space in the La,Lb dimensions. La, Lb are the discrete decision variables with the constraint of La < Lb

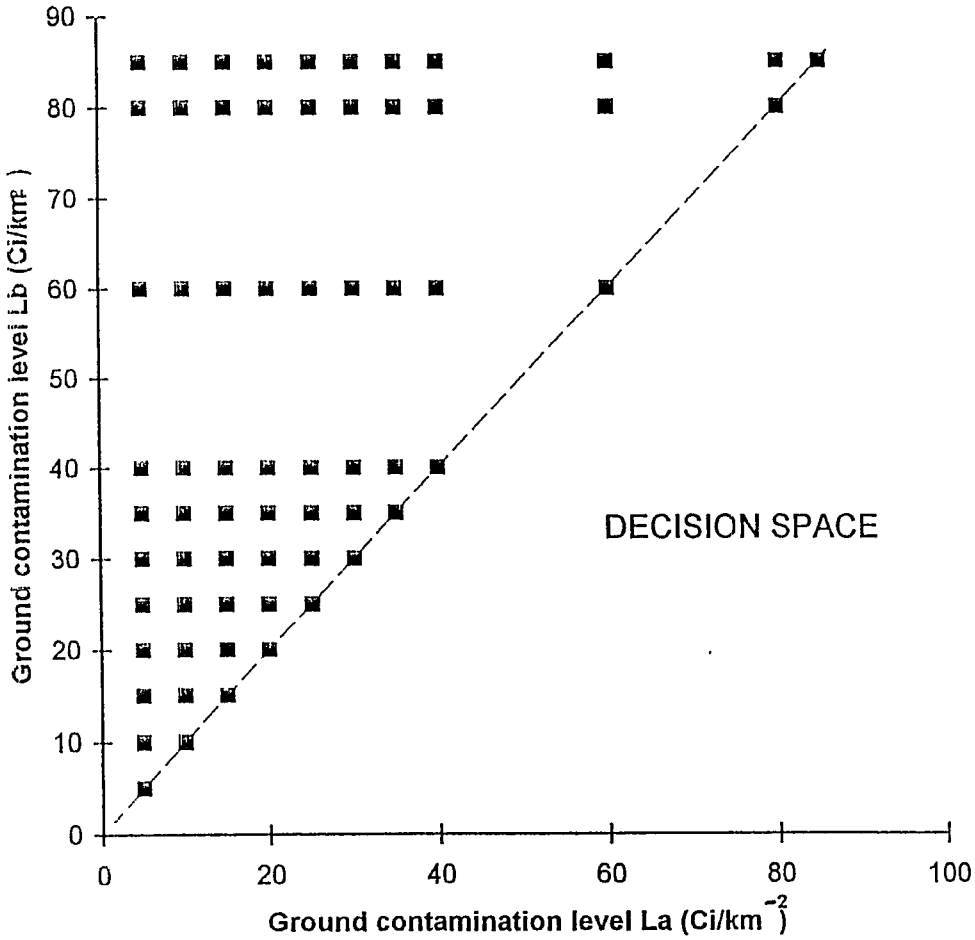
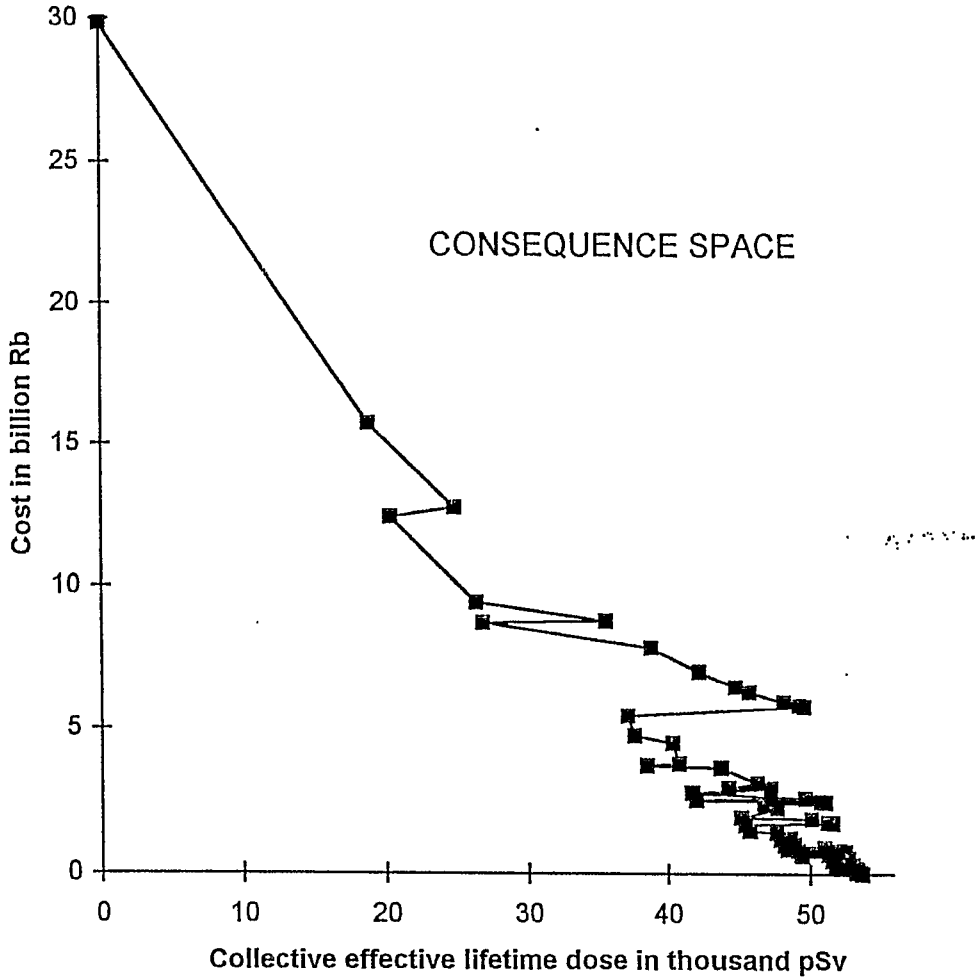


