Seminar on Case Studies in Operations Research (Mat-2.4177)

Evidential Uncertainties in the Reliability Assessment - Study of Non-Destructive Testing of Final Disposal Canisters

VTT, Posiva

Backlund, Ville-Pekka
Piironen, Juho
Tuovila, Henri
Wolf, Sebastian

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Aalto University
School of Science

1 Background and Goals

In Finland nuclear power companies are responsible for nuclear waste management [1]. In 1995 therefore the two big operating power companies Teollisuuden Voima Oyj and Fortum Power and Heat Oy established Posiva Ltd. as an expert organization responsible for their spent nuclear fuel [1] generated in the four power plants in Eurajoki and Loviisa and also for three more power plants which will be built in the future.

Posiva's goal is to find and to implement a way to encapsulate and store the nuclear fuel which is not harmful for any organic nature and to ensure that it will remain intact for very long time due to the low decay rate of certain nuclear waste.

In order to realize this it is planned to store the fuel in the bedrock of Olkiluoto in 400m depth, packed in copper canisters [1]. The first canisters shall be stored in 2020 and the whole installation will have a capacity of 4500 canisters. The Olkiluoto installation shall take the fuel of the seven nuclear plants mentioned above for the following 100 years. Then it will be sealed mainly by concrