Model Description of the Early Countermeasures Module EmerSim in RODOS PV 6.0 final

Version RODOS PV 6.0 Final

RODOS migration

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REPORT
DECISION SUPPORT FOR NUCLEAR EMERGENCIES

RODOS(RA3)-TN(04)-03

Model Description of the Early Contermeasures Module EmerSim -in RODOS PV 6.0 Final

RODOS(RA3)-TN(04)-03

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Management Summary

This report describes the early countermeasures model EmerSim. It contains descriptions of the methods used for calculating potential doses, for defining the areas with emergency actions, for determining the doses with and without emergency actions, and of the simulation models for emergency action scenarios, which are combinations of the single actions sheltering, administration of stable iodine, and evacuation. The actions are simulated using country specific criteria and intervention levels, considering the concepts of projected and avertable dose.

The methods, models, and corresponding computer codes are described, which enable the definition of emergency actions and the simulation of their effects in the RODOS subsystem CSY. The basis for the emergency action simulation calculations are the radiological situation data produced with the prognosis module ALSMC of the subsystem ASY.

Finally the internal structure of the EmerSim code and its application with RODOS diagnosis- and prognosis calculations is shown.

1 Model description of EmerSim

1.1 Method for simulation of time dependent emergency actions

A scenario of emergency actions in case of a radioactive release generally is a combination of single actions varying spatially and temporally, carried out before or during a developing radiological situation. The simulation models installed in the RODOS subsystems ASY and CSY consider this variability by modelling and storing all processes defining the radiological situation on a spatial and temporal grid. The spatial grid is the non-uniform co-ordinate grid (calculation grid) covering the desired part of the geographical map with its square grid cells. In ASY and CSY the grid consists of 2520 cells with a size of 1 x 1 km^2 in the inner frame region reaching to about 12 km growing to a size of 8 x 8 km^2 at the outer edge at about 80 km. The temporal grid is the scale of maximum 48 EmerSim time steps each with 30 minutes duration or 24 time steps with 1 hour duration, the whole time scale covering maximum 24 hours. Alternatively time steps of 10 minutes (*) can be used then covering only the last 8 hours of the scenario. Time zero point is always at the beginning of the EmerSim time interval, or short the **EmerSim-Interval**. The EmerSim-Interval generally covers the last 24 hours (*: 8 hours respectively) of the radiological scenario simulated with the RODOS LSMC modules; it covers the scenario completely if it is shorter than 24 hours (*: 8 hours respectively). A complete description of EmerSim timings is given in chapter 1.5.

The method for simulation of time dependent emergency actions in a scenario developed for RODOS is the following one: First a radiological scenario is generated by running a prognosis with the RODOS modules QUICKPRO or LSMC. By using long source term and release data, corresponding meteorological data and an atmospheric dispersion module (ADM, here: **ATSTEP** [1]), a radiological scenario developing during several days is generated. The temporal development of activity concentrations, gamma radiation, and potential doses is calculated during all time steps of the scenario. Especially during the EmerSim-Interval the nuclide specific fields of activity concentrations and gamma radiation are combined with organ- and exposure pathway specific dose factors. This yields **histories** of potential individual doses for each **grid location,** each **pathway,** and each **organ** (module **DOSBAU** [1] of QUICKPRO and LSMC). This large set of dose histories is referred to as array of **'dose bricks'**. It is archived at the end of each prognosis run and is available for EmerSim. There the effect of time dependent emergency actions can be modelled according to the specific conditions in each grid cell by multiplying the dose bricks with suitable time dependent sequences of location or reduction factors. The results are modified dose histories which reflect the effects of the simulated emergency actions. From these modified dose histories the individual doses with emergency actions are calculated.

1.2 Histories of potential doses

The calculation of dose bricks on the calculation grid is carried out in the module DOSBAU starting from a time sequence of radiological situation data generated by an ASY-Prognosis run. The input data from ASY into DOSBAU consists for each of the time steps during the EmerSim-Interval of the three grid arrays A0 (air concentration near ground), A2 (ground contamination) and A3 (cloud gamma rate), all nuclide specific and valid for the centre points of all grid cells. During each time step M of the EmerSim-Interval potential dose bricks DBAU are derived from these arrays. The time sequences of the dose bricks represent the

potential dose histories and are the basis of emergency actions simulation in EmerSim. The definition of a dose brick is given in Eq.1. 'EPW' denotes the three exposure pathways: external gamma radiation from the cloud and from ground, and inhalation. The index L counts the 2520 grid points (cells of the calculation grid). The index O counts the organs the individual doses are calculated for: lung, bone marrow, thyroid, uterus, and effective. The index I counts the dose integration times in the case of inhalation and duration of exposure in the case of ground gamma radiation: I = 1,2,3,4,5 (1 day, 7 days, 30 days, 1 year and 50 years).

$$DBAU_{EPW}(L, O, I, M) = D_{EPW}(L, O, I, M) - D_{EPW}(L, O, I, M-1)$$

The sum of the time sequence of the dose-bricks yields the potential dose after the Mmax time steps of the EmerSim-Interval; the whole dose is obtained by adding the dose offset from the time before the EmerSim-Interval, Mmax ≤ 48, (Eq.2):

$$D_{EPW}(L, O, I) = \sum_{M=1}^{Mmax} DBAU_{EPW}(L, O, I, M) + DoseOffset_{EPW}$$

The dose bricks for external gamma radiation from cloud are defined in (Eq.3). The sum goes over 15 nuclides NU.:

$$DBAU_{CL}(L, O, M)[Sv] = \sum_{NU=1}^{15} A3(L, NU, M)\left[\frac{Sv}{s}\right] \cdot DRF_{CL}(NU, O) \cdot \Delta T[s]$$

A3 is the effective gamma dose rate from cloud. The cloud gamma dose rate factors DRF_{CL} consist only of the ratio of the organ specific dose factors and the effective dose factor.
The dose bricks for the external gamma radiation from ground are (Eq. 4):

$$DBAU_{GR}(L, O, M)[Sv] = \sum_{NU=1}^{15} A2(L, NU, M)\left[\frac{Bq}{m^2}\right] \cdot DRF_{GR}(NU, O)\left[\frac{Sv/s}{Bq/(m^2)}\right] \cdot \Delta T[s]$$

The dose contributions from longer term exposure by ground gamma radiation are calculated from the contamination A2 at the end of the prognosis and the dose factors DF_{GR} (Eq. 5).:

$$DINT_{GR}(L, O, I)[Sv] = \sum_{NU=1}^{15} A2(L, NU, 25)\left[\frac{Bq}{m^2}\right] \cdot DF_{GR}(NU, O, I)\left[\frac{Sv}{Bq/(m^2)}\right]$$

The dose bricks for inhalation of contaminated air are (Eq. 6):

$$DBAU_{IH}(L, O, I, M)[Sv]$$

$$= \sum_{NU=1}^{15} A0(L, NU, M)\left[\frac{Bq}{m^3}\right] \cdot DF_{IH}(NU, O, I)\left[\frac{Sv}{Bq/(m^2)}\right] \cdot R_{IH}\left[\frac{m^3}{s}\right] \cdot \Delta T[s]$$

Here the DF_{IH} are the nuclide- and organ specific dose factors with the integration times I=1, 5 and R_{IH} is the breathing rate in [m³/s].

