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SPRINT: A TOOL FOR PROBABILISTIC SOURCE TERM PREDICTION FOR USE WITH DECISION SUPPORT SYSTEMS

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This paper describes a software tool, SPRINT, that has been developed within the FP5 STERPS project for rapid source term prediction. It is based entirely on a probabilistic approach to the diagnosis and prognosis of Nuclear Power Plant status, based on key instrument readings and other observations. In principle, the method can be applied to any accident sequence from the benign to the most severe. However, the main benefits are seen for the diagnosis of plant status during degraded core conditions where the accident phenomenology is either uncertain or essentially non-deterministic in nature. The output from SPRINT consists of a set of potential source terms with an estimate of the likelihood of each.

BACKGROUND

Computer-based decision support systems (DSSs) are becoming accepted as a useful means of managing and sharing information during any incident at a Nuclear Power Plant (NPP) within Europe where an off-site emergency response is required. Ultimately, it is hoped that their use would supply decision makers with high quality information with minimum delays. Part of this process that is not so well developed is the initial prediction of the radioactive release to the environment (the ‘source term’). Rapid prediction of the source term is crucial to the appropriate early management of a nuclear emergency. The information exchange between the inward-looking plant control room team and the outward-looking off-site emergency management team can determine the quality of the initial source term prediction. This is not an easy interface to manage as these two distinct disciplines have little common ground from which to communicate their immediate findings and concerns.

Traditionally, source term estimates have relied on assessing the potential accident characteristics using a simple rule-based procedure backed up by expert judgement. A suitable source term is then selected from a set of pre-calculated accident source terms. It is likely that this approach would lead to very conservative source terms being adopted in the early phase of any incident to allow for the unquantified uncertainties. These uncertainties arise principally from incomplete information on the current plant status and on the potential of future plant system failures to influence the eventual outcome. The advent of DSS has resulted in a more dynamic approach to analysing the consequences of any abnormal release. Hence, attention has now turned to how real-time source term prediction could be improved. Within the European Commission Fifth Framework Programme (FP5), complementary deterministic and probabilistic methods are being developed, each based on software tools to help bridge this gap.

This paper describes a software tool, System for the Probabilistic Inference of Nuclear Power Plant Transients (SPRINT), that has been developed within the FP5 STERPS project for rapid source term prediction. It is based entirely on a probabilistic approach to the diagnosis and prognosis of the accident sequence. In principle, the method can be applied to any accident sequence from the benign to the most severe. However, the main benefits are seen for the diagnosis of plant status during degraded core conditions. The output from SPRINT consists of a set of potential source terms with an estimate of the likelihood of each. This contrasts with the traditional deterministic approach that generates a single source term. Arguably, the former better reflects the realities of the accident situation, but equally it is apparent that it complicates the interpretation of the results. An overview of the methodology adopted in SPRINT is presented below.

THE PROBABILISTIC APPROACH

Bayesian belief networks and the NPP model

Bayesian belief networks (BBNs)(1) can be used to model the interdependences of plant systems and potential accident phenomenology and to hold *a priori* probabilities for key instrument readings and other observables. The simple graphical representation of a BBN using nodes and links is a powerful way of capturing complex dependencies in a mathematically consistent manner. Within the BBN, some nodes represent plant parameters/conditions that are observable by plant operators (at least in principle) or are parameters made available off-site via remote readout. These observables are the starting point for building the NPP model. Other nodes represent conditions that are intrinsically unobservable

