RESEARCH REPORT

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Proceedings of the IDPSA-2012 Integrated Deterministic-Probabilistic Safety Analysis Workshop November 2012

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Summary

This report describes the outcome of IDPSA-2012 - Integrated Deterministic-Probabilistic Safety Analysis (IDPSA) Workshop November 2012 organised November 19-21, 2012 at KTH, Stockholm. About 50 nuclear safety analysis experts from Europe and USA participated in the workshop. The objective with the workshop was 1) to identify and discuss needs within industry and how they can be solved with IDPSA, 2) to discuss development of IDPSA methods and applications and 3) to plan joint research activities on deployment of IDPSA in the framework of research agenda. The next action is to develop a joint project proposal within NUGENIA (Nuclear Generation II & III Association).

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Abbreviations

ADAPT	Analysis of Dynamic Accident Progression Trees
ATHLET	Analysis of THermal-hydraulics of LEaks and Transients
BDMP	Boolean logic Driven Markov Processes
CCMT	Cell-to-Cell Mapping Technique
CDF	Core damage frequency
CET	Containment event tree
CFD	Computational fluid dynamics
CSN	Consejo de Seguridad Nuclear
DET	Dynamic Event Tree
DFM	Dynamic flowgraph modelling
DID	Defence-in-depth
DSA	Deterministic safety analysis
EDF	Électricité de France S.A.
EPRI	Electric Power Research Institute
ERIN	Engineering and Research, Inc.
GRS	Gesellschaft für Anlagen- und Reaktorsicherheit mbH
HRA	Human reliability analysis
I&C	Instrumentation and Control
IDPSA	Integrated Deterministic-Probabilistic Safety Analysis
IPR	Intellectual property rights
KTH	Kungliga tekniska högskolan, Royal Institute of Technology, Stockholm
LOCA	Loss of coolant accident
LOOP	Loss of offsite power
MC	Monte Carlo
NASA	National Aeronautics and Space Administration
NRC	U.S. Nuclear regulatory commission
NUGENIA	NUClear GENeration II & III Association
OSU	The Ohio state university
PAR	Passive autocatalytic recombiner
PAR	Passive autocatalytic recombinator
PCT	Peak cladding temperature
PDMP	Piecewise deterministic Markov processes
POLIMI	Politecnico di Milano
PRA	Probabilistic risk analysis
PSA	Probabilistic safety assessment, Probabilistic safety analysis
PSI	Paul Scherrer Institute
ROAAM	Risk oriented accident analysis methodology
RPV	Reactor pressure vessel
SARNET	Severe Accident Research NETwork of Excellence
SBO	Station blackout
SCAIS	Simulation Code System for Integrated Safety Assessment
SNE-TP	The Sustainable Nuclear Energy Technology Platform
SSM	Swedish Radiation Safety Authority
TSD	Theory of stimulated dynamics

UPM	Universidad Politécnica de Madrid
V&V	Verification and validation
VTT	Technical research centre of Finland

1 Introduction

IDPSA - Integrated Deterministic-Probabilistic Safety Assessment, is a family of methods to enable Risk informed decision making. The starting point of the IDPSA framework is that safety justification must be based on the coupling of deterministic (consequences) and probabilistic (frequency) considerations to address the mutual interactions between

- stochastic disturbances (e.g. failures of the equipment) and
- deterministic response of the plant (i.e. transients).

Objectives with the workshop:
- Discuss identified needs within industry and how they can be solved with IDPSA
- Discuss development of IDPSA methods and applications
- Plan joint research activities on deployment of IDPSA in the framework of research agenda.

The workshop was organised by a scientific committee:
- Yvonne Adolfsson, Scandpower, Sweden
- Jan Erik Holmberg, VTT, Finland
- Pavel Kudinov, Royal Institute of Technology (KTH), Sweden

Altogether 50 experts from Europe and USA participated in the workshop (see Figure 1 and Att. 1). The agenda of the workshop is in Attachment 2. Two keynote speakers were invited to the workshop on topics:
- The ADAPT Framework for Dynamic Probabilistic Safety Assessment, Kyle Metzroth (OSU)
- Application of IDPSA in the formulation of the Safety Case, Robert Youngblood.

10 technical presentations were given by other workshop participants.

In addition, four discussion sessions were organised on the following topics:
1. To clarify the needs for risk informed decision making approaches and tools, and current obstacles to putting IDPSA into practice
2. To clarify which pilot applications would be of highest priority to industry
3. To clarify the needs for methodology development to facilitate the deployment of IDPSA in industrial practice (Part I and II)

Presentations are summarised in Ch. 2 and discussion in Ch. 3. Chapter 4 summarizes the discussions regarding the IDPSA project proposal and next actions.

2 Presentations by the participants

Presentation slides have been distributed to the participants electronically.

2.1 Integration of deterministic-probabilistic safety analysis in SNE-TP and NUGENIA, Göran Hultqvist (Vattenfall)

Göran Hultqvist gave an overview of NUGENIA (Nuclear Generation II & III Association). NUGENIA was formally established in the end of 2011 and has now about 60 members from 20 countries. The technical scope of NUGENIA is Gen II and III reactors.

NUGENIA+ is a project application submitted to FP7 Euratom in November 2013. If accepted by Euratom, NUGENIA+ will be able to financially support R&D projects and to develop a process for selecting projects, using the ranking in NUGENIA roadmap. NUGENIA+ could start in mid or late 2013.

NUGENIA application process consists of the following phases. In the first phase, an idea is proposed, it is reviewed by area leader(s), and registered area members may express interest in it. Then the proposer(s) refine the project idea into a template which is submitted and subjected to review; at this phase, registered area members may express their interest in joining the project. Finally, the NUGENIA executive committee makes the funding decision and gives orientations and advice. There are no deadlines. The first step for IDPSA would be to register it in the NUGENIA process.