1.3 Calculation of individual doses without emergency actions

In the module **NOACDOS** fields of organ- and pathway specific individual doses without the effect of emergency actions are calculated on the calculation grid. two sets of dose data are generated: potential doses (unshielded, in open air over lawn) and doses assuming normal living in buildings (shielding against external gamma radiation, not as strong as in the case of 'sheltering').

The potential doses (without dose offset from before the EmerSim-Interval) are calculated as in Eq. 7:

$$D_{EPW}^{pot}(L, O, I) = \sum_{M=1}^{Mmax} DBAU_{EPW}(L, O, I, M) + DINT_{GR}(L, O, I) \cdot \delta_{EPW,GR}$$

with $\delta_{EPW,GR}$=1 for EPW=GR and =0 for EPW not=GR. The index L again counts the grid cells on the calculation grid and runs from 1 to 2520. The index O denotes the organs (lung, bone marrow, thyroid, uterus, effective and skin). The index I counts the 5 dose integration times (ground radiation and inhalation only).

The corresponding doses for normal living are derived from the potential doses by location factors $FN_{CL,GR,IH}$ for external cloud- and ground-gamma radiation, and inhalation (Eq. 8):

$$D_{CL,GR,IN}^{normal}(L, O, I) = D_{CL,GR,IN}^{pot}(L, O, I) \cdot FN_{CL,GR,IN}(L)$$

1.4 Determination of areas with emergency actions

There are three possibilities for the definition of areas with simulated emergency actions in EmerSim:
• 	by dose intervention levels,
• 	by dose intervention levels and following expansion to sectors- and zones,
• 	by graphic user input.

1.4.1 Determination of areas by dose intervention levels

Corresponding to the multitude of emergency strategies in different countries EmerSim has to deal with different dose criteria, different intervention levels, and intervention concepts. There are two common intervention concepts, one based on **projected dose**, the other based on **avertable dose**.

Independent of the intervention concept, i.e. if it is based on projected dose or avertable dose, the module EmerSim needs input from the dose calculations carried out during the atmospheric dispersion and deposition run with the modules Quickpro or ALSMC. This input consists of the Dose Bricks Array filled within the last 24 hours of the scenario, dose offsets from the time before, and ground gamma doses with country specific integration times.

Also independent of the intervention concept is the calculation method of so called ´no-action-doses´ and ´action doses´ in the population. No-action doses are potential ´open air´- and ´normal-living´-doses that people would receive if no countermeasures were carried out. Both are calculated in all cells of the RODOS calculation grid. Action doses are the doses with the effect of simulated emergency actions. They are calculated only in those areas with dose criteria exceeding the intervention levels.

The size and shape of these areas depend on
- the radiological situation,
- the dose intervention levels,
- and the intervention concept,

i.e. the projected or the avertable dose concept. In case of the avertable dose concept the areas with actions depend also on time: the more time has elapsed since the onset of exposure the smaller the remaining areas with early countermeasures will be. In case of the projected dose intervention concept the areas do not depend on the starting time of the actions.

Calculation of Areas with Early Countermeasures

Generally the area for each specific countermeasure results from a comparison between effective or organ **dose criteria** and **dose intervention levels**. The intervention concept, the dose criteria, and the intervention levels are country specific and are read in by RODOS during the Quickpro or ALSMC run.

Concept P: Intervention Based on Projected Doses

The **criterion dose** for implementation of **sheltering** and **evacuation** is generally a **projected potential dose**, i.e. a dose without any actions or shielding factors at the end of the dispersion prognosis of Quickpro or ALSMC. Generally the criterion dose is the sum of projected organ doses of the exposure pathways cloudshine, groundshine, and inhalation:

Criterion Projected dose =   pathway sum of potential projected doses =
[cloud gamma dose, effective or organs]

+   [ground gamma dose, effective or organs,

integrated over an exposure time varying between 1 and 14 days]

+   [committed inhalation dose, effective or organs,

received during inhalation time].

For **intake of stable iodine** generally holds:

Criterion Projected dose=

[committed iodine inhalation dose to thyroid

of adults and children, received during inhalation time].

The values of the criterion doses depend on location. For a given scenario they do not depend on time. Locations with a criterion dose value which is greater than the intervention level of dose (DIL) belong to an area with countermeasures to be carried out.

Concept A: Intervention Based on Avertable Doses

The criterion dose for implementation of a single countermeasure (either **sheltering or evacuation**) is generally the difference of a no-action dose (normal living) and an action dose reduced by the countermeasure which is called averted dose:

Criterion Averted dose   = dose (normal living) - dose (with countermeasure)

Generally the criterion averted dose is the sum of the averted doses of the exposure pathways cloudshine, groundshine, and inhalation:

Criterion Averted dose　　　=　　　pathway sum of averted doses =

　　　　　　　　　[averted cloud gamma dose, effective or organs]

　　　　　+　　　[averted ground gamma dose, effective or organs,

　　　　　　　　　integrated over an exposure time varying between 1 and 14 days]

　　　　　+　　　[averted committed inhalation dose, effective or organs,

　　　　　　　　　received during inhalation time].

For **intake of stable iodine** generally holds:
Criterion Averted dose=

　　　　　　　　　[averted committed iodine inhalation dose to thyroid

　　　　　　　　　of adults and children, received during inhalation time].

The values of the criterion doses depend on location. They also depend on the starting time of countermeasure actions because the dose fraction avertable by countermeasures decreases with increasing time. Locations with a criterion dose value which is greater than the intervention level of avertable dose (AVDIL) belong to an area with countermeasures to be carried out.

Input needed for determination of Areas with Countermeasures:

Input definition of countermeasure actions to be carried out in EmerSim.
Input of action timing
Input of national intervention levels
Input of national definitions of criterion doses, projected or avertable concept.

The criterion doses of all three countermeasures are calculated in all 2520 cells of the RODOS calculation grid. Then they are compared in each cell with the corresponding national DIL or AVDIL of the countermeasure. If a criterion dose exceeds the corresponding DIL or AVDIL in a grid cell then it is marked as a cell with the countermeasure to be carried out potentially. The intervention area for a countermeasure results from the whole of the marked cells. This procedure is carried out independently for all three countermeasures.

Which countermeasures shall be carried out with the EmerSim simulation is defined during input.

