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# Evaluation of Incident Risks in a Repository for Radioactive Waste

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## ABSTRACT

A probabilistic safety assessment of the operation phase of a repository for radioactive waste requires the knowledge of incident risks. These are evaluated from generic observations. The present method accounts for the uncertainty (1) of whether an incident occurs, (2) of the incident rate, (3) of the duration of generic observation, and (4) of the duration of operation phase of the repository. It yields a mean risk and its standard deviation from a minimum of generic data, comprising only the number of observed incidents and the duration of the observation, as more comprehensive generic data are seldom available. It was shown that incidents sharing a common generic observation must be either merged together to a total incident or the generic observation must be split up in sub-observations, one for each such incident. The method was tested on the example of the German Konrad repository for low-level waste in a deep geological formation.

## INTRODUCTION

A safety assessment of a repository for radioactive waste is primarily concerned about long-term release of radiotoxic substances. However, it may also be concerned about release of radiotoxic substances due to potential incidents during the operation phase. In both cases, a safety assessment may be deterministic or probabilistic. A deterministic safety assessment proves that adequate safety measures have been undertaken to prevent a release of radiotoxic substances or to limit a release to within the dose limits prescribed by regulations. A probabilistic safety assessment evaluates the risk of exposure to radiotoxic substances from the repository. This risk depends primarily on the risk of release of radiotoxic substances from the repository. In the operation phase the risk of release depends on the risk of incidents that may result in a release. The evaluation of the latter risk from the available (in contrast to hypothetical) generic observations is the topic of this paper.

## DEFINITION OF AN INCIDENT RISK

The risk of an incident may be defined in several ways. For the present purpose it will be defined as the total risk of some specific incident during the planned operation phase of a repository. This definition accounts for all multiple occurrences of the same kind of incident, e.g. a simultaneous second incident due to a common cause or a hypothetical second incident after the cause has been eliminated or the repository shut-down as a consequence of the first incident.

## METHOD FOR THE EVALUATION OF INCIDENT RISKS FROM THE AVAILABLE GENERIC OBSERVATIONS

An incident that may release radiotoxic substances is, e.g., a fire of a truck loaded with radioactive waste. Generic observations (i.e. those for trucks with conventional freight and empty trucks) are available for this incident. They give the number of trucks that caught fire and the duration of the observation. The cause of fire may be known (e.g. a crash or a technical defect). The duration of the observation may be available as the number of trucks observed during a period of time or alternatively as the total distance driven by the observed trucks. Seldom are more data than these available. Therefore, a method for the evaluation of the incident risk must come out with these generic data.

To characterize an incident risk not only is its mean value needed, but also its standard deviation. The evaluation of both quantities from the available generic observations requires assumptions about the following four distributions: (1) that of incidents, (2) that of the incident rate, (3) that of the duration of generic observation, and (4) that of the duration of operation phase of the repository. The incidents are assumed to be distributed according to Poisson, as this is the only one-parameter non-negative unlimited discrete distribution. The incident rate is complementarily distributed, i.e. it is gamma-distributed when incidents are Poisson-distributed. The durations are non-negative. They are assumed to be gamma-distributed and scalable. Scalability enables expert judgment about their confidence.

With these boundary conditions and assumptions the following expressions are obtained for the mean incident risk P and its standard deviation $\sigma_P$:

$$P\left(k>0 \mid m,\mathcal{C},\mathcal{T},t_s/\tau_s\right)=\int_0^\infty\int_0^\infty \tau_s\cdot\tau\cdot g\left(\tau_s\cdot\tau\cdot\lambda \mid m+1\right)\cdot g\left(\tau \mid \mathcal{T}+1\right)d\tau\cdot \int_0^\infty g\left(t \mid \mathcal{C}+1\right)\cdot\sum_{k=1}^{\infty}p\left(k \mid \lambda\cdot t_s\cdot t\right)dt\,d\lambda$$

