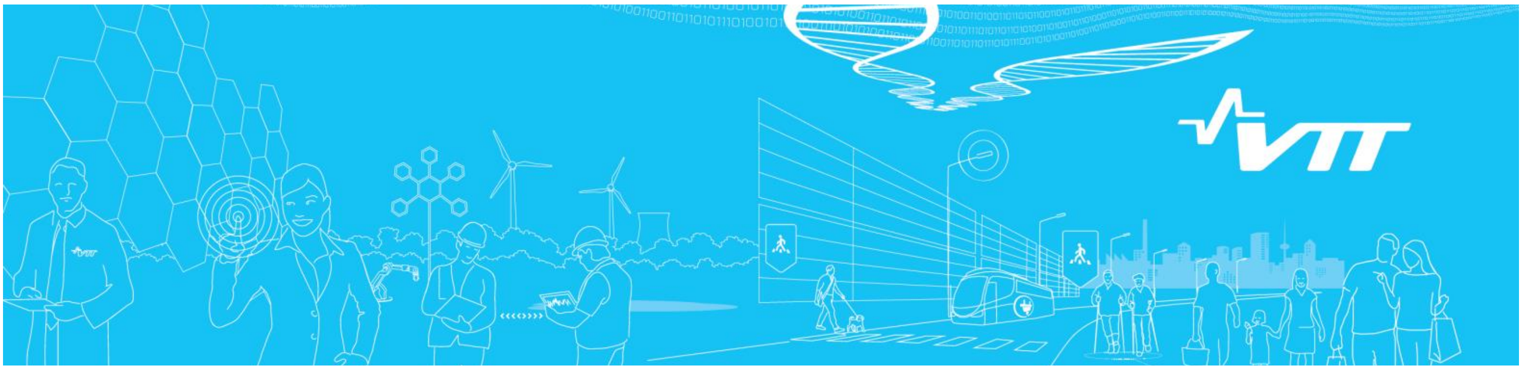

RESEARCH REPORT

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Seasonal and contextual factors in level 3 PSA

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Summary

There are several factors that - through their implications to nuclear accident consequences - may affect level 3 probabilistic safety assessment (PSA) results significantly. For example, now, ice cover and frost may affect the transport of radionuclides; an initiating event, such as tsunami or loss of external electric power, may cause the population to be evacuated before release or impede evacuation; extreme snow as an initiating event implies that the season in question is winter, and therefore winter weather should be used in atmospheric dispersion calculations. In this report, such factors are called seasonal and contextual factors (SCF). These factors are not systematically taken into account in level 3 modelling currently.

This report makes an overview of possible SCF's and their potential impacts to accident consequences and level 3 analysis. SCF's are listed together with their implications. SCF's affect many important level 3 phenomena such as aquatic dispersion, transport of radionuclides in the environment and biosphere, population demography and behaviour, and attenuation of ionizing radiation. These, in turn, affect level 3 analyses concerning population dose, evacuation, sheltering and distribution of radionuclides in the environment.

Ways of incorporating SCF's in level 3 analyses are discussed. For example, they affect dose assessment parameters, use of weather data, and estimation of contaminated land area. Constructing a framework for incorporating SCF's in level 3 analyses, in a manner similar to those widely used for external events, would make this incorporation easier.

Systematic research is needed to find out which SCF's are significant enough to merit incorporation in PSA, and how to incorporate them in a reasonable manner. This will involve multidisciplinary modelling, analysis and experimentation.

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1. Introduction

Level 3 probabilistic risk assessment (PRA) of nuclear power plants (NPP) concerns the consequences of a release of radionuclides from an NPP to the environment. The standard inputs to level 3 PRA analyses include the source term (amounts of different radionuclides, timing, release height and temperature), geographic and demographic information (locations and numbers of people that may be exposed to ionizing radiation, water systems etc.), and weather information. These analyses contain large uncertainties. Reduction of these uncertainties would contribute towards more accurate risk estimates, better accident consequence management and improved credibility of analyses. This report considers certain improvements to level 3 modeling and analysis that have potential to reduce these uncertainties.

We consider the effects of seasonal and contextual factors (SCF) on the consequences of a nuclear accident. Seasonal factors mean phenomena that vary by season, for example weather phenomena (outdoor temperature), terrestrial and weather systems conditions (e.g. amount of ice coverage), and population behaviour (e.g. clothing used, propensity of people to visit their summer cottages). Context factors mean for example the implications of the initiating event that led to the nuclear accident.

The motivation for this work is that SCF's may have significant impact on nuclear accident consequences. The present author is unaware of level 3 studies that would take seasonal and context factors into account in level 3 analyses systematically if at all (for some major level 3 studies see [1] and [6], and for a relatively recent code see [10]). Thus there seems to be a need for SCF's to be analysed and potentially incorporated in level 3 PRA analyses to improve their accuracy.

This report has two main objectives. The first is to lay groundwork for the incorporation of SCF's in level 3 analyses. It is hoped that listing the SCF's, their potential impacts on accident consequences, and research and data needs contributes to future level 3 PRA method development. The second objective is to raise awareness of these factors, and thus to motivate wider research in this aspect of level 3 PRA.

The development of methods to handle SCF's is at its early stages, and therefore this report aims to be an inventory of the issues involved rather than a prescriptive account of how to deal with contextual factors in level 3 PRA. Research contributing to the latter direction is a matter of years to come.