Tables containing National Intervention Criteria, Definitions

Organs used: lung, bone marrow, thyroid, uterus, effective dose, local skin dose.
Abbreviations are: LU, BM, TH, UT, effective, SK.

Organ dose intervention levels and local skin doses for Sheltering, Evacuation
DILSH, DILEV, DILSHSK, DILEVSK.
Thyroid iodine inhalation dose intervention levels for adults and children
DILIOA, DILIOC.

KEYPROAV=1 or 2 means PROJECTED or AVERTABLE dose concept.

IORG=0 or =1.

ITime means Integration Time in days and serves for the country specific calculation of the pathway components of Criterion Doses. It is either the extrapolation time of exposure to ground gamma radiation, or in case of cloud gamma and inhalation pathways the upper limit of exposure time in the calculation.

ITime≤49 days means exposure time is cloud passage time with no upper limit given by national specifications (the only limitation is by RODOS which has a maximum scenario length of 49 days).

ITime=0 days means no relevant exposure is assumed, e. g. thyroid cloud gamma dose as criterion dose for stable iodine action.

Definitions of national criterion doses in the EmerSim code

IORG=1: general case, any organ dose may appear in the definition of the national criterion doses for sheltering (She) or evacuation (Eva).

Criterion Dose is either Projected Potential Dose or Avertable Dose:

DosePathwaySumSH(LP,Org) =   DoseCL(LP,Org)   *KeySheCL(Org)
                            +   DoseSheGR(LP,Org) *KeySheGR(Org)
                            +   DoseComIH(LP,Org) *KeySheIH(Org)

DosePathwaySumEV(LP,Org) =   DoseCL(LP,Org)   *KeyEvaCL(Org)
                            +   DoseEvaGR(LP,Org) *KeyEvaGR(Org)
                            +   DoseComIH(LP,Org) *KeyEvaIH(Org)
For Iodine Tabs: Dose to thyroid.

The Key-factors(Org) are 1 if the organ "Org" contributes to the definition of the criterion dose, otherwise they are 0. They are shown in the following tables.

IORG=0: special case like in Germany, only for the projected dose concept, in the definition of the national criterion doses only effective and thyroid iodine inhalation doses appear:

$$\text{EffDosePSumSH(LP)=EffDosePotCL(LP)+EffDosePotSheGR(LP)+EffDosePotComIH(LP)}$$
$$\text{EffDosePSumEV(LP)=EffDosePotCL(LP)+EffDosePotEvaGR(LP)+EffDosePotComIH(LP)}$$

For Iodine Tabs: Iodine inhalation dose to thyroid.

NATIONAL INTERVENTION LEVEL AND ORGAN KEY TABLES (Examples)

GERMANY (GER), PROJECTED, IORG=0
Intervention levels

Organ	LU	BM	TH	UT	effective	SK
DILSH	-	-	-	-	10	-
DILEV	-	-	-	-	100	-
DILIOA			250			
DILIOC			50			

Organ Key Table for Criterion Doses

KEY	LU	BM	TH	UT	effective	SK	ITime [d]
Shelt CL	0	0	0	0	1	0	7
Shelt GR	0	0	0	0	1	0	7
Shelt IH	0	0	0	0	1	0	7
Evac CL	0	0	0	0	1	0	7
Evac GR	0	0	0	0	1	0	7
Evac IH	0	0	0	0	1	0	7
Iod CL	0	0	0	0	0	0	0
Iod GR	0	0	0	0	0	0	0
Iod IH	0	0	1	0	0	0	7

SLOVAK REPUBLIC (SVK), AVERTABLE
Intervention levels

Organ	LU	BM	TH	UT	effective	SK
DILSH	-	-	-	-	10	-
DILEV	-	-	-	-	50	-
DILIOA			100			
DILIOC			(100)			

Organ Key Table for Criterion Doses

KEY	LU	BM	TH	UT	effective	SK	ITime [d]
Shelt CL	0	0	0	0	1	0	2
Shelt GR	0	0	0	0	1	0	2
Shelt IH	0	0	0	0	1	0	2
Evac CL	0	0	0	0	1	0	7
Evac GR	0	0	0	0	1	0	7
Evac IH	0	0	0	0	1	0	7
Iod CL	0	0	1	0	0	0	≤49
Iod GR	0	0	1	0	0	0	≤49
Iod IH	0	0	1	0	0	0	≤49

In the module **AREA** the potential organ doses are compared with the dose intervention levels for the emergency actions 'sheltering', ' evacuation', and 'administration of stable iodine', and for the action 'relocation' on the whole calculation grid. Grid cells with an organ dose higher than the dose-intervention level of a certain countermeasure are marked as to belong to the corresponding countermeasure actions area.

The dose criterion for children is (most sensitive age group: 5 years children) (Eq. 11):

$$D_{CHILD} = 2.2 \cdot D_{IH}^{pot}(L, 3, 5)$$

For determination of the area for the measures 'temporary and permanent **relocation**' the potential effective ground gamma doses with 1 month and 1 year exposure time are used as criterion.

- **the value for 'temporary relocation'**   **30 mSv**
- **the value for 'permanent relocation'**   **100 mSv**

The areas with potential emergency actions are formed by the set of grid cells L with the above defined potential doses exceeding the intervention levels for the emergency actions. These cells are correspondingly marked with numerical values of flag variables KENxxx:

TABLE 1.

Kind of action	Flag name	Flag off	Flag on
Sheltering	KENNSH(L)	0	10
Evacuation	KENNEV(L)	0	100
Iodine tablets adults	KENIAD(L)	0	10
Iodine tablets children	KENICH(L)	0	10
Relocation temporary	KENUMT(L)	0	10
Relocation permanent	KENUMP(L)	0	10

1.4.2   Sectors and zones

The action areas defined in the module AREA can be redefined by the user by expanding the outlines of the areas to the sectors and zones around NPPs. Typically in Germany the centre zone has a radius of 2 km, the middle zone is between two circles of 2 km and 10 km radius, and the outer zone reaches from 10 km to 25 km radius. The middle and outer zones are each divided into 12 sectors with 30 degrees angular width. In this way the region around a NPP is covered with the area elements of a coarse polar co-ordinate grid. For a selected NPP the numbers given here can be changed by the user.
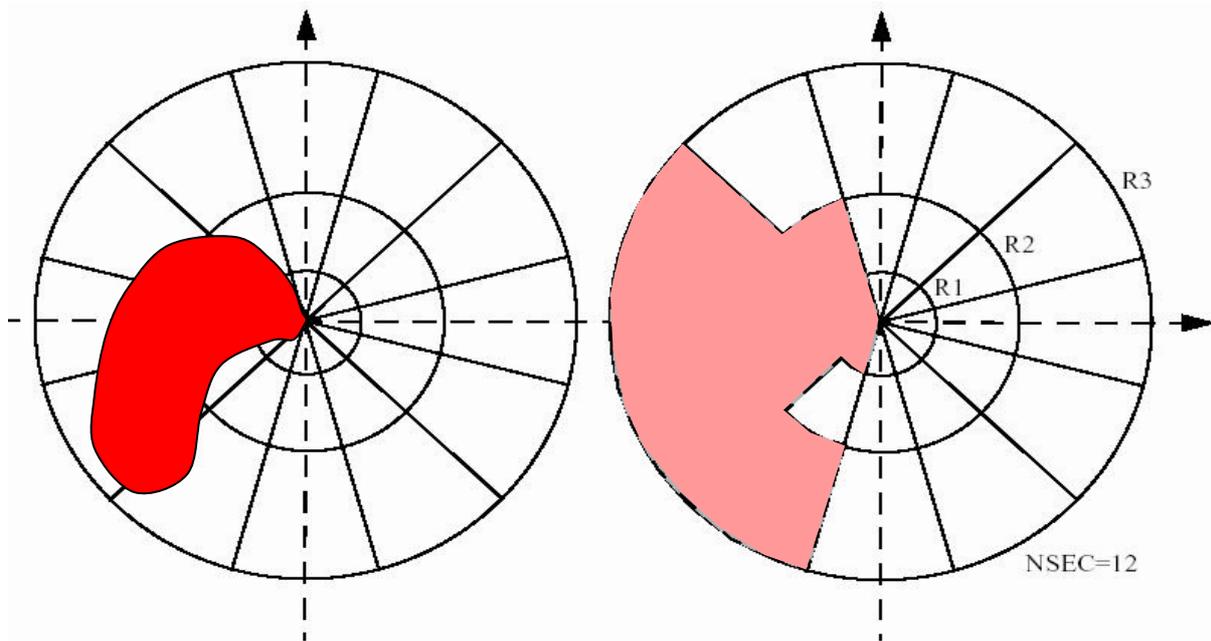
Fig.1: Sectors and zones. a) intervention level areas, b) sectors and zones overlapped by this area

If there is an overlap of at least one grid cell of an action area defined by intervention levels with such a sector zone area element then the whole element is added to the action area, i.e. all grid cells in this area element will be marked with a numerical flag according to table 1. Finally the resulting emergency actions area only consists of the 'flagged' area elements of the sector and zone co-ordinates.

1.4.3 Graphic input of action areas

The areas for potential emergency actions generated by a run of EmerSim using dose intervention levels can be modified by the user directly on the graphical screen during a second run with EmerSim. The emergency actions scenario will be simulated in the modified areas then.
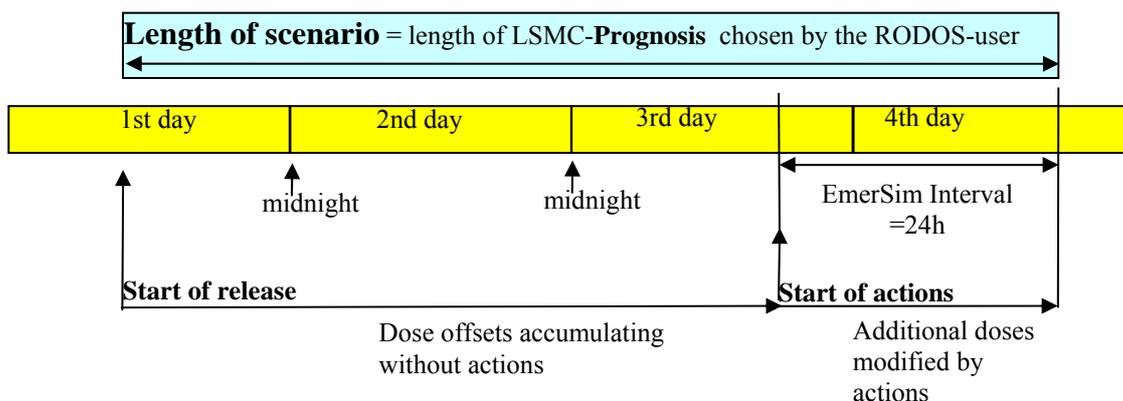
1.5 Preparation of the parameters of the emergency actions scenario

In the module **ACTIONS** the data put in or chosen by the user for defining the emergency actions scenario are transformed into the form needed by the emergency actions and doses module ACDOS (2.6). The transformations refer to switch variables, intervention levels, and scenario timing variables put in by the user.

Timing of emergency actions

The explanations and figures concerning **timing of simulated emergency actions** in the following chapter refer to ADM time step lengths of 0.5 or 1.0 hour and an EmerSim-Interval length of 24 hours (see chapter 1.1: *). For an EmerSim-Interval of 8 hours the numbers have to be changed accordingly. All emergency actions generally are simulated in the **EmerSim-Interval** (see Fig. 2 and 4). In the case of an **interactive prognosis run of 1 day or shorter** the EmerSim-Interval fully covers this, in case of a longer run the EmerSim-Interval covers the last 24 hours. In case of an **automatic prognosis run** after a diagnosis the EmerSim day starts from the present time of the scenario and ends 24 h later, covering the time interval of the automatic prognosis following the diagnosis.

Interactive Prognosis:

Length of scenario = length of LSMC-**Prognosis** chosen by the RODOS-user

1st day	2nd day	3rd day	4th day

midnight   midnight

EmerSim Interval
=24h

Start of release

Start of actions

Dose offsets accumulating
without actions

Additional doses
modified by
actions

Auto Prognosis after Diagnosis:

Length of scenario = length of LSMC **automatc diagnosis run + 24 h prognosis**

Past diagnosis days	24 h Auto EmerSim

Start of release

Diagnosis

Auto-Prognosis
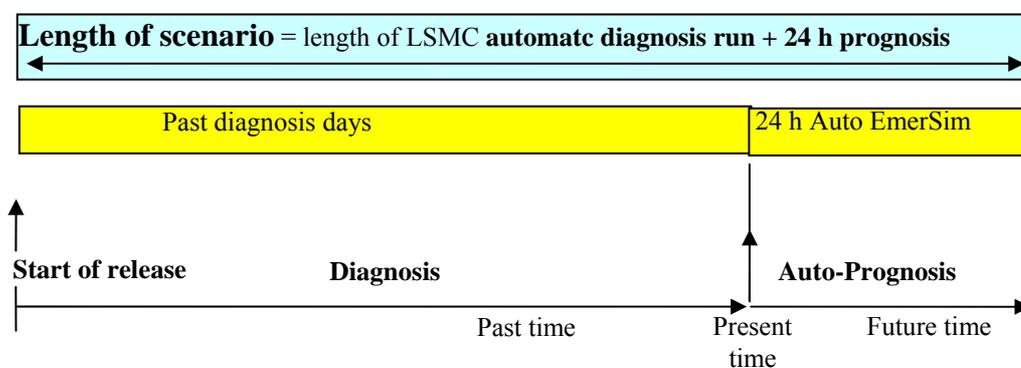
Past time   Present time   Future time

Fig.2: Scenario timing and emergency action timing

The emergency action timing of 'sheltering' is defined by putting in starting time and duration, in the case of 'evacuation' starting time and travel time has to be put in by the user. In the case of 'administration of stable iodine' only the time of intake has to be put in.
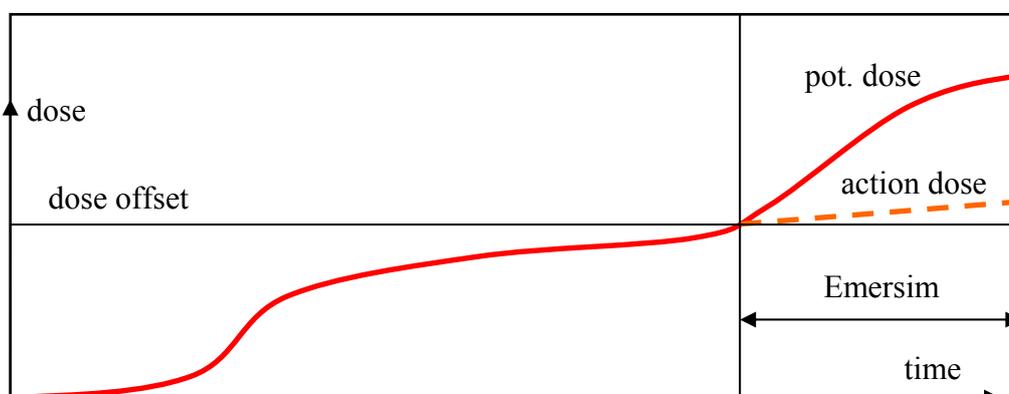
dose

pot. dose

action dose

dose offset

Emersim

time

Fig. 3: Example of the effect of emergency action on a dose curve

Action	Status before Action	Start	End	Status after Action
Sheltering	normal living	Tsh	≤TEmersim	normal living
Evacuation	normal living or sheltering	Tev	Tev+Ttrav	return 30 days after TEmersim, then normal living
Shelt. + Evac	normal living	Tshev	≤Tev	Evacuation
Iodine Tabs	normal living	Tintake		

Table 2: Simulated actions - status and timing

Meaning of times used in Table 2 and Fig.4:

TEmersim = Duration of EmerSim-Interval (24 h or less)

Tsh   = Starting time of Sheltering

Tev   = Starting time of Evacuation Travel

Ttrav   = Duration of Evacuation Travel

Tshev   = Starting time of Sheltering before Evacuation
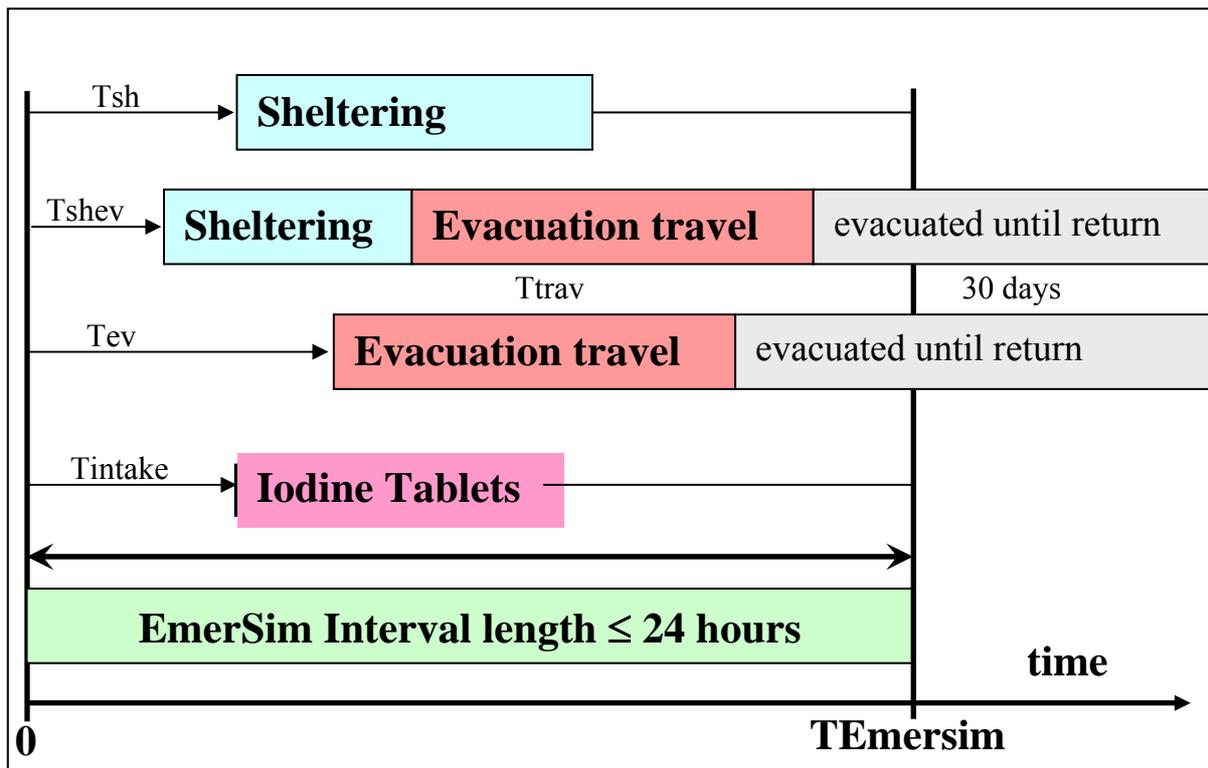
Tintake   = Time of Intake of Iodine Tabs

Fig. 4: Definition of tining of emergency actions during the EmerSim-Interval

1.6   Calculation of individual doses with emergency actions

In the module **ACDOS** the same set of doses as in the module NOACDOS (i. e. organ and exposure pathway specific individual doses) is calculated on the calculation grid. But now the effects of the simulated emergency actions on the doses are considered in the areas with emergency actions. Outside of these areas the dose field data for normal living in buildings are copied from the module NOACDOS (2.3).

