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# Source Term Treatment for Nuclear Accidents in RODOS PV6final

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**RODOS**  
REPORT

DECISION SUPPORT FOR NUCLEAR EMERGENCIES



**Source Term Treatment for Nuclear Accidents in RODOS PV6final**  
RODOS(RA2)-TN(04)-04

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## Management Summary<sup>1</sup>

This report describes the role source terms play in the RODOS system, the source term input for RODOS, and the conversion of that input to information usable for the RODOS atmospheric transport and deposition models. It also contains a list of all source term related documents.

**Note:** Since RODOS Version PV6.0 Patch 07 it is not only possible to consider accident scenarios for nuclear power plants (nuclear accidents), but also radiological emergencies, for example the explosion of a radiological dispersion device. **Report RODOS(RA2)-TN(04)-04 applies exclusively to nuclear accidents. The source term treatment for radiological emergencies is described elsewhere.**

The report is valid for RODOS version PV6final.

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## 1. Overview

**Note:** Since RODOS Version PV6.0 Patch 07 it is not only possible to consider accident scenarios for nuclear power plants (nuclear accidents), but also radiological emergencies, for example the explosion of a radiological dispersion device. **Report RODOS(RA2)-TN(04)-04 applies exclusively to nuclear accidents. The source term treatment for radiological emergencies is described elsewhere.**

### 1.1 Background

In case of a nuclear accident in Europe, the Real-time Online Decision Support System RODOS [1] for off-site emergency management provides consistent and comprehensive information on the radiological situation, emergency actions and countermeasures, and support for taking decisions on emergency response strategies. Accordingly, the RODOS system is split into three distinct subsystems, the Analysing Subsystem (ASY), the Countermeasure Subsystem (CSY), and the Evaluating Subsystem (ESY).

RODOS uses meteorological and radiological monitoring data and field measurements to improve the accuracy of its model predictions of atmospheric and hydrological dispersion and radio-ecological processes. It can cope with differences in site and source term characteristics, in the availability and quality of monitoring data, and in national regulations and emergency plans. The use of RODOS for training and education in radiological protection and emergency management has been one of the major objectives from the beginning.

The dialogue between RODOS and a user is organised in two different modes. In the so-called "automatic mode" the system automatically presents all information which is relevant to decision making and quantifiable in accordance with the current state of knowledge in the real cycle time. Interaction with the system is limited to a minimum amount of user input necessary to characterise the current situation and to adapt models and data. RODOS can be operated in the "interactive mode" either in parallel to the automatic mode or alone. In this dialogue mode, the user of category A communicates with the system via a menu interface. The users of category B interact with the system via a Web based interface.

The RODOS project was launched in 1989 and continued through the European Commission's 3<sup>rd</sup>, 4<sup>th</sup> and 5<sup>th</sup> Framework Programmes. Significant additional funds have been provided by many national R&D programs, research institutions and industrial collaborators. In particular, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) contributed to the project financially with a special focus on early emergency response after

nuclear accidents. Up to 40 institutes from some 20 countries in the European Union, Central and Eastern Europe and the Former Soviet Union were actively involved in the project. Within the European Integrated Project EURANOS of the 6<sup>th</sup> Framework Programme, the RODOS system is being enhanced, among others, for radiological emergencies such as dirty bombs attacks, transport accidents and satellite crashes by extensions of the nuclide list, the source term characteristics and the atmospheric dispersion model.

## 1.2 Role of nuclear accident source term interface in RODOS

In this report, considerations are limited to airborne accidental releases from Nuclear Power Plants and the respective radiological source terms and accident consequences. Figure 1 shows the role of the nuclear accident source term interface in the model chain of RODOS for the assessment of the radiological consequences for such releases.

Release data together with meteorological data are the basic input for atmospheric dispersion and deposition models for the near range (Near\_ADMs) that produce contamination fields and other information for the assessment of the off-site radiological consequences.

As RODOS was designed for use in a real emergency as well as for training and exercises, on the one hand it must be able to deal with frequently used source term parameterisations in order to make adaptations to real or fictive scenarios as easy as possible. The RODOS Near\_ADMs, on the other hand, require a special parameterisation and a fixed format for the source term. In the RODOS system, a source term interface, program package STERM, produces that information from the input data.

## 1.3 RODOS source term input in the different phases of a nuclear accident

Figure 2 illustrates the RODOS source term input and dialogue modes in the different phases of a nuclear accident.

The Interactive Mode can be run at any time with all source terms that are at the command of the A-users<sup>2</sup> of RODOS; these will be collectively referred to as "user source terms" in this report:

- Source terms created by hand interactively with RODOS.
- Source terms from one of the source term libraries of RODOS, from other RODOS users, or from external providers, with or without modifications made by the user.

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<sup>2</sup> This report refers only to RODOS A-users, which have all source term applications and operation modes at their disposal. The possibilities of B-users in this respect are limited, and C-users cannot carry out at all RODOS calculations of their own.

The Automatic Mode is applicable in connection with a real or fictive accident and the possibilities for source term input<sup>2</sup> are determined by the availability of source term information in the different release phases.

If there is *no accident*, RODOS can be run in the Automatic Mode <Normal Operation>, thereby using a fixed fictive source term that serves as a tracer for displaying the current atmospheric dispersion and deposition conditions with RODOS. The default normal operation source term is shown in Table 1.

In the *threat phase*, when the radioactive material is still confined inside the plant, source term information is purely prognostic and comes only from expert judgement. Accordingly, only user source terms can be applied.

In the *release phase*, monitoring data about the source term may become available. If RODOS runs in the automatic mode <Emergency|Monitored Stack Release>, it uses measured data showing the parameterisation in Table 2, which is the one used in the nuclear reactor remote surveillance system (KFÜ) in Germany for stack monitoring of nuclear power plants. With the RODOS PV6final Automatic Mode, it is now also possible to assess the situation that a monitored release is followed by unmonitored releases by continuing the measured source term with a user source term, either in the diagnostic and the prognostic phases, or in the prognostic phases only.

When there are no data from source term measurements, because the monitoring system fails or the release occurs fully via unmonitored escape routes, user source terms can be applied.

Releases going on simultaneously via the monitored stack and via other routes (e.g. leaks in the containment building) can be tackled with RODOS only indirectly. Either, the user must decide which is the most relevant route and define a source term accordingly, or try out both routes separately by performing two interactive calculations with two respective source terms.

#### 1.4 Specification of user source terms in RODOS PV6final

Figure 3 shows the possibilities to specify user source terms in RODOS PV6final.

In direct interaction with RODOS via dynamic initialisation windows that open automatically at run time, the user can build up source terms from scratch by hand, or base the input on an already existing "start-up source term" taken from:

- A "RODOS Library" containing established source terms for Pressurised Water Reactors (PWRs|VVERs), for other reactor types, and for exercise scenarios, see Table 3<sup>3</sup>.
- A "Public Library" that mainly serves for source term exchange between RODOS users working at the same RODOS system.
- The "Private Library", in which each user can keep source terms inaccessible for other users. Apart from that, this library always contains the last previously applied source term of the user, which is stored there automatically.

A start-up source term can be used in a RODOS calculation with or without modifications made by the user.

On termination of the interactive phase, the general user may add the freshly defined source term to the private or to the public library, but not to the RODOS library - this only a system administrator can do. This facility enables to build up a private source term library, or to share source terms with other users working at the same RODOS system.

With the *Export* and *Import* features [2] of the RODOS operating system, users can exchange source terms with users working at the same or other RODOS systems, or with non-RODOS programs. Imported source terms are added to the private library of the user applying the feature, see Figure 3.

## 1.5 Tasks distribution in the source term interface STERM

The interface STERM between the input of source terms for RODOS on the one hand and the source term input for the Near\_ADMs on the other hand is realised with four functionally independent program packages that are all embedded in the Analysing Subsystem ASY of RODOS. In addition, all code packages can operate as self-consistent stand-alone programs with all source term libraries and data; however, a user interaction at runtime is then not possible.