$$=1-\frac{B\left(\mathcal{C}+1,m+\mathcal{T}+2\right)}{B\left(\mathcal{C}+1,\mathcal{T}+1\right)}\cdot F\left(\mathcal{C}+1;m+1;m+\mathcal{C}+\mathcal{T}+3;1-t_s/\tau_s\right) \qquad \text{(Eq. 1)}$$

$$\sigma_{P\left(k>0|m,\mathcal{C},\mathcal{T},t_s/\tau_s\right)}=\sqrt{\int_0^\infty\int_0^\infty \tau_s\cdot\tau\cdot g\left(\tau_s\cdot\tau\cdot\lambda \mid m+1\right)\cdot g\left(\tau \mid \mathcal{T}+1\right)d\tau\cdot \int_0^\infty g\left(t \mid \mathcal{C}+1\right)\cdot\left[\sum_{k=1}^{\infty}p\left(k \mid \lambda\cdot t_s\cdot t\right)-P\left(k>0 \mid m,\mathcal{C},\mathcal{T},t_s/\tau_s\right)\right]^2 dt\,d\lambda}$$

$$=\sqrt{1-P\left(k>0 \mid m,\mathcal{C},\mathcal{T},2\cdot t_s/\tau_s\right)-\left[1-P\left(k>0 \mid m,\mathcal{C},\mathcal{T},t_s/\tau_s\right)\right]^2} \qquad \text{(Eq. 2)}$$

**The generic observations are:**

$\mathcal{T}$ estimated gamma-distributed duration of the generic observation,

$\tau_s$ scaling factor (ratio of the estimated total duration $\mathcal{T}_{total}$ to the estimated gamma-distributed duration $\mathcal{T}$ of the generic observation),

m number of observed generic incidents.

**The characteristics of a repository are:**

$\mathcal{C}$ estimated gamma-distributed duration of the operation phase of the repository,

$t_s$ scaling factor (ratio of the estimated total duration $\mathcal{C}_{total}$ to the estimated gamma-distributed duration $\mathcal{C}$ of the operation phase of the repository).

**The auxiliary quantities eliminated via integration or summation are:**

| | |
|---|---|
| $\tau$ | gamma-distributed duration of the generic observation, |
| $\lambda$ | gamma-distributed generic incident rate, |
| t | gamma-distributed duration of the operation phase of the repository, |
| k | Poisson-distributed number of incidents during the operation phase of the repository. |

**The functions are:**

| | |
|---|---|
| g | density function of the gamma distribution, |
| p | density function of the Poisson distribution, |
| B | beta function, |
| F | hypergeometric function (Ref. 1). |

## INCIDENTS SHARING A COMMON GENERIC OBSERVATION

A previous method for evaluating mean incident risks is a linear approximation to Eqs. (1) and (2):

$$P(k > 0 \mid m, \mathcal{T}, \mathcal{J}, t_s/\tau_s) \approx \frac{\mathcal{T}_{total}}{\mathcal{J}_{total}} \cdot (m+1) \qquad \text{(Eq. 3)}$$

$$\sigma_{P(k>0|m,\mathcal{T},\mathcal{J},t_s/\tau_s)} \approx \frac{\mathcal{T}_{total}}{\mathcal{J}_{total}} \cdot \sqrt{m+1} \qquad \text{(Eq. 4)}$$

where $\mathcal{T}_{total} = \mathcal{T} \cdot t_s$ and $\mathcal{J}_{total} = \mathcal{J} \cdot \tau_s$ are the estimated total duration of the operation phase of a repository and that of the generic observation, respectively.