1.6.1 Modelling of single emergency actions

Sheltering

This action is simulated during the EmerSim-Interval by reducing the potential exposure of the population in the sheltering area with shielding factors $FS_{CL,GR,IH}$ (location factors) during the sheltering time interval. The location factors in each grid cell are derived from the local type of buildings. The building type is currently simply derived from the local population density, because better data are missing. Different factors are used for the exposure pathways EPW=CL,GR,IH, i.e., external gamma radiation from the cloud, from ground, and inhalation. Before and after the sheltering time interval (from M1 to M2) normal living in buildings is assumed (2.3); the location factors $FN_{CL,GR,IH}$ are used then:

people/sq-km	open air	<100	100 - 250	≥250
shielding	no	low	medium	high
FS groundshine	1.0	0.5	0.1	0.01
FS cloudshine	1.0	0.8	0.5	0.2
FS inhalation	1.0	0.5	0.5	0.5

FN normal living: occupancy factor=0.8, i.e. *FN = 0.2*1.0 + 0.8*FS*

The resulting dose of the EmerSim-Interval of a given pathway EPW is then (Eq.13):

$$D_{EPW}^{shelter} = \sum_{M=1}^{M1-1} FN_{EPW} \cdot DBAU_{EPW}(M) + \sum_{M=M1}^{M2} FS_{EPW} \cdot DBAU_{EPW}(M) + \sum_{M=M2+1}^{M\max} FN_{EPW} \cdot DBAU_{EPW}(M)$$

For the total doses these doses have to be added to the dose offsets (with normal living factor FN) received on the days before the EmerSim-Interval (Eq.14):

$$D_{EPW}^{total} = D_{EPW}^{shelter} + D_{EPW}^{offset} \cdot FN_{EPW}$$

The **effect of sheltering** on the dose bricks in a sheltering grid cell is shown in Fig. 5. In the upper part the potential effective dose bricks for external gamma radiation are displayed as an example; in the lower part the dose reduction in the sheltering time interval can be seen:
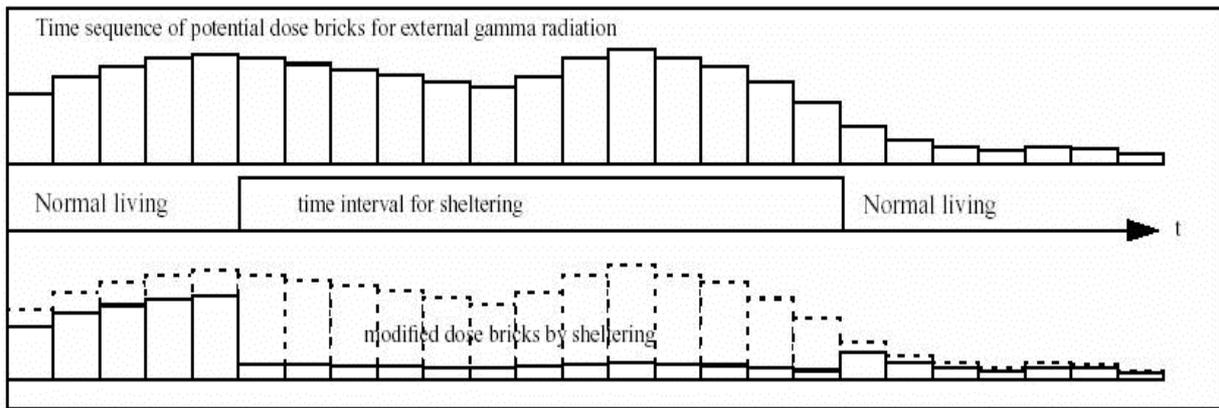
Fig. 5: Modification of potential dose bricks by sheltering

Evacuation

This action is simulated by assuming the unshielded exposure of the starting location of the population during the evacuation travel. Before the evacuation either sheltering or normal living is assumed, depending on the kind of emergency actions chosen. After the evacuation travel the exposure to external radiation or inhalation is stopped, as long as the population stays evacuated. For simulating the returning of the evacuated population into the evacuated areas the input of a time given in days defines that after this time the evacuation is finished and the population is back at its starting areas. Here generally a further radiation exposure takes place. As it is assumed that at this time there is no exposure to cloudshine anymore only external gamma radiation from contaminated surfaces (ground gamma radiation) contributes to the exposure. From this results an additional dose rate since the time of returning. The dose is calculated from the contamination after the EmerSim-Interval and the ground gamma dose factors for different exposure times by interpolation. Normal living in buildings is assumed.

The **effect of evacuation** on the dose bricks is shown in Fig. 6. In the upper part the potential dose bricks (for an arbitrary pathway) are displayed as an example; in the lower part the dose reduction in the evacuation interval can be seen.
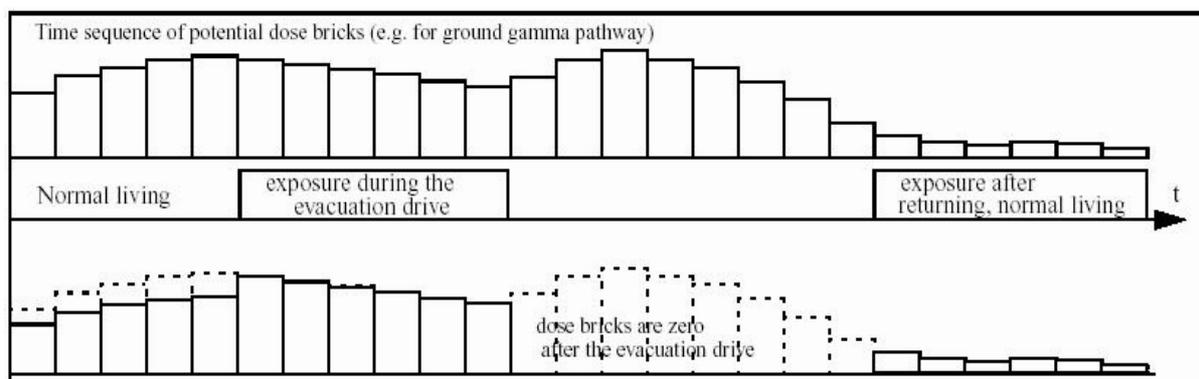

Fig. 6: Modification of potential dose bricks by evacuation

Administration (intake) of iodine tablets

In the areas with intake of iodine tablets the iodine inhalation dose of the thyroid is reduced. The reduction factor depends on the time difference between intake and iodine inhalation. The iodine tablets suppress the accumulation in the thyroid of that fraction of radio-iodine that was inhaled before the intake of the iodine tablets but has not yet arrived at the thyroid due to its metabolism. This is modelled by an exponential function with the time constant λ=0.00289 [min^{-1}] corresponding to a half life time of 4 hours. When the tablets have been taken in the accumulation of radio-iodine in the thyroid will be fully suppressed after a short time. In the model this is managed by a time shift of 15 minutes in the exponent and by setting the reduction factor to zero for later inhalations times [2](Eq.15, 16):

$$a = 1 - e^{-\lambda((t_{tablet} - t_{inhal})+15\,min)}$$
$$a = 0 \text{ if } (t_{inhal} - t_{tablet}) > 15\,min$$

The course of the factor a is shown in Fig. 7. The right part of the curve with a=0 corresponds to full thyroid blocking, because the iodine tablets had been taken in at least 15 minutes before the inhalation. The left part of the curve, increasing to past inhalation times, shows the decreasing effectiveness of the tablets, if the inhalation was a longer time before the intake of the tablets.