STERM/DIAG steers in the automatic operation mode of RODOS the construction of the diagnosis and prognosis Near\_ADM source term from the normal operation, measured, user, or measurement+user input source term.

The flow of the user input with the dynamic initialisation windows is controlled by STERM/UINPUT. Directly after the input was made, checks are performed. If there are errors, the user is forced to correct them interactively. On termination of STERM/UINPUT the user source term is "approved".

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<sup>3</sup> This "RODOS-library" replaces the former fixdata source term library.

From the approved user source term, STERM/UMAKEQ calculates the complete Near\_ADM source term, starting from the begin and ending with the termination of all (significant) releases, as defined by the user, in time steps of fixed duration determined by the target Near\_ADM.

STERM/UINPUT and STERM/UMAKEQ work in the automatic as well as in the interactive operation mode. If in a given context it is only relevant to know that the "user source term package" is involved, they are summarily referred to as "STERM/USER".

The source term input by the user and the calculation of the complete Near\_ADM source term is totally de-coupled from the time-step-wise delivery of portions of the entire Near\_ADM source term to the Near\_ADM. The latter task is the domain of STERM/UTONear\_ADM, that is not only applied for user source terms, but also for source terms from measurements and mixed "measurement + user" source terms.

### 1.6 Documentation of the source term interface

The documentation of the source term treatment in RODOS consists of several RODOS internal reports that are listed below.

Overview and Model Description	
RODOS(RA2)-TN(03)-03 (Draft Version 2)	Source Term Treatment for Nuclear Accidents in RODOS PV6final
User Guides (Source Term Related Parts of the Guides)	
(RODOS internal report without internal number)	User Guide for the Prognosis Models of RODOS PV6final
(RODOS internal report without internal number)	User Guide for the Automatic Mode of RODOS PV6final
STERM Code and Files	
RODOS(RA2)-TN(04)-03 (Draft Version 2)	User Source Term Interface STERM/USER(NPP) in RODOS PV6final
RODOS(RA2)-TN(04)-04 (Draft Version 2)	Near_ADM Source Term Interface STERM/UTOADM(NPP) in RODOS PV6final
RODOS(RA2)-TN(04)-05	Diagnosis Source Term Interface STERM/DIAG(NPP) in RODOS PV6final REPORT DOES NOT EXIST ---
STERM-Associated Codes and Files	
RODOS(RA1)-TN(02)-04 (Draft Version 2)	FixData nuclides, near range nuclides, and far range nuclides, in RODOS PV6final
RODOS(RA1)-TN(03)-01 (Final Draft)	

Mapping of data between user-defined and Near_ADM time intervals
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RODOS(RA1)-TN(04)-01 (Draft Version 2)
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RODOS MODEM source term files (ASCII) for nuclear accidents in RODOS PV6final
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## 2. From the source term input for RODOS to the Near\_ADM source term

### 2.1 Source term information required in RODOS

A radiological source term characterises the quantity, composition, and time behaviour of a release of radioactivity to the environment. In that respect, RODOS needs the following information:

1. The time delay between the end of the chain reaction and the beginning of the release (hours).
2. The beginning of the release (date and time).
3. The released activity (various parameterisations and units, see text).
4. The release height above ground (m).
5. The released thermal power (MW).
6. (SINCE RODOS PV6.0) Vertically volume flux released to the atmosphere ( $\text{m}^3/\text{s}$ ).
7. (SINCE RODOS PV6.0) Vent area of the release to the atmosphere ( $\text{m}^2$ ).
8. The percentage of the total amount of iodine released as elementary and organically bound iodine, and iodine in aerosol form (e. g. CsI), the so-called iodine fractions.

Items 3 to 8 in above list depend on the time. The Near\_ADMs work with source term information given in contiguous time steps with constant duration of 10 minutes for diagnosis and 30 minutes for prognosis or episode calculations. On side of the source term input, however, the time specification is completely different. The input time intervals are described in Chapter 2.2, the Near\_ADM time intervals in Chapter 3.1.1, and the mapping between the two in Chapter 3.4.

With respect to the activity release, the Near\_ADMs work with activity release rates for individual radionuclides (Bq/s). However, on input RODOS accepts also a variety of other parameterisations that are wanted by the users or predetermined by measurements, see Chapter 2.3.

Activity release specifications in other formats must be converted to activity release rates for the Near\_ADMs. The ideas and problems involved in the corresponding calculations are outlined in Chapters 2.4 and 2.5. A detailed description of the formalism and the underlying assumptions is given in Chapter 3. Actually, it is that conversion that demands the specification of the time delay between the end of the

chain reaction and release begin; this information is not used by the Near\_ADMs.

The release height corresponds normally to the height of the stack or to the point of release from the reactor building. In case of a release of unknown thermal energy with an estimation of the excess height of the plume being available, the latter may be taken into account by specifying the estimated effective height for the height of release and zero for the thermal power.

Some source term providers give the release of iodine directly as the iodine activities released in the three chemical forms. If such source terms are to be used in RODOS, the available information must first be converted to the total amount of iodine released and the three relative iodine fractions. If only the total iodine release is available without reference to the chemical form, it will automatically be assumed in RODOS that iodine is released purely in elemental form; this is the most conservative assumption for the near range because elemental iodine has the strongest atmospheric deposition.

More details about the input items and the allowed value ranges are given in the RODOS "User Guide for the Prognosis Models".

## **2.2 Source term time specifications on the input side**

From RODOS version PV5.0 onwards, the input of time-dependent source term items is accepted for time intervals with variable duration that are defined by the provider of the source term. Between 1 and 24 time intervals can be used for a source term specification. That means, for example, if a release would be constant over time, one time interval suffices. On the other hand, if a release would strongly vary over time, the information must be condensed so that it fits into the 24 "time boxes" maximally available.

The lower and upper boundaries of the time intervals must be given in terms of decimal hours after the start of the release. The time intervals must not overlap but need not to be ordered with respect to ascending time. There is no principal upper limit for the duration of a source term, provided that the specification fits into 24 time intervals; however, there is a practical limit as the duration of an interactive prognosis calculation is 47 days since RODOS-PV5.0.

The time span between the onset and the final termination of all (significant) releases needs not to be covered continuously. For time periods without release specification it is assumed in RODOS that there is no release. However, for any time period with release

specification there must be non-zero release data (else error message and run termination).

### 2.3 Activity release specifications on the input side

RODOS version PV6final allow for seven ways, or "source term input modes", to specify the activity release for a nuclear accident. They are listed in Table 6, together with an identification key; the numbering of the keys is historical<sup>4</sup>.

The data to be put in for modes F2 and F6 are the same. However, with mode F2 it is checked in each time step, that the activity release does not exceed the activity present in the reactor, which is calculated taking into account the activity release from the reactor and radioactive decay and build-up from radioactive decay chains in the reactor. If the calculated value is exceeded the latter is taken, a message is issued, and program execution continues.

The release specifications for the artificial normal operation source term and for exchange source terms between RODOS and external programs have all the type F6.

The release data in the automatic mode <Emergency|Monitored Stack Release> are parameterised in the mode F3. For the release fractions for aerosols, the data from release category FK2 of the German Risk Study Phase A are used<sup>5</sup>.

Library source terms and source terms created by the user with the dynamic initialisation windows can have all allowed formats.

Several modes in Table 4 refer to "nuclide release groups", which are groups of nuclides showing similar behaviour with respect to their accidental release from a reactor. In RODOS PV6final, different release group schemes, or "nuclide release blocks" can be considered<sup>6</sup>. Table 7 shows the currently implemented release blocks, by means of a block key and the release groups making up the block.

### 2.4 Calculation of the activity release rates for the Near\_ADMs

The Near\_ADMs of RODOS demand the activity release as release rates for individual radionuclides. The "radionuclides" are here a subset of 1 to 25 "near range nuclides" selected for the near range Near\_ADM

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<sup>4</sup> And difficult to re-arrange!

<sup>5</sup> This is hard-wired in the code.

<sup>6</sup> This is now already possible on the level of the dynamic initialisation windows. In all predecessor versions, it was only possible on the level of "source term input from file".

from all possible "RODOS nuclides", that is defined by the user during a RODOS run. Table 4 and Table 5 show the default setting for the near range nuclides for nuclear accidents and the nuclides possible in RODOS, respectively.

From Table 6 it can be seen that only input mode F7 shows the Near\_ADM parameterisation. However, input modes F2 and F6 need obviously only a conversion of "activity released" to "activity release rate", which is performed by assuming a constant release rate in each time interval.

For input mode F1, the activity release is specified as initial release fractions for nuclide groups, and for modes F3, F4, and F5 as released activity for nuclide groups or a combination of individual nuclides and nuclide groups. All these modes require a decomposition of the information into data for individual radionuclides. For that purpose, a nuclide-specific activity inventory is used to provide a reference radionuclide spectrum. The start-up inventory is taken from a RODOS library, see Chapter 3.3. During each Near\_ADM time step the inventory is updated, taking into account the activity released from the reactor as given by the release specifications, and, for the activity remaining inside, the radioactive decay and the build-up of daughter nuclides from radioactive decay chains.

The conversion of the initial release fractions of mode F1 to activity release rates causes no conceptual ambiguities between the input side and the Near\_ADM side. Modes F3, F4, F5, however, have the inherent general problem that the input data refer to sums of radionuclides without unambiguous specification of the nuclides that were taken into account when generating the sums. In RODOS, there is the additional specific problem that the sums refer to the "calculation nuclides" subset described in the 1<sup>st</sup> paragraph of this Chapter. This means that the resulting Near\_ADM release rates necessarily depend on the selection of the calculation nuclides.

(SINCE RODOS PV6.0) For the "last applied user source term" STERM/UMAKEQ always produces data for all those modes in Table 6 that are derivable from the original input mode, in the time parameterisation of the input side. Such source terms have the mode key "FX", indicating that they are in "multiple-input mode format", and are kept in the private library of the user. They can be re-used as start-up source terms in another RODOS run, thereby exploiting the possibilities to switch between input modes with the dynamic initialisation windows, see the "User Guide for the Prognosis Models", Chapter on "Source Term Initialisation Windows".

All conversion processes are described in detail in Chapter 3.

## 2.5 Ranges of application of the different source term input modes

The activity release data for source terms of generic nature from PSA-studies are always derived for a utility representative of its kind and are usually given as initial release fractions (key F1). This parameterisation makes possible to apply them to reactors of similar type but different power. Of course they should not be applied blindly to reactors of types other than those they were intended for.

Release data in the form "Bq or Bq/s for individual radionuclides" (keys F6, F7) are taken in RODOS without any reference to a reactor inventory. This allows to use them even in the case that an inventory is by some reason not available because none is provided for the site under consideration, or not foreseen, or not of interest for a particular application, for example in some exercises. Release data of this type must only be used for the special application, reactor type and state they were originally intended for.

There exist accident scenarios without reactor shutdown prior or during a release. This means that application of the formalism from Chapter 3 for modes F1, F2, F3, F4, and F5, makes no sense because nuclides are created or destroyed at any moment by fission processes not accounted for at all. In such situations, input modes F6 and F7 are the only remaining options.

Because of the conceptual difficulties described in Chapter 2.4, input modes F3, F4, F5 should be used only if release information in other form is not available. The results of calculations with such source terms should be carefully analysed and interpreted, and used with the necessary caution.

The multiple-input mode FX-source terms must be applied only for a utility with the same thermal power and days of operation, and for the same selection of calculation nuclides, as in the run in which the source term was calculated. All these conditions are checked and lead to an error exit when violated.

### 3. Physical formalism for generating the Near\_ADM source term

#### 3.1 General formalism; treatment of source term input modes F7, F6

##### 3.1.1 *Near\_ADM time intervals; necessary conversions; modes F7 and F6*

Figure 4 illustrates the times and time intervals involved in the calculation of Near\_ADM source terms. The time of the initial onset of the release(s),  $t_0$ , is given directly by the user, the release duration is derived from the specifications of the input source term.

$T_0$  becomes the time zero for the Near\_ADM time intervals that have equal widths  $\Delta t_{ADM}$  defined by the target Near\_ADM: 10 minutes for diagnoses, and 30 minutes for prognoses. One of these intervals, the one denoted by the interval number  $i_{max}$  in Figure 4, contains the end of all (significant) releases. For the source term calculations, only the first  $1 \dots i_{max}$  NEAR\_ADM time intervals are relevant.

Each value of a source term item on the input side must be converted into values in the Near\_ADM time intervals. In addition, activity release specifications referring to nuclide groups, or to a combination of individual nuclides and nuclide groups, must be converted into nuclide-specific activity release rates representing constant average rates in each Near\_ADM time interval, for each of the Near\_ADM calculation nuclides mentioned in Chapter 2.4.

The conversion process always begins with the mapping of all source term input quantities given for one of the modes from Table 6 from the input time intervals onto the Near\_ADM time intervals. How this is handled is described in Chapter 3.4.

For source term input mode F7, the Near\_ADM source term generation is therewith finished.

For input mode F6, the resulting total nuclide-specific activity releases in every Near\_ADM time interval only have to be divided by  $\Delta t_{ADM}$  [s] to generate the average release rates [Bq/s].

All other modes need further processing, see below.

##### 3.1.2 *Calculation of radioactive decay; STERM nuclides*

Time zero for the source term calculations is the time  $t_{EOC}$  of the end of the chain reaction (EOC). The time span  $\Delta t_{EOC}$  between  $t_{EOC}$  and  $t_0$  is given by the input specifications (see Figure 4).

In the following,  $I(t,n)$  shall denote the activity inventory of some nuclide  $n$  in the reactor known at some time  $t$  after the end of the chain reaction. In a time period  $\Delta t$  following  $t$ , in which no releases occur,

only radioactive decay is accounted for, but no other physical or chemical processes.

Equation 1a describes the decrease of  $I(t,n)$  by radioactive decay for a nuclide  $n$  that is not member of a decay chain. If nuclide  $n$  does belong to a decay chain, the decrease of  $I(t,n)$  is accounted for, and also the increase from all first-level decays  $m \rightarrow n$  that feed nuclide  $n$ , by using the analytical Equation 1b.

**Equation 1: Radioactive decay and decay chain contributions**

**(Equation 1a)**

$$I(t + \Delta t, n) = I(t, n) \cdot e^{-\lambda_n \Delta t}$$

**(Equation 1b)**

$$I(t + \Delta t, n) = I(t, n) \cdot e^{-\lambda_n \Delta t} + \sum_m \left\{ \frac{\lambda_n}{\lambda_n - \lambda_m} \cdot f_{mn} \cdot I(t, m) \cdot [e^{-\lambda_m \Delta t} - e^{-\lambda_n \Delta t}] \right\}$$

with

$I(t+\Delta t, n)$  (wanted) activity inventory [Bq] of nuclide  $n$  at time  $t+\Delta t$

$I(t, n)$  (given) activity inventory [Bq] of nuclide  $n$  at time  $t$

$t$  time [s] after EOC

$\Delta t$  duration [s] of interval following time  $t$  without releases

$n$  radionuclide (see text)

$m$  radionuclide with decay  $m \rightarrow n$  (see text)

$f_{mn}$  fraction of decays of nuclide  $m$  that lead to nuclide  $n$ ,  
with  $0 < f_{mn} \leq 1$

$\lambda$  radioactive decay constant [1/s]

For the radioactive decay calculations with Equation 1b, a special subset of the RODOS nuclides, the "STERM-nuclides", is used. This subset contains all Near\_ADM calculation nuclides  $n_c$ , plus all possible RODOS nuclides  $m^k$  from decay chains  $m^k \rightarrow m^{k-1} \rightarrow \dots \rightarrow m^1 \rightarrow n_c$  that finally feed calculation nuclide  $n_c$ . By evaluating Equation 1b for a time interval  $(t, t+\Delta t)$  for all STERM nuclides  $m^k$ , the 1<sup>st</sup> order decays  $m^1 \rightarrow n_c$  and all other pairwise decays  $m^k \rightarrow m^{k-1}$  are exactly described. However, each higher-level contribution appears at the next lower level  $(k-1)$  only after time span  $\Delta t$ , and it would take  $(k-1)$  repetitive calculations of that type before a contribution from the  $k$ 'th level would have made the way down to the target nuclide  $n_c$ . For improving the accuracy of the approximation for nuclides with radioactive half-lives in the order of  $\Delta t$  or smaller, each interval  $\Delta t$  is subdivided into finer

intervals, and the calculations are carried out with Equation 1b recursively with these finer intervals until time  $t+\Delta t$  is reached. The nuclides for off-site accident consequence assessments for nuclear power plants and their respective mothers typically possess radioactive-half lives not shorter than 10 minutes and decay chains with one or two levels; for them, a division of  $\Delta t/10$  suffices.

A recursive representation of Equation 1 is implemented in program package STERM. The decay chain definitions from [4] are contained in a file in a symbolical representation as mother-daughter pairs especially developed for this purpose, together with the respective decay fractions  $f(m^k, m^{k-1})$  from [4]. Thereby, decays via intermediate states with radioactive half-lives in the order of a few minutes or less are represented by the direct decay route. A special code package, SETCHN ("SETUp of decay CHaiNs"), was developed for the reading of the file, followed by an automated analysis and setting-up of the corresponding STERM nuclides and mother-daughter decays relevant for the current Near\_ADM calculation nuclides in a RODOS run. In this way, STERM and SETCHN work completely automatically with pair-wise relations without any reference to the sequence of decays in the decay chains.

Equation 1b and the idea for the formalism base on reference [5], Chapter 15. It has been tested with the reactions  $\text{Bi-211} \rightarrow \text{Tl-207} \rightarrow \text{Pb-207}$  and  $\text{Bi-212} \rightarrow \text{Tl-208} \rightarrow \text{Pb-208}$  that are displayed and discussed in P. Marmier and E. Sheldon, Physics of Nuclei and Particles, Volume 1, Academic Press 1969, pp. 275-281.

### 3.1.3 Recursive calculation of the activity released in each Near\_ADM time step

With Equation 2a below, the activity  $A(t+\Delta t, n)$  [Bq] of nuclide  $n$  released at time  $t+\Delta t$  after a release-free time interval  $\Delta t$  is expressed by an "instantaneous release fraction"  $x_i$  of the current activity inventory  $I(t+\Delta t, n)$  from Equation 1 that is released. The fractions  $x_i$  refer to the groups of nuclides showing similar behaviour with respect to accidental releases from a reactor already mentioned in Chapter 2.3, so that by definition all nuclides belonging to the same group have the same release fraction.

The activity inventory  $I'$  remaining in the reactor after the release is then simply obtained by the subtraction of  $A$  from  $I$ , see Equation 2b.

#### Equation 2: Recursive calculation of released activity

<p><b>(Equation 2a)</b>     <math>A(t + \Delta t, n) = x_i(t + \Delta t, j_n) \cdot I(t + \Delta t, n)</math></p>
---

**(Equation 2b)**  $I'(t' = t + \Delta t, n) = I(t + \Delta t, n) - A(t + \Delta t, n)$

with

$A(t+\Delta t, n)$  (*wanted*) released activity [Bq] at time  $t+\Delta t$

$I(t+\Delta t, n)$  (*given*) activity inventory [Bq] at time  $t+\Delta t$ , from Equation 1

$x_i(t+\Delta t, j_n)$  instantaneous release fraction

$t$  time [s] after EOC

$\Delta t$  duration [s] of interval following time  $t$  without releases

$n, j_n$  nuclide  $n$  belonging to release group  $j_n$

In program package STERM, the activity inventory  $I'$  is used in Equation 1 to provide the start-up inventory for the calculation of the released activity with Equation 2 after the next release-free time period  $\Delta t$  following time  $t+\Delta t$ , and so on. This is a recursive solution of the problem that requires only a start-up inventory and the instantaneous release fractions as input.

For each of the  $1 \dots i_{\max}$  Near\_ADM time intervals in Figure 4, the simplifying assumption is made that all releases occurring in the interval take place condensed in time at the centre point<sup>7</sup>, and that the rest of the interval is release-free. Under this assumption, the tandem of Equation 1 and Equation 2 are applied recursively at each centre point of the  $1 \dots i_{\max}$  intervals, for each STERM nuclide. In the first interval, the duration of the release-free time period is  $\Delta t = \Delta t_{\text{EOC}} + \Delta t_{\text{ADM}}/2$ , and for the remaining  $2 \dots i_{\max}$  intervals it is  $\Delta t = \Delta t_{\text{ADM}}$ <sup>8</sup>. For each Near\_ADM calculation nuclide, the resulting activities are then divided by the duration  $\Delta t_{\text{ADM}}$  to yield release rates, and these are passed to the Near\_ADMs.

The shorter the radioactive half-lives are in comparison with the duration of a time interval, the larger the error due to this approximation becomes; it is negligible for radionuclides with radioactive half-lives significantly exceeding the interval duration. The most relevant radionuclides for off-site accident consequence

<sup>7</sup> This is NEW in RODOS PV6.0. In previous versions it was the lower edge of the Near\_ADM interval. Therefore, if one wants to exactly reproduce the results from older runs,  $\Delta t_{\text{EOC}}$  must be reduced by  $0.5 \cdot \Delta t_{\text{Near\_ADM}}$  for otherwise identical source terms.

<sup>8</sup> In fact, to minimise the number of calculation steps,  $k$  consecutive Near\_ADM time intervals without release followed by one time interval with release are condensed to one time interval with duration  $\Delta t = (k+1) \cdot \Delta t_{\text{Near\_ADM}}$ .

assessments for nuclear power plants have radioactive half-lives in the order of half an hour or more, and the Near\_ADM time interval duration in RODOS is currently 10 or 30 minutes, respectively. Given that, and given that the uncertainties in the knowledge of source terms are typically large, the accuracy of the above approximation seems sufficient.

When the algorithm sets in with the end of the chain reaction, the start-up inventory is the inventory at EOC that is provided for in RODOS, see Chapter 3.3.

The conversion into nuclide-specific activity release rates from input specifications referring to nuclide groups or to a combination of individual nuclides and nuclide groups, requires additional procedures to determine the instantaneous release fractions for Equation 2b, see Chapter 3.2.

### 3.2 Application of general formalism for source term input mode F1 to F5

#### 3.2.1 Mode F1

The release specifications for F1-source terms are "initial release fractions"  $x_{EOC}$  in percent applying to the initial radionuclide inventory,  $I_{EOC}$ , in the reactor at the end of the chain reaction, and to nuclide release groups  $j_n$ .

The release fractions  $x_{EOC}(i, j_n)$  after the time-mapping described in Chapter 3.1.1 divide the initial inventory into compartments  $A(i, n) = 0.01 \cdot x_{EOC}(i, j_n) \cdot I_{EOC}(n)$  to be released in Near\_ADM-time interval  $i$  ( $1 \leq i \leq i_{max}$ ). For  $i > 1$ , the released activity  $A(i, n)$  can alternatively also be expressed with instantaneous release fractions  $x_i$  and the inventory remaining in the reactor after the release in the previous time step as  $A(i, n) = x_i(i, j_n) \cdot I(i-1, n)$ , and  $I(i-1, n)$  can be expressed by  $(1 - 0.01 \cdot x_{EOC}(1, j_n) - 0.01 \cdot x_{EOC}(2, j_n) - \dots - 0.01 \cdot x_{EOC}(i-1, j_n)) \cdot I_{EOC}(n)$ , which provides a method to obtain for each time step an instantaneous release fraction from the initial ones, see Equation 3.

#### Equation 3: Derived instantaneous release fractions for input mode F1

$$\text{For } i = 1 : \quad x_i(1, j_n) = 0.01 \cdot x_{eoc}(1, j_n)$$

$$\text{For } i = 2 \text{ to } i_{max} : \quad x_i(i, j_n) = 0.01 \cdot x_{eoc}(i, j_n) / \left( 1 - \sum_{k=1}^{i-1} 0.01 \cdot x_{eoc}(k, j_n) \right)$$

with

$x_i$  (wanted) instantaneous release fraction

$x_{EOC}$  (given) initial release fraction in percent,

$$\text{with } x_{EOC}(k, j_n) \leq 100 \text{ and } \sum_{k=1}^{k=i_{\max}} x_{EOC}(k, j_n) \leq 100$$

i            index of Near\_ADM time interval,  $1 \leq i \leq i_{\max}$   
n, j<sub>n</sub>        nuclide n belonging to release group j<sub>n</sub>

In order to obtain the instantaneous release fractions  $x_i(i, j_n)$  required for the application of Equation 2a, program package STERM evaluates Equation 3 for all Near\_ADM time intervals and nuclide release groups before beginning with the recursive source term calculations. Apart from that, the calculations proceed as described in Chapter 3.1.3.

### 3.2.2 Mode F5

The release specifications for F5-source terms quantify after the time-mapping the activity [Bq] released,  $A(i, j_n)$ , in each Near\_ADM-time interval  $i$  ( $1 \leq i \leq i_{\max}$ ) for the different release groups  $j_n$ .

According to Equation 2a,  $A(i, j_n)$  can be used together with the calculated activity inventory in the reactor,  $I(i, n)$ , to obtain for each time step an approximate instantaneous release fraction, see Equation 4.

#### Equation 4: Derived instantaneous release fractions for input mode F5

$$x_I(i, j_n) = A(i, j_n) / \sum_{n \in j_n} I(i, n)$$

with

$x_I$             (*wanted*) instantaneous release fraction  
 $A(i, j_n)$     (*given*) activity [Bq] released in Near\_ADM time interval  $i$ ,  
for release group  $j_n$   
 $I(i, n)$       (*given*) activity inventory [Bq] in Near\_ADM time interval  
 $i$ ,  
for radionuclide  $n$   
 $i$             index of Near\_ADM time interval,  $1 \leq i \leq i_{\max}$   
 $n, j_n$         nuclide  $n$  (see text) belonging to release group  $j_n$

In program package STERM, Equation 4 is evaluated for all release groups  $j$  in each Near\_ADM time step  $i$  to obtain the instantaneous

release fractions  $x_{i,j_n}$  required for the application of Equation 2a. Apart from that, the calculations proceed as described in Chapter 3.1.3.

There are two problems with Equation 4. The first problem is inherent in the formalism, namely which radionuclides shall be taken into account when summing up the activity inventories. This problem is discussed in Chapter 3.2.6.

The second problem is that the specified value for the released activity may exceed the calculated activity inventory in a time interval. In such cases, the calculated value is taken, a corresponding message is issued, and program execution continues.

### 3.2.3 Mode F2

With respect to the input data, mode F2 is identical to F6 and only the conversion from [Bq] to [Bq/s] described in Chapter 3.1.1 is needed. However, for F2 it shall be checked that the specified activity release does not exceed the activity present in the reactor in each time step.

Therefore, the same calculations as for mode F4 are carried out, with two differences. The first difference is that the sums of the released activity  $A(i,j_n)$  in each Near\_ADM-time interval  $i$  for each release group  $j_n$  are not given directly by the input specification, but have to be determined by summing up the nuclide contributions from the individual radionuclides. The second difference is that the result of the evaluation from Equation 2a, the released activity  $A(i,n)$ , is not used as a result but as a reference for the input specification. If the input value is smaller or equal to the reference value, the input value is taken. If the input value exceeds the reference value, the reference value is taken, a corresponding message is issued, but program execution continues.

### 3.2.4 Mode F4

The user specification with source term input mode F4 consists of two different types of data. The first is the released activities  $A(i,NOB)$ ,  $A(i,IOD)$ ,  $A(i,AER)$  for the sum of nuclides belonging to the three release groups noble gases, iodine, total aerosol, respectively, for each Near\_ADM-time interval  $i$  (after the time mapping). The second are the initial release fractions  $x_{EOC}(j_{aer})$  for aerosol release groups  $j_{aer}$ , which account for the fact that different aerosol nuclides can have different release properties. In RODOS PV6final, these fractions cannot be given for different time intervals, that is, they are assumed to represent average values with respect to time.

The release fractions for the noble gas group and the iodine group are calculated with Equation 4, using the calculation nuclides belonging to each group and the user-specified activities for the respective group.

For the aerosol nuclides, account is taken for the user-supplied initial release fractions  $x_{EOC}(j_{aer})$  by using these fractions as weights for the different aerosol nuclide release groups to the user-specified total released aerosol activity in the manner described below.

To start with, the fractions  $x_{EOC}(j_{aer})$  are divided by the total number of Near\_ADM time steps to ensure that the algorithm does not artificially create an emptied reactor in the process of the calculations. Then, intermediate fractions  $x_i(i,j_{aer})$  applying to the inventory remaining in the reactor before the releases take place are derived: for time intervals with aerosol release by using  $x_{EOC}(j_{aer})$  in Equation 3; for time intervals  $i$  without aerosol release  $x_i(i,j_{aer})$  is zero. In a next step, these intermediate fractions  $x_i(i,j_{aer})$  are used to calculate the nuclide-specific activity releases  $A(i,n)$  with Equation 2a for all aerosol nuclides, and after that the quantity  $A(i,aer)$  is calculated by summing up all aerosol calculation nuclides contributions  $A(i,n)$ . Finally, the fractions  $x_i(i,j_{aer})$  are multiplied with the ratio  $F=A(i,AER)/A(i,aer)$  to obtain fractions  $x_i(i,j_{aer})$  which are applicable in Equation 2a and yield  $A(i,AER)$  as a total.

Finally, equipped with the release fractions  $x_i(i,j_n)$  for all times  $t_i$  and release groups  $j_n$ , the calculation of the nuclide-specific activity release proceeds as described in Chapter 3.1.3.

If the user specification of the released activity exceeds the calculated activity inventory in the reactor in a time interval, the calculated value is taken, a corresponding message is issued, and program execution continues.

### 3.2.5 Mode F3

The user specification in source term input mode F/ST3 consists of three different types of data for each Near\_ADM-time interval  $i$  (after the time mapping): The released activities  $A(i,NOB)$  and  $A(i,AER)$  for the sum of nuclides belonging to the noble gas and aerosol group, respectively, the released activity  $A(i,I-131)$  for the Iodine-131 isotope, and the initial release fractions  $x_{EOC}(j_{aer})$  already described for mode F4.

The procedure for obtaining the release fractions for the noble gas group is the same as in Chapter 3.2.2. The procedure for obtaining the release fractions for the various aerosol groups is the same as in Chapter 3.2.4. The release fractions for the iodine group are obtained with Equation 4 and the user-specified activities of I-131.

Equipped with the release fractions  $x_i(i,j_n)$  for all times  $t_i$  and release groups  $j_n$ , the calculation of the nuclide-specific activity release proceeds as described in Chapter 3.1.3.

If the user specification of the released activity exceeds the calculated activity inventory in the reactor in a time interval, the calculated value

is taken, a corresponding message is issued, and program execution continues.

### 3.2.6 *Remark on the nuclides contributing to the sums*

When Equation 4 is applied to obtain the release fractions  $x(t_i, j)$ , it is clear that the result depends on which nuclides belonging to group  $j$  are included in the evaluation of the sum.

It is less clear what to do - take into account all nuclides of the respective group with activity inventory data  $\neq$  zero, or all STERM internal nuclides, or only the calculation nuclides selected by the user for the run? An in addition, it is not too clear what exactly the user expects or intends specifying the activity released for a nuclide group, but selecting only some nuclides from the group for the calculations.