2.2 Expectations and needs for IDPSA in solving practical safety issues, Harri Tuomisto (Fortum)

Harri Tuomisto gave an overview of history of safety considerations of nuclear power plants starting from design basis accident concept and defence-in-depth principle. He listed application areas for combined deterministic and probabilistic safety assessment:

- Pressurized thermal shock to reactor pressure vessel. Deterministic assessments were too conservative. Probabilistic approach was developed to support obtaining licenses to RPV. Parallel development of deterministic and probabilistic studies were most crucial for selection of representative transients.
- Boron dilution issue. There are several possible mechanisms both in case inherent and external boron dilution. Different approaches (probabilistic and deterministic) have been used in the assessment of boron dilution depending on the mechanism. Shutdown conditions are biggest contributors and they are governed with administrative instructions, procedures and related human errors.
- Severe accident management. Loviisa has applied ROOAM approach in the assessment of uncertainties. The safety goal is that containment failure is a physically unreasonable event for for any accident sequence that is not remote and speculative. This is a hard target for older designs. Several issues were resolved

Life span of Loviisa NPP has had three phases: 1) planning, construction and commissioning, 2) major safety modifications, 3) plant life management phase. Current operating licenses are for 50 years (2027/2030).

Main tools of safety assessments at Fortum include: full scope living PRA, APROS simulation and accident analysis tool, multi-physics tools such as CFD, and structural analysis.

Lessons learnt from Loviisa's cases are that assessments should be more intelligent than a formal activity, and should be adjusted to plant specific conditions. Time should not be wasted on insignificant issues. Special methods and design changes are necessary in the case of non-quantifiable uncertainties. Nassim Taleb has concluded that "sceptical empiricism" is a preferred method in the economics. It is better to be "broadly right" than "precisely wrong".

Main concern for Fortum is at the moment the licensing (V&V) of digital I&C; from Fortum's viewpoint, this topic would be of great interest in a NUGENIA application, too.

2.3 A regulator view of the need of IDPSA computer platforms to ensure consistency of deterministic and probabilistic licensing approaches, Jose Maria Izquierdo, (CSN)

Jose Maria Izquierdo presented some aspects of the CSN experience in licensing from the point of view of quantitative risk assessment. He discussed consistency issues raised by the historic evolution of regulations and quantitative methods to fulfil them, including the recent trend towards risk informed approaches. He claimed that, to ensure consistency, the regulatory verification of the adequacy of public protection measures proposed by industry, based on PSA and DSA, will require a full integration of both. There are several candidates to IDPSA theories and the potential for its rigorous implementation in a way compatible with the risk tools, methods, models and data already available in DSA and PSA.

2.4 Dynamic Probabilistic Safety Assessment using the BDMP formalism: Application to long term loss of internal sources (H3 situation) risk estimation, Valentin Rychkov (EdF)

Valentin Rychkov presented the work done by Roland Donat. In long term transients, the static PSA models may give pessimistic results and cannot be used for practical applications. Indeed, event trees and fault trees are not well fitted to represent redundancies, reconfigurations and repairing of equipment which make the static approach irrelevant for long term studies. To overcome these limitations, dynamic approaches turn out to be interesting since they allow representing the behaviour of complex systems in a more realistic way.

EDF R&D has developed a dynamic formalism called Boolean logic Driven Markov Processes (BDMP). Station blackout was used as an example to illustrate the formalism and the kind of results the BDMP-related computational tools can provide.

2.5 Some insights from ongoing projects on the use of risk information, Per Hellström (Scandpower)

Per Hellström presented an overview of Scandpower experience and insights from the recent projects focused on the use of information about risk. He analysed the difference between risk based (criteria based solely on risk values) and risk informed (criteria based on risk insights along with deterministic and other information) decision making; risk informed is a part of an integrated decision making process. Connections between risk assessment methods, information about the risk and decision making process were discussed.

2.6 LOOP/SBO scenarios with power recovery, Jörg Peschke (GRS)

Jörg Peschke outlined how both PSA and IDPSA methods can benefit from each other in providing a more comprehensive safety assessment of a SBO-scenario. IDPSA is useful, if significant interactions between system, process and human interactions in the course of time have to be taken into account. For an effective application of IDPSA, it is necessary to use the experience and appropriate information from conventional PSA. On the other side, the detailed probabilistic information which can be achieved by IDPSA methods can be used as input for conventional PSA.

An exemplary application of an IDPSA method to a total SBO-scenario was described with focus on the input provided by conventional PSA and on the kind of results which can be derived from IDPSA, and which again can be used for PSA applications. The description addressed accident progression under the influence of various aleatory uncertainties such as the failure behaviour of safety systems and components, human errors, and the corresponding timings. Potential influences of the accident progression on the failure behaviour were considered as well. The presentation emphasized the importance for considering aleatory uncertainties more comprehensively.

Results from the IDPSA-application can be used as input information for analyses of severe accidents with large releases of radionuclides like, for instance, Level 2 PSA analyses. Of special interest is the evolution of the pressure in the reactor pressure vessel (RPV) during core melt and the probability of a high pressure core melt scenario. This information could be helpful to estimate the probability of a RPV bottom failure.

2.7 Variability and uncertainties in LOCA scenarios – motivation and background to IDPSA WP3, Pavel Kudinov on behalf of Vinh Dang and Martin Zimmermann, (PSI)

Pavel Kudinov presented the slides on behalf of PSI. The results of MLOCA analyses performed for the CSNI’s Safety Margins Applications and Assessment (SM2A) and follow-up work at PSI motivate the work proposed in IDPSA WP3. The SM2A analyses focused on the impact of uncertainties on a limited number of sequences. In contrast, PSI’s subsequent work looked at delineation and success criteria – these analyses examined a comprehensive set of scenarios but left uncertainties out of the picture. The aim of the proposed work, outlined in this presentation, is to evaluate the impact of uncertainties on the broader (and probabilistic) understanding of LOCAs.

2.8 Containment over-pressurization due to hydrogen combustions, Iván Fernández (Indizen)

Iván Fernández presented the IDPSA application to PSA2 scenario of containment over-pressurization due to hydrogen combustions and results achieved so far. Fukushima visibly demonstrated the energetic that can be associated with hydrogen deflagrations and that the potential may even exist for hydrogen detonations in severe accident scenarios. The scenario of containment over-pressurization due to H2 deflagrations with different consequences depending on different in-vessel core degradation and possible reflooding sequences is studied in the application. This scenario is known to be a significant contributor to the containment failure probabilities in PSA level 2. Historically, little credit was provided in PSA for recovery scenarios under the assumption that such an approach was conservative.

The scenario chosen in WP4 is based on that already proposed in European excellence network SARNET WP5.3. A more realistic description of the application in the new context is under preparation. A CSN/TSD prototype can be shared with interested participants, although the problem specification will be improved to the extent possible to allow other tools and methods to be used as well.

2.9 Hybrid modelling of control systems, research program proposal, Gilles Deleuze (EdF)

Gilles Deleuze discussed the reliability modelling of complex control systems. Classical methodologies such as even-trees/fault-trees or Petri nets may not represent adequately the dynamic interactions existing between the physical processes (modelled by continuous variables) and the functional (I&C) and dysfunctional behaviour of its components (modelled by discrete variables). EDF has proposed a framework based on various implementations of piecewise deterministic Markov processes (PDMP).

The test case is a water level control system of a steam generator in the secondary circuit of a nuclear power plant. A similar benchmark system was described by the U.S. Nuclear Regulatory Commission to compare two approaches to dynamic reliability: DFM (Dynamic Flowgraph Methodology) and Markov/CCMT (Cell-to-Cell Mapping Technique). The report released by the NRC is not sufficient to reconstruct a realistic model and the idea is to complete the benchmark case. EDF has operating data. Benchmarks are available for open research. Full description of the case is available in French in internet.

2.10 The needs and dreams for methodologies of IDPSA, Francesco Di Maio (POLIMI)

Francesco Di Maio addressed the requirements and expectations of methods for pre-processing, processing and post-processing scenarios for IDPSA. The presentation covered following topics:
(Pre-processing)
1. Clustering of the scenarios for classifying the end state of a sequence at an early stage of its simulation, thus saving computation time.

(Processing)

2. Efficient coupling of advanced Monte Carlo (MC) simulation with the DSA models.
3. DSA meta-modelling using e.g. neural networks.
4. Propagating epistemic and aleatory uncertainties using possibilistic interval analysis and innovative MC methods.

(Post-processing)

5. Post-processing the results by clustering the calculated accident sequences and identifying prototypical sequences for the different failure domains.
6. Embedding NN-based meta-models in genetic algorithms and differential evolution for identifying risk significant scenarios, based on the outcomes of the scenarios calculations.
7. Identifying prime implicants from implicants via genetic algorithms and differential evolution.

They also recommend using metamodels and fuzzy classification for online classification of developing scenarios, due to their relatively low computational burden and easy quantification of uncertainties. In the discussion few questions were raised. Can meta-models be used in regulatory context (validation challenge)? Can meta-model find something that is not present in the original data interpolated by meta-model?

2.11 The ADAPT Framework for Dynamic Probabilistic Safety Assessment, Kyle Metzroth (OSU)

The ADAPT (Analysis of Dynamic Accident Progression Trees) framework is a methodology and tool set that can be used to propagate uncertainties through a model of a complex dynamic system (such as a nuclear power plant) in a phenomenologically consistent manner with a user-desired simulation tool. The ADAPT methodology was originally developed to provide increased insight into the possible scenario evolutions that could occur in nuclear plant severe accidents (i.e. Level 2 PSA) but has been extended to also consider human action, passive systems in Generation IV nuclear power plants, and integrated plant transient/severe accident/consequence analysis.

Kyle Metzroth discussed the major features of the ADAPT framework that can aid in design and operational decisions of complex systems. Several recent applications were discussed to demonstrate the insight that can be gained through ADAPT analysis. In addition, future development needs were identified to facilitate ADAPT's use as a safety analysis tool.

2.12 Overview of TSD-SCAIS. Recent developments and current state, Ivan Fernandez (Indizen) and Javier Hortal (CSN)

The TSD-SCAIS methodology was already presented at the first IDPSA workshop in Espoo. Since then, theoretical developments have been oriented towards the incorporation of PSA fault tree models into the TSD framework. To this aim, system configurations are being explicitly modelled. At the same time the SCAIS modules "Path Assessment" (determination of damage domains) and "Risk Assessment" (integration of the TSD equations) have been implemented and are being assessed and tested. Different discretization strategies are being considered and some application exercises on NPP accident scenarios have been performed. Different types of damage domains have been observed and some potentialities of both methodology and tool have been clearly identified.

2.13 Overview on the MCDET method and further developments, Martina Kloos (GRS)

Martina Kloos presented GRS development work to achieve a more realistic modelling of the accident scenarios to be considered in a PSA and to provide a well-founded probabilistic safety assessment. She presented the developments of the MCDET method which is a combination of Monte Carlo (MC) simulation and the Dynamic Event Tree (DET) approach. The method considers discrete aleatory uncertainties (e.g., on the behavior of safety systems or on the performance of human actions) by the DET approach and continuous aleatory uncertainties (e.g., failure times of safety systems, execution times of human actions, or physical quantities like injection rates, depressurization rates or leakage rates) by MC simulation. The values to be considered for continuous aleatory parameters are sampled and supplied as input to the calculation of a DET. Then a DET is constructed on condition of a set of values randomly sampled for the continuous parameters. The sampling is not necessarily performed a priori, i.e. before the calculations of a DET are launched. It can be performed when needed during the course of the calculation. The application of the MCDET method provides a sample of DETs which accounts for various sets of values for the continuous parameters.