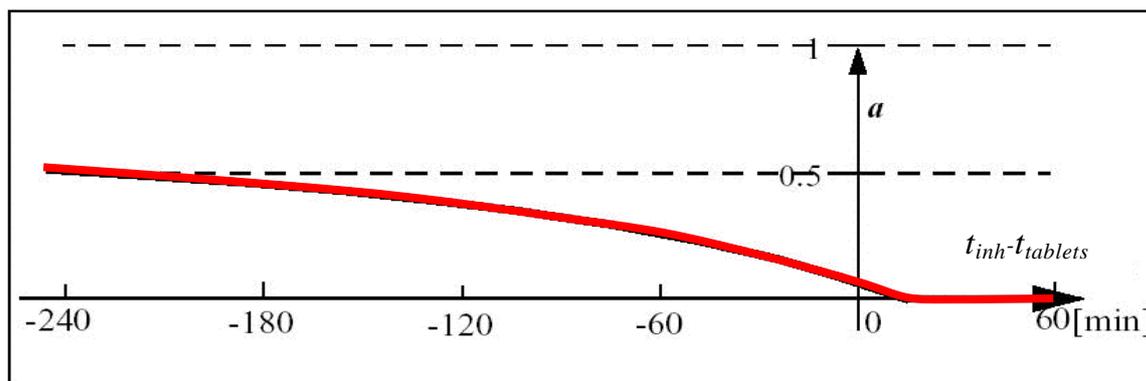Fig. 7: Effectiveness of the iodine tablets: factor a

The **effect of the iodine tablets** on the dose bricks is shown in Fig. 8. In the upper part the potential thyroid inhalation dose bricks are displayed; in the lower part the dose reduction around the time of intake of the tablets can be seen.
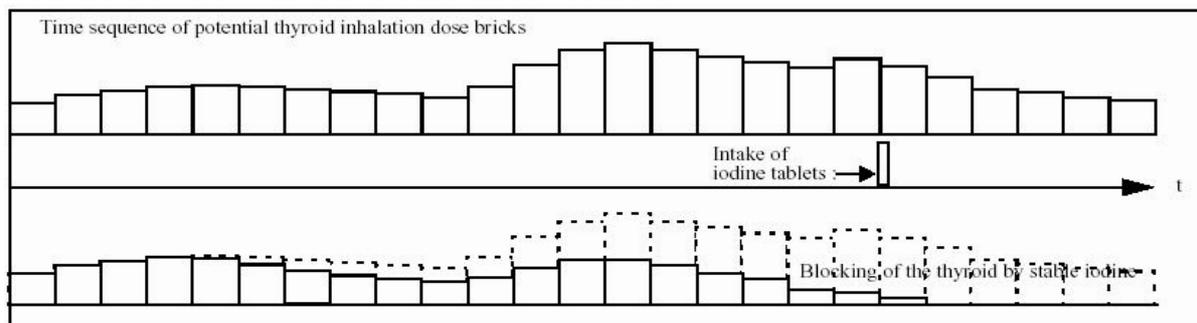

Fig. 8: Modification of the potential dose bricks (iodine inhalation thyroid) by intake of stable iodine

The reduction of the iodine causes a reduction of the effective inhalation dose too (Eq.17):

$$D_{IH}^{red}(L,5,I) = D_{IH}(L,5,I) - w_{TH} \cdot (1-a) \cdot D_{IH}^{pot}(L,3,I)$$

The reduced effective dose $D_{IH}{}^{red}$ follows from the unchanged dose D_{IH} by subtraction of the thyroid dose reduction times the weight factor w_{TH} of the organ thyroid in the definition of the effective dose. The indices L and I again denote the grid cell number and the dose integration time; the values 5 and 3 mean effective dose and thyroid dose.

1.7 Gamma Radiation from Contaminated Areas

The module **Groundtime** aims at the display of **the temporal dependency of groundshine doses and rates** during the period of the scenario and at future times. Therefore the effective local gamma doses and dose rates resulting from contaminated areas are selected at particular points in time to result in **local curves** showing the increase of gamma dose with time and the initial increase and final decrease of dose rates. The sequence of the time points of the curves depends on the mode (automatic or interactive), and in the case of interactive mode on the length tp of the prognosis. They are defined as follows (t=0 is always at the start of the prognosis) :

EmerSim based on an **automatic prognosis** or an **interactive prognosis** with duration **tp shorter than or equal to 24 hours (*: 8 hours)**:

time point	section of scenario
t1 = 0.5 h,	during prognosis and EmerSim
t2 = tp	during prognosis and EmerSim
t3 = tp + 1d,	future development
t4 = tp + 7d,	"
t5 = tp + 14d,	"
t6 = tp + 30d,	"
t7 = tp +0.5y,	"
t8 = tp + 1y,	"
t9 = tp + 50y.	"

EmerSim based on an **interactive prognosis** with duration **tp of several days**:

time point	section of scenario
t1 = time of 1. midnight,	during prognosis
t2 = time of 2. midnight,	"
t3 = time of 3. midnight,	"
. . . .	"
t3+i = time at start of EmerSim,	during prognosis and EmerSim
t4+i = time at end of EmerSim,	during prognosis and EmerSim
t5+i = tp + 1d,	future development
t6+i = tp + 7d,	"
t7+i = tp + 14d,	"
t8+i = tp + 30d,	"
t9+i = tp +0.5y,	"
t10+i = tp + 1y,	"
t11+i = tp + 50y	".

The gamma doses and dose rates are given in mSv and mSv/h. The corresponding curves

showing the temporal dependency appear on the screen after clicking into the grid cell. In case of **automatic mode** (i. e. the scenario is a combination of a past diagnosis and an auto prognosis started at present time) the curves of the **ground dose** start at the first half hour of the auto prognosis and contain already the dose accumulated during the diagnosis phase. In the same way the **ground rates** are derived from the sum of contamination from diagnosis and prognosis.
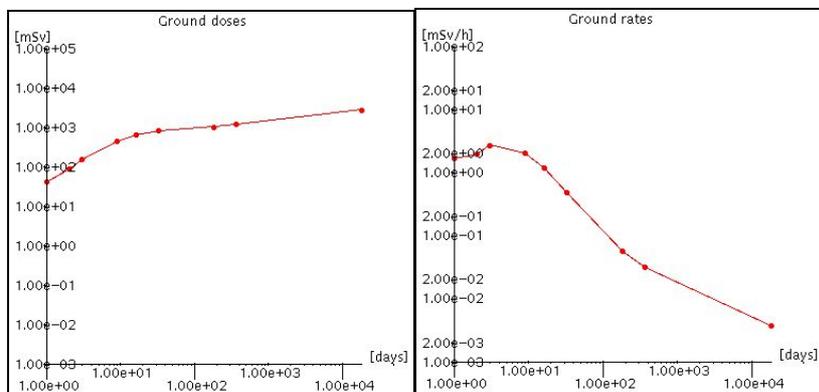
1.8 Exercise Preparation: Simulated Emergency Care Centre