For the time being, the sums in STERM are calculated with the calculation nuclides only, because this provides a unique and controllable reference for the quantity "released activity for nuclides in a given group" by specifying exactly which nuclides contribute to the sum value for the group.

## 3.3 **Activity inventory at the end of the chain reaction**

For source term input modes F1 to F5, the nuclide-specific activity inventory at the end of the chain reaction for the reactor under consideration is required as start-up inventory for the Near\_ADM source term calculations. For each nuclear power plant installed in its fixdata base, RODOS contains a reference to an applicable radionuclide inventory file. Reference [7] lists the cross-references between sites and files<sup>9</sup>, and reference [8] all inventory files provided with the RODOS system. The file format and content is described in the code documentation or STERM/USER [1].

The files contain the activity inventory in [Bq] in a reactor for different radionuclides, for one value of the nominal thermal power, and for between one and four values of the operation time at the given nominal thermal power. According to [9], p. 1 and p. 10, these data can be interpolated linearly with Equation 5 to approximate the inventory for other values of thermal power and operation time, if necessary.

### **Equation 5: Interpolation of radionuclide inventory**

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<sup>9</sup> If, by some reason, there is no applicable inventory file for a given site, "UNDEFINED" is specified in the reference field. In that case, source term input modes F1 to F5 are not applicable, and STERM will reject any attempts use them.

$$I(n;t,p) = \frac{p}{p_g} \cdot I(n;t_i,p_g) + \frac{p}{p_g} \cdot \left[ I(n;t_{i+1},p_g) - I(n;t_i,p_g) \cdot \frac{t-t_i}{t_{i+1}-t_i} \right]$$

with

$I_{EOC}(n;t,p)$       (*Wanted*) Activity inventory [Bq] at EOC of nuclide n,  
for thermal power p [MW],  
after operation time t [days] with  $t_j < t < t_{j+1}$ .

$I_{EOC}(n;t_i,p_g)$ ,  
 $I_{EOC}(n;t_{i+1},p_g)$       (*Given*) Activity inventories [Bq] at EOC of nuclide n,  
for thermal power  $p_g$  [MW],  
after operation times [days]  $t_i$  and  $t_{i+1}$ ,  
operation time indices i and i+1 in the inventory file,  
with  $t_i < t_{i+1}$ .

In STERM, it is the task of code package "SETINV ↔ SETup of INVenTory" to providing the start-up radionuclide inventory by using the respective data file and Equation 5. With respect to the operation time, three special cases can occur; Equation 6 describes their treatment.

**Equation 6: Special cases for calculating the radionuclide inventory**

$$t < t_1 \quad I(n;t,p) = \frac{p}{p_g} \cdot I(n;t_1,p_g)$$

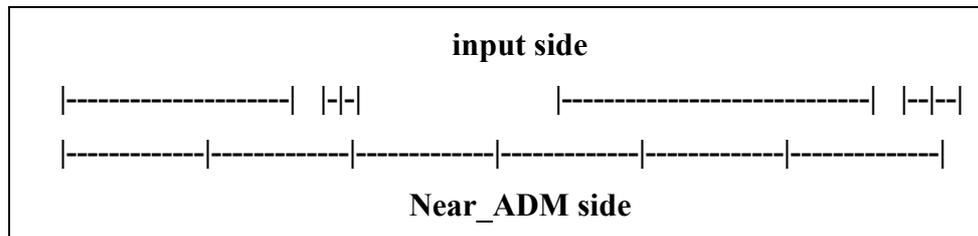
$$t > t_{imax} \quad I(n;t,p) = \frac{p}{p_g} \cdot I(n;t_{imax},p_g)$$

$$t = t_i \quad I(n;t,p) = \frac{p}{p_g} \cdot I(n;t_i,p_g)$$

**3.4 Mapping of source term and meteorological items between input and Near\_ADM time intervals**

Since RODOS PV5.0, the input specification of time-dependent source term and meteorological items comes in time intervals of variable duration defined by the provider, but the Near\_ADMs still work with the contiguous time intervals of equal width. As a consequence, one input interval may cover several Near\_ADM intervals, or more than one input interval lie in the same Near\_ADM interval, or an

Near\_ADM time interval is not covered by any input interval (the latter is possible only for source terms) as the diagram below illustrates:



The "contents" of each input interval, that is, the numerical values of the different physical quantities, have to be mapped from the input side to the Near\_ADM side. In order to yield one value for the respective target interval, the value(s) from all input intervals covering the target interval must be split or combined or taken as they are. With respect to the behaviour when subjected to such procedures, all physical source term and meteorological quantities can be attributed to one of the four classes below:

1. Quantities that behave additive, as for instance the amount of activity released in a time interval in [Bq] or percent of the initial activity inventory.
2. If one divides an additive quantity given in a time interval by the interval duration, the resulting value describes a rate that is constant in the time interval. Rate-like behaviour is expressed by the activity release rate [Bq/s], the released thermal power [MW], and the vertically released volume flux [m<sup>3</sup>/s].
3. Some physical quantities are connected to a special "marker" event in the sense that without that event they lose their meaning. Such quantities do not allow straightforward averaging over time periods with and without the marker event. An example is the release height [m]. When a release is going on, the release height has some definite value  $\geq 0$  m. However, when there is no release, there is simply no release height, and not a release height of 0 m. The vent area of the release [m<sup>2</sup>], and the relative iodine fractions also belong to this category.
4. Some quantities defy an easy treatment with respect to the time mapping, because there are either mathematical or conceptual problems, or both. Examples are the meteorological quantities "wind direction" (no straightforward treatment because of the cyclic value range) and the "Pasquill-Gifford diffusion category" (conceptually difficult).

For each of the above type classification, a procedure was developed for the mapping from incoherent disordered (but not overlapping) time

intervals with variable widths on the one side to contiguous equidistant time intervals on the other side<sup>10</sup>, and realised in code package UMAPIT [10]. Tables 1 and 2 of [10] link all source term and meteorological quantities to suitable UMAPIT subroutine(s). The actual mapping is then carried out in STERM by calling for each source term variable the appropriate UMAPIT subroutine.

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<sup>10</sup> For additive quantities, there exists also a procedure for the most general problem, the mapping between incoherent disordered (but not overlapping) time intervals with variable widths on both sides.