Figure 3.2(b). Concequence space in the C, D dimensions corresponding to the discrete (La, Lb) decision space



Each alternative policy is evaluated in terms of two criteria or attributes:

(i) The degree of protection it offers to the affected population as it is measured with the collective effective lifetime dose received by the population after the implementation of each policy; and

(ii) The amount of resources required to implement the policy expressed in monetary value.

A much richer decision space can be generated if an alternative policy generating scheme is adopted.

According to this scheme each population segment living in areas with ^{137}Cs contamination levels in one of the 10 intervals given in Table 1 is considered as a unit subject to a single protective measure to be chosen among the following three:

- Relocation of the population
- Improvement of living conditions for a time period extending from 1990 to 1992; and
- No restrictions.

Table 1. Distribution of the population according to level of ground contamination of ^{137}Cs in 1990

Ci km^{-2} of ^{137}Cs	Number of inhabitants	Level ID
5-10	411,800	1
10-15	87,200	2
15-20	117,900	3
20-25	28,100	4
25-30	24,900	5
30-35	15,700	6
35-40	5,300	7
40-60	10,400	8
60-80	3,400	9
>80	900	10

Table 2. Collective lifetime effective dose equivalent (1990-2060) in kp-Sv for 10 levels of ^{137}Cs ground contamination

Level ID	Relocation	Improvement	No Restrictions
1	0.0	18.85	20.37
2	0.0	5.99	6.47
3	0.0	10.78	11.67
4	0.0	3.20	3.48
5	0.0	3.40	3.70
6	0.0	2.50	2.72
7	0.0	0.96	1.05
8	0.0	2.47	2.70
9	0.0	1.11	1.22
10	0.0	0.38	0.41