2. Seasonal and context factors and their impacts

Level 3 PSA analyses handle an immensely complex whole. The system that they deal with encompasses meteorology in atmospheric dispersion, hydrology in aquatic dispersion, soil science in environmental transport, biology in biospheric transport, logistical science in evacuation assessment, behavioural sciences in countermeasures analysis, and many other branches of science. To make this complexity manageable, level 3 analyses have largely dismissed the implications of assumptions or input data in one part of analysis to other parts, and also "non-typical" environmental phenomena and events. Here we call such factors contextual factors.

We aim to identify contextual factors that may influence nuclear accident consequences, describe those influences, and clarify how contextual information should be taken into account in level 3 modelling and analysis.

Contextual factors can be classified to the following broad categories:

- Seasonal variations. The time of year when the accident happens affects many factors that have influence on accident consequences: the number of people residing in the emergency planning zone (and even beyond), as well as their demographic properties, may vary by season; weather patterns (e.g. precipitation, wind patterns) vary by season; snow cover and ice cover usually exist only in the winter time; etc.

- Circadian variations. The number of people in the emergency planning zone varies by time of day as most people normally work only in the daytime and are at home in the nighttime. Time of day may have effect also on evacuation times as it is harder to get communication through to people when they are asleep. Also weather patterns vary by time of day.

- Influence of the initiating event and accident progression on level 3. The initiating event may indicate the season when the accident is happening: for example, if the initiating event is ice slush blocking seawater intake, it is highly likely that it is wintertime and therefore seasonal variations associated with winter must be observed in modelling and analysis. Naturally, the shorter the time delays related to accident progression are, the more credible it is that this conclusion holds. Accident progression may also affect level 3 analyses through the source term.

- Implications of environmental circumstances to level 3 PRA entities beyond atmospheric and aquatic dispersion. For example, bad weather (hard rain) will affect groundshine by transporting radionuclides from the ground through washout; this may radically reduce the population dose from groundshine. On the other hand, bad weather may impede evacuation.

It seems that seasonal variations produce the most significant class of contextual factors especially in Finland and other Nordic countries where seasonal variations are large. To acknowledge this, we shall call the general class of contextual factors as seasonal and contextual factors (SCF's) in this report.

Contextual factors may affect for example the following circumstance factors:

- Meteorological, terrestial and hydrological conditions

- Amount of radionuclides on the ground as a function of time and location

- Dampening of ionizing radiation

- Population in the affected regions: number of persons by location, their demographic properties, the means of sheltering and transport available to them, population behavior etc.

- Critical infrastructure in the affected areas: communications network reliability, transportation equipment reliability and safety, state of transportation networks (e.g. road segments), etc.

The circumstances, in turn, may affect modelling and analysis of the following level 3 PRA domains:

- Atmospheric and aquatic dispersion

- Transportation of radionuclides on the ground, in water systems and in ecosystems

- Population dose assessment and through it, health effects assessment

- Countermeasures (evacuation, sheltering, distribution of iodine tablets etc.) modelling and analysis: communication, coordination, time delays involved, effectiveness
- Environmental consequences assessment (e.g. the area of contaminated land)
- Economic consequences assessment: loss of agricultural produce, loss of production, evacuation costs, healthcare costs etc.

This report concentrates on the effects of seasonal variations, but also the other contextual factors will be dealt with briefly. Dependences between multiple factors (e.g. multiple weather factors affecting many aspects of evacuation) will be dealt with only superficially.

3. Level 3 PRA from a seasonal and context factors point of view

3.1 The general framework of level 3 probabilistic risk assessments

Level 3 PRA aims at assessing the consequences of a radionuclide release from a nuclear power plant. To handle the large uncertainties involved, the analysis is carried out in a probabilistic manner which differentiates level 3 PRA from other (deterministic) consequence analyses of radionuclide release. Level 3 PRA provides a systematic framework that combines and arranges the results of deterministic analyses.

Level 3 probabilistic risk analysis (PRA) usually proceeds as follows. The transport of the radionuclides in the source term is estimated in the air (atmospheric dispersion), and possibly in water systems (aquatic dispersion). Then population dose is estimated, taking into account countermeasures (evacuation, shielding etc.) and population behavior. Health consequences are assessed from population doses. Environmental consequences are assessed from the distribution of radionuclides over the land area and water systems. Economic consequences are assessed from population dose, contaminated area, and demographic and economic data.

A simplified model of level 3 PRA analyses is depicted in Figure 1. Generally, the analysis proceeds from input data - source term, geographic data, demographic data, meteorological forecasts etc. - towards the assessment of consequences.

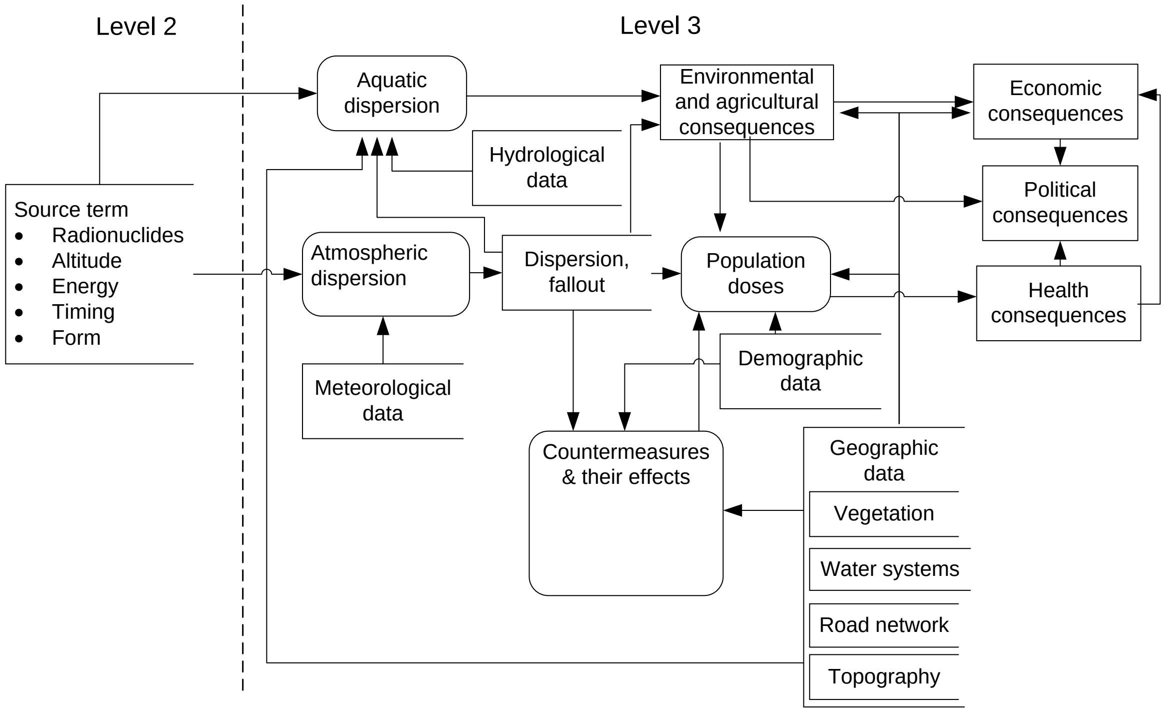

Figure 1. Level 3 probabilistic risk assessment process

The major analysis steps at level 3 concern atmospheric [11] (and aquatic) dispersion, possible countermeasures [9], and population doses [3]. Population dose assessment uses the results of dispersion computations and countermeasure assessments. It may also use the results of the analysis of radionuclide transportation in the environment and biosphere (for example, radionuclides accumulated in fish or crops may enter humans when they eat those).

Using results of these major analysis steps as a starting point, health, economic, environmental and agricultural consequences may be assessed. Usually the emphasis is on health consequences (radiation sickness in the short run, cancers in the long run). However, quite often at least some economic consequences (loss of electricity production, loss of other production, value depreciation of real estate, evacuation costs, healthcare costs, value of lost lives etc.) are also analysed. Sometimes also environmental and agricultural consequences (area of contaminated fields, lost lifestock, contaminated sea produce etc.) are analysed.

3.2 Impacts of seasonal and contextual factors

On the general level, seasonal and contextual factors may affect data used in the analyses, or the analyses themselves.

The most obvious way that seasonal factors affect data is that weather data has different profiles on different seasons, with differences in mean temperature, frequency of storms, rain/snowfall and so on. However, this is usually taken into account in level 3 analyses by using actual weather data from different seasons, or by using weather patterns corresponding to a given season. Also hydrological data is quite different for different seasons due to ice cap, volume of water flow and so on. Demographic data may vary by season: summer cottages near a plant might be empty in the winter, whereas during holiday seasons the number of people in towns may be significantly reduced. All of this indicates that level 3 analyses should be carried out by season.

SCF’s may, or should, affect also all major analysis steps. For example, hydrological computations are quite different when there is an ice cap on significant parts of the water system. The effectiveness of countermeasures may be significantly affected (e.g. evacuation efforts may be hampered by weakened road conditions if there is slippery ice). SCF’s should also be taken into account in long-run analyses, because for example washout caused by spring thaw may alter the transport of radionuclides in the environment significantly.

4. Seasonal factors and their implications

Here we go through seasons, seasonal factors (mainly weather-related) that may affect nuclear accident consequences and mitigation actions, and their potential effects.

First, we go through seasons, their definitions and some of their potential effects in section 4.1. Then in sections 4.2-4.5, we consider the effects of each season in turn.

4.1 Seasons

Seasons can be defined on astronomical grounds or on climatic grounds. Astronomical seasons result from the perihelic motion of the Earth: as the Earth’s rotation axis is tilted approximately 23.5 with respect to its orbital plane, different parts of the Earth receive different amounts of sunlight by season. When the northern end of the axis points away from the Sun, there is winter in the Northern Hemisphere, and when it points toward the Sun, there is summer. The amount of light may have some impact on e.g. evacuation times, but on the whole its impact is probably quite small, and any effects the amount of light has may quite likely be sufficiently accurately be taken into account by associating them with thermal seasons. Therefore astronomical seasons will not be dealt with here further.

Thermal seasons [2] are defined on the basis of daily average temperatures. In Finland, they are defined as follows:

- Thermal spring begins when the average daily temperature rises permanently above 0 ℃.
- Thermal summer begins when the average daily temperature rises permanently above 10 ℃.
- Thermal autumn begins when the average daily temperature falls permanently below 10 ℃.
- Thermal winter begins when the average daily temperature falls permanently below 0 ℃.

Thermal and astronomical seasons in a given region correlate, because atmospheric temperatures depend on the amount of radiation received from the Sun. However, they do not coincide because earth and water systems absorb the Sun’s radiation energy and yield it over lengthy periods of time.

In Finland, average daily temperatures may vary around the limiting values for long periods of time, and year by year, and therefore the date of seasonal change is ambiguous. However, for level 3 PRA modelling and analysis purposes, the long-time averages for a given region (e.g. the evacuation planning zone or a weather mast close to it) may well be used.

As an example, in Turku - which is climatically reasonably similar to the Olkiluoto and Hästholmen NPP sites - thermal winter lasts from late November to late March, thermal spring from late March to mid-May, thermal Summer from mid-May to mid-September, and thermal autumn from mid-September to late November.

4.2 Winter

Most nuclear power plants are in countries where winter is shorter and its effects milder than in the Nordic countries. Therefore summer or summer-like conditions most likely are currently the basis of most level 3 analyses. Since winter deviates from this "standard" most, the list of effects associated with it in the SCF context is longest.

The following factors and effects connected with winter have been identified:

- Winter has different weather patterns from other seasons. Thus, weather data/weather patterns from winter must be used in atmospheric and aquatic dispersion analyses.

- Frost (frozen ground) affects the transport of radionuclides. Generally, radionuclides are not absorbed to the ground by rain but stay on the surface which will increase radiation and increase the propensity of radionuclides being transported by wind. In the spring, much of the radionuclide fallout accumulated in the preceding winter will be washed out when snow melts and spring rains (rather than snowstorms) set in, because the ground is largely still frozen. This will transport much of the radionuclides to water systems, dikes, ditches etc. Thus, ground contamination may be radically reduced.

- Snowfall washes radionuclides from the air, and covers radionuclide fallout already on the ground/on ice. This layer on top of the fallout will dampen ionizing radiation: alpha and beta mostly or totally, and also gamma to at least some extent. This will reduce population dose from groundshine.

- Heavy snowfall may slow down or delay evacuation. More generally, weather conditions used in atmospheric dispersion computations should be taken into account in evacuation assessments.

- Snow may also reduce groundshine even when radionuclide fallout falls on already existing snow. Particles containing radionuclides will sink into the snow at least somewhat, which reduces groundshine. This, in turn, will reduce population dose. On the other hand, those particles will not enter the ground but a layer of snow will be between the particles and ground, and when the snow melts in spring, a portion of those particles will be washed away with melting waters, the more so if the snow layer is thick; this has the effects of reducing ground contamination and increasing the amount of radionuclides in water systems.

- Snow and hard rime that accumulates on tree branches and structures may block air intakes and cause problems to electricity distribution, which may affect shielding and evacuation. Also disturbances to communication systems are possible (blocking of base stations etc.), which may cause harm to accident management including coordination of countermeasures.

- Ice cover, both on ground and on water, will dampen radiation coming from below it. Thus groundshine and radiation coming from water systems will be reduced. Ice will also bind radionuclides in or below it, thus preventing winds from transporting radionuclides.

- Ice cover may also provide new evacuation routes if it is strong enough. This may affect evacuation assessments especially on coasts and in the archipelago.

- Ice on roads may make them slippery and therefore slow down or delay evacuation under disadvantageous conditions.

- The amount, locations and demographic structure of people in the emergency planning zone may vary by season. If there are many summer cottages in the emergency planning zone (EPZ), the number of people in the EPZ may be lower in the winter because people will not be at their summer cottages. On the other hand, if there is permanent settlement in the EPZ, the number of people may be larger in the winter when people are not spending their holidays elsewhere but are at home or at work.

- In the wintertime, people tend to stay more inside, which will reduce population dose from cloudshine, groundshine and skin contact.

- Deep frost affects evacuation conditions because people cannot stay outside for long, and because cars are more prone to fail in those circumstances.

- No crops are growing in the wintertime, which affects doses through the ingestion pathway, and also some countermeasures (crops can be used to bind radionuclides).

- Domestic animals are inside, which reduces the amount of radionuclides that they accumulate. This will later reduce population dose through ingestion, and the need for food bans.

- Living organisms are generally less active, many of them dormant, during wintertime. This reduces the accumulation of radionuclides in them.

It should be noted that many of these factors depend on one another. For example, long-lasting cold temperature implies both frost on the ground and ice on water systems; furthermore, if there is rain during a cold spell, it will come down as snow. These dependences should be taken into account in analyses.

4.3 Spring

Spring and autumn are intermediate seasons between summer and winter, and therefore have fewer characteristics that set them apart from those two. Spring and autumn could be said to be characterized by the lack or rarity of such weather features as extreme temperature and extreme winds. The following phenomena may significantly affect accident consequences:

- The melting of snow in the spring means that much of ground deposition is washed away by the melting waters. This phenomenon is accentuated by the fact that in spring, ground is usually frozen and therefore melting waters mostly will not be absorbed to the ground but rather will float to water systems. This reduces groundshine (implying reduction in population dose) due to the washout of radionuclides, and also reduces the land area of contaminated land. On the other hand, it increases the amount of radionuclides in water systems, and thus may increase population dose through digestion if fish in the water systems is used for food.

- In spring, ice on inland water systems (rivers, lakes) will typically break, and the resulting ice blocks will float toward sea. If the ice is contaminated by radionuclides, this will reduce contamination in inland water systems and increase it in seas near estuaries.

- Frost heave may slow down evacuation, and temporarily prevent supplies and crew from being transferred to the accident site. In the archipelago, this may mean that evacuation cannot be conducted with boats but helicopters and/or hovercrafts may have to be deployed, which may cause evacuation delays due to lack of capacity.

- Possible spring floods have similar effects to frost heave. In addition, they may wash radionuclide particles from ground surface on the flood-affected areas.

4.4 Summer

The following features of summer may affect accident consequences:

- People are usually lightly clothed, which increases dose through cloudshine, groundshine and skin contact pathways

- Living organisms (as well as their metabolism) are more active in the summer, increasing their intake of radionuclides through different pathways, and thus increasing the amount of radionuclides in the local ecosystem

- If there are summer cottages in the emergency planning zone, the number of people staying in them usually increases in the summer. This affects evacuation calculations, and may affect population dose if evacuation is not successfully carried out in time. It may also be that summer cottages provide less shielding against ionizing radiation, and they may also be less practicable places to stay during shielding, which affects shielding decisions and the assessment of shielding as a countermeasure.

4.5 Autumn

No seasonal effects specific to autumn have been identified. Nevertheless, some seasonal effects associated with winter may take place already in autumn. An example is snowfall, which may result in snow cover for a few days.

5. Contextual factors and their implications

Here we constrain ourselves to external contextual factors; it is unclear if there are any internal contextual factors (that is, factors originating from within the plant) that might affect accident consequences beyond those that are already taken into account in PRA, and the effects of which can be reduced to the source term, its properties and timing.

5.1 Initiating events

The initiating event of a nuclear power plant accident may affect radionuclide release consequences in two ways:

- Causally. Here the initiating event has caused, either directly or through a causal chain, significant changes in the circumstances that affect radionuclide release consequences. For example, the initiating event of the Fukushima nuclear accident, earthquake, caused a tsunami. The tsunami, in turn, caused the depopulation of large areas surrounding the Fukushima Daiichi site, because people that had lived in those areas had either been killed by the tsunami or evacuated. This naturally reduced population dose radically.

- By implication. By this, we mean that the nature of the initiating event may imply various things about the circumstances during the accident. For example, if the initiating event is extreme snow, we may assume that the season in question is winter, and therefore weather data used must be from winter, and the effects of winter (see section 4.2) must be taken into account.

The frequency of many initiating external events varies seasonally. Some external events may even be associated with specific seasons, because they occur rarely if ever outside those seasons. In Table 1, external events listed in [7] have been associated with seasons. External events that are not relevant in the Nordic countries have been left out.

Table 1. Association of external events in [7] with seasons.

Season	Initiating events	Implications	Comments
Winter	Low air temperature (A04) Extreme snow (A07) White frost (A10) Soil frost (G02) Low sea water temperature (W05) Surface ice (W07) Frazil ice (W08) Ice barriers (W09)	All of these imply the same: the season has been winter at the time of IE. It will probably be winter (with factors listed in section 4.2), and temperatures low also at the time of the release.	
Spring	Extreme rain (A06) Mist (A09) Above-water landslide (G06) External fire (G07)	It can be inferred from these that it is not winter at the time of the IE.	None of these external events are associated to spring alone.
Summer	Tornado (A02) High air temperature (A03) Extreme rain (A06) Extreme hail (A08) Mist (A09) Drought (A11) Lightning (A14) Above-water landslide (G06) External fire (G07) High sea water temperature (W04) Organic material in water (W10)	Tornado, high air temperature, extreme hail, drought, lightning and high sea water temperature imply that it has been summer at the time of the initiating event.	Although lightning can occur also in spring or autumn, it is so rare that it has been listed only for summer.

Autumn	Extreme rain (A06) Mist (A09) Above-water landslide (G06) External fire (G07) Organic material in water (W10)		See the implications and comments related to spring.

It should be noted that some external events occur more frequently in some seasons although they may occur in any season. Such is the case with low sea water level (W02) and high sea water level (W03): in the Nordic countries where earthquakes are rare, these initiating events occur predominantly as a result of strong winds blowing from a suitable direction; ice cover will make them less probable or even improbable, but it is also possible that there is no ice cover in the winter.

There are also initiating events that may occur during any season, but still may have impact on accident consequences. Strong winds may affect evacuation conditions by cutting out electricity or telecommunications from the population. If the time from the initiating event to the release is sufficiently short, it may be that these have not been restored by the time of the release. This affects evacuation.

Loss of off-site electric power as an initiating may also affect accident consequences, if accident progression is quick enough. Then it may be that electric power is still unavailable regionally when release begins. This has two main consequences. The first is that a large portion of the population may have fled or been moved away. The second is that whatever population remains, is affected by loss of heating, air conditioning, communications etc. This may make evacuation more difficult and sheltering more intolerable.

Sabotage, terror strike or war may affect accident progression in the way that time from initiating event to release may be short, which also affects evacuation. These acts of organized violence also include the possibility that further damage has been or will be done after the actual attack (initiating event). This damage may include destruction of bridges or other elements of the road network, damaging elements of the communication or electricity network, laying mines, and other such acts. Furthermore, the perpetrators may stay in the area, making it unsafe. All of this gives compelling reasons for evacuating civilians from the emergency planning zone, but at the same time it may severely undermine evacuation efforts and countermeasure management.

Making inferences from initiating events is usually defeasible. This is so due to the following reasons:

- The initiating event does not force the conclusion through logic, but rather through a statistical relationship. For example, extreme snow as an initiating event suggests that the season in question is winter. However, sometimes - though rarely - heavy snowfall may occur in spring or autumn.

- The time delays of accident progression may cause that the circumstances implied by or effects caused by the initiating event are no longer valid or significant. For example, extreme cold as an initiating event does not imply that it will be cold at the time of the release, if it has taken a long time until containment integrity is lost. Therefore, an initiating event may significantly affect accident consequences by implication only if the underlying phenomenon is sufficiently long-lived.

5.2 Other contextual factors

Some factors may affect radionuclide release consequences even though they are not directly connected to initiating events.

For example, if the evacuation decision is made in the nighttime, evacuation is affected by factors related to population behaviour. First, most people are at their homes (rather than at work) in the nighttime, which affects population distribution in the emergency planning zone, and evacuation times. Second, getting the evacuation instructions through, and carrying out the evacuation itself may take longer in the nighttime.

Weather conditions used in atmospheric dispersion computations should be taken into account in countermeasure (especially evacuation) assessments. For example, bad weather may affect evacuation.

6. Incorporation of seasonal and context factors in level 3 analyses

Systematic introduction and incorporation of seasonal and context factors in level 3 PRA analyses has not been conducted anywhere to the present author's knowledge. However, it is worthwhile to ponder how such a thing could be done.

First, let us summarize main SCF impacts identified in sections 4 and 5, the level 3 analysis tasks those influence, and the consequence classes thus affected. This is done in Figure 2. It is based on the observation that the identified SCF's affect mainly radionuclide transport (in the air, water systems, ground); the attenuation of ionizing radiation; population distribution and behaviour; and the condition of technical systems (road conditions, electricity availability etc.).

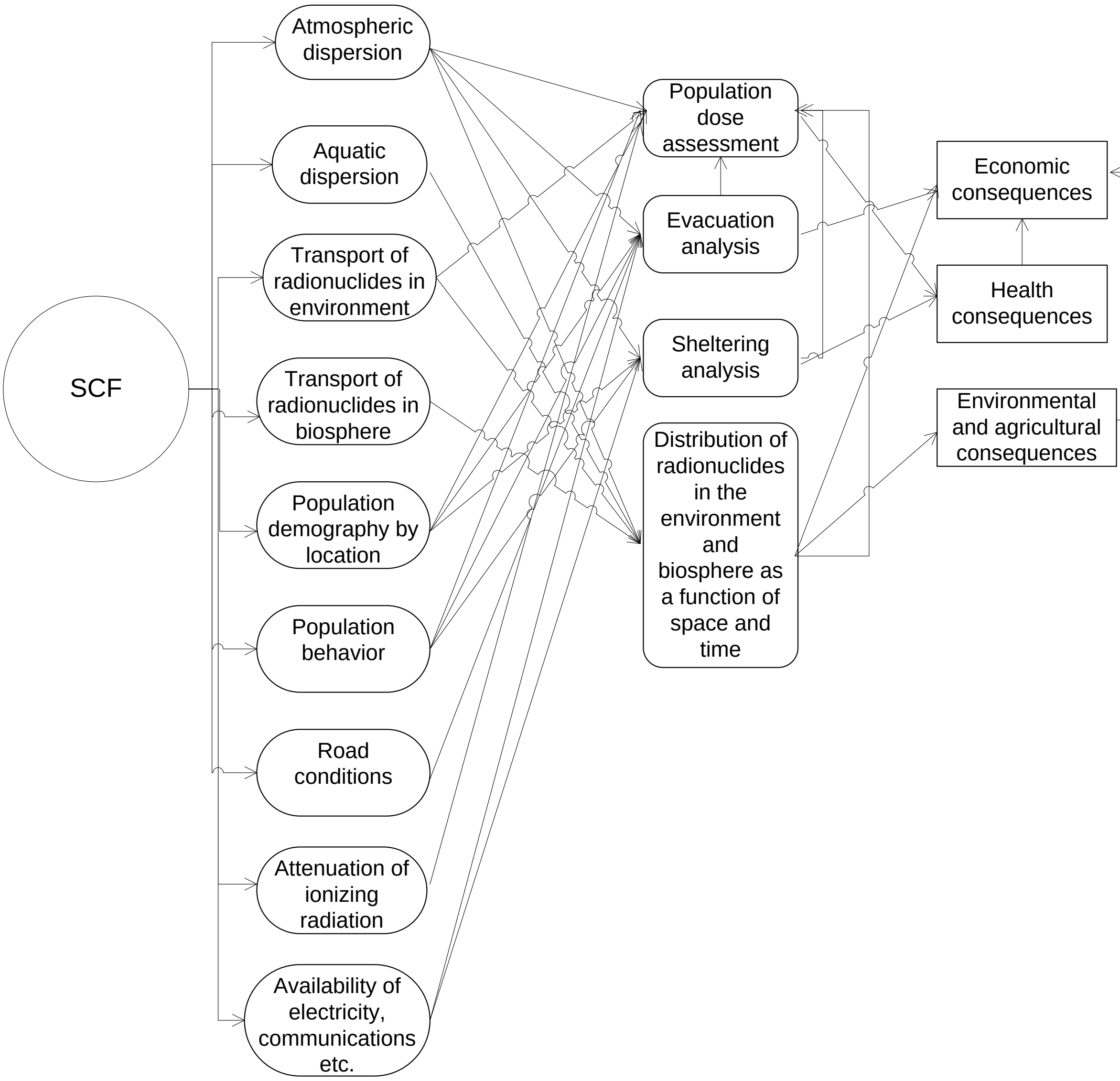

Figure 2. Some impacts of seasonal and contextual factors on level 3 analyses and results

SCF's can be incorporated in level 3 PRA analyses on two levels. The first is the actual analyses themselves. This is handled in section 6.1. The second is the general framework within which the analyses are made, which includes analysis guidance, standards, regulatory requirements etc. Because the treatment of SCF's in level 3 is yet in a very early stage, only the construction of guidance is dealt with on a speculative level in section 6.2.

6.1 Level 3 analyses that take seasonal and context factors into account

As current level 3 analyses generally take SCF's into account only in the form of using weather data or weather patterns from different seasons, quite a lot of research is needed before they can be incorporated in analyses in a satisfactory manner.

When all SCF's affecting level 3 analysis of an accident occurring in a given season have been identified and modelled, seasonal level 3 analyses should be carried out. This means that the analyses should use the weather patterns/weather data of the season, use radionuclide transport analysis methods fit for the season, use demographic patterns valid for the season, and take these into account in assessing the distribution of radionuclides on the ground and in water systems, the effectiveness of countermeasures and so on. The results of these analyses should be compared with generic level 3 PRA analyses to find out if there are significant differences in results.

In the following, we outline some ways to take seasonal and context factors into account in level 3 analyses. It is evident that alternative methods can be proposed (and some may even exist). The proposals below should be seen as conceptualizations and proposals for further study rather than instructions on how to carry out the analyses. We assume that level 3 PRA analyses are conducted by first simulating accident consequences in different scenarios (weather, conduct of evacuation etc.), and then analysing the simulation results. This seems to be currently the only way to carry out level 3 analyses in a probabilistic manner. For one possible method for carrying out level 3 analyses in this way, see [4] and [5].

Level 3 analyses aiming at comprehensiveness should be conducted in a manner that takes all seasons into account in a balanced manner, together with associated seasonal factors. This means using weather data or weather patterns from all seasons, and taking into account seasonal factors in the analyses. In longer-term analyses, the progression of seasons (spring follows winter etc.) should be taken into account by changing the weather data and SCF's to correspond to the current season in simulations.

When analysing accident consequences in a given season, analyses of atmospheric/aquatic dispersion, transport of radionuclides on the ground, countermeasure analyses and other assessments sensitive to SCF's should take into account the factors identified for the season (see sections 4.2-4.5). This sensitivity should first be assessed by screening out SCF's that for some reason do not apply to the particular site. For example, groundshine should be assumed to be damped by snow with a factor that may be determined by empirical analyses or by means of physical modelling. The analyses should also take into account that when making longer-term assessments, seasons change and the effects of each season should be considered in turn.

Further ways in which SCF's can be taken into account in level 3 PRA are as follows:

- Use season-specific weather data/weather patterns used when doing level 3 analyses
- Taking into account that the frequency of many initiating external events varies by season (see section). This seasonal variation should be assessed, and the resulting frequencies with seasonal variation be used when analysing a given season. This affects the frequencies of release categories that level 3 PSA inherits from PSA level 2.
- Take seasonal effects into account in those analyses where season-specific weather data is used

Concerning the effects of external initiating events, a few remarks are in order. First, to assess their effects on level 3, it would be useful to know the proportions of different initiating events from the frequencies of different release categories that are propagated from level 2 PRA to level 3 PRA. Thus, there is some need for the tight integration of levels 2 and 3. Second, as the frequencies of certain external initiating events vary by season, it would be worth considering that level 1 and level 2 analyses would also be conducted by season. Third, the effects of initiating events must be taken into account on level 3 in a probabilistic manner, due to the uncertainties associated with their effects. Fourth, initiating events can be taken into account on level 3 in the following probabilistic manner. We assume that level 1 and level 2 analysis results are available, including the time (preferably with an uncertainty distribution) elapsed from the initiating event to the start of the release. Then the probability with which a given seasonal effect is assumed to occur is the probability of its occurrence in the given season times the probability that it is that season at the time of the release given that it was the season implied by the initiating event at the time of the initiating event. The latter probability depends on accident progression, namely the delays between the occurrence of the initiating event and the release. The seasonal effects of the given season are then taken to occur in the simulation round with that probability. Also the weather conditions of the given season are used based on that probability.

SCF's should be also taken into account in uncertainty analyses [8]. SCF's make uncertainty analyses more tedious, because uncertainties related to SCF's must be propagated from one analysis to another, and because these uncertainties may have complex mutual dependences.

6.2 On the construction of a general framework for seasonal and context factors

Level 3 PRA analyses that take (at least some) SCF's into account can be conducted without a general framework. However, such a framework would provide several benefits: reduction of effort in conducting analyses; ensuring that all relevant SCF's have been taken into account; and making different analyses commensurable. A natural way to proceed is analogous to the one that is used widely in the analysis of external events [7]. Its phases may be listed as follows:

- Listing of all SCF's that could have a significant impact on consequences in level 3. It would be advantageous that these would be arranged in a taxonomy or ontology. However, the taxonomic principle used in [7] (land-based, air-based etc.) is not appropriate because SCF's cover also factors related to human behaviour etc. A better taxonomic principle would rely on the main phenomenon that the SCF affects (e.g. transport of radionuclides in biosphere), or on the level 3 activity where the SCF should be taken into account (e.g. population dose assessment).

- Formulation of qualitative and quantitative screening criteria for SCF's. Only those SCF's should be selected for analyses which may significantly alter level 3 analysis results, and which occur often enough to merit treatment.

- Analysis of SCF's and their impacts. This should lead to mathematical/physical models of the SCF's and their interactions with level 3 analyses, numerical estimates of parameters used in quantitatively assessing SCF impacts, and probabilities/frequencies of SCF phenomena. Research is also needed e.g. to find the nature and strength of dependences between initiating event and SCF's at the time of release as a function of the total time delay in accident progression from the initiating event to the release.

- Analysis of interrelationships and dependences between SCF's. For example, long-lasting low temperature implies both frost on the ground and ice on water systems. Methods to account for these dependences should be specified.

- Example analyses. These should not only cover exemplifying the analysis of SCF's and their impacts, but also level 3 PRA analyses where SCF's have been taken into account.

7. Data needs and requirements

Serious analysis of the effects of seasonal and context factors requires a multitude of parametric data and physical models. Some of this data is available - a prime example is weather data from different seasons. However, much of this data does not seem to be publicly available, if at all. In this section, a partial inventory of data needs is made, with a view of emphasizing those SCF's that seem to have potential to be more significant.

Models of the dampening of ionizing radiation by snow and ice would improve understanding of the effects of groundshine in the winter. Models of dampening would be needed for the situation that radionuclides are covered by snow or ice, and for the situation that the radionuclides are mixed within snow or ice. The first situation describes circumstances where radionuclides are covered after snowing, and the second the circumstances where wind has mixed radionuclide particles with snow or radionuclide particles have mixed with water. Analysis would be needed also about the thickness of layers of covering snow or ice, and of layers where radionuclide particles have mixed with water/snow. Data needed includes for example the dampening factors of ionizing radiation in a given medium and with a given geometry.

Models of radionuclide transport in the winter would also shed light on the distribution of radionuclides in the environment.

Concerning the washing away of radionuclide particles in the spring by melting snow also would need to be analysed. What portions of radionuclides are washed away to water systems, and what portions stay on the ground or close to it in different circumstances? Does this depend on the kinds of particles, and what kinds of particles are created in a severe nuclear accident? Do some radionuclides (e.g. cesium) dissolve in water?

Transport of radionuclides in the environment and biosphere in the winter is of interest to dose assessment via the ingestion pathway. If the radionuclides are washed away when animals and plants are less active or dormant, it might be that not much radionuclides would be accumulated in them, a large part of radionuclides ending up in water system sediments. Data is needed on the absorption of radionuclides by living organisms, and their accumulation.

Effects of heavy snowfall or slippery ice on evacuation times would be also of interest.

The locations and behaviour of the population also greatly affect population doses. How much does the amount of people close enough to the plant that evacuation might be necessary vary between summer and winter? Are there any differences in the demographic structure of those people in different seasons? What kind of clothing can people be expected to wear in the summer and in the winter? How much does heavy winter clothing dampen ionizing radiation, and how much does light summer clothing? How much difference is there in dose by skin contact between summer and winter?

8. Discussion

Systematic research on the effects of seasonal and context factors in level 3 PRA seems to be lacking. Therefore there are many research issues that should be solved before SCF's can be taken into account in a systematic and reliable manner.

The first research issue is whether each proposed SCF could have a sufficiently significant effect on accident consequences that it merits taking into account in level 3 analyses. This is so because there are significant uncertainties related to level 3 analyses in general, and small effects will drown in those uncertainties. Such studies should be started from factors that appear to have the potential to affect accident consequences significantly. Examples of such factors are the dampening effect of snow, and washout of radionuclides from frozen ground in the spring (if the accident has happened in winter).

Such studies would also produce model and parameter information useful in the incorporation of SCF's in level 3 studies. This information would allow pilot studies in level 3 PSA where some selected SCF's would be included, and modelling and analyses themselves could be conducted in the manner described in section 6.1. Such pilot studies would give valuable information not only on how to do modelling and analysis on level 3 in a way that takes SCF's into account, but also on the significance of individual SCF's to accident consequences.

After gaining experience in this way, a framework for including SCF's in level 3 analyses could be constructed for example in the manner outlined in section 6.2. This could be accomplished in international cooperation, for example utilizing the existing means of cooperation provided by OECD/NEA and IAEA.

9. Conclusions

This report has tried to lay groundwork for the analysis of seasonal and context factors and their incorporation in level 3 probabilistic risk assessments. It seems that very little systematic research in this domain has been carried out. On the other hand, seasonal and context factors may greatly affect nuclear accident consequences, and therefore more research in this domain is needed.

This report has listed factors that may potentially affect accident consequences significantly, and that therefore should be considered at least as topics of further research. If that research shows that the impact of such a factor is small, it may be left out of consideration; however, if its impact is considerable at least in some scenarios, it should be included in a systematic treatment of seasonal and contextual factors in level 3 PRA. Such research would also produce quantitative data (e.g. damping constants of ionizing radiation through snow) that could be used in level 3 studies.

The ultimate objective of research in SCF's is to enable their incorporation in level 3 PRA analyses in a systematic and scientifically valid way, contributing to improved nuclear safety via better accuracy and credibility of level 3 PSA analyses.

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