#### 4. Figures

Figure 1: Role of Source Term Interface in RODOS

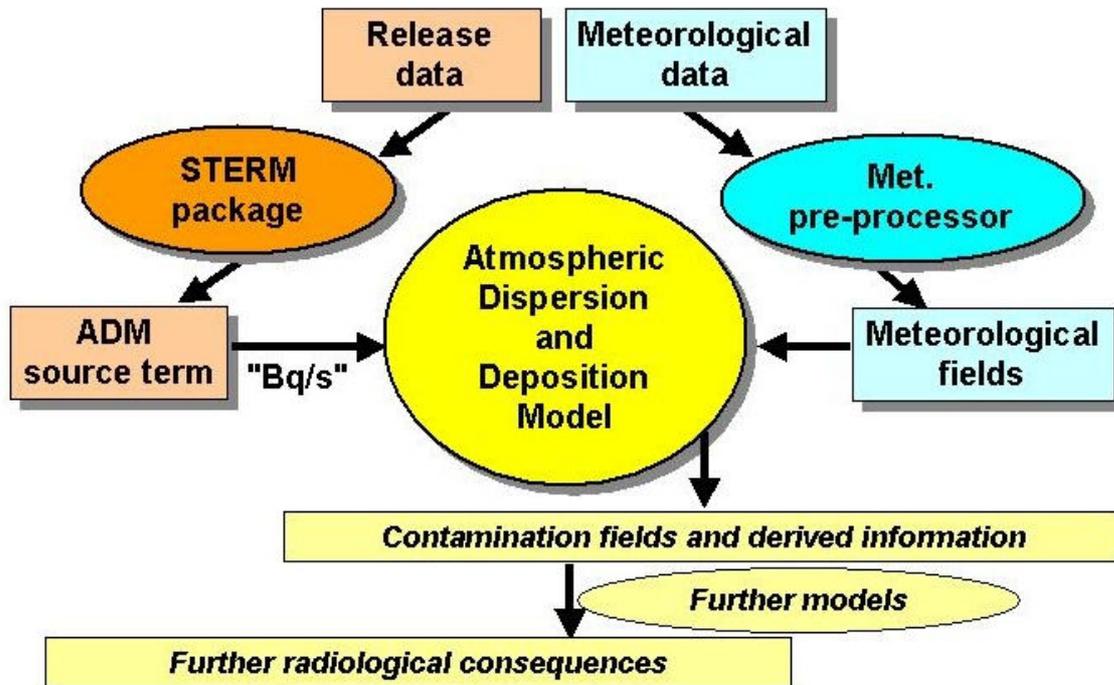


Figure 2: Nuclear Accident Phases and RODOS Source Term Input

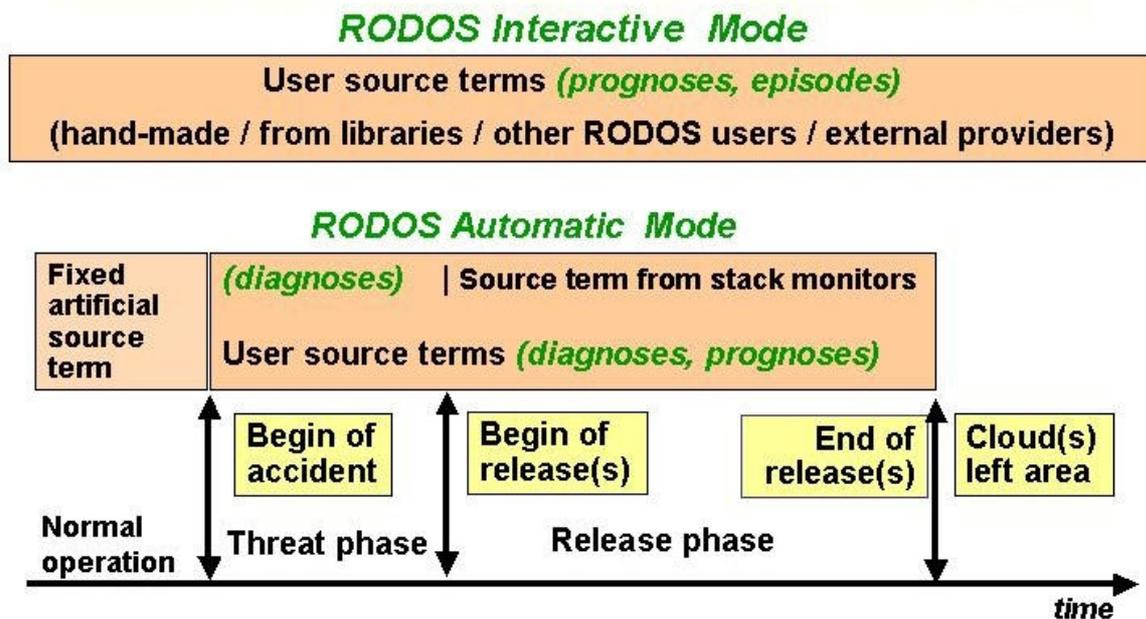


Figure 3: Possibilities for User Source Term Input in RODOS

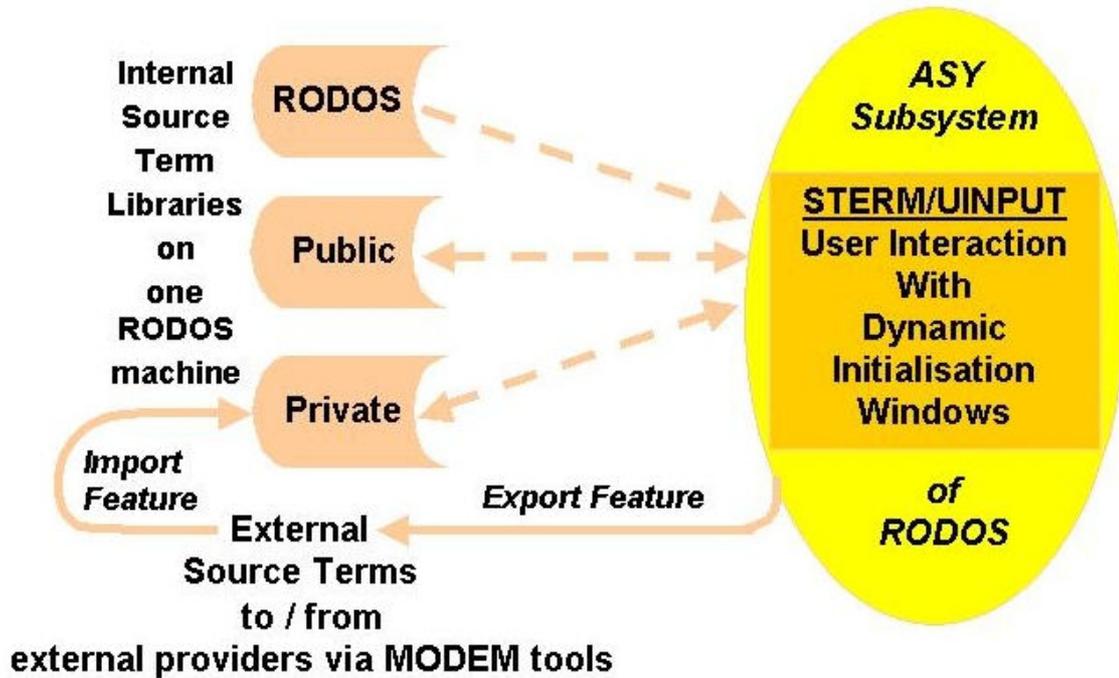
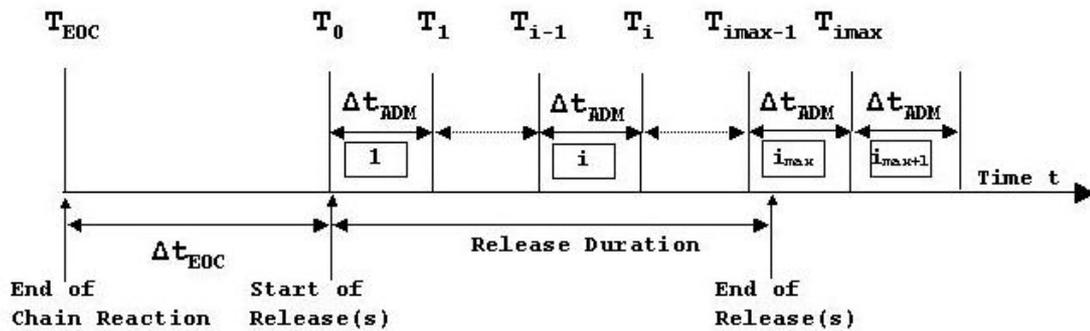


Figure 4: Time Axis and Denotations for Source Term Calculations



## 5. Tables

**Table 1: Default Source Term in RODOS Automatic Mode <Normal Operation>**

Release assumed at stack height with the following artificial release rates:	
Kr- 88	: 1.0 10 <sup>17</sup> [Bq/h]
Xe-133	: 3.0 10 <sup>17</sup> [Bq/h]
Xe-135	: 0.6 10 <sup>17</sup> [Bq/h]
I -131	: 1.6 10 <sup>14</sup> [Bq/h]
Zr- 95	: 1.6 10 <sup>14</sup> [Bq/h]
Te-132	: 1.6 10 <sup>14</sup> [Bq/h]
Cs-137	: 1.6 10 <sup>14</sup> [Bq/h]

**Notes:** Zr-95 is included for the German Far Range Near\_ADM. The system administrator may change the default normal operation source term to satisfy national preferences, see reference [11].

