



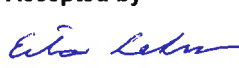
**RESEARCH REPORT**

VTT-R-04644-17

# **Computation of conditional large early release probabilities of piping components**

Authors: Tero Tyrväinen

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| <b>Summary</b>   |   |
| <p>In-service inspections are applied to safety important pipe components in nuclear power plants (NPPs) to ensure their structural reliability. In risk-informed in-service inspections (RI-ISI), these inspections are planned according to risk importance of piping components. The quantitatively computed risk of a piping component combines the probability of the failure and the associated consequences.</p> <p>This report focuses on estimating the consequences of piping component failures. Conditional large early release probability (CLERP) is used as the consequence measure. It is demonstrated how CLERP values of piping component failures can be calculated automatically in the new RI-ISI feature of probabilistic risk assessment (PRA) software FinPSA. The RI-ISI feature enables detailed modelling of the consequences of piping component failures without complicating the PRA model itself.</p> |   |
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| <b>Written by</b>  | <b>Reviewed by</b>  |
|   |  |
| Tero Tyrväinen<br>Research Scientist   | Otso Cronvall<br>Senior Scientist   |
| <b>Accepted by</b>   |   |
|   |   |
| Eila Lehmus<br>Research Team Leader  |   |
| <b>VTT's contact address</b>   |   |
| P.O. Box 1000, 02044 VTT   |   |
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## 1. Introduction

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In-service-inspections are applied to safety important pipe components in nuclear power plants (NPPs) to ensure their structural reliability. In Finland, in-service-inspections are planned carefully so that the risk of nuclear accident, employees' exposure to radiation and the cost of inspections are in balance and within acceptable limits. This approach is called risk informed in-service inspection (RI-ISI) [1].

Probabilistic risk assessment (PRA) is used to calculate the quantitative risk of a nuclear accident and to analyse the importance of different systems and components [2]. PRA's main purpose is to support risk informed decision making. PRA also supports RI-ISI analyses by quantifying the consequences of pipe failures.

A previous research project report [3] presents a study concerning the connection between PRA and RI-ISI analyses. In that report, it was identified that it would be beneficial to develop automatic piping failure consequence calculator in PRA software. Hence, report [4] introduced a new RI-ISI feature which calculates the conditional core damage probabilities (CCDPs) of piping component failures in the PRA software FinPSA [5]. Conditional large early release probability (CLERP) is another important consequence measure. Therefore, this report extends the previously developed RI-ISI feature by adding CLERP computation capability.

The rest of this report is structured as follows. FinPSA software is briefly presented in Section 2. Section 3 discusses how CLERP values can be calculated. Section 4 presents the RI-ISI feature in FinPSA software, and Section 5 demonstrates the CLERP computation with a simplified example model. In Section 6, the software design of the CLERP computation is elaborated. Section 7 concludes the study.

## 2. FinPSA

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FinPSA is a software tool for full-scope PRA [5]. FinPSA supports PRA levels 1 and 2. Level 1 PRA concerns accident sequences leading to core damage and calculation of the core damage frequency. Level 2 PRA concerns the progression of severe accidents after core damage and calculation of frequencies and amounts of radioactive releases.

In level 1 PRA, FinPSA uses event trees and fault trees [2, 6]. An event tree represents how an accident can evolve from an initiating event via failures of safety systems to a consequence, e.g. core damage. A fault tree represents which events can cause the analysed system to fail. Fault trees are linked to branching points in event trees. From fault trees, minimal cut sets are solved. Minimal cut sets are minimal combinations of events that can cause the top event, e.g. core damage. Probabilistic analysis is performed based on minimal cut sets and reliability data of components.

Level 2 PRA part of FinPSA is based on dynamic containment event trees (CETs) and CETL programming language [7]. The CETL language is used to define functions to calculate conditional probabilities of event tree branches, timings of the accident progression and amounts of releases. The CET models are solved by Monte Carlo simulations.

Large early release frequency (LERF) is usually considered as the main result of level 2 PRA. PRA levels 1 and 2 need to be integrated so that LERF can be calculated. In FinPSA, level 1 results are passed to level 2 as plant damage states (PDS). Level 1 results are categorised into PDSs using interface trees which are similar to event trees except that they take level 1 sequences as inputs. Each PDS has its own CET in level 2. Using level 1 event trees and interface trees in combination, minimal cut sets are generated for a PDS, and the frequency of the PDS is calculated from the minimal cut sets.

Verification and validation (V&V) procedures have been established for FinPSA [8, 9]. For each new version, a set of V&V runs/tests is performed. This set contains the most important validation runs (e.g. generation of minimal cut sets for a set of models) and tests for new and modified properties.

### 3. Conditional large early release probability

This chapter develops formulas for the computation of the CLERP. The first step is to calculate the probability/frequency of each PDS with the condition that the analysed piping failure occurs. Conditional plant damage state probability/frequency (CPDSP/CPDSF) can be calculated from the minimal cut sets in the same way as CCDP/CCDF in ref. [4].

Level 2 PRA part of the calculation is different because it contains a complex non-binary simulation model which does not contain basic events like level 1. Level 2 accident sequences are categorised into release categories. However, typically there is no release category for large early release. Instead, there are multiple release categories that correspond to large early release. The large early release can therefore be defined as a union of particular release categories.

#### 3.1 Basic case

The simplest computation case is that the analysed piping failure does not affect level 2 at all (except via PDSs), which is also the most common case. The existing level 2 results include mean frequencies of release categories separately for each CET. These frequencies are scaled by the CPDSP/CPDSF values divided by the original PDS frequencies. The resulting mean conditional probabilities/frequencies of the release categories belonging to the large early release from each CET are summed, and the result is the CLERP/CLERF. The CLERP of initiating event  $E$  is computed as:

$$CLERP_E = \sum_{l=1}^L \sum_{R \in LER} f_{R(l)} \times \frac{P(PDS_l | E=1)}{f_{PDS_l}}, \quad (1)$$

where  $L$  is the number of CETs/PDSs,  $R$  is release category,  $LER$  is the set of release categories belonging to the large early release,  $f_{R(l)}$  is the mean frequency of release category  $R$  in  $l$ :th CET,  $P(PDS_l | E = 1)$  is the conditional probability of  $l$ :th PDS and  $f_{PDS_l}$  is the frequency of  $l$ :th PDS. Equation (1) can easily be generalised for an event combination containing an initiating event and one or more basic events.

If the analysed piping failure is represented by basic event(s), CLERF is calculated first. The equation for CLERF is similar, except that the conditional frequency of the  $l$ :th PDS is included instead of conditional probability. However, CLERF values are not comparable to CLERP values. Therefore, CLERF values can be transformed into CLERP values using the following formula:

$$CLERP = 1 - e^{-CLERF \times t}, \quad (2)$$

where  $t$  is the time the piping failure is in effect.

#### 3.2 Tight integration of PRA levels 1 and 2

If tight integration of PRA levels 1 and 2 [10] is applied so that level 1 information is used in level 2 computation, the computation of CLERP is more complicated than in the "basic case". A typical way to use level 1 information in level 2 is to divide level 1 accident sequences into categories, and then calculate conditional probability of such sequence category in level 2 in order to calculate the probability of a CET branch. This conditional probability is the

probability that an accident sequence from the category has led to the plant damage state, given that the accident has progressed to the point where the conditional probability is calculated. The “basic case” assumes that all level 1 accident sequences leading to the same PDS affect the level 2 analysis similarly, but that is not the case if the conditional probability of a sequence category is used in level 2 computation.

When tight integration of PRA levels is used, contributions of level 1 sequences to release category frequencies are calculated. These contributions are conditional probabilities of level 1 sequences, given that the analysed release category is realised. They can be utilised in the computation of CLERP, because they show how different level 1 sequences affect level 2 results, and large early release frequencies related to different level 1 sequences can be calculated based on them.

To calculate CLERP correctly, one solution is to perform the computation with one level 1 sequence at the time:

$$CLERP_E = \sum_{l=1}^L \sum_{R \in LER} \sum_{k \in K(l)} f_{R(l)} \times F_{R(l)}(k) \times \frac{P(Seq_k|E=1)}{f_{Seq_k}}, \quad (3)$$

where  $K(l)$  is the set of level 1 sequences leading to  $l$ :th PDS,  $F_{R(l)}$  is the conditional probability of sequence  $k$  given release from category  $R$  with  $l$ :th PDS,  $P(Seq_k|E = 1)$  is the conditional probability of sequence  $k$  given event  $E$ , and  $f_{Seq_k}$  is the frequency of sequence  $k$ . Term  $f_{R(l)} \times F_{R(l)}(k)$  is the frequency of the release from release category  $R$  based on accident sequence  $k$ .

The above solution covers only the case where CETL language function SC\_INCL (see ref. [10]) is used, and the conditional probability of a level 1 sequence category determines the probability of a CET branch. This is the most typical case in the tight integration of PRA levels 1 and 2, but if level 1 information is used in some other way in level 2, there is no guarantee that the formula works, because the effects that the piping failure has on the level 2 results might not be correctly captured. In other cases, it is likely that correct CLERP cannot be calculated based on existing results, and that the PRA model needs to be solved again with modified input parameters (piping component set failed).

### 3.3 Piping failure in level 2 PRA

There is a possibility that a piping failure affects directly level 2 PRA (i.e. not only through PDSs), for example if some cooling system is used in severe accident management. Automatic computation of the CLERP for such piping failure is difficult because:

1. there is no standard way of modelling piping failures in FinPSA level 2,
2. it is difficult to trace back the effects of a particular variable value in level 2 only based on level 2 results in FinPSA.

Presumably, a piping failure would typically cause a failure of a cooling system either conditionally or unconditionally, and the cooling system failure would be a nodal question in a CET. Practically, it should then be calculated what the LERF is if the CET branch representing the cooling system failure has probability 1. It seems that this is not possible based on current FinPSA level 2 results. It would however be possible to add to the results some information (e.g. probabilities of CET branches) that would enable the conditional re-quantification, but only based on this speculation it is not considered worthwhile. The CLERP of a piping failure in level 2 can be calculated by setting the corresponding failure probability to 1 in the model and simulating the model again. Automatic computation support is not developed at this point.

It should be noticed that equation (6) proposed in the previous report [4] is incorrect. The equation is not revised in this report because of the above mentioned difficulties.

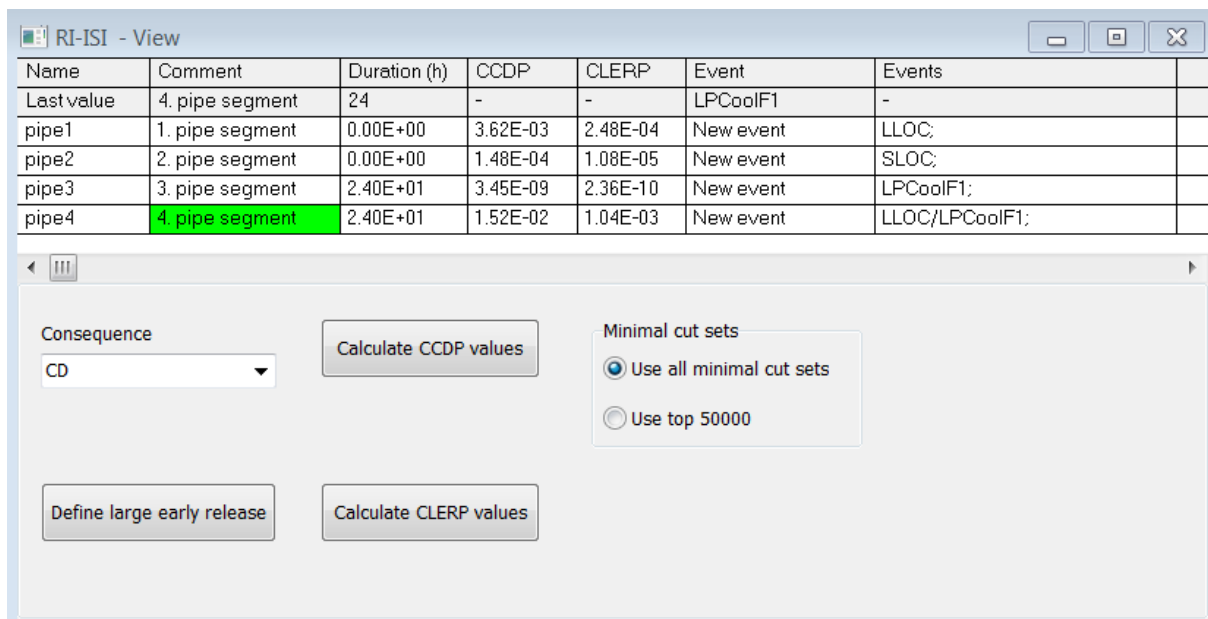
Sometimes severe accident management systems are modelled in interface trees instead of CETs. In that case, the computation can be performed as presented in Sections 3.1 and 3.2. Level 1 sequences in Section 3.2 are actually combinations of event tree and interface tree sequences (i.e. level 1 sequence is the whole path from the initiating event to the PDS).

## 4. RI-ISI table in FinPSA

This section presents a RI-ISI feature developed for FinPSA software [5]. The feature has been updated from [4] by adding CLERP computation. It is a table that specifies piping components and their consequences, and calculates CCDP and CLERP values based on PRA results. The table is a part of the FinPSA database. It is opened from FinPSA menu by choosing Database > RI-ISI. The feature contains two parts: the main part that can be used alone, and an additional part that can be used for more detailed modelling of piping failure consequences.

### 4.1 RI-ISI table

The main part of the RI-ISI feature is a table that contains a row for each piping component in the model. A RI-ISI table with four piping components is presented in Figure 1. The name column contains the name of the piping component, which is defined by user. The comment column can contain any further information of the piping component. Duration refers to the time the piping failure is in effect and is needed only when the piping failure causes a basic event (failure of a safety system component) in the PRA model. The CCDP column contains the calculated CCDP values, and the CLERP column contains the calculated CLERP values. The event column is used to add an initiating event or a basic event that is caused by the piping component failure. The events column contains the initiating events and basic events that the piping component failure causes.



| Name       | Comment         | Duration (h) | CCDP     | CLERP    | Event     | Events         |
|------------|-----------------|--------------|----------|----------|-----------|----------------|
| Last value | 4. pipe segment | 24           | -        | -        | LPCoolF1  | -              |
| pipe1      | 1. pipe segment | 0.00E+00     | 3.62E-03 | 2.48E-04 | New event | LLOC;          |
| pipe2      | 2. pipe segment | 0.00E+00     | 1.48E-04 | 1.08E-05 | New event | SLOC;          |
| pipe3      | 3. pipe segment | 2.40E+01     | 3.45E-09 | 2.36E-10 | New event | LPCoolF1;      |
| pipe4      | 4. pipe segment | 2.40E+01     | 1.52E-02 | 1.04E-03 | New event | LLOC/LPCoolF1; |

Figure 1. RI-ISI table.

The data records of FinPSA contain all the basic events and initiating events that are used in the PRA model. In this approach, piping components are separate from those events and do not appear in the PRA model (e.g. in fault trees). In the RI-ISI table, it is specified which

initiating events and basic events each piping component failure causes. One piping component failure can cause multiple events that are modelled in PRA. An initiating event or a basic event is assigned to the piping component by writing its name in the event column. Then, it is automatically added to the events column, which contains the list of all events that are caused by the piping component failure. For example, in Figure 1, pipe4 failure causes initiating event LLOC and basic event LPCoolF1.

Below the RI-ISI table in Figure 1, there is a function where a consequence is selected. CCDP computation has to be performed based on the PRA results of the consequence that represents core damage, but PRA model can contain several consequences for which results are calculated (e.g. different core damage types and economic consequences). Therefore, the user has to select which consequence represents the core damage in the model. In principle, the computation can also be performed with regard to other PRA consequences, but that is not the idea here.

The Define large early release button opens another window where release categories representing large early release can be selected, see Figure 2.

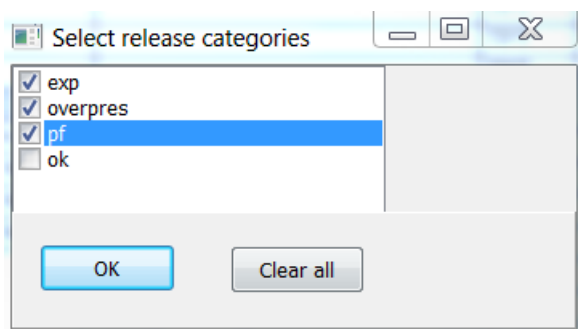


Figure 2. Release category selection window for large early release.

CCDP values for all the components of the table can be calculated using Calculate CCDP values button, and similarly, CLERP values can be calculated using Calculate CLERP values button. When a row in the table is modified, the corresponding CCDP and CLERP values are also updated automatically if the consequence and large early release have been defined.

## 4.2 Event combinations table

When a row is double-clicked in the RI-ISI table and the table is in view mode, another window is opened (respectively, the table is modified in edit mode). This window contains detailed analysis of the chosen piping component. An example of this window, event combinations table, is presented in Figure 3. The upper part of the window contains data from the RI-ISI table. The lower part contains a table that specifies different failure scenarios that can occur due to the piping component failure. In the table, it is possible to specify conditional probabilities for different piping failure consequences, e.g. a small LOCA occurs with a probability of 0.5 and a large LOCA occurs with a probability of 0.3. This table will be called “event combinations table” from this point forward.



| RI-ISI pipe11 - Edit     |                               |                        |              |                 |          |          |          |
|--------------------------|-------------------------------|------------------------|--------------|-----------------|----------|----------|----------|
| RI-ISI Component: pipe11 |                               | Duration: 0.00E+00 (h) |              | CCDP: 4.19E-03  |          |          |          |
| 1. pipe segment          |                               | Consequence: CD        |              | CLERP: 2.88E-04 |          |          |          |
| Index                    | Comment                       | Probability            | Duration (h) | 1. event        | 2. event | 3. event | 4. event |
| -                        | Large LOCA with LP cooling SS | -                      | 24           | -               | -        | -        | -        |
| 0                        | Small LOCA                    | 5.00E-01               | 0.00E+00     | SLOC            |          |          |          |
| 1                        | Large LOCA                    | 3.00E-01               | 0.00E+00     | LLOC            |          |          |          |
| 2                        | Large LOCA with LP cooling SS | 2.00E-01               | 2.40E+01     | LLOC            | LPCoolF1 |          |          |

Figure 3. Event combinations table.

Whereas in the table presented in Figure 1 it was possible to define only one combination of events that occur due to the piping failure, in the table presented in Figure 3, it is possible to define multiple combinations and assign conditional probabilities to them. The table of Figure 3 contains nine event columns where the names of the initiating events and basic events are placed (only four are shown in the figure). There is also a column for other events if the number of events is larger than nine, see Figure 4. In this column, the names of other events are listed and separated by '/'. A new event can be added (in addition to using the nine numbered event columns) using the event column, which is the last column in the table (by default) and works similarly as the event column of the RI-ISI table. It is also possible to define separate duration for each event combination. Duration longer than 0 in the table overrides the duration that appears in the upper part of the window. If the duration in the table is 0, the duration that appears in the upper part of the window is used in the computation.

| 5. event | 6. event | 7. event | 8. event | 9. event | Other events | Event     |
|----------|----------|----------|----------|----------|--------------|-----------|
| -        | -        | -        | -        | -        | -            | -         |
| adsg     | dsdg     | adfse    | qa       | fff      | g/jty/goo    | New event |
|          |          |          |          |          |              | New event |

Figure 4. The last columns in the event combinations table.

The CLERP is calculated as a weighted sum of the CLERP values of the event combinations (rows of the table):

$$CLERP = \sum_{i=1}^n P_i \times CLERP_i, \quad (5)$$

where  $P_i$  is the conditional probability of the event combination and  $n$  is the number of the event combinations. The CLERP values of the event combinations are calculated as described in Section 3.

The modifications that are made in this window affect the main RI-ISI table. For example, Figure 5 shows how the row of "pipe11" looks after the detailed piping failure consequence modelling. In the events column, different event combinations are separated by a semicolon. Conditional probabilities or combination specific durations are not shown in this table, but they belong to the "pipe11" data and affect the CCDP and CLERP computations.

| Name       | Comment         | Duration (h) | CCDP     | CLERP    | Event     | Events                     |
|------------|-----------------|--------------|----------|----------|-----------|----------------------------|
| Last value | 2. pipe segment | -            | -        | -        | -         | -                          |
| pipe11     | 1. pipe segment | 0.00E+00     | 4.19E-03 | 2.91E-04 | New event | SLOC; LLOC; LLOC/LPCoolF1; |
| pipe12     | 2. pipe segment | 0.00E+00     | 6.04E-03 | 4.19E-04 | New event | SLOC; LLOC; LLOC/LPCoolF1; |
| pipe13     | 3. pipe segment | 0.00E+00     | 8.35E-03 | 5.79E-04 | New event | SLOC; LLOC; LLOC/LPCoolF1; |
| pipe14     | 4. pipe segment | 0.00E+00     | 2.58E-03 | 1.79E-04 | New event | SLOC; LLOC;                |
| pipe15     | 5. pipe segment | 2.40E+01     | 3.45E-09 | 2.39E-10 | New event | LPCoolF1;                  |
| pipe16     | 6. pipe segment | 2.40E+01     | 4.50E-10 | 3.30E-11 | New event | HPCoolF2;                  |

RI-ISI - View

Consequence: CD Calculate CCDP values

Minimal cut sets:  Use all minimal cut sets  Use top 50000

Define large early release Calculate CLERP values

Figure 5. RI-ISI table after detailed piping failure consequence modelling.

## 5. Simple example case

A simple model with two LOCA scenarios is used to demonstrate the CLERP computation. The PRA model contains two initiating events, large LOCA and small LOCA, and corresponding event trees. The event trees are presented in Figures 6 and 7.

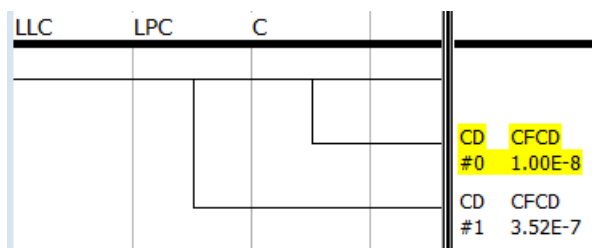


Figure 6. Event tree for large LOCA.

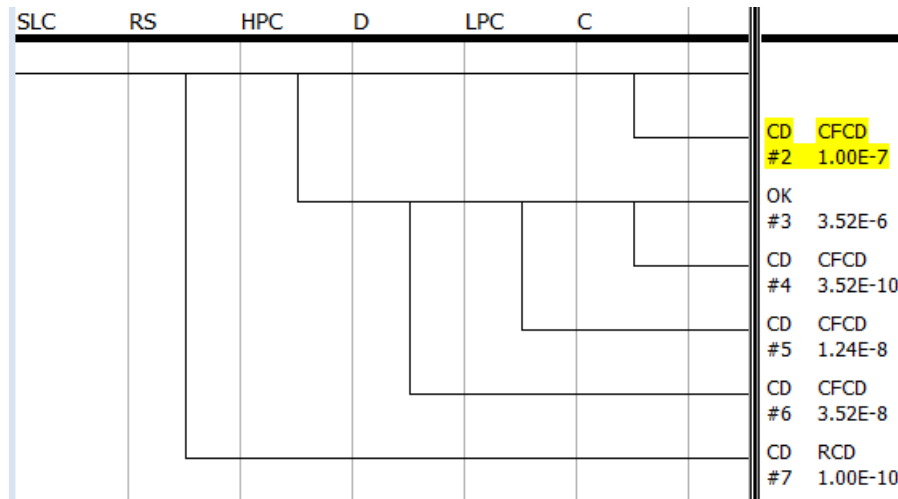


Figure 7. Event tree for small LOCA.

The event trees could correspond to a pressurized water reactor NPP, but they are very simplified and, thus, do not represent any actual NPP. In the case of large LOCA (LLC), core damage (CD) occurs if low pressure cooling (LPC) or recirculation cooling (C) does not work. In the case of small LOCA (SLC), core damage (CD) occurs if reactor scram (RS) does not work. If reactor scram works, core damage can be avoided if high pressure cooling (HPC) and recirculation cooling (C) work, or if depressurisation system (D), low pressure cooling (LPC) and recirculation cooling work. For HPC and LPC, two out of four subsystems are enough to provide adequate cooling. Failure probabilities for the safety systems are presented in Table 1. The frequency for large LOCA is  $1E-4$  and the frequency for small LOCA is  $1E-3$ .

Table 1. Failure probabilities of safety systems.

| System                              | Probability of failure |
|-------------------------------------|------------------------|
| Low pressure cooling – 1 subsystem  | $5E-2$                 |
| Recirculation cooling system        | $1E-4$                 |
| Reactor scram system                | $1E-7$                 |
| High pressure cooling – 1 subsystem | $5E-2$                 |
| Depressurization system             | $1E-2$                 |

The model contains two plant damage states: core damage with cooling failure (CFCF) and core damage with reactivity control failure (RCD). Figures 6 and 7 show the plant damage states of different accident sequences. The model contains two containment event trees representing severe accident progression of the two plant damage states. They are presented in Figures 8 and 9. The CETs are very simplified. They only consider initial pressure, depressurization, cooling system failure and hydrogen management. Four release categories are included in the model: containment failure due to over-pressurization, failure of containment penetrations, containment rupture due to hydrogen explosion and no release. All release categories except 'no release' are included in large early release. The CETL scripts of different sections of the CETs are presented in Appendix. They are the same for both CETs. The pressure is determined based on level 1 results, which means that levels 1 and 2 are tightly integrated in this model.

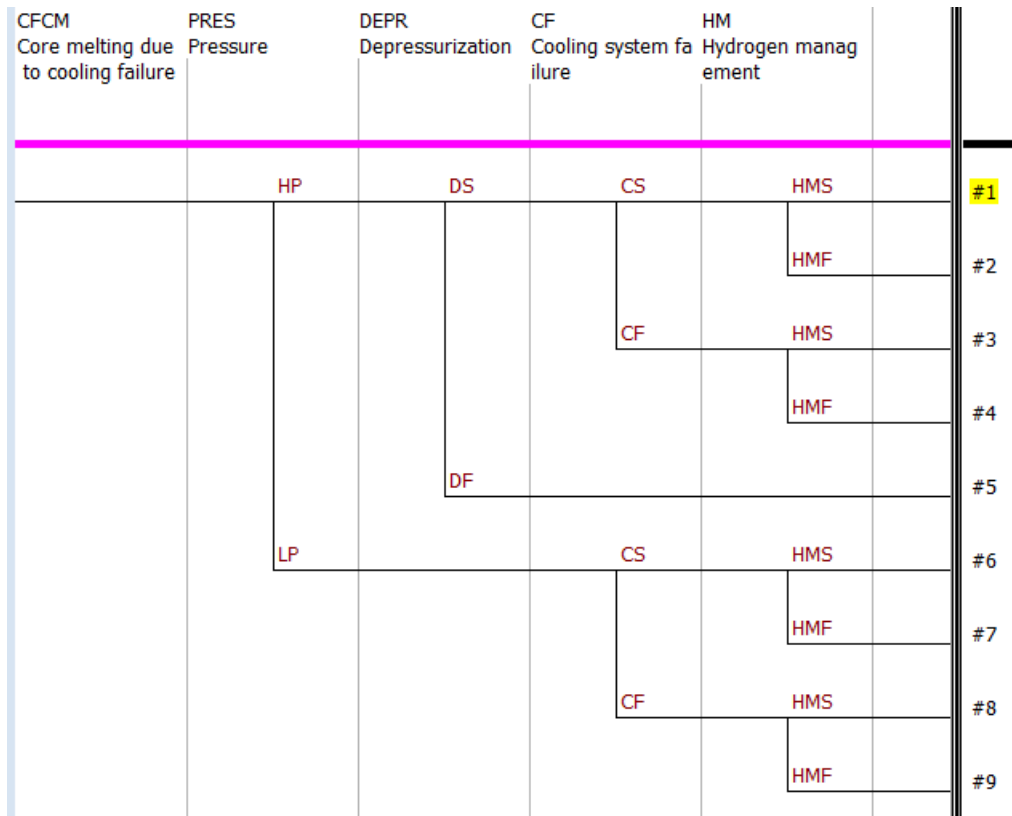


Figure 8. Containment event tree for high pressure core melting.

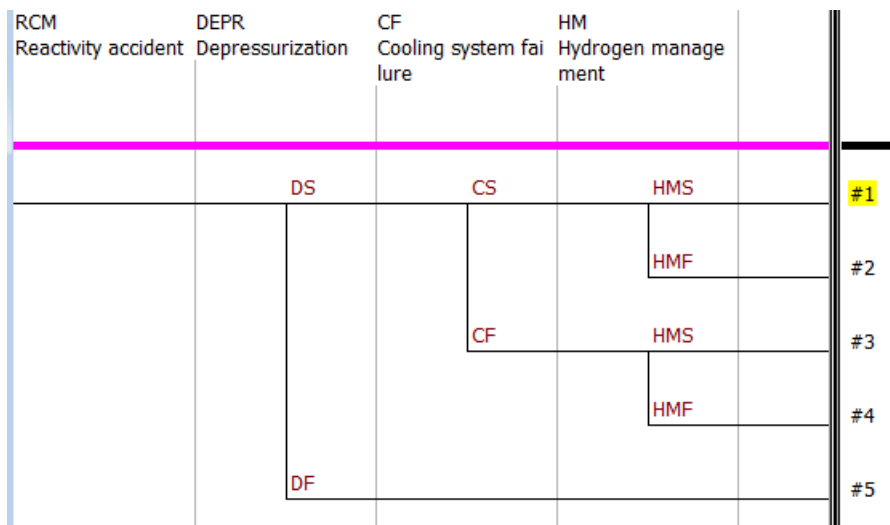
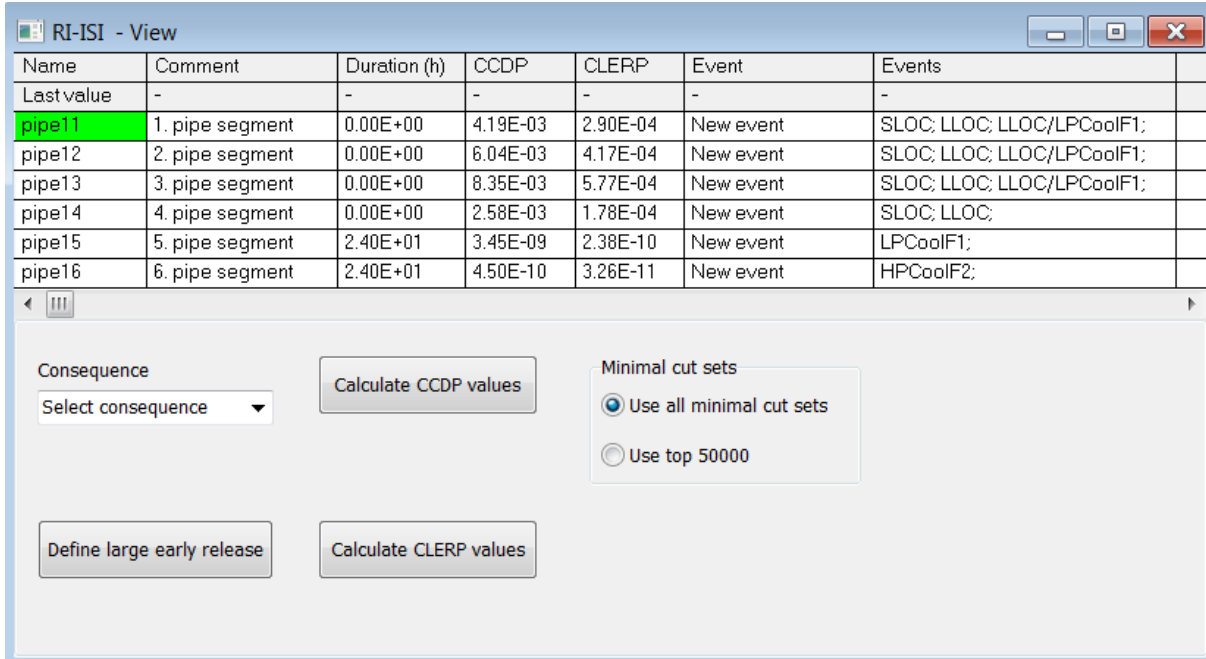


Figure 9. Containment event tree for reactivity accident.

Six different types of piping failures are considered possible in the model. They are represented by piping components pipe11-16. Piping failures can cause either a small LOCA (SLOC), a large LOCA (LLOC), combination of large LOCA and failure of one subsystem of low pressure cooling (LLOC/LPCoolF1), failure of one subsystem of low pressure cooling (LPCoolF1) or failure of one sub-system of high pressure cooling (HPCoolF1). It is assumed, that cooling functions are out of function for 24 hours if they fail.