Table 3. Total costs of countermeasure policies in 10^9 Rbs for 10 levels of ^{137}Cs ground contamination

Level ID	Relocation	Improvement	No Restrictions
1	17.40	3.323	0.0
2	3.69	0.704	0.0
3	4.98	1.015	0.0
4	1.19	0.242	0.0
5	1.05	0.214	0.0
6	0.66	0.135	0.0
7	0.22	0.046	0.0
8	0.44	0.090	0.0
9	0.14	0.029	0.0
10	0.04	0.008	0.0

Intervention Policy Based on ^{137}Cs Levels

10 levels of ^{137}Cs ground contamination

3 possible countermeasures

Total number of countermeasure policies:

3^{10}, i.e. 59,049 policies

Efficient frontier: *only 259 policies*

Figure 3.3. Efficient frontier with protective policies based on soil contamination level

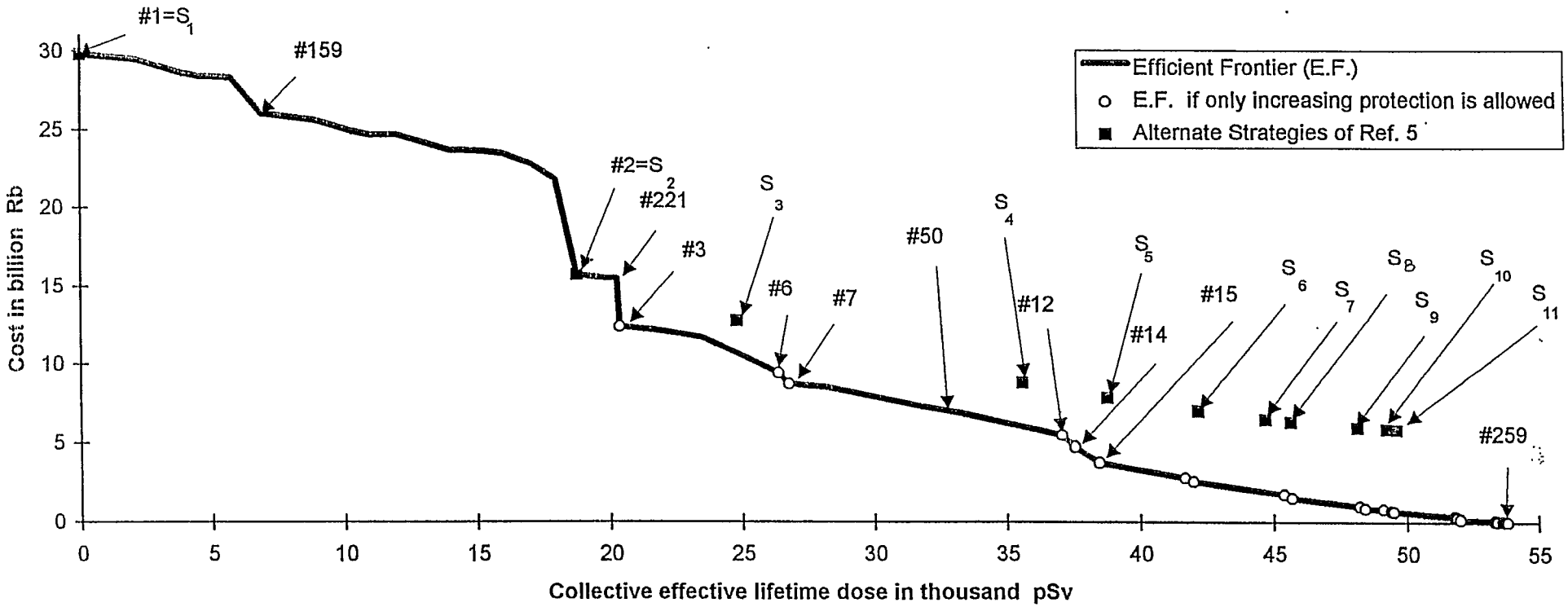


Table 5 Cost and collective dose associated with the different strategies

Strategy	Cost (million Rb)	Residual collective effective dose equivalent 1990-2060 (kp-Sv)
S1	29.819	0
S2	15.739	18.852
S3	12.758	24.842
S4	8.791	35.618
S5	7.845	38.821
S6	7.007	42.221
S7	6.479	44.718
S8	6.300	45.679
S9	5.950	48.150
S10	5.836	49.262
S11	5.806	49.637

The efficient set of alternatives includes policies that dictate more severe countermeasures in areas with a given contamination level (L) than in others with a higher contamination level.