Beside the event sequences and time series of process quantities, the MCDET method calculates the probability distributions for key process quantities corresponding to each DET. Since the distributions are DET-specific and conditional on the set of values sampled for the continuous parameters, the unconditional scenario-specific distributions are estimated from the mean over all corresponding distributions of the DETs. Each mean distribution is given together with confidence intervals indicating the sampling error with which the corresponding mean probability derived from only a sample of DETs (generated according to a limited set of values for the continuous parameters) may estimate the true probability.

The probabilistic issues of the MCDET method are implemented as a library of routines which has to be linked to a program scheduling the calculations of the MCDET routines and a deterministic code. In principal, MCDET can be coupled with any deterministic dynamics code. So far, it was combined with MELCOR, the ATHLET code from GRS and with some less complex codes, for instance, for a hold-up tank problem and for hydrogen combustion.

Current and next developments are and will be mainly concerned with the implementation of a comfortable graphical user interface and the reduction of the computing time. Reduction of the computing time is intended to be reached by a more efficient scheduling of the calculations and by an online identification of DET-sequences which do not need to be calculated to the end. Post-processing of the immense amount of results is another issue where further developments will be focused on.

2.14 The challenge to include dynamic features into an existing PSA, Pavel Krcal (Scandpower)

Pavel Krcal discussed the challenges to including dynamic features in PSA. He described the complexity of modelling and possible solutions to implement dynamic features. Dynamic features can be implemented by increasing granularity of the model, using boundary condition sets etc. Handling of success logic for sequences is complicated, or it is ignored.

Complexity in the model can soon increase the calculation time considerably due to combinatorial explosion. Complex models are also very difficult to review. Therefore it is not feasible to include the full complexity in the model.

2.15 Failure domain characterization: Loss of main and auxiliary feedwater example, Valentin Rychkov (EdF)

Valentin Rychkov presented an example related to coupling of PSA and DSA. The example was from the EPRI/ERIN (2010-) study where safety margins in loss of main and auxiliary feedwater systems for a 4-loop PWR are studied.

In the case, an analysis was made to study the time available for two operator actions: 1) stop of RCP pump, 2) start feed-and-bleed. Kriging interpolation method seems to be the effective method to identify and quantify the failure domain space in this case.

2.16 Application of IDPSA in the formulation of the Safety Case, Robert Youngblood

Robert Youngblood discussed a concept of “safety case” and potential applications of IDPSA. By definition, “Safety case” is a documented body of evidence that provides a convincing and valid argument that a system is adequately safe for a given application in a given environment. The safety case is much more than a presentation of hazards and controls, or risk metrics derived from static inputs. Depending on context, there may be a need to demonstrate a kind of optimization: “as safe as reasonably practicable”. There is also value to showing explicitly what proactive measures will serve to keep the promise of safety.

IDPSA could be useful not only for prediction of the risk frequency but also for the prevention analysis: given the target, what parameter distributions are needed. Vulnerability search and optimization is similar problem.

Example of IDPSA application in NASA was given (which uncertainties affect the result most) and NASA standards for modelling and simulation results credibility NASA-STD-7009 were discussed.

2.17 Reliability analysis of a passive autocatalytic recombiner system – integrated use of SPSA tool and MELCOR, Taneli Silvonen (VTT)

Taneli Silvonen presented a framework of how to incorporate reliability analysis of a safety function or a device into a PSA of a nuclear power plant. The framework was applied to a passive autocatalytic recombiner (PAR) system which is designed to remove hydrogen from the containment atmosphere during an accident sequence. The scope of the probabilistic safety assessment is limited to level 2. The approach taken here characterizes the PAR system primarily by redundancy and its passive functioning.

Loviisa nuclear power plant has a PAR system included in its severe accident management strategy. MELCOR computer code was used for deterministic simulations of accident progression in order to provide information on both phenomenological matters during the accident sequence and performance of the PAR system. SPSA code was used for probabilistic containment event tree (CET) modelling. The SPSA results were quantified as source terms for three radionuclide groups and measured in core release fractions. The results highlighted the importance of an efficient hydrogen management strategy.

2.18 Adaptive exploration of event space for vulnerability search IDPSA, Pavel Kudinov (KTH)

Pavel Kudinov discussed the problem of achieving a reasonable balance between completeness of the event space exploration and computational costs. KTH’s work is focused on the approaches which use methods of global optimum search (such as genetic algorithm) for identification of failure domains. Unlike brute force Monte-Carlo based methods, proposed methods rely on the information obtained in the process of the event space exploration in order to guide the search process towards failure domain boundaries, thus increasing computational efficiency while ensuring completeness of the analysis. One issue is how to assess probabilistic characteristics based on the produced data which is biased towards failure domains.

2.19 Application of ISA methodology to SBO and LOCA sequences, Gonzalo Jimenez (UPM)

Gonzalo Jimenez presented two applications within the ISA methodology framework: SBO and LOCA sequences. The LOCA sequences have been analyzed taking into account a full spectrum of break sizes, comparing the different human and system action during the transients. SBO sequences have been studied considering multiple damages during the transient development. The main results obtained were shown and the most important conclusions at the moment were outlined.

3 Summary of the discussion sessions and conclusions of the workshop

Main theme: Deployment of IDPSA, why not yet?

IDPSA tools have been under development for decades. Considerable experience of IDPSA applications has been accumulated. Yet, IDPSA is not a part of every-day practice of safety assessment and decision making process.

What is the bottleneck in putting IDPSA methods and tools into practice of risk informed decision making? Is it a lack of:

- Interest (no pressing needs)?
- Awareness (underestimation of capabilities)?
- Methodology?
- Tools?
- Data?
- Implementation strategy?
- … all together?

What can we, as a community, do together to help accelerate deployment of IDPSA?

Main questions which were discussed during the sessions:

1. End-users needs for risk informed decision making approaches and tools, and current obstacles for putting IDPSA into practice.
    - Possible pilot applications of highest priority for industry.