**Table 2: Source Term Data in RODOS Automatic Mode <Emergency|Monitored Stack Release>**

Measured 10 minutes averages, release at stack height:	
Gamma activity for I-131	[Bq/h]
Gamma activity for "total noble gas"	[Bq/h]
Gamma activity for "total aerosol"	[Bq/h]

**Note:** Also recorded are the stack exhaust temperature and the air volume stream that are used in RODOS to derive the thermal energy associated with the release.

**Table 3: Source terms in the RODOS source term library (August 2004)**

Source terms for PWR-type reactors, e.g. <ul style="list-style-type: none"> <li>from "Deutsche Risikostudie Kernkraftwerke - Phase A" (German Risk Study - Phase A) [12]</li> <li>from "Deutsche Risikostudie Kernkraftwerke - Phase B" (German Risk Study - Phase B) [13]</li> </ul>
Source terms for BWR-type reactors, e.g. COFRENTES (General Electric) in Spain.
VVER source terms for severe accidents (VVER440, VVER1000), and design basis accidents (VVER1000) developed for the RODOS project in the EC Fourth Framework Programme
Source terms for other reactor types (pool, heavy water, ...)
Source terms for exercises and demonstrations with RODOS (e.g. LWR exercise source terms of the International Nuclear Emergency Exercise INEX 1 adapted for use

in RODOS)

**Note:** Reference [8] contains a list of all source terms in the RODOS source term library.

**Table 4: Default near range nuclides in RODOS**

Kr- 85m \* Kr- 85 \* Kr- 88 \* Xe-133 \* Xe-135  
 I -131 \* I -132 \* I -133 \* I -135  
 Rb- 88 \* Sr- 89 \* Sr- 90 \* Zr- 95 \* Ru-103 \* Ru-106 \* Te-131m \*  
 Te-132 \* Cs-134 \* Cs-136 \* Cs-137 \* Ba-140 \*  
 Pu-238 \* Pu-241 \* Cm-242 \* Cm-242

**Note:** Zr-95 is included for the German Far Range Near\_ADM.

**Table 5: Radionuclides and radionuclide compounds in RODOS**

T -3x (HT) <sup>11</sup>	TO-3x (HTO) <sup>11</sup>				
Na-24					
Mn-54					
Co-58	Co-60				
Se-75					
Kr-85m	Kr-85	Kr-87	Kr-88		
Rb-86	Rb-88				
Sr-89	Sr-90	Sr-91	Sr-92		
Y -90	Y -91				
Zr-95	Zr-97				
Nb-95					
Mo-99					
Tc-99m					
Ru-103	Ru-105	Ru-106			
Rh-105					
Ag-110m					
Sb-127	Sb-129				
Te-127m	Te-127	Te-129m	Te-129	Te-131m	Te-131
Te-132	Te-133m	Te-133	Te-134		
I -129	I -131	I -132	I -133	I -134	I -135
Xe-133	Xe-135	Xe-138			

<sup>11</sup> Due to the RODOS naming rules, HT is coded as "T^3x", and HTO as "TO-3x".

Cs-134	Cs-136	Cs-137	Cs-138		
Ba-140					
La-140					
Ce-141	Ce-143	Ce-144			
Pr-143					
Nd-147					
Yb-169					
W -185	W-187				
Ir-192					
Po-210					
Ra-226					
U -234	U -235	U -238			
Np-239					
Pu-238	Pu-239	Pu-240	Pu-241		
Am-241					
Cm-242	Cm-244				
Cf-252					

**Notes:**

Table 5 contains currently 79 radionuclides comprising:

- All radionuclides considered for LWR accidents in the German Risk Study Phase A [12, p. 17] and the German Leitfaden [9, p. 8, 9].
- Additional radionuclides for complementation of some potentially important radioactive decay chains.
- Some activation products or other radionuclides that may be of relevance for LWR reactors in normal operation mode, for Fast Breeder Reactors, or for fusion reactors. They were put into the database on request of RODOS users.
- The radionuclide compounds HT and HTO for fusion reactors.
- Nuclides identified as potentially relevant for RODOS calculations involving radiological emergencies [14], plus Po-210 (due to the Po-210 incident in England in 2006).

**Table 6: Activity release input modes for nuclear accidents in RODOS**

key	specification of the activity release <sup>1)</sup>
F1	Fractions [%] of the initial activity inventory released for some set of nuclide release groups known to RODOS <sup>2)</sup> .
F5	Released activity [Bq] for the sum of calculation nuclides <sup>3)</sup> in some set of nuclide release groups known to RODOS <sup>2)</sup> .
F3	Released activity [Bq] for I-131 and the sums of calculation nuclides <sup>3)</sup> in the noble gas and

	total aerosol <sup>5)</sup> group, together with release fractions for a fixed set of aerosol release groups <sup>4)</sup> .
F4	Released activity [Bq] for the sums of calculation nuclides <sup>3)</sup> in the noble gas, iodine and total aerosol <sup>5)</sup> group, together with release fractions for a fixed set of aerosol release groups <sup>4)</sup> .
F2	Activity release [Bq] for individual nuclides - with inventory reference.
F6	Activity release [Bq] for individual nuclides - without inventory reference.
F7	Activity release rate [Bq/s] for individual nuclides - without inventory reference.

**Notes**

- 1) All input modes also need the specification of the start of initial release, the release height, the released thermal power, the vertically released volume flux, the vent area of the release, and the iodine fractions.
- 2) The sets of nuclide release groups (also called "nuclide release blocks") known to RODOS are shown in Table 7.
- 3) Calculation nuclides are a subset of 1 to 15 nuclides from all possible nuclides selected for a run. If, for instance, a release of 10E18 Bq is specified for the noble gas group, the results would be different if Kr- 88 only or Kr- 88, Xe-133, Xe-135 were selected as calculation nuclides.
- 4) These are the aerosol groups in nuclide release block "DRS-A\_7\_GROUPS" of Table 7.
- 5) "Aerosols" means here fission products released to the atmosphere as solid or liquid suspensions in air via a carrier (e.g. CsJ, NaOH etc.).

**Table 7: Possible nuclide release blocks and groups**

<b>release block key</b>	<b>release groups contained in nuclide release block</b>
NOBLE-JOD-AEROSO	01 noble gases 02 iodine 03 aerosols (all aerosol nuclides are treated equally!)
DRS-A_7_GROUPS	Groups from the German Risk Study, Phase A [12]: 01 noble gases 02 iodine 03 alkaline metal 04 tellurium/antimony 05 alkaline earth 06 ruthenium group 07 lanthanides
DRS-A_7_GROUPS09	As DRS-A_7_GROUPS plus HT and HTO: Groups No1 to 7 as for DRS-A_7_GROUPS 08 tritium (HT) 09 tritiated water (HTO)
DRS-B_9_GROUPS	Groups from the German Risk Study, Phase B [13]: 01 noble gases 02 iodine 03 alkaline metal 04 tellurium/antimony 05 strontium 06 barium 07 ruthenium group 08 lanthanides 09 cerium group
MAAP4_10_GROUPS	01 noble gases 02 iodine 03 rubidium 04 strontium 05 ruthenium group 06 alkaline earth 07 barium 08 lanthanides 09 actinides 10 tellurium

## 6. Abbreviations and Acronyms

Near_ADM Model	Atmospheric Dispersion and Deposition Model
ASY	Analysing subSYstem of RODOS
EOC	End Of Chain reaction
LWR	Light Water Reactor
KFÜ	German nuclear reactor remote surveillance system ("KernreaktorFernÜberwachung")
PSA	Probabilistic Safety Assessment
RODOS	Real-time On-line Decision support System
SETCHN	code package "SETup of decay CHaiNs"
SETINV	code package "SETup of INVentory"
SETNUK	code package "SETup of NUKlides"
SETRLG	code package "SETup of ReLease Groups"
STERM	RODOS Source TERM Interface
VVER	VVER is the Soviet (now, Russian Federation) designation for pressurised (light) water reactor. In western countries, PWR is used as acronym.

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