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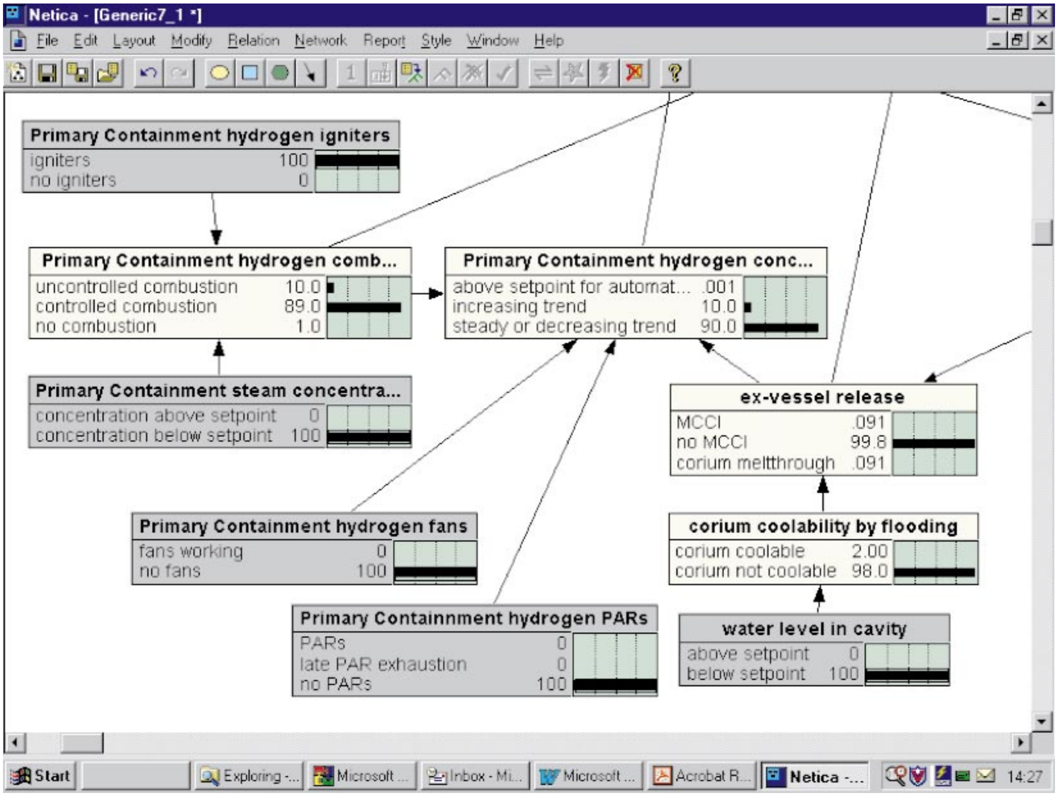

Figure 1. Part of belief network model (status of 'observable' nodes shown in grey).

but are necessary to model the plant behaviour. In general, the network is based on identifying causal relationships between parent and child nodes. A sample of the generic model, which forms the starting point for any plant-specific customisation (and is subsequently termed 'the model'), is shown in Figure 1.

Each node is described by a number of discrete states that have an associated probability, and the sum of these state probabilities is unity. Individual nodes are connected together by directed links that represent an influence of one node on another node, e.g. a child node state depends on the states of its parent nodes. The strength of these dependences is specified by pre-assigned conditional probabilities. When an observation of a variable (node) is made, the probability of the observed state becomes unity and the probabilities of the other states of that node become zero. Probabilistic inference is then applied to determine the implications of the observation for all other nodes in the network, both observable and unobservable.

For independent observables (i.e. observable nodes that have no parents), if no observation is available then *a priori* probabilities, derived where possible from probabilistic safety assessments (PSAs), are used instead. An example of this is the node representing the availability of a safety system such as the containment sprays.