2. The needs for methodology development to facilitate deployment IDPSA into industrial practice.

3. Revision of the research agenda on deployment of IDPSA as complimentary to PSA and DSA methods.

End-users needs (Industry)

As outcomes of the post Fukushima stress tests different suggestions emerged for safety improvement. However, effectiveness of these suggestions in reduction of risk is not self-evident due to the fact that:

- There are possible positive and negative effects.
- Impact on risk is plant specific.
- Residual risk is not always clearly defined.

Specific examples of the issues which can be of interest for industry are:

- Filtered containment venting (Pan European problem as an outcome of the stress tests):
    - Positive and negative outcomes should be considered.
    - Design specific consideration should be taken into account.
    - Which scenarios to consider?
- Loss of ultimate heat sink (a need for a backup):
    - Oil spill accident (concern in Finland due to increased ship traffic).
- Flood protection:
    - Sealing of buildings is not necessarily a good method for long term flooding.
- Digital I&C (software driven)
    - Assessment of reliability.
- Combination of HRA with
    - Shutdown states (considerable contributor, but difficult to address), large role of HRA, no availability of some systems
    - DI&C (previous experience to be considered e.g. for (i) impact of modern control room design on operator actions, and how to analyze them in PRA and (ii) design and V&V of software in connection with HRA)

        - Application IDPSA for a practical HRA case.
        - Availability of information for operator can significantly change probabilities.
        - Different (conflicting, competing in time?) criteria for making decision by operator.
        - Current modelling on PSA uses "available time" concept (which depends on previous timing, history).
        - IDPSA can be used to identify combinations of operator actions and DI&C malfunctioning which lead to failure domain.
    - Human and organisational behaviour related scenarios.
    - Multiple operator actions in a sequence is a challenge to analyse.
- Plants modifications:
    - Lack of experts who have global view on the system and interdependencies.
    - Difficult to provide comprehensive assessment.
- Assessments of beyond design basis events.

Requirement for consistency in safety analysis leads to IDPSA.

End-users needs (Regulator)
There is a need for verification of current decision making process and criteria (note that regulatory, utility, vendor decision criteria are different)

- Verification of DID.
    - Analysis of precursor.
- Verification of consistency between PSA and DSA.
    - E.g. success criteria and probabilities, missed sequences, activation of set points, etc.
- IDPSA is a way towards "assumption free" approach in determining what is "conservative", e.g.
    - Worst case scenarios (maximum credible accidents) for DSA analysis.
    - Conservatism of PSA models in describing scenarios where expert judgement is limited.

Why every time there is a new issue at NPPs, we go back to classic PSA/DSA?

Licensing of new reactors with traditional approaches might be difficult with state of the art approaches:

- Gen II safety surrogates (e.g. main steam line double guillotine break, PCT, etc…) are
    - questionable as representative for major safety concerns relevant to safety assessment of Gen III+ with
        - Digital I&C + HRA and
        - Passive safety systems.
    - …even less relevant to Gen IV.

Concerns for deployment of IDSA: industry view.
Better understanding of the system should be the goal of analysis, thus intelligent approach to risk assessment is favored. There is a concern that formal approach to

risk assessment using advanced computational models can increase uncertainty by producing data instead of knowledge.

Treatment of the uncertainties including intangible (unquantifiable) uncertainties should be consistent, complete, and credible. Experimental support and validation of results is important.

Eventually, the measure of success for industry is issue resolution.

Concerns for deployment of IDSA: regulatory view.
There are evolutionary changes towards considering risk-informed approaches, but risk informed decision making is not yet a mainstream approach.

PSA standards are in the process of “harmonization”. The motivation for harmonization is to establish a confidence in PSA results.

There is a (legitimate) concern that IDPSA will also require efforts on development of best practice guidelines in order to establish ***confidence in the results*** of IDPSA analysis.

Organizational and cultural obstacles for deployment of IDPSA
End users (regulator and industry) have problems which require ***risk informed*** approaches to assessment and decision making. At the same time, there is apparent lack of awareness about IDPSA approaches, tools and capabilities.

There is apparent “***Catch-22***” situation

- Risk assessment tools (IDPSA) are not adopted by industry/regulator because Risk informed decision making is not a common practice.
- Risk informed decision making is not a common practice because Risk assessment tools are not adopted yet.

Opportunities and challenges for IDPSA deployment
There is a consensus that to break the “22 loop” a ***successful demonstration cases*** are necessary.

According to the end users view, **successful** means **issue resolution**, not just successful run of a code.

Consistent, complete and credible assessment of selected problems (e.g. stress test suggestions) in order to “***resolve the issues”*** can be a way for IDPSA to break the “22 loop”

Safety margin assessment requires both and integrated Probabilistic and Deterministic assessments and IDPSA provides these capabilities. However, there is a question about benefit versus costs of IDPSA application in risk informed decision making. Clear communication of the cost and benefits of Risk informed approach is a must for successful deployment.

How do decisions makers would like to make decisions:

- Answering to wrong questions “precisely, cheaply and quickly”? or

- Answering to the right questions costly, time consuming, with explicit quantification of uncertainties, but with ***confidence***?
- …is there even a choice?

EdF experience suggests that application of IDPSA analysis to a dynamic system can be:

- Simpler than application of state of the art PSA.
- Leading to cost effective solutions (~50 MEUR/year for one problem on maintenance schedule).

The needs for methodology development to facilitate deployment IDPSA into industrial practice.

“it is better to be broadly right than precisely wrong”

» **Nassim Taleb** (author of bestseller "The Black Swan” about unexpected events of large magnitude and consequence and their dominant role in history):

1) IDPSA methods and decision making process.

It is difficult to judge about “readiness” of a tool if there is no clear

- Criteria of successful application
  - Specific to the decision making process and goal.
- Goal of analysis
  - Should be formulated on problem specific basis.

Figure of merit (consequences) in definition of risk and selection of adequate safety goals and success criteria are necessary input from decision making context.

Currently available IDPSA methods present a set of tools which are generally capable in quantifying different sources of uncertainties with major focus on

- Aleatory uncertainties in time dependent scenarios.
  - Historical reason for that was to demonstrate that “Dynamic PSA is needed because it can do what “static” PSA can’t”.

While timing is important source of uncertainties (especially for HRA, DI&C, passive safety systems, etc.), we have to accept that this argument helped IDPSA only to “survive”, mostly in academia, but didn’t work out quite well for deployment in industry.

It might be a good time to reconsider the focus and the message, looking at the actual needs of decision makers …

- What is more important for decision maker
  - ***By which tool the analysis was provided? or***
  - ***What kind of information is provided?***

What kind of data is needed for decision maker to make a ***robust*** and ***least imperfect*** decision (besides a number which quantifies the Risk) ?

- Credibility
  - Why even bother to look in the results if we cannot establish a credibility of those?

- Uncertainty quantification (*robustness of decision*)
  - Sensitivity of the decision consequences to the uncertain parameters.
- Comprehensiveness
  - Risk profile instead of one number (e.g. CDF).
- Understanding
  - To be able to judge consequences of ***different decisions.***
  - How to choose the surrogate risk metrics?
  - What are the key parameters which can change the decision?
    - Decision should be robust even if uncertainties exist.
    - These parameters should be in the focus of the analysis.

Consistent and comprehensive approaches and tools to communicate analysis result to the decision maker are necessary, considering:

- Different decision types (regulatory, industry) require different information to be provided (e.g. regulator don't care about the costs).
- Complexity of the technical problem, e.g.
  - How to visualize damage domain in a multi-parameter space? Is such presentation even needed?
  - What are the characteristics to be visualized for the decision maker to reach "sufficient" understanding of an issue?
  - The results of IDPSA should be post-processed so that the meaning of certain sequences etc. could be explained to a decision maker with deterministic engineering background.
  - In other words, the "physical" meaning of the results should be explained.

Previous experience in nuclear and other fields on development of decision (resolution) oriented approaches, e.g.:

- **ROAAM** (See also presentation by Harri Tuomisto)
- NASA approaches and **Safety case** (presentation by Robert Youngblood)

Example of decision making oriented approach is **ROAAM** (Risk Oriented Accident Analysis Methodology). ROAAM is based on **defense-in-depth**, and is focused at **reducing the uncertainty** sufficiently to recognize that such a defense-in-depth has been achieved.

The basic premise is that once the ***whole community of experts in a given problem area*** *is* convinced (that the demonstration has been effected), the problem may be considered solved, in a robust and final way.

Eventually the complete reaching of all experts is effected by publication in the technical literature, with additional iterations thereof if necessary.

The use of risk for effective management and regulation of rare and high-consequence hazards requires the simultaneous (coherent) consideration of

- Safety Goal
- Assessment Methodology
- Application Specifics

Effectiveness of ROAAM is achieved as a result of **integrated approach to Risk Assessment** and **Risk Management**.

ROAAM provides guidelines for development of **frameworks for bounding** of **Epistemic** (modeling), and **Aleatory** (scenario) **uncertainties** in a ***transparent and verifiable*** manner that enables ***convergence of experts' opinions on the outcome of the analysis*** (not necessarily on the uncertainties in the input information).

Principal ingredients of ROAAM include:

- identification, **separate treatment**, and maintenance of this separation (to the end results), **of aleatory and epistemic uncertainties**;
- identification and **bounding/conservative treatment of intangibles and splinters**,
  - that is, of epistemic uncertainties (in parameters and scenarios, respectively) that are beyond the reach of any reasonably verifiable quantification; and
- the use of external experts in a review, rather than in a primary quantification capacity.

2) Needs for methodology development to facilitate deployment of IDPSA.

Can IDPSA help to reduce uncertainty or it would increase uncertainty? It is a matter of analysis:

- Completeness, Consistency and Credibility.

Completeness vs. computational costs.

- Where to stop (residual risk, screening frequency)?
  - Considering only frequencies might be misleading for high consequence hazards.
- Consistency vs. assumptions and simplifications.
  - "Assumptions free" is it achievable? If not, then
    - IDPSA analysis assumptions should be explicitly documented.
    - The effect of the assumptions should be addressed explicitly.
    - Awareness about the simplifications and assumptions in the deterministic code. IDPSA may fall in the same trap as PSA by trusting too much to the deterministic model.

Understanding and "tracing" of uncertainty sources for transparency and verifiability of the analysis:

- IDPSA aims at quantification of aleatory and epistemic uncertainties.
- Uncertainty of deterministic codes
  - Relevant validation.
  - Numerical uncertainties (reduction, quantification).
  - Uncertainty of surrogate (meta) models.
- Uncertainty of the data
  - Availability of "adequate" input data with "pedigree".
  - New type of data is not requested before thus not readily available
    - » e.g. occurrence rate of dynamic events?
- Epistemic uncertainties require adequate approaches:

  - Possibilities vs. probabilities?
- Intangible uncertainties have to be addressed
  - Both aleatory and epistemic.

Validation of IDPSA is not much different from validating of the deterministic model. Important is to apply deterministic code within the domain of input parameters and regimes for which it was previously validated.

New generation deterministic codes with significantly reduced numerical uncertainties and improved stability are necessary for efficient and reliable application of IDPSA.

There is a general consensus that **any source of uncertainty (including domains of applicability/validation for deterministic codes) should be subject to sensitivity and, if necessary uncertainty quantification** studies with appropriate (existing) approaches.

3) Connection between IDPSA and PSA, DSA.

