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CAMS ACHIEVEMENTS IN 1995

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ABSTRACT

CAMS (Computerised Accident Management Support) is a system being developed as a joint research activity at the Halden Reactor Project with additional financing from the Swedish Nuclear Inspectorate (SKI) and the Nordic NKS/RAK-2 project. Three types of users are envisaged: the staff in the control room, the staff in the technical support centre, and the staff at a national emergency centre. It is still an experimental system.

The Swedish Nuclear Inspectorate kindly accepted to test CAMS at a safety exercise on the 4th of May, 1995. CAMS is designed assuming automatic data transfer from the plant. Missing the data link, a simulator running in the next room was updated now and then with data received by phone. As seen from CAMS, it did not matter if the data came from a fake plant or from a real plant, except that the data were delayed.

Overall, it seemed that CAMS can be a very important tool for a national authority. A data link from the plant would increase its usefulness.

Several comments to design features were collected, and will be used to improve the system.

The model needs more inputs to control the main parameters, and a larger repertoire of fault conditions should be put into the model.

In the second half of 1995, the work on CAMS has concentrated upon designing new modules for signal validation, tracking simulation, and state identification. This will provide better capabilities for on-line monitoring and assessment of the plant state. Further, it has been proposed to introduce Probabilistic Safety Assessment (PSA) to assist in risk monitoring. A first prototype has been made on a PC showing the main features of such a PSA module.

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1. INTRODUCTION

1.1 Background

The objective of the CAMS research project is to develop a computerised accident management support system (CAMS) assisting the staff in the control room and the technical support centre of a nuclear power plant in their management of reactor accidents. The CAMS system will also be a valuable aid for the national authorities in training, analysis and evaluation of accident scenarios.

CAMS is being developed as a joint research activity at the Halden Reactor Project with additional financial support from SKI and the Nordic NKS/RAK-2 project. The expected result of the CAMS project is the development of a prototype system demonstrating all essential functions of an accident management support system and evaluation of this prototype in simulator runs of typical accident scenarios.

A first prototype of CAMS was established in 1994. It covers the predictive mode of operation and comprises a predictive simulator, a strategy generator, an interactive graphical user interface and a data communication system supporting distributed object-oriented data base management, ref. [1], [2].

A major milestone was reached on the 1st November 1994 when the first integrated version of CAMS was demonstrated at the Enlarged Halden Programme Group meeting at Bolkesjø, Norway. Participants from 15 countries were exposed to an accident scenario demonstrating the main capabilities of CAMS for predictive analysis. The demonstrated prototype created enthusiasm among participants and several organisations indicated their interest in systems like CAMS.

The technical merits of CAMS at the end of 1994 can be summarised as follows: The predictive simulator is running with a speed of 6 times faster than real time. Models of the main process and safety systems of Forsmark, unit 2 were made and integrated with a model of the containment. A first design of the user interface sufficient for initial testing was made and a strategy generator containing limited set of rules for handling accident sequences was established based on safety objective trees.

1.2 Main Results in 1995

- *The use of CAMS during a Safety Exercise at the Swedish Nuclear Inspectorate*

CAMS was tested as a predictive tool at the Swedish Nuclear Inspectorate at a safety exercise on the 4th of May, 1995, and the main results are described thoroughly in this report. In this exercise unit 1 of the Barsebäck nuclear power plant was supposed to have an accident. Consequently, the CAMS prototype had to be adapted to this plant.

During the exercise CAMS was to provide support to the analysis group in the SKI operations room. SKI staff members were using output from the CAMS predictions as a basis for some of their analyses during the exercise. Overall, it seemed that CAMS can be a very important tool for the national authority. Several comments to design features were collected, and will be used to improve the system.

- *Designing new Modules in CAMS*

In the second half of 1995, the work on CAMS has concentrated upon designing new modules for signal validation, tracking simulation, state identification and probabilistic safety assessment. As a background for this work the experience from earlier work at the Project within the area of on-line simulation and estimation has been collected in a lessons learned report [3].