The software SPRINT

SPRINT is a software suite designed for use in NPP accident diagnosis/prognosis situations, with its main purpose being to generate an accident source term file for use by a DSS. SPRINT takes, as input, observations and trends in key instrument readings from the NPP and passes these 'findings' to the BBN model of the NPP. It uses the 'Netica' software package from Norsys (Netica is a Registered Trademark of Norsys Software Corporation) for building the model and the probabilistic inference engine for all BBN computations. The SPRINT interface was written in the Visual Basic 6 programming language (Visual Basic 6 is a Registered Trademark of Microsoft Corporation) and communicates with the BBN through the application programming interface (API) of the Netica executable file. The Netica inference engine uses efficient algorithms to calculate global changes in the node state probabilities as findings are entered—even for an NPP

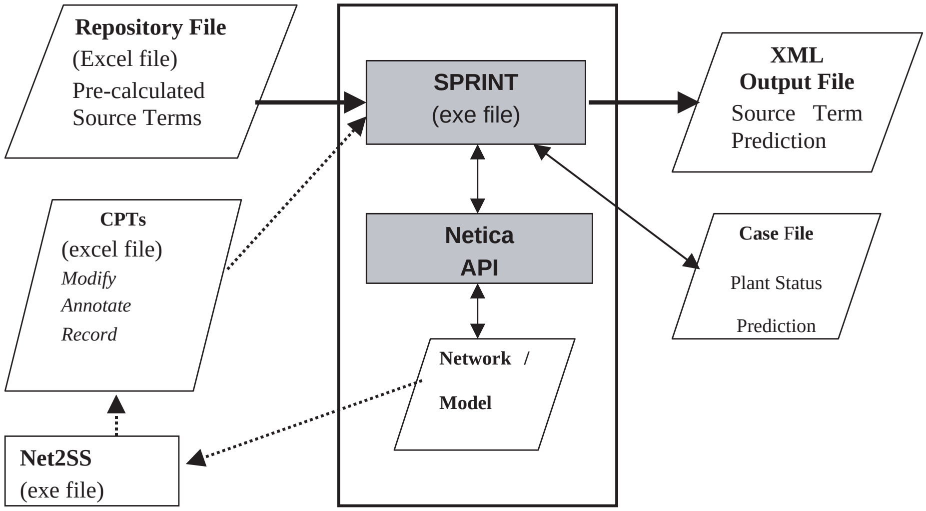

Figure 2. SPRINT architecture.

network of over 100 nodes the calculations are so rapid as to appear instantaneous. Taking the calculated probabilities for certain key 'output' nodes and using a correspondence between the plant states defined by these nodes and a set of pre-defined accident source terms, SPRINT is able to display the predicted source terms. The set of pre-defined accident source terms are stored in a source term repository assembled typically from NPP source term analyses performed as part of Level 2 PSA studies.

An important consideration during the design of the software was to modularise the architecture so as to ensure that all plant-specific data is stored in data files rather than in the application itself. This means that the same software can be used for many different BBNs, which may represent different NPPs. As part of the STERPS project, plant-specific networks were created for five PWR plants (of Westinghouse, KWU and WWER design) and a single BWR (ABB Atom BWR-75). This separation of plant-specific information was achieved by the application architecture shown in Figure 2. The principal software components are as follows.

The SPRINT application

This is the combination of the SPRINT executable (exe file) that provides a customisable user interface to the BBN model of a NPP and the BBN NPP model file itself (a Netica dne file). The exe file is responsible for the user interface, for communicating with the Netica probabilistic inference engine and for file input/output. The user interface has been designed to be as simple as possible as the application must be usable in a high stress environment. It consists primarily of:

- a box displaying a question related to some key plant observable,
- a box containing the set of possible responses (including 'not known'),
- a box containing all answered questions,
- a box containing all unanswered questions.

Each new case within SPRINT starts an interrogation aimed at determining the likely state of the plant. The first question is asked, and when a response is entered by selecting one of a number of possible responses, the BBN is updated immediately through the Netica API. Then the next question is asked, and the cycle repeats until all questions are asked or the user elects to end the question phase. If new information becomes available on a question visited previously, e.g. answered 'Not known', this can be changed at any time. At the end of the interrogation process, or at any point in the middle of it, the user can review the predicted source terms and their probabilities based on the responses entered. The user can elect to generate an output file or printed output of the response history and source terms at any time. SPRINT also has a design mode that allows more advanced users to change much of the data stored in the dne file directly.

The conditional probability tables

In addition to the network structure, the key data in the model are the conditional probabilities that define the strength of the influence of a parent node on a daughter node. These values are stored in conditional probability tables (CPTs) in the dne file, one table per node. The CPTs reflect currently a NPP operating at full power; however, in principle both low power and shutdown states could be modelled. In order to facilitate the annotation and maintenance of the CPT data during model development, a software utility program (Net2SS) was written to copy CPT data stored in a dne file to an Excel workbook (Excel is a Registered Trademark of Microsoft Corporation)—one CPT table per worksheet for easy readability. This spreadsheet file can be read in by SPRINT so that any changes made can be copied back to the CPTs in the dne file.

The repository file

Pre-calculated source terms are stored in an Excel workbook file known as the repository file. The parameters needed to specify a SPRINT source term were influenced by the requirement that SPRINT be capable of generating source term message files for DSSs such as RODOS. The information can be summarised as:

- general information about the NPP unit,
- approximate release in bequerels of a named set of nuclides over a series of non-overlapping time intervals, including provisional information on iodine speciation,
- provisional estimates of effective release height and release energy in each time interval,
- provisional estimates of warning time (delay until the main phase of the environmental release) and potential INES categorisation.

The XML output file

The FP5 MODEM project was tasked with devising a general messaging system to link DSS software running at various locations including plants, Technical Support Centres and National Emergency Response Centres possibly in different countries. SPRINT generates an output file that is compatible with the requirements of this messaging system as defined by the Source Term XML Schema Definition file.

The case file

All the responses entered by the user during a SPRINT interrogation can be saved as a case file. These case files can then be read in at a later time, replayed from the start and/or updated.

FEATURES OF THE PROBABILISTIC APPROACH

In traditional plant analysis, the source term is calculated on a deterministic basis by assuming the parameters that define the input conditions and using the calculated event progression based on the accident phenomenology in the analytical models. When using the deterministic approach to source term prediction for emergency response, the same constraints apply; i.e. a single, deterministic scenario to describe the plant status must be made before any predictive source term calculation can start. This is appropriate where the plant status can be diagnosed positively from instrument readings, as is typically the case for design basis/beyond design basis faults. However, and particularly in degraded core conditions, this is not always the case: it may be difficult to determine the initial conditions for a deterministic calculation, instrumentation may be operating beyond its designated range (and so provide unreliable readings) or it may fail altogether. In order to make a source term prediction in this situation, decisions about the reliability of conflicting instrument readings and suitable substitutions for any missing information must be made in a 'real-time' stressful environment. In this situation probabilistic methods resort to *a prior* probabilities determined by the plant experts who set up the model, thus overcoming the need for such data substitutions. One of the other major benefits of using probabilistic methods is that they can incorporate in a natural way the uncertainties associated with the accident phenomenology during degraded core conditions. These are usually very uncertain and/or essentially non-deterministic in nature, e.g. hydrogen combustion events. Such methods also alert the user automatically to the existence of other possible plant states, based on the outcome of the probabilistic inference process. Thus, the outcome is typically a number of possible alternative plant states, each with an associated source term and likelihood. These represent both the best estimate and the spread of the likely source term.

Remaining issues

This is a novel approach, and the usefulness of such a probabilistic source term prediction is yet to be tested on a wide scale, particularly in how decision makers will respond to source term information couched in a fully probabilistic language. Initial customisation and an initial verification (by comparison with other approaches and test data) have been carried out for six reference plants. This verification has shown the plant-specific networks produce reasonable trends and are considered suitable for a formal demonstration. The next step is a wider dissemination/demonstration of the SPRINT tool with the objective of soliciting the opinions of plant operators, Technical Support Centre staff and decision makers within the off-site Emergency Response Organisations across Europe. This will be accomplished in the European-Commission-sponsored Sixth Framework Programme (FP6) EURANOS project.

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