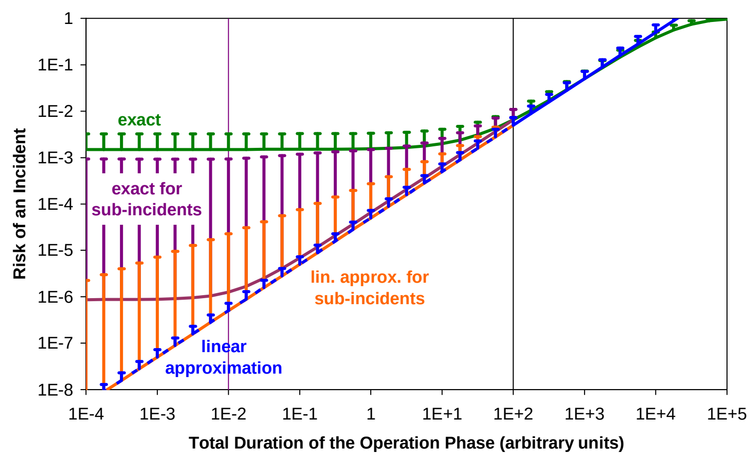


Fig. 1: comparison of different approaches for evaluating incident risks

Fig. 1 compares the linear approximation (blue) with the exact solution (green). Lines represent mean risks, bars are standard deviations. It shows the risk of an incident as a function of $\mathcal{T}_{total}$. The latter is given in arbitrary units, e.g. (number of components or number of demands per year) × (number of years of operation). m and $\mathcal{J}_{total}$ are constant. The largest risk is per definition one. At large $\mathcal{T}_{total}$ the linear approximation exceeds one, but for seldom incidents this is irrelevant. The exact solution converges to one. At low $\mathcal{T}_{total}$ the exact solution converges to some non-zero incident risk due to the uncertainty of whether a component of the repository is available on demand or not. In contrast, the linear approximation vanishes.

Due to its linearity in $\mathcal{C}_{total}$, the linear approximation allows an incident to be split up in an infinite number of sub-incidents. The mean risk of a sub-incident (e.g. a specific vehicle catches fire while transporting radioactive waste along a specific section) is in this approximation always lower than that of the total incident (e.g. any of several vehicles catches fire while transporting radioactive waste along any of several sections). Infinite subdivision (e.g. of transport sections) yields sub-incidents with infinitely low mean risks. As low-risk incidents are per definition irrelevant, it leads to false conclusions about the relevance of sub-incidents.

The problem was traced down to the fact that the previous method evaluates the risks of sub-incidents using the same generic observation as for the total incident. Thus the generic observation is reused for each sub-incident. The correct procedure is to split it up in sub-observations, one for each sub-incident, keeping the ratios $(m + 1)/\mathcal{T}_{total}$ and $\mathcal{C}_{total}/\mathcal{T}_{total}$ constant. Split up is in Fig. 1 an incident at $\mathcal{C}_{total} = 100$ (black vertical line). In the linear approximation the mean risks of sub-incidents (orange line) remain unchanged as compared to a reused generic observation (blue line). However, their standard deviations (orange bars) vanish at infinite subdivision less rapidly than for a reused generic observation (blue bars). In the exact solution the mean risks of sub-incidents (violet line) follow with increasing subdivision at first those in the linear approximation (orange line) but then converge below $\mathcal{C}_{total} = 0.01$ (violet vertical line) to some non-zero incident risk due to the uncertainty of whether a component of the generic facility is available on demand or not. Their standard deviations (violet bars) converge earlier and predict much larger risks due to the uncertainty whether a component of the repository is available on demand or not. Thus, sub-incidents cannot be excluded with sufficient certainty to make them irrelevant. Subdivision of incidents is therefore pointless.

## RESULTS

The above method was tested on the example of the German Konrad repository for low-level waste in a deep geological formation. The safety assessment of this repository considers about 100 incidents, some of which share common generic observations. The method proved suitable for the evaluation of the incident risks. Incidents that share a common generic observation were merged together to a total incident. A previous analysis based on a linear approximation to Eq. (1) has not recognized the necessity for merging such incidents. As a result, it has led to some false conclusions about their relevance.

## CONCLUSION

The conclusions reached in a probabilistic safety assessment of the operation phase of a repository for radioactive waste are sensitive not only to the availability of generic observations but also to the statistical methods used for evaluating incident risks. Any statistical method is based on some assumptions. A common assumption is that of maximum likelihood, the implementation of which requires additional assumptions. The restricted comprehensiveness of the available generic observations necessitates further assumptions. Assumptions underlying the method of choice should be carefully examined for potentially misleading conclusions.

## REFERENCES

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