Figure 10 and Table 2 present CLERP results for the example model. The middle part of Table 2 shows the conditional probabilities of event combinations. The same information is included in the FinPSA model in the same way as in the example of Figure 3. The last column of Table 2 shows the CLERP values of the piping components and the last row shows the CLERP values of the event combinations.



| Name       | Comment         | Duration (h) | CCDP     | CLERP    | Event     | Events                     |
|------------|-----------------|--------------|----------|----------|-----------|----------------------------|
| Last value | -               | -            | -        | -        | -         | -                          |
| pipe11     | 1. pipe segment | 0.00E+00     | 4.19E-03 | 2.90E-04 | New event | SLOC; LLOC; LLOC/LPCoolF1; |
| pipe12     | 2. pipe segment | 0.00E+00     | 6.04E-03 | 4.17E-04 | New event | SLOC; LLOC; LLOC/LPCoolF1; |
| pipe13     | 3. pipe segment | 0.00E+00     | 8.35E-03 | 5.77E-04 | New event | SLOC; LLOC; LLOC/LPCoolF1; |
| pipe14     | 4. pipe segment | 0.00E+00     | 2.58E-03 | 1.78E-04 | New event | SLOC; LLOC;                |
| pipe15     | 5. pipe segment | 2.40E+01     | 3.45E-09 | 2.38E-10 | New event | LPCoolF1;                  |
| pipe16     | 6. pipe segment | 2.40E+01     | 4.50E-10 | 3.26E-11 | New event | HPCoolF2;                  |

Consequence: Select consequence (dropdown)  
 Calculate CCDP values (button)  
 Minimal cut sets:  Use all minimal cut sets,  Use top 50000  
 Define large early release (button)  
 Calculate CLERP values (button)

Figure 10. RI-ISI table for the example model.

Table 2. CLERP computation for the example model.

| Failure combination | SLOC    | LLOC    | LLOC/LPCoolF1 | LPCoolF1 | HPCoolF1 | CLERP    |
|---------------------|---------|---------|---------------|----------|----------|----------|
| pipe11              | 0.5     | 0.3     | 0.2           | -        | -        | 2.90E-4  |
| pipe12              | 0.3     | 0.4     | 0.3           | -        | -        | 4.17E-4  |
| pipe13              | 0.3     | 0.2     | 0.5           | -        | -        | 5.77E-4  |
| pipe14              | 0.3     | 0.7     | -             | -        | -        | 1.78E-4  |
| pipe15              | -       | -       | -             | 1.0      | -        | 2.38E-10 |
| pipe16              | -       | -       | -             | -        | 1.0      | 3.26E-11 |
| CLERP               | 1.08E-5 | 2.50E-4 | 1.05E-3       | 2.38E-10 | 3.26E-11 |          |

Piping component pipe13 has the highest CLERP (5.77E-4) because it causes both large LOCA and failure of one subsystem of low pressure cooling with the highest probability (0.5). Those piping failures that cause only failures of safety cooling functions, but not initiating events, have insignificant CLERP values compared to piping failures that cause initiating events.

## 6. Software design for CLERP computation

This chapter is mainly targeted to the developers of FinPSA. The original software design of the RI-ISI table was presented in ref. [4]. The same structure has been maintained and, therefore, is not repeated in this report. The implementation of CLERP is similar to the implementation of CCDP, except for the computational part.

The functionality of the feature has also slightly changed. CCDP and CLERP values are calculated when the corresponding buttons are clicked, see Figure 1. It is also now possible to select whether all minimal cut sets or 50000 most important minimal cut sets are used in the calculation, see Figure 1. These updates required small changes in classes TRIISIForm and TRIISI compared to ref. [4].

The computation of CCDP has also been improved so that modules (sets of basic events with logically similar consequences) [11] can be utilised in the computation. This makes the computation much faster, because a smaller number of minimal cut sets needs to be handled. This improvement required an addition to take the modules into account in the ComputeCCDP function of CutLoad unit, and computation with closed modules needed also to be enabled in the SetCCDP function of the TRIISI class.

## 6.1 Selection of release categories

To calculate CLERP, release categories representing large early release have to be selected first. Therefore, new unit ReleaseCategories and new class TRCForm have been introduced to FinPSA. The user interface of TRCForm can be seen in Figure 2. The task of the class is to enable the selection of the release categories.

Class TRCForm has function UpdateInterface, which reads the release categories from the statistical analysis results files of all CETs (there is one for each CET if the whole model has been calculated). Then, the function sets a check box for each release category.

The class also contains function getLER, which returns the list of selected release categories.

## 6.2 Computation of CLERP

Class TRIISI contains function setCLERP, which performs the computation of CLERP. It is called from CLERPButtonClick procedure in the TRIISIForm class, which is executed when the Calculate CLERP values button is clicked. CLERPButtonClick procedure goes through the RI-ISI table and calls setCLERP for each TRIISI object.

Function setCLERP first calls getLER function of TRCForm to obtain the list of release categories. Then it goes through each containment event tree in the model. The computation can progress in two ways, as presented in Sections 3.1 and 3.2. For each CET, it is checked whether SC\_INCL function is used in the computation. This is done using variable ScInclUsed that was added to TLev1PDS class. The value of the variable is true if SC\_INCL is called during CET simulations. The value of ScInclUsed is written in the level 2 results after the simulations, and setCLERP function receives it from a TStatisticalResults object (see ref. [12]), which is created in setCLERP function. First, ReadStatisticalResults procedure of TStatisticalResults reads the meta data of existing CET results, and then, newly developed GetScIncl function of TStatisticalResults is called.

For each CET that does not contain SC\_INCL, setCLERP function:

1. finds the corresponding PDS minimal cut sets,
2. calculates the conditional plant damage state probability,
3. calculates the PDS frequency,
4. calculates the large early release frequency related to the considered PDS,
5. calculates the CLERP related to the considered PDS.

The conditional PDS probability is calculated based on existing minimal cut sets in the same way as CCDP in ref. [4]. The large early release frequency is calculated by summing the mean frequencies of different release categories. The frequencies of the release categories are received from the TStatisticalResults object. First, ReadStatisticalResults procedure of TStatisticalResults reads the summary table of existing CET results. Then, newly developed GetRCFrequency function of TStatisticalResults is called for each release category defined as large early release.