If RODOS is used as an exercise preparation tool EmerSim will provide data for a simulated Emergency Care Centre (ECC). For this purpose a number of virtual persons (players) is generated in the module EMCENT [3]. These players come from various locations around the NPP with high and low exposure. According to the developing radiological situation simulated by ALSMC each player gets his own dose and contamination history. The history includes also the emergency actions "sheltering" and "intake of iodine tablets". By using these histories the final doses and contaminations of each player when he enters the ECC are calculated. In a real ECC thyroid doses are assessed from external gamma rates of a person's thyroid, and contamination is measured by beta and gamma detectors. In the simulated ECC the external gamma rates and beta counting rates are derived from the players' histories. Based on the results a simulated decontamination is carried out, like in a real ECC.

The output of the ECC simulation is a large table with all players' location and history data, dose and contamination data, and simulated measuring and decontamination results. The UNIX Fortran format writes each player's data into one line. The whole can be pasted into a Microsoft-WORD document, and furthermore into an EXCEL table.

1.9 Assessment of health effects

In the module HEALTH the numbers of persons with deterministic and stochastic somatic health effects are assessed. The models correspond to the methods used in the programme system COSYMA [4]. Input for the health effects model are the organ doses and dose rates, which depend on the radiological situation and the simulated emergency actions scenario in the modules NOACDOS and ACDOS in EmerSim, and the population distribution. Output data are the following individual risks for different health effects in the form of fields on the calculation grid:
- individual risks of deterministic health effects;
- a) Morbidity: lung function impairment, hypothyroidism, mental retardation
- b) Mortality: pulmonary syndrome, hematopoietic syndrome, pre- and neo-natal deaths
- risk of stochastic somatic effects
- additional cancer deaths.

The numbers of persons with different health effects are calculated from the risk fields and the population distribution.

1.10 Assessment of monetary costs

In the cost module ECONOM various off-site economic consequences of the accident are assessed in the form of monetary costs. The different kinds of costs are calculated in corresponding sub-models:

- model for the costs of the medical treatment of persons
- model for the costs of the evacuation and accommodation of persons
- models for the production losses to society caused by the evacuation, illness or death of persons

The models contain realistic economic parameters and data. Input Data of ECONOM are the population distribution, the health effects, and the number of evacuated persons. The modelling of the economic consequences is similar to the methods used in COSYMA [5].

2   The EmerSim Code

The EmerSim code (programming language: FORTRAN) is integrated into RODOS as a module in the subsystem CSY. EmerSim can be run after a prognosis run with the subsystem ASY, because the radiological situation data in the form of dose bricks are produced there, or with equivalent data of archived prognosis runs.

After the start of EmerSim the radiological situation data of the prognosis run (in the form of a large array of potential dose bricks, see 2.1), the population data, the location factor data, and the economic data are read in by the subroutine INPUT.

In the submodule NOACDOS the organ dose fields without the effects of emergency actions are calculated. Both "Open-Air" doses (potential doses) and doses under the conditions of normal living in buildings (expected doses) are calculated.

After this the emergency actions steering parameters are transformed in ACTIONS into the data needed for the simulation, and in AREA the areas for the emergency actions are derived either from dose intervention levels or defined by graphical user input.

In the submodule ACDOS the organ dose fields are calculated with the effects of simulated emergency action combinations. Outside of the areas with emergency actions the dose fields from NOACDOS are taken.

Following to EmerSim health effects and economic consequences are assessed for the case *without emergency actions simulation* and the case *with emergency actions simulation.* in the modules HEALTH and ECONOM.

2.1   EmerSim and other modules in the RODOS-subsystem CSY

The simulation of late countermeasures in the LCMT module [6] and the simulation of emergency actions in the EmerSim shall not be carried out independently. Contradictions between evacuation and relocation results have to be avoided. Therefore the information which areas have been evacuated for what time is transferred from EmerSim to LCMT.

If emergency actions *and* late countermeasures shall be simulated *as one scenario*, the health effects and the economical consequences of the doses in the population including the emergency actions *and* the late countermeasures have to be assessed. Therefore the dose results of EmerSim and LCMT are put together in a module for the final dose and then put into the modules HEALTH and ECONOM. In this case the module ECONOM is enhanced for the assessment of late countermeasure costs.

2.2 Modular structure of EmerSim/RODOS 6.0:

Modules

Subroutines	Task

INIT

INPUT	Input of ROGIS data, Archived data of Prognosis run

NOACDOS	Calculation of all potential organ dose fields
	Generation of population dose spectra without action
ESYnot	**Generation of special (no action) output for ESY**

ACTIONS	Derive all action parameters from user input
Outact	**Output table with chosen emergency action parameters**

AREA	Calculate action areas
Areas	**Calculation of intervention areas for actions**
Autosect	**Derive automatically sectors and zones from intervention areas**
EmDoseRead	**Read in the doses of all days of the prognosis and show exceeding of intervention levels day by day**
Kennin	**Allow for hand input areas**
Groundtime	**Show time functions of ground gamma doses and rates**

ACDOS	Calculation of all doses modified by the simulated actions
	Generation of population dose spectra with action
Esyact	**Generation of special (with action) output for ESY**
Outtab	**Output table with selected NOACDOS and ACDOS results**
Emcent	**Output of a Player Data Table for a simulated Emergency Care Station ECC for Emergency Exercises.**

draft

References

[1] Päsler-Sauer, J., Description of the atmospheric dispersion model ATSTEP - version RODOS PV 6.0, RODOS internal report: RODOS(RA2)-TN(04)03

[2] Kovari, Michael, Effect of delay time on effectiveness of stable iodine prophylaxis after intake of radioiodine. Journal of.Radiological.Protection, 1994, Vol 14, No. 2, p.131-136.

[3] Päsler-Sauer, J., Functional specification of an emergency exercise preparation module in RODOS PV 6.0, RODOS internal report: EURANOS(CAT2)-TN(04)09

[4] COSYMA- A New Programme Package for Accident Consequence Assessment. Report EUR 13028 EN. (Brussels: CEC)(1990).

[5] Faude, D. COSYMA- modelling of Economic Consequences. KfK Report 4336 Forschungszentrum Karlsruhe (1992).

[6] Brown, J., Mansfield, P.A., Smith, J.G., Modelling approach in the terrestrial late countermeasures module LCMT within RODOS 4.0,. RODOS internal report: RODOS(WG3)-TN(99)-43

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