For example, one point in the efficient frontier corresponds to the following protective strategy:

No restrictions	for	$L < 15$ Ci km^{-2}
Relocate population	for	15 Ci km^{-2} $< L <$ 20 Ci km^{-2}
No restrictions	for	20 Ci km^{-2} $< L <$ 25 Ci km^{-2}
Relocate populations	for	25 Ci km^{-2} $< L <$ 30 Ci km^{-2}
Take protective measures	for	30 Ci km^{-2} $< L <$ 35 Ci km^{-2}
Relocate population	for	$L > 35$ Ci km^{-2}

having as consequences a cost of 7.0×10^9 Rb and a collective dose of 32.8 kp-Sv.

This is of course expected since the only two criteria applied for evaluating policies are the collective effective lifetime dose and the monetary cost resulting from the protective policy.

Cs-137 LEVEL (6)

Additional Constraint:

"If a particular measure is adopted for a given contamination level, then only equivalent or more drastic measures are allowed for higher contamination levels"

This constraint results in efficient alternatives that are reduced to *only 25 policies*

Table 4 New efficient frontier remaining policies

Point		Contamination Level Policy (1=Relocation,2=Improve,3=No restrictions)										Total Dose (Sv)	Total Cost (Rbs)
A	B	ID=1	2	3	4	5	6	7	8	9	10	(see Table 1)	
1	1	1	1	1	1	1	1	1	1	1	1	0.000E+00	0.298E+11
2	2	2	1	1	1	1	1	1	1	1	1	0.189E+05	0.157E+11
3	3	3	1	1	1	1	1	1	1	1	1	0.204E+05	0.124E+11
4	6	3	2	1	1	1	1	1	1	1	1	0.264E+05	0.943E+10
5	7	3	3	1	1	1	1	1	1	1	1	0.268E+05	0.873E+10
6	12	3	2	2	1	1	1	1	1	1	1	0.371E+05	0.547E+10
7	14	3	3	2	1	1	1	1	1	1	1	0.376E+05	0.476E+10
8	15	3	3	3	1	1	1	1	1	1	1	0.385E+05	0.375E+10
9	24	3	3	3	2	1	1	1	1	1	1	0.417E+05	0.280E+10
10	25	3	3	3	3	1	1	1	1	1	1	0.420E+05	0.256E+10
11	30	3	3	3	3	2	1	1	1	1	1	0.454E+05	0.172E+10
12	31	3	3	3	3	3	1	1	1	1	1	0.457E+05	0.151E+10
13	62	3	3	3	3	3	2	1	1	1	1	0.482E+05	0.980E+09
14	63	3	3	3	3	3	3	1	1	1	1	0.484E+05	0.845E+09
15	95	3	3	3	3	3	2	2	1	1	1	0.491E+05	0.802E+09
16	97	3	3	3	3	3	3	2	1	1	1	0.494E+05	0.667E+09
17	98	3	3	3	3	3	3	3	1	1	1	0.495E+05	0.621E+09
18	100	3	3	3	3	3	3	2	2	1	1	0.518E+05	0.317E+09
19	102	3	3	3	3	3	3	3	2	1	1	0.519E+05	0.271E+09
20	103	3	3	3	3	3	3	3	3	1	1	0.522E+05	0.182E+09
21	148	3	3	3	3	3	3	3	3	2	1	0.533E+05	0.673E+08
22	149	3	3	3	3	3	3	3	3	3	1	0.534E+05	0.380E+08
23	256	3	3	3	3	3	3	3	3	2	2	0.536E+05	0.370E+08
24	258	3	3	3	3	3	3	3	3	3	2	0.537E+05	0.775E+07
25	259	3	3	3	3	3	3	3	3	3	3	0.538E+05	0.000E+00

A: New Efficient Frontier Policy Number; B: Original Efficient Frontier Policy Number

Table 6. Collective lifetime effective dose equivalent (1990-2060) in 10^3 p-Sv for 32 cells

Cell ID	Relocation	Improvement	No restrictions
1	0.0	0.17	0.18
2	0.0	1.65	1.79
3	0.0	2.49	2.69
4	0.0	1.97	2.14
5	0.0	2.24	2.42
6	0.0	2.89	3.14
7	0.0	2.53	2.75
8	0.0	1.80	1.96
9	0.0	1.75	1.89
10	0.0	2.62	2.85
11	0.0	3.44	3.73
12	0.0	1.59	1.72
13	0.0	1.41	1.53
14	0.0	2.61	2.84
15	0.0	2.68	2.91
16	0.0	0.67	0.73
17	0.0	0.66	0.71
18	0.0	0.50	0.54
19	0.0	0.99	1.07
20	0.0	1.58	1.71
21	0.0	2.51	2.71
22	0.0	2.62	2.84
23	0.0	1.07	1.15
24	0.0	0.17	0.18
25	0.0	2.76	2.99
26	0.0	1.83	1.99
27	0.0	0.97	1.05
28	0.0	0.33	0.36
29	0.0	1.16	1.25
30	0.0	1.14	1.24
31	0.0	0.33	0.36
32	0.0	0.17	0.18

Table 7. Total costs of countermeasure policies in 10^9 Rbs for 32 cells

Cell ID	Relocation	Improvement	No Restrictions
1	0.14	0.03	0.0
2	1.24	0.24	0.0
3	1.55	0.30	0.0
4	1.18	0.23	0.0
5	1.79	0.34	0.0
6	1.44	0.28	0.0
7	1.27	0.25	0.0
8	0.86	0.17	0.0
9	1.37	0.26	0.0
10	1.40	0.27	0.0
11	1.71	0.34	0.0
12	1.00	0.19	0.0
13	0.91	0.18	0.0
14	1.05	0.21	0.0
15	1.58	0.31	0.0
16	0.34	0.07	0.0
17	0.39	0.08	0.0
18	0.42	0.08	0.0
19	0.85	0.16	0.0
20	1.23	0.23	0.0
21	1.67	0.32	0.0
22	1.23	0.24	0.0
23	0.86	0.16	0.0
24	0.14	0.03	0.0
25	1.59	0.31	0.0
26	0.64	0.13	0.0
27	0.56	0.11	0.0
28	0.28	0.05	0.0
29	0.99	0.19	0.0
30	0.47	0.09	0.0
31	0.28	0.05	0.0
32	0.14	0.03	0.0

REGIONAL (1)

Intervention Policy Based on Regions

32 distinct geographical areas

3 possible countermeasures

Total number of countermeasure policies:

3^{32}, i.e. ~ $1.85 \cdot 10^{15}$ policies

Efficient frontier: *only 205 policies*

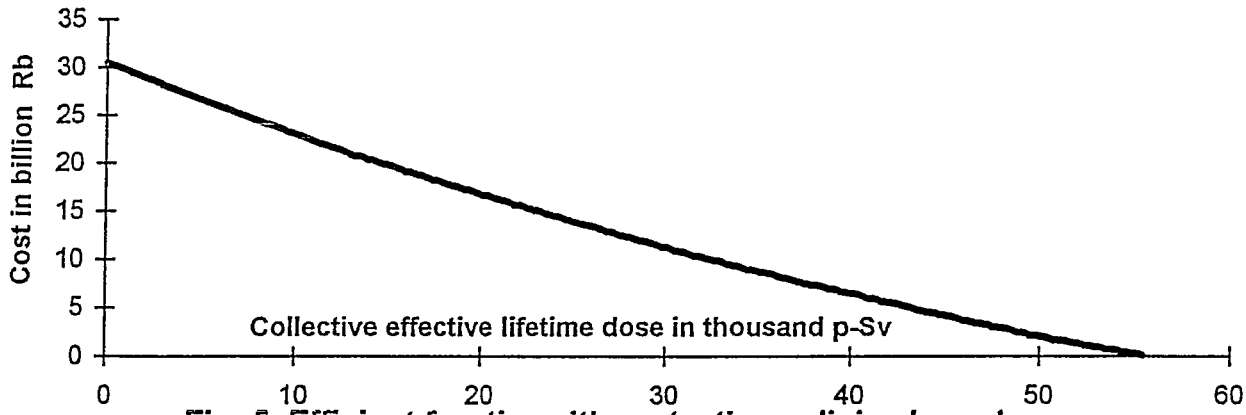


Fig. 5 Efficient frontier with protective policies based on geographical regions

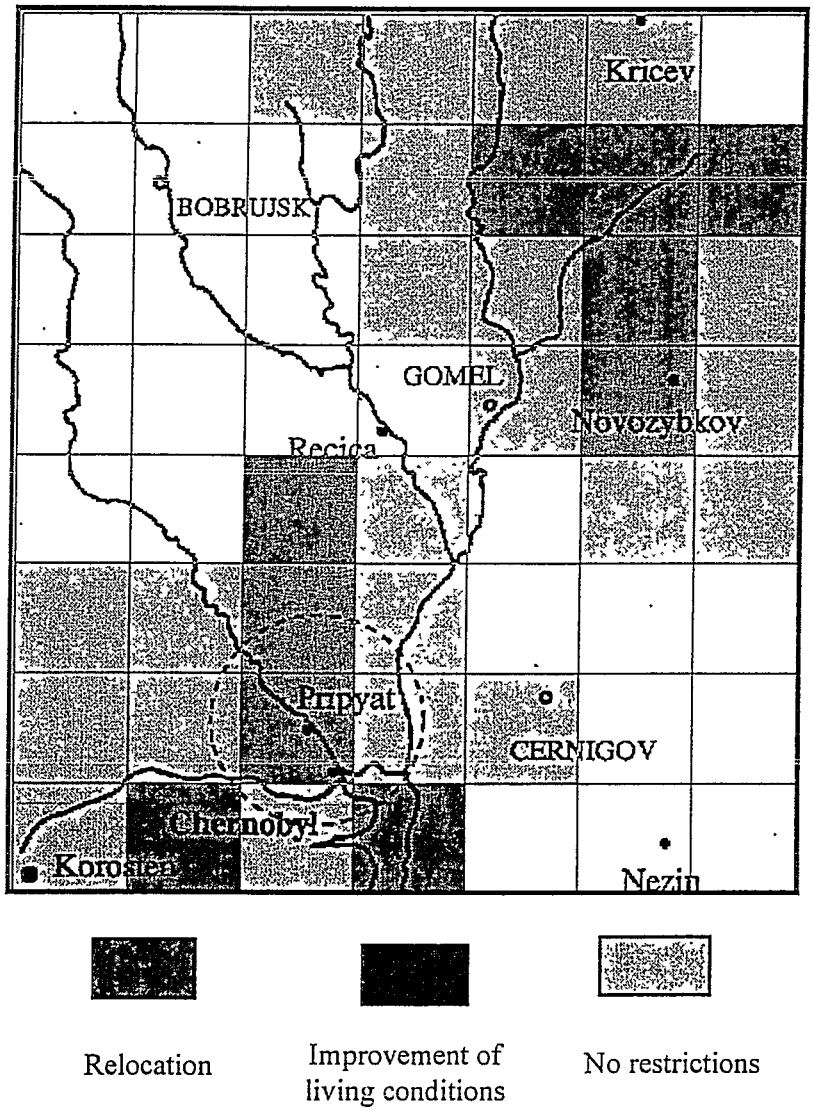


Fig. 6 An efficient policy applied on different geographical regions

CONCLUSIONS

Multiattribute decision analysis provides a methodological framework for supporting decisions on the establishment of long term protective measures after severe nuclear accidents.