For each CET that contains SC\_INCL function, setCLERP function finds the corresponding PDS minimal cut sets, and goes through each release category leading to the large early release. For each large early release category, it goes through the list of contributing level 1 sequences. For each level 1 sequence, the function:

1. calculates the conditional probability of the sequence given the piping failure,
2. calculates the frequency of the sequence,
3. calculates the release category frequency related to the considered sequence,
4. calculates the CLERP related to the considered sequence.

The conditional probability of the level 1 sequence is calculated based on existing minimal cut sets of the corresponding PDS. The computation is similar to the CCDP computation presented in ref. [4] except that only minimal cut sets coming from the considered level 1 sequence are taken into account. The frequency of the sequence is also calculated based on PDS minimal cut sets. The release category frequency related to the considered sequence is calculated as the frequency of the release category multiplied by the contribution of the sequence to the release category frequency ( $f_{R(l)} \times F_{R(l)}(k)$  in equation (3)). These values are received from the TStatisticalResults object. First, ReadStatisticalResults procedure of TStatisticalResults reads the results related to the release category frequency. Then, newly developed GetRCFrequency and GetL1Seq functions of TStatisticalResults are called. GetL1Seq returns TPDSSeq object which contains the contribution of the sequence.

Finally, the CLERP is calculated as defined in equation (1) or equation (3). It can also be a combination of those, if some CETs contain SC\_INCL function and some do not.

## 7. Conclusions

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This report presents how CLERP computation is added to the previously developed RI-ISI table of FinPSA. The CCDP and CLERP values of all piping component failures can be calculated automatically at once in the same RI-ISI table, based on the results of the PRA model. This feature does not complicate the PRA model at all, regardless of how many piping components are included. The use of the RI-ISI table may however require pre-processing of the PRA model, because the worst pipe break location is typically assumed e.g. for LOCA. This means that a special configuration of the PRA model is created where some conservative assumptions related to piping failure consequences are removed, and piping failure consequence modelling is performed in the RI-ISI table instead.

The feature contains two levels and it supports, respectively, both simple and detailed piping failure consequence modelling. If there is one initiating or basic event for each piping component in the PRA model, only the first level of the feature can be used. It is, however, also possible to assign combinations of initiating and basic events to piping components, and even give conditional probabilities to different event combinations, if the user wants to model uncertainty in piping failure consequences.

CLERP computation does not appear in the official version of FinPSA. Currently, it is just a prototype. But it can be added to the official FinPSA release when the implementation is considered mature enough, and verification and validation have been performed. Currently, a significant problem is that the developer version containing CLERP computation is generally very slow for some reason. It would not be acceptable if the official version was that slow. It is important to get rid of this problem before the update can be released.

CLERP computation for an event that appears in level 2 part of the model is not implemented in FinPSA because of the difficulties discussed in Section 3.3. If a customer need arouses, it could however be possible to develop such computation support considering some specific type of cases. For now, the computation of CLERP values requires complete recalculation of the relevant model parts (e.g. particular CETs) with modified input parameters.

CCDP computation was improved significantly by enabling the computation with modules as described in Section 6. This improvement made also the level 1 part of CLERP computation much faster. However, CLERP computation has not been tested with a large model because there are no large models containing integrated levels 1 and 2 as available. This means that it is not possible to judge if the current solution is fast enough. The efficiency of the computation could be developed more, if needed. More efficient ways to structure the analysis could be found, and possibly some insignificant model parts could be left out of the computation.

Currently, the RI-ISI feature calculates only CCDP and CLERP values, but RI-ISI analyses require also failure probabilities of piping components. It could be possible to add failure probabilities to the RI-ISI table of FinPSA and implement some sort of inspection interval decision rules or optimisation algorithm. However, the approach to determine inspection intervals should be decided first. On the other hand, it is also simple to export CCDP and CLERP values to other applications, where inspection interval optimisation can be performed based on the results.

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## Appendix: CETL scripts of the example model

### Initial section:

```
real ST

source ST

sc_id LPC, HPC

routine sc_def
  LPC = 'LPC' | (('HPC' | 'LLC') & 'C')
  HPC = ~LPC
return

routine init
  binfreq = PDSCUTSFREQ()
return

routine finish

return

string FM

class FM

routine Binner active
('HE', 'Exp'),
('HP', 'OverPres'),
('CF', 'PF'),
(*, 'OK')
return
```

**PRES section:**

```
real p, y

routine init

return

function real LP
  FM = 'OK'
  ST = 0
  p = sc_incl(LPC)
return p

function nil HP
  y = sc_incl(HPC)
return nil
```

**DEPR section:**

```
real p, x

routine init
  p = ranlogn(0.005, 2)
  x = ranlogn(0.5, 1.5)
  if x > 1 then x = 1
return

function real DF
  FM = 'HP'
  ST = x
return p

function nil DS
  FM = 'OK'
  ST = 0
return nil
```

**CF section:**

```
real p, x

routine init
  p = ranlogn(0.05, 2)
  x = ranlogn(0.2, 2)
  if x > 1 then x = 1
return

function real CF
  FM = 'CF'
  ST = x
return p
```

```
function nil CS
  FM = 'OK'
  ST = 0
return nil
```

**HM section:**

```
real p1, p2, x
```

```
routine init
  p1 = ranlogn(0.02, 2)
  p2 = ranlogn(0.005, 2)
  x = ranlogn(0.1, 2)
  if x > 1 then x = 1
return
```

```
function real HMF
  real p
  if SAMESTR(FM, 'CF') then p = p2 else p = p1
  FM = 'HE'
  ST = 1-x
return p
```

```
function nil HMS
```

```
return nil
```