Main potential benefit from PSA/DSA application in combination with IDPSA is establishment of consistent conservatism in PSA and DSA analyses:

- PSA conservatism: clarification of consistency in assumptions:
  - IDPSA can provide information about phenomenology to the PSA experts when there is large uncertainty about it.
    - Epistemic uncertainty concerning model uncertainties (not parameter uncertainties) is not taken into account in the probabilistic part of PSA, but should.
  - Even if PSA is on “average conservative” but locally it can be “non-conservative”.
    - Example: an effort in USA on IDPSA analysis for Feed and Bleed to increase NRC’s confidence in PSA.
  - Misunderstanding of the true sources of safety margins can lead to decisions which might increase the risk.
- DSA conservatism: clarification of conservatism in assumptions about the transients to be run as “enveloping” or maximum credible accident.
- Identification of major uncertainty sources in deterministic modelling.
  - Basis for code improvement and
  - Validation.
- Eventually, aiming at consistency between success criteria in PSA and DSA analysis.

Other issues related to connection between PSA, DSA and IDPSA:

- It is important to identify where (in which scenarios, for which purposes) IDPSA is needed.
- There can be a “cliff edge” effect. How to determine how far away are we from the cliff?
- Plant modifications
  - Power uprate changes the success criteria. Re-evaluation of all success criteria is a huge effort.
  - Changing of the PSA model is a huge effort when the plant changes.

  - How to change the IDPSA model when the plant changes?
    - A model consists also of the assumptions made. These assumptions should be verified to see which ones are no longer valid and what new assumptions are to be made.

4 Revision of the research agenda for deployment of IDPSA as complimentary to PSA and DSA methods.

Key elements for research agenda in short and near future terms (2013) are:

Increase awareness about IDPSA

- NURETH-15 The International Topical Meeting on Nuclear Reactor Thermal Hydraulics 12-17 May, 2013, Pisa, Italy, Workshop/Seminar W1 "Combining deterministic and probabilistic methods for comprehensive safety margin assessment"
- Nordic PSA Conference – Castle Meeting 2013, 10th -12th April, Stockholm, Sweden.

Revise EU-IDPSA proposal to prepare IDPSA project proposal for NUGENIA (earliest start is in the fall of 2013).

- Focus on the end-users is a must for success in NUGENIA.

The project — and thus the application — must be based on doing research that the end users find relevant to them.

5 Discussion of the ideas for NUGENIA-IDPSA project proposal

5.1 Pilot applications

WP2: SBO with focus on development of approaches for verification and Improvement of SAMGs

- Preventive and Mitigative measures.
- Decision making on severe accident management.
  - HRA plus Uncertainty in process variables
- Study of the impact of implementation of filtered containment venting.
  - Should be addressed for design specific conditions.
- Unavailabilities:
  - How important?
  - Risk effective and cost efficient measures?
- Additional options:
  - Seal LOCA (leak before break in SBO)

It is important to communicate clearly in the application what we mean by verification and improvement of SAMG with a link to HRA. There is a link to WP5 activities.

WP3: LOCA uncertainties and Risk with focus on:

- Implications for optimization (cost efficient) of in-service inspections to

  - Keep (or improve) the figure of merit in terms of CFD (risk effective)
  - Decrease
    - Dose for workers (risk effective),
    - Associated costs (cost efficient).
- There is ongoing activity for many years.
  - How it was done before?
  - Reference analysis exists for comparison.

WP4: Hydrogen management effectiveness

- Effectiveness of PARs?
- Role of containment spray activation
  - Connection to (Level 1 – Level 2) EOP-SAMG, links to
    - WP2 uncertainty in process variables, verification of procedures.
    - WP5 general issues on connection between Level 1-2.
- Difficulties in modeling
  - Importance of 3D effects on stratification and mixing in the containment atmosphere.
  - Traceable and quantifiable uncertainties.
  - Use of metamodels (physics based + data mining)?

WP6: Dynamic reliability, validation of hybrid control systems and logic.

- In addition to the benchmark, consider a practical case on optimization of maintenance.
- Address cost efficiency and
- Consider decision making process.

A case that would interest EDF would be maintenance of an auxiliary transformer so that it can be done online. For example, maintenance of diesel engines – maintenance not needed because the probability of accident is low enough already. The issue is effective and cost-efficient management of risk.

5.2 Other work packages

WP5: Level 1 and level 2 interface

No major changes so far.

WP7: IDPSA Methodology and tools

- Stress on decision making process (see IDPSA-2012 workshop discussions).
- Emphasis on methods and tools for
  - Presenting results to decision makers
  - IDPSA-DSA/PSA connections
    - System engineering,
    - Data structure for two-way exchange between IDPSA PSA and DSA.
- Harmonization of terminology

5.3 Intellectual Property Rights (IPR) and NUGENIA

To be proposed to NUGENIA to follow EC model for IPR.

5.4 NUGENIA actions

KTH, VTT, Scandpower: (Deadline: new year)

- Clarify about NUGENIA project registration process

IDPSA WP leaders and partners: (Deadline: January 25, 2013)

- Comments on the Ideas for modification of the EU-IDPSA proposal for NUGENIA.

Expected start of proposal modification:

- **March** (After NUGENIA meeting in Budapest).