This approach allows for the comparison of alternative protective policies on a multitude of dimensions as for example health effects and monetary cost.

Use of the efficient set of alternative policies greatly facilitates the decision making process by potentially establishing general conclusions independent of particular value tradeoffs among the various attributes that characterize each alternative policy.

Furthermore when a final choice is made its sensitivity to specific preference characteristics (e.g. aversion) and value tradeoffs can be performed easily.

In particular, conditional on the specific quantitative assumptions made, the following general conclusions can be reached without any assumption on value tradeoffs between monetary cost and dose.

- Improvement of living conditions a non-efficient protective measure when evaluated against collective effective lifetime dose and cost. This is true for both alternative generating strategies. Only a few points on the efficient frontier correspond to protective policies involving improvement of living conditions. Even these will be chosen as the most preferred ones only under very peculiar preference structures.

- The constrain of "increasing protection" that is the assumption that protective policy should be governed by the principle that higher contamination levels must be assigned higher or equal protective measures than lower contamination levels, provides optimum solutions under the vast majority of preference structures.

- Consideration of the totality of the decision space and not only a subsection of it (defined ad-hoc) is necessary in order to avoid non-optimal solutions as those generated by assuming "a lower limit of contamination level above which some sort of protective action should be taken".

Characteristics of the Graphic User Interface (GUI)

- The GUI has been developed for the Microsoft Windows® environment and requires the prior calculation of the efficient frontier and its availability in a FILE of special specifications. This FILE is produced as an output of the computer program implementing the optimization algorithm used for the determination of the efficient frontier

- The main objective of the GUI is to offer a visualization of the various courses of action when the decision maker has selected a specific point in the multidimensional efficient frontier. For this reason the GUI can be distinguished into two parts: the visualization of the decision space; and the visualization of the consequence space

- Most of the problems concerning the establishment of an intervention policy can be set in the form of a series of discrete partial decisions. When each and every one of the partial decisions are made the intervention policy is defined. In the case of ground contamination, intervention policies almost always refer to the contaminated geographical area and the possible protective actions that can be established in parts of the overall region.

- This particular GUI has adopted the convention that the affected area is contained in a rectangular part of a map and that this rectangular is divided into a number of orthogonal rectangles or cells. A protective action can be adopted in each cell and an overall intervention policy has been established when a protective action has been adopted at each cell of the area under consideration. Graphically the specific protective action in a rectangle is depicted by coloring the rectangle according to an adopted color scheme where each protective action corresponds to a specific color.

- Every time an alternative intervention policy is chosen a new version of the map, accordingly colored, will appear to graphically depict the constituent elements of the policy. Such a visual representation allows the decision maker to examine additional features of the intervention policy that might not have been explicitly considered in the set of the evaluation criteria. Such aspects might be: the geographical uniformity of the applied protective action; uniformity of protective actions with ground contamination, and population density, industrial activities, agricultural activities, and so on. It is believed that the adoption of a GIS platform for the representation of specific alternatives will greatly enhance these features.

- Graphical representation of the efficient frontier in the consequence space is achieved through a number of 2-dimensional projections of the efficient frontier.

- With the help of the mouse a specific point on the efficient frontier can be selected. Once the point is selected, and if the point is the one intended to be chosen by the decision maker, then "pressing" an OK button will produce the particular intervention policy on the map of the left hand side window.

- Zoom capabilities are available in each window. In the Map window a sub-area can be defined with the help of the mouse, and exploded for better view. In the consequences window specific areas of the efficient frontier can be viewed by specifying the lower and upper limits of the axes in each of the 2-D projections.