- *Signal Validation*

Signal validation is carried out by application of two main techniques. Key measurements are first validated by neural network techniques and then fed to a tracking simulator. The tracking simulator will provide still another method called *analytical redundancy* for signal validation. Robustness is obtained by combining the two different methods for signal validation. Signal validation is particularly important in accident situations because instruments may be brought into harsh conditions which are outside their specifications.

- *Tracking Simulator*

The tracking simulator will also serve the purpose of calculating non-measured variables such as fuel cladding temperatures, leakages, estimates, etc. By following the plant behaviour, the tracking simulator will provide initial values for the predictive simulator. One will use the principle of running several decoupled plant models in parallel. In this first prototype, a model of the reactor core and vessel will be included.

- *Plant State Identification and Fuzzy Diagnosis*

Plant state identification is one of the basic functions required in the CAMS system, and fuzzy logic techniques are one of the possible approaches to plant state identification. It has been demonstrated how a fuzzy logic diagnosis method can promptly detect and determine the cause of the problem in the plant [4]. The fuzzy reasoning method tested in this work infers the cause of the disturbance from observed symptoms in the plant. However, this work did not cover enough cases to provide a method directly applicable to a real power plant, and further studies should be performed.

- *Probabilistic Safety Assessment (PSA)*

It has been proposed to introduce Probabilistic Safety Assessment (PSA) techniques in CAMS. The purpose of the PSA module is to assist in risk monitoring and provide on-line accident prevention and mitigation strategies. This module contains plant specific PSA data, comprising event trees, failure probabilities etc. The event trees are categorised according to the initiating events. The risk or core damage frequency is re-calculated based on the current state of the plant and the pre-calculated level 1 PSA.

A first prototype has been made on a PC showing the main features of the system. Work is in progress to implement the system on UNIX workstations and integrate the module in the CAMS prototype.

- *Planning On-site Testing of CAMS Modules*

The various modules of CAMS should be evaluated and tested in a realistic environment. In particular the methods for signal validation and tracking simulation should be tested with real plant data. Although good results have been obtained using advanced plant simulators, there is always uncertainty before testing under various real plant conditions has been performed. Meetings have been arranged with Swedish utilities and representatives from EDF in France to discuss testing of certain modules of CAMS. The plan is to collect data from different plants to evaluate different cases and learn about the strength and weakness of the various methods proposed.

- *Future Eextension to Severe Accident Phenomena*

A paper was presented at the OECD/CSNI SESAM Specialist meeting on Severe Accident Management Implementation, June 12-14, 1995, Niantic, Connecticut, USA, ref [5]. This was a joint paper with VTT and TVO on *Severe Accident Phenomenology and Need for Computerised Accident Management Support*. This paper also discusses future extensions of CAMS into the severe accident regime. The paper was well received at the conference, because it was the only paper that dealt with decision support by on-line simulation.

The use of CAMS during the safety exercise at the Swedish Nuclear Inspectorate is described in more detail in the following chapters.

2. THE EXPERIMENTAL SETUP FOR TESTING CAMS

2.1 The Purpose of the Experiment

Statens kärnkraftinspektion (the Swedish Nuclear Inspectorate) kindly accepted to test CAMS at a safety exercise on the 4th of May, 1995. This is thus a user of the 3rd type mentioned above. A similar safety exercise takes place once a year, involving another plant each time. Such an exercise is a large arrangement, and the CAMS experiment was a very small part of it.

The purpose of the experiment was to see how CAMS would serve one of the three groups of users, in a situation as close to a real accident situation as possible: Does CAMS provide the sort of information actually needed? Is it fast enough? Will the user be able to operate it? Is the user interface adapted to the needs of the user?

The conclusions will be used as feedback to the further development of CAMS.

2.2 The Exercise

In this exercise, unit 1 at the nuclear power plant Barsebäck was supposed to have an accident. Most of the exercise took place at the plant or close to it. In addition, *Länsstyrelsen* (The County Council), *Statens kärnkraftinspektion* (the Swedish Nuclear Inspectorate), and *Statens Strålskyddsinstitut* (The Radiation Protection Institute) took part in the exercise. Altogether, about 1200 people participated.

The role of the Swedish Nuclear Inspectorate during the exercise was to give advice to the Radiation Protection Institute and to the County Council on the following questions:

- Will there be a radioactive release?
- If so, when?
- How large?

Data from the plant were transferred from the technical support centre at the plant by telephone and fax. The advice to the Radiation Protection Institute and the County Council was also given by telephone. Such advice may be the basis for deciding whether to evacuate the local population or not, whether to distribute iodine tablets, etc.

The CAMS is designed assuming automatic data transfer from the plant. Missing the data link, a simulator running on a computer in an office next to the operation room was updated now and then with the data received by phone. A UNIX workstation, borrowed from HRP, ran the fake plant.

The fake plant then transmits data to CAMS by a data network. As seen from CAMS, it does not matter if the data come from the fake plant or from the real plant. CAMS was run on another workstation kindly lent to us by Hewlett Packard Norway.

2.3 Emergency Organisation of the Nuclear Inspectorate

In an emergency situation the operations room is manned by four groups of people: the communications group, the status group, the analysis group, and the management. The communications group received incoming calls and forwarded them to the relevant people. The status group described the main features of the current state by writing the information on a whiteboard. The analysis group tried to evaluate the risk situation from the information available, and the management took decisions on which advice to give out and also decided on timing of the activities.

CAMS was planned to be a tool to assist the analysis group. During the exercise, one person from the status group also used CAMS.

2.4 Preparations before the Exercise

CAMS was originally designed with the plant Forsmark unit 2 as the example plant. To fit the exercise, the entire system was changed to model Barsebäck unit 1. Both are boiling-water reactors, but otherwise they differ in many ways. For instance, Barsebäck has external recirculation pumps while Forsmark has internal. Barsebäck has one turbine whereas Forsmark has two. Barsebäck has a two-volume containment, while Forsmark has a three-volume containment. A few Forsmark features still remained, due to lack of time, and testing had been insufficient.

Three persons from the Swedish Nuclear Inspectorate visited Halden for a one-day course with teaching and training on the 29th of March. The teaching consisted in knowing what kind of assistance CAMS can and cannot offer. They were trained in interpreting the various pictures, but not in pushing the buttons, this was to be performed by people from HRP.

The system was installed in the operation room at the 25th and 26th of April. The last-minute changes were put in at the 3rd of May. At both these occasions the future users had a short repetition of the training.

2.5 Features of CAMS Useful for a National Centre

CAMS consists of the following modules:

• Signal validation	Non-existing
• Tracking simulator	Non-existing
• Predictive simulator	Prototype
• Strategy generator	Early prototype
• Critical function monitor	Existing, but not integrated
• Man-machine interface	Prototype

The man-machine interface consists partly of tools to help the user rapidly to understand the status of the plant, partly in tools to operate the strategy generator and the predictive simulator. Given the role of the Nuclear Inspectorate, the tools to facilitate understanding the plant state is not so important, as the state of the plant is reported to them by telephone. Strategy generation is also not so important, decisions on starting pumps and opening valves are taken at the plant, not at the Nuclear Inspectorate. Prediction of what will happen is the task of the Nuclear Inspectorate, **the predictive simulator** is therefore the important tool for them.

2.6 The Accident Scenario

The scenario was very detailed and only the most important features shall be mentioned here.

The exercise started at 07.00 o'clock by a simulated fire in an electrical equipment room. The fire was extinguished at 07.45, but large damage to the electrical equipment was reported. The control equipment for the main feedwater pumps failed, the pumps were running at full speed. A reactor high water-level alarm resulted, then a scram, until the reactor vessel was completely filled with water. This resulted in a pressure shock of 120 bar at 08.00. A leakage took place outside the containment at 08.05. Radioactive water was running out. By 08.10 the main feedwater pumps stopped, and it was impossible to make them start again after this event. At 08.15 the water level was decreasing.

A relevant subset of all the available information was transferred from the control room to the technical support centre by phone, where it was reorganised, and a smaller subset further transferred by phone to the Nuclear Inspectorate. All such operations will inevitably take time, so there will always be a delay. At 08.30 the first message arrived that there had been a fire, that was now extinguished, and that there was a high pressure in the reactor. How high was not known. At 09.30 there is a more detailed message on what happened at 07.30. The leakage outside the containment was correctly diagnosed and reported.

During this first part of the exercise there were problems operating the telephone system. A call to the analysis group came to the status group. Some incoming calls were not received, remarks like "Try to push button A!" were heard. CAMS was of no use, as there were almost no data available.

We can only speculate what a complete CAMS with a data link from the process computer could have done. Hopefully the delay of the information transfer could have been substantially reduced, and the information more correct and also more complete. But this of course remains to be proved.

Later in the exercise the understanding of what happened at the plant was much better, and the information was more complete and also less delayed.

At about 11.30 the auxiliary feedwater system was in operation with only one of the two pumps running, the other pump being unavailable because of the fire. The situation was aggravated by the fact that the low-pressure emergency feedwater system was also unavailable due to the fire, and so was the suppression pool cooling system. The single pump in the auxiliary feedwater system was therefore essential. The pressure was about 60 bar. The estimated time to core uncovery was comfortably long. The analysis group used CAMS to predict what would happen if the pump running should also fail. They did the necessary pushing of buttons themselves, not asking the CAMS people for help, and came to the conclusion that the available time to core uncovery would be dramatically shortened to about 1 hour. The trend curves describing this hypothetical event were printed on paper.

CAMS was mentioned in the discussions at the staff meeting at 11.45.

Then came the message that the only available pump had also failed. At the staff meeting at 13.00 the analysis group predicted a considerable release at 16.00 or perhaps as early as 15.00, if the two pumps both remained unavailable. To obtain at least some cooling, the boron-system pumps were started, using non-borated water. If an auxiliary-feedwater pump would start in the meantime, the situation would be much better. It was suggested to send the trend picture of what would happen to Barsebäck by fax, but this was not done. The County Council decided on certain actions at least partially based on CAMS predictions. It should have been made clearer to the Nuclear Inspectorate that CAMS had not been properly validated against the Barsebäck plant, and that its predictions should not be trusted.

At 14.40 it was reported that all the systems that had been down had started to function, and the exercise was at its end.

3 EXPERIMENTAL RESULTS

3.1 General Debriefing

At the general debriefing session after the exercise it was mentioned that CAMS had actually been useful. In the beginning of the exercise there had not been the necessary input data to arrive at any conclusions, neither for people nor for computers. The data were not only too scarce but also too delayed. It was expressed that later in the exercise CAMS provided much interesting information even in the present situation, with no data link from the plant.

3.2 Special CAMS Debriefing

Everybody agreed that a data link from all plants is very desirable, it would improve the situation with or without CAMS. But an electronic data handling system, with its capability to handle large amounts of data in a short time, would particularly benefit from a data link. The stumble stone here is money. One should discuss very thoroughly how much data is necessary and how often it should be transferred.

The users found it difficult to know when to initialize the predictor to the process, when to start, the predictor, and when to stop it. These controls should be redesigned. Improved training may also improve the situation. But basically, when something is felt to be difficult, improved design is to be preferred to improved training.

CAMS should have an operator of its own, rather than the way it was done at the exercise, where the analysis team member wanting a piece of information would leave his place and go up to the CAMS station to push the buttons.

The following will describe in a bit more detail the use of CAMS in the accident exercise at the Swedish Nuclear Inspectorate (SKI). First there is presented a flow diagram (called "Hierarchical Task Analysis - HTA) where we have identified the main goal with CAMS, and several subgoals (Fig. 1). To each level belongs a plan, which describes how the task should be carried out. After this diagram follows a table (called "Tabular Task Analysis" - TTA) where the different task steps from the HTA are referred in the first column (Table 1). Hierarchical Task Analysis and Tabular Task Analysis are further explained in reference [6]. Every task in the TTA is described in the following columns: what information is relevant for the task, what displays are used, what actions are needed and what kind of feedback is given. In the end there is a separate column for comments. Not every task step has been described in all categories, as there is not always relevant information to report for all the columns.

HIERARCHICAL TASK ANALYSIS:
USE OF CAMS IN AN ACCIDENT EXERCISE
AT THE SWEDISH NUCLEAR INSPECTORATE

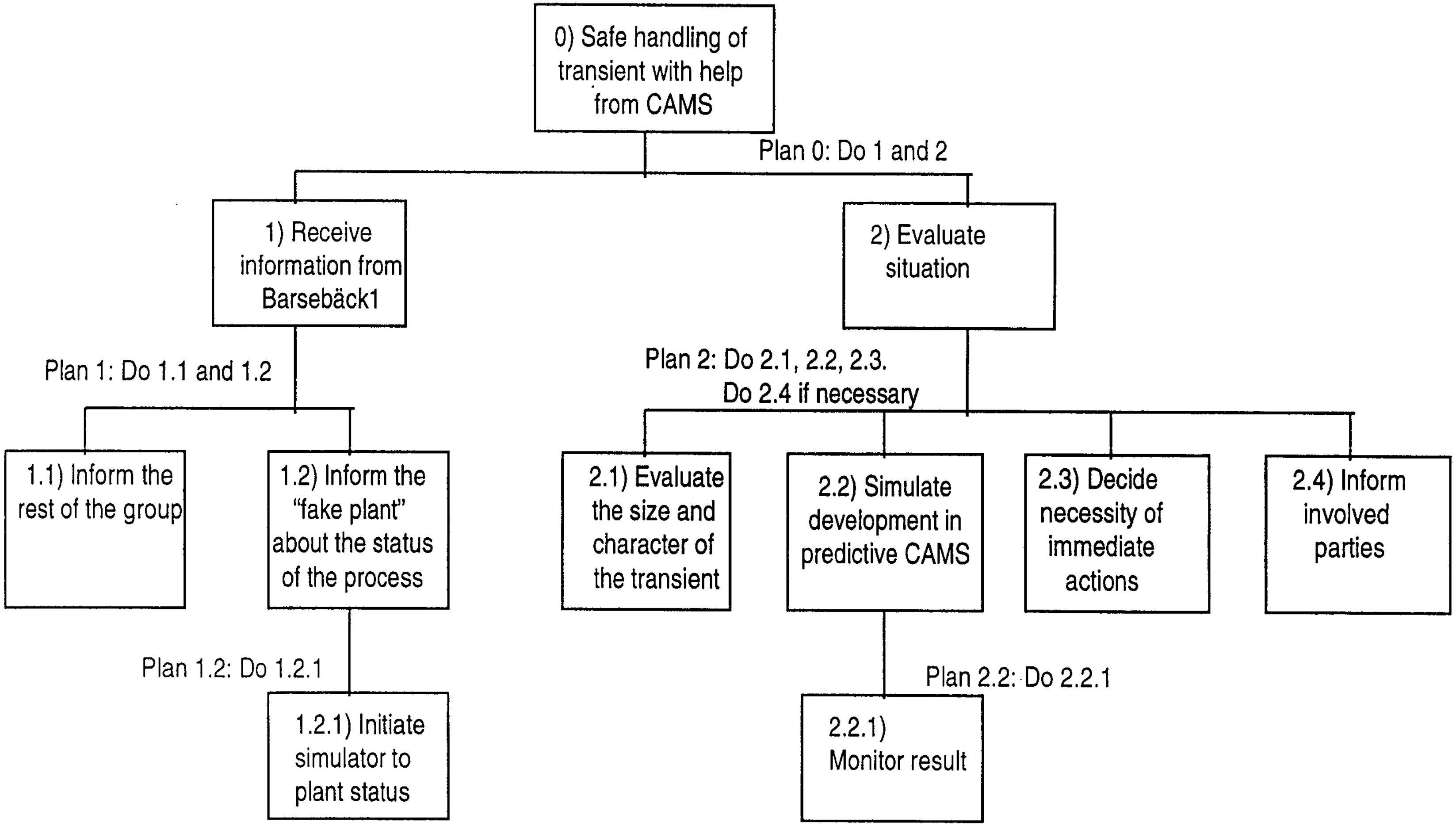

Fig. 1 Hierarchical task analysis: use of CAMS in an accident exercise at the Swedish Nuclear Inspectorate

Task step	Information relevant	Displays in use	Actions needed	Feedback	Comments
0) Safe handling of transient with help from CAMS	All	All			General: Yellow letters on grey background is a little difficult to read. Bad contrast. Black letters better? The colours yellow, red and green are usually coded in this way: green means normal, yellow means caution, and red means danger/alarm. Try not to use those colours to other coding.
1) Receive status information from Barsebäck 1	All relevant information about the plant (L, P, T, status of valves, pumps etc.)	Process display Predictive display	Answer phone calls Take notes	Delayed feedback from CAMS in the beginning of the exercise due to delayed information from the plant	If there had been a direct datalink, there would have been much quicker information about the status of the plant, and CAMS would have been useful from the very start.
1.1) Inform the rest of the group	All new information from the plant	None	Write status at whiteboard. Give status when staff meetings were held		
1.2) Inform the “fake plant” about the process status	All relevant and new information received from the plant		Walk into the side room to tell the “fake plant” what information to put into the system		
1.2.1) Initiate simulator to plant status		Process display Predictive display Trends	Call a display. Initialise the predictive simulator		The SKI staff initialised predictions at CAMS whenever new status information arrived.

Table 1 Tabular task analysis: use of CAMS in an accident exercise at the Swedish Nuclear Inspectorate

Task step	Information relevant	Displays in use	Actions needed	Feedback	Comments
2) Evaluate situation	Current status, handbooks	Process display Predictive display	Calculations, analyses		The analysis group evaluated the severity of the situation. The process display was not used particularly much in the exercise. This was because there was no direct data link to the process.
2.1) Evaluate the size and character of the transient	Process parameters Status reports from Barsebäck Handbooks	Predictive display Trend diagrams	Calculations, analyses		CAMS was not used to a great extent to evaluate the size of the disturbance. Status reports from B were used more for this purpose.

Table 1 Tabular task analysis (cont.)

Task step	Information relevant	Displays in use	Actions needed	Feedback	Comments
2.2) Simulate development in predictive CAMS	Status of process	Predictive display Control panel Trend diagrams	Simulate development of the process	Good feedback on how the process is developing. Control panel: no feedback when you try to open a closed valve. Trend diagrams could include a mark on the y-axis of what is the normal areas of T, P, F etc. Sometimes difficult to initiate manipulations in the predictive simulator	At one point the SKI staff predicted what would happen if they lost 327. They got a prediction that said that the temperature would increase after an hour, and that the core was uncovered in half an hour. One hour later they actually lost that pump, and so they knew the further development already. Usually manual calculations of this kind take about 1h. Need better communication on control panel. Too difficult to interpret the interaction effects. Need some ranges on the trend diagrams. Could may be make a more natural sequence of how to initialise manipulations (or give better training?)

Table 1 Tabular task analysis (cont.)

Task step	Information relevant	Displays in use	Actions needed	Feedback	Comments
2.2.1) Monitor result	Status of predictive simulator	Predictive display Control panel Trend diagrams	Evaluate severity of initiated actions	The simulator is fast. Feedback is given to the operator when the predictive simulator is reinitiated. It is sometimes difficult to distinguish between the process and the prediction	It could sometimes be possible to forget to reinitiate the predictive simulator May be more different back-ground colours could help.
2.3) Decide necessity of immediate actions	Predictions Calculations Description of scenarios	Predictive display Trend diagrams	Make a decision		Some of the predictions given by CAMS were used as background material for some of the decisions made by the status group and the County Council.
2.4) Inform involved parties	The nature of the decisions	Predictive display Trend diagrams	Inform media, SKI, and the City Council about the decisions		There was a lot of interest for CAMS. Printouts were taken and sent around in the room. It was even considered to send the prediction they made to the plant.

Table 1 Tabular task analysis (cont.)

3.3 Overall Impression

Overall, it seemed as CAMS can be a very important tool for SKI; both when analysing the development of scenarios and when giving information to The Radiation Protection Institute and The County Council about the severity of the accident, threats, and probable radioactive releases. This information can also be useful for important decisions. The use of CAMS would have been even greater if it had been possible to utilise a direct data-link from the actual process. It is recommended to test this out in the next exercise, by a connection to a simulator where the scenario is played from.

CAMS is designed for three main purposes:

- To identify the status of the process
- To evaluate the future development
- To plan strategies for coping with the accident

The first of those purposes was difficult to fulfil, as there was no direct data-link from the actual process. The second and the third, however, were well fulfilled in this actual exercise.

What the users found most useful with CAMS in this scenario, was its possibility a bit into the scenario to predict the time at which the core would be uncovered. Usually such predictions are based on handbooks and experience. Such a prediction may take from 5 seconds up to 1 hour.

The users did not use CAMS to decide the size of the leak, or the seriousness of the accident. For those evaluations, information directly from the plant was used.

CAMS was evaluated as more useful in accident scenarios than in normal situations. However, if CAMS is to be installed at the Swedish Nuclear Inspectorate, it will probably be used as a simulator, to predict different developments etc. Now, the different plants are reporting their status to the Swedish Nuclear Inspectorate every 24 hours. With a direct data-link, this reporting could be limited.

3.4 Displays in Use/Displays not in Use during the Exercise

The SKI staff did not look at the process display at all. (This would of course have been different if there had been a direct link.) Nor did they find the motor-way diagram of much use. They did not feel comfortable with this display, and said that they were not used to think like this. The usefulness of this display is of course dependent on how often CAMS is used. If CAMS is used very seldom, it should be considered to use more intuitively understandable displays. The control panel was also not much in use. It was said that it was difficult to interpret the coding of open and closed valves in this format.

Apparently the users concentrated so much on the predictive simulator that they forgot to check if the process had changed in the meantime. Better training on this point may improve the situation. The planned improvement of the trend diagrams, so that the process trends and the predictor trends will be shown in the same view, will attract the attention of the user to the fact that things may have happened in the process that make the prediction invalid.

The displays that were most in use were the predictive process and the trend diagrams; both feedwater, core and containment. The water level and the pressure measurements were said to be very valuable parameters. They missed trends for steam, all feedwater measurements and residual heat. It was suggested to make a separate display for emergency cooling: core cooling system and residual heat. This is also very interesting from a PSA (Probabalistic Safety Analysis) perspective.

The Inspectorate staff did not look too much at the condensers and the turbines. When the Inspectorate is called in, the condensers are not in use for their main purpose, however, they may still be used as a reservoir of water.

3.5 Trend Diagrams

The trends were evaluated as the absolutely most informative part of CAMS. It could be an advantage to include trends that show whether the process follows the prediction or not.

For the core, the water-level indication in the trend diagrams could be improved by indicate the top and the bottom of the core. On the tank-pressure diagrams, the 70 bar limit should be indicated. It was also suggested that if several trends should be included in one diagram, they would like a colour distinction between the curves. As CAMS probably only is going to be used once a year, it must be easy to use.

The time axis should be divided differently. The most common way of reading trends, is to divide the time axis into 15 minutes or 1/2 hours intervals.

3.6 Navigation

The CAMS functions were considered to be easy to operate. To know which display was up and how to change to another display was described as easy. But the changing between displays in CAMS could be quite slow sometimes.

What was difficult, however, was the starting of the predictive simulator. The sequence of the necessary operations could be made clearer. At one occasion during the exercise the "Initialise to Process" had been pushed twice. This indicate that an improvement of the design is desirable.

3.7 Perform Actions

To make actions in the system was generally easy. Sometimes it was difficult to know the meaning of number codes (0/1), and sometimes it took a while before the action was followed by a consequence.

3.8 Readability

The users thought that the letters were clear and easy to read, and that the status of pumps and valves had a clear meaning. Colours and contrasts were also considered OK. They also thought that it was useful to know the structure of the system in advance (it was useful with training).

3.9 Feedback

At the moment, there is very little feedback from the system. The users did not feel that they needed much more feedback than already available. There are some dialogue boxes which are useful.