Att. 1. Workshop participants

1	Yvonne	Adolfsson	Scandpower
2	Luciano	Burgazzi	ENEA
3	Gilles	Deleuze	EDF
4	Micaela	Demichela	Politecnico di Torino
5	Fransesco	Di Dedda	Scandpower
6	Francesco	Di Maio	Politecnico di Milano
7	Iván	Fernández	Indizen Technologies
8	Sergey	Galushin	KTH
9	Peter	Hägglöf	Vattenfall
10	Vidar	Hedtjärn Swaling	Scandpower
11	Per	Hellström	Scandpower
12	Jan-Erik	Holmberg	VTT
13	Javier	HORTAL	CSN
14	Göran	Hultqvist	Vattenfall
15	Elena	Ilina	SSM
16	Jose Maria	Izquierdo	CSN
17	Anna-Maria	Jakobsson	Vattenfall
18	Gonzalo	Jimenez	UPM
19	Ilkka	Karanta	VTT
20	Martina	Kloos	GRS mbH
21	Joakim	Klug	Vattenfall
22	Yoshiyuki	Kondo	Mitsubishi HI
23	Kaspar	Kööp	KTH
24	Pavel	Krcal	Scandpower
25	Pavel	Kudinov	KTH
26	Pierre-Etienne	Labeau	Université libre de Bruxelles
27	Robert	Larsson	Vattenfall
28	Kyle	Metzroth	The Ohio State University
29	Ari-Petri	Miettinen	Teollisuuden Voima Oyj
30	Ralph	Nyman	SSM
31	Antti	Paajanen	Fortum
32	Jörg	Peschke	GRS
33	Viet-Anh	Phung	KTH
34	Sebastian	Raub	KTH
35	Valentin	Rychkov	EDF
36	Taneli	Silvonen	VTT
37	Sachin	Thakre	KTH
38	Harri	Tuomisto	Fortum
39	Fabio	Veronese	GRNSPG
40	Walter	Villanueva	KTH
41	Yury	Vorobyev	MEI
42	Robert	Youngblood	INL
45	Enrico	Zio	Politecnico di Milano
46	Seiho	Utsumi	Mitsubishi HI

Att. 2. Workshop agenda

Monday November 19, 2012

Time	Title	Presenter
08:30	Registration, coffee	
09:00	Opening of the workshop Meeting logistics Introduction to the workshop and IDPSA Research agenda	Pavel Kudinov (KTH)
	Session 1: Industry and regulator views on the needs for risk informed decision making approaches and tools.	Session chair: Pavel Kudinov
09:25	Integration of deterministic-probabilistic safety analysis in SNE-TP and NUGENIA	Göran Hultqvist (Vattenfall)
09:55	Expectations and needs for IDPSA in solving practical safety issues	Harri Tuomisto (Fortum)
10:25	Coffee break	
10:45	A regulator view of the need of IDPSA computer platforms to ensure consistency of deterministic and probabilistic licensing approaches	Jose Maria Izquierdo, (CSN)
11:15	Dynamic Probabilistic Safety Assessment using the BDMP formalism Application to long term loss of internal sources (H3 situation) risk estimation	Valentin Rychkov, Roland Donat (EdF)
11:45	Some insights from ongoing projects on the use of risk information	Per Hellström (Scandpower)
12:15	Discussion session 1: To clarify the needs for risk informed decision making approaches and tools, and current obstacles for putting IDPSA into practice.	Moderator: Göran Hultqvist
13:00	Lunch	
	Session 2: Pilot applications of IDPSA, PSA and DSA	Session chair: Jan-Erik Holmberg
14:30	LOOP/SBO scenarios with power recovery	Jörg Peschke, Martina Kloos (GRS)
15:00	Variability and uncertainties in LOCA scenarios – motivation and background to IDPSA WP3	Vinh Dang, Martin Zimmermann, (PSI)
15:30	Coffee break	
15:50	Containment over-pressurization due to hydrogen combustions	Iván FERNÁNDEZ (Indizen)
16:20	Hybrid modelling of control systems, research program proposal	Gilles DELEUZE (EdF)
16:50	Discussion session 2: To clarify which pilot applications would be of highest priority for industry	Moderator: Yvonne Adolfsson
17:30	Adjourn day 1	
19:00	Dinner	

Tuesday November 20, 2012

Time	Title	Presenter
	Session 3: Development of methodology and recommendations for deployment of IDPSA (1)	Session chair: Yvonne Adolfsson
08:45	Summary of day 1	Göran Hultqvist, Yvonne Adolfsson
09:00	The needs and dreams for methodologies of IDPSA	Enrico Zio, Francesco Di Maio (POLIMI)
09:30	The ADAPT Framework for Dynamic Probabilistic Safety Assessment	Kyle Metzroth, Tunc Aldemir (OSU)
10:00	Overview of TSD-SCAIS. Recent developments and current state	Javier Hortal (CSN)
10:30	Coffee break	
10:50	Overview on the MCDET method and further developments	Martina Kloos, Jörg Peschke (GRS)
11:20	The challenge to include dynamic features into an existing PSA	Ola Bäckström (Scandpower)
11:50	Failure domain characterization. Loss of Main and Aux. feed water example.	Valentin Rychkov (EdF)
12:20	Discussion session 3: To clarify the needs for methodology development to facilitate deployment IDPSA into industrial practice.	Moderator: Valentin Rychkov
13:00	Lunch	
	Session 4: Development of methodology and recommendations for deployment of IDPSA (2)	Session chair: Ola Bäckström
14:30	Application of IDPSA in the formulation of the Safety Case	Robert Youngblood
15:00	Reliability analysis of a passive autocatalytic recombiner system – integrated use of SPSA tool and MELCOR	Taneli Silvonen (VTT)
15:30	Coffee break	
15:50	Adaptive exploration of event space for vulnerability search IDPSA	Pavel Kudinov (KTH)
16:20	Application of ISA methodology to SBO and LOCA sequences	Gonzalo Jimenez (UPM)
16:35	Discussion session 4: To clarify the needs for methodology development to facilitate deployment IDPSA into industrial practice.	Moderator: Pavel Kudinov
17:20	Adjourn day 2	

Wednesday November 21, 2012

Time	Title	Presenter
	Session 5: Summary discussion session and revision of the IDPSA research agenda	Session chair: Jan-Erik Holmberg
09:00	Presentation of the workshop summary and IDPSA research agenda	Organisation committee
09:30	Discussion of the summary and conclusions and closure of the workshop.	Moderator: Yvonne Adolfsson
10:10	Coffee break	
10:30	Adjourn of the workshop participants	
10:50	EU-IDPSA Partners Meeting: Discussion on revision of the EU-IDPSA proposal for NUGENIA	
13:00	Lunch	
14:30	Adjourn of the EU-IDPSA meeting participants	
	Preparation of the proceedings of the workshop	Organisation committee