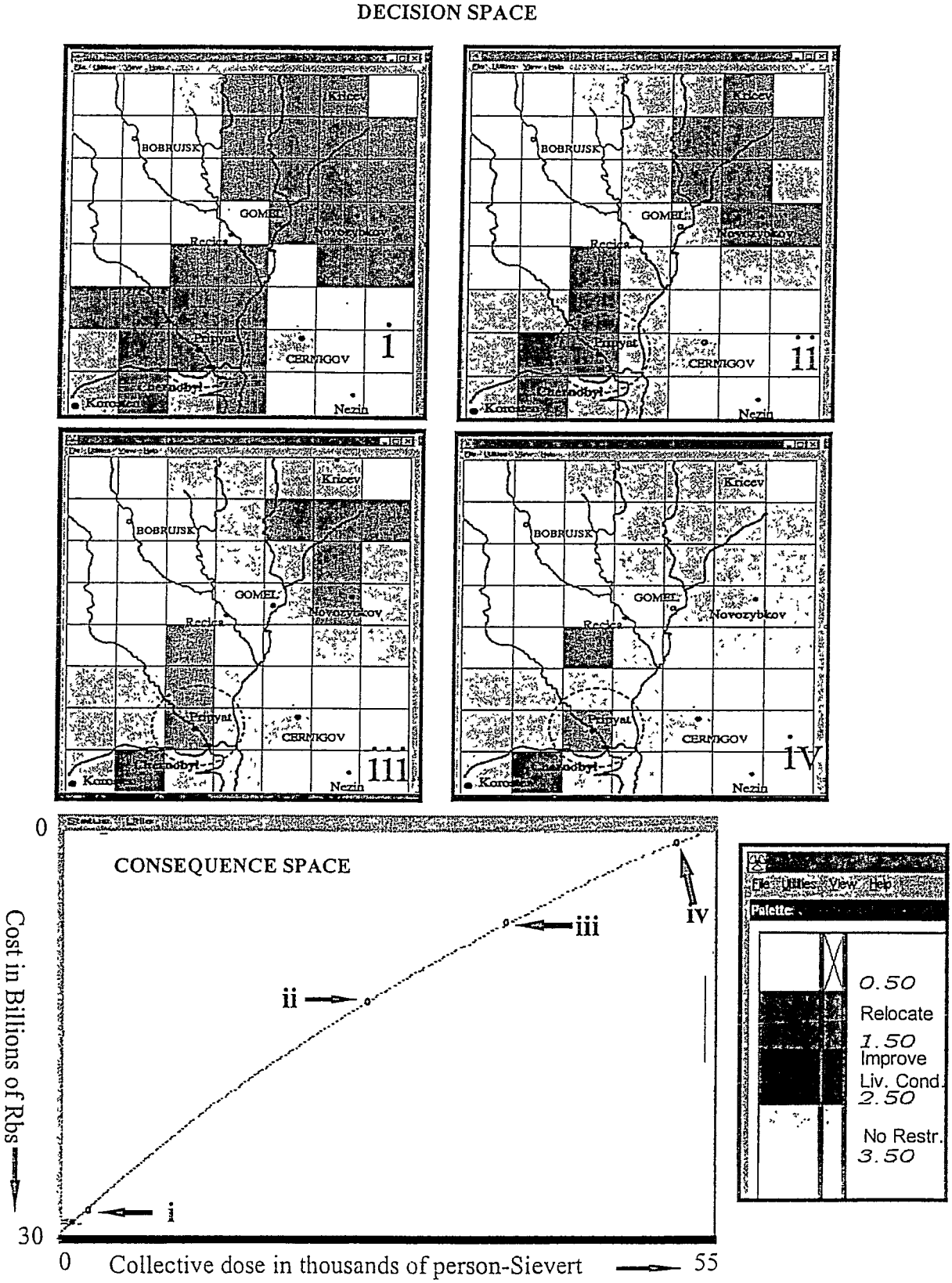


Fig. 9 Graphic User Interface: Four different intervention policies in order of decreasing protection (i.e. increasing collective dose and decreasing cost)