3.10 Different Users

There might be different users of the CAMS system. It is important to investigate the different users' needs. What is included in the system as it is today, is sufficient for SKI, with some small modifications. The control room operators and the staff at a national centre might have other ideas of what should be included in the system. It seems that CAMS will have great possibilities both for use and for further development.

4 EXPERIENCE GAINED BY USING CAMS WITHOUT A DATA LINK TO THE NUCLEAR POWER PLANT

4.1 Data Link

The ideal situation is to have a direct data link between CAMS and the power plant in question. This would give us a true, real time (dependent on the update frequency) picture of the current state of the plant. In Stockholm, we got information that was delayed approximately 30 minutes. In the worst case we were two hours behind.

We should not forget that *if* we have a data link, we cannot use that during an exercise, since the plant will be running at normal steady state. The scenario is only that: a scenario. One way to solve this would be to run the scenario on a full scope simulator and connect to that one.

There is no such data link at the present time, and most likely not in the near future. Because of this we should look into ways to change the state of the plant simulator in CAMS in a more flexible and easy manner. This is important also when CAMS is used as a training tool.

4.2 Getting Information

The information from the plant came at odd intervals. First time about two hours after the incident started (according to the scenario) and then later when things changed at the plant (a pump stopped working, etc.). We would also have liked to get regular information on the more basic values, like water level and pressure in the vessel. With this information we could have verified that our plant simulator really looked like the plant. This is rather important since predictions are made on the basis of the plant-simulator state.

Further, the information was not always as precise as we would have preferred. Information like "the pressure is high" is a bit difficult to put into a simulator.

Since we do not have a data-link, there is no signal validation. It means that the operator of CAMS will have to do some signal validation in his own head. This happened in Stockholm, where people were sceptical to some of the information received.

4.3 Putting Information into the Plant Simulator

In the beginning of the scenario, the vessel was filled up with water and therefore the pressure increased to approximately 120 bar. The information was at this point two hours behind, and the first data that we could enter into CAMS were: Pressure 100 bar, water level 10 meter.

We had created files in advance with different pressures and different water levels. Alas, we did not have this one. The closest we had was one with pressure 80 bar, water level 7 meters. Because of this it took us a long time to run the simulator to the correct state (we had to increase the feed-water flow and run this in the real-time simulator). In fact, before we had got to 100 bar, 10 meters we received new information : Pressure 80 bar, water level 8 meters. This time we reloaded the 80 bar, 7 meters file and simulated relatively quickly to the desired water level.

This example shows us that it is important to be able to manipulate the process with controls that are not in the real process. At the point where we needed to increase the pressure, we should have had some valve we could open and pump high-pressure steam into the vessel. We would also need to have a different valve to decrease the pressure. Such valves do of course not appear in the power plant. The same applies to the water level. With valves like this we could have tuned our plant-simulator quickly into the state given through the telephone. Careful thought must be given on which effects such rapid modifications will have on the plant. For instance, putting water into the plant will not only affect the water level, but also the reactivity etc.

After a while the plant had come to steady state. From this point on we had no difficulties in following the process -> there was a leak : open leak valve, the auxiliary feed water failed partially : stop one pump, the emergency core cooling system would not start : disable core cooling pumps.

4.4 Possible Modifications to the Model

The model needs more inputs to control the main parameters, pressure and water level.

In the Omega exercise, pure water was pumped into the vessel through the boron pumps. We had not modelled this, so we started the boron system instead, even if this meant inserting boron. This shows us that we should model all / most safety-related systems, or give alternative methods that have the same effect.

A library of different containments, vessels and safety systems could be made, making it even easier to add a new plant.

In addition, a larger repertoire of fault conditions should be put into the model, for instance more leakages.

4.5 Some of the Experience Gained

CAMS in its present state is too difficult to get up to date with the real plant state. This could be improved by modifying the model and introducing more control input. Such modifications would enable the CAMS operator to receive plant status via the telephone, put this information into the plant-simulator and run the simulator to this new state easily and quickly. A CAMS like this would be useful for the national authorities, also without signal validation since the predictor is the most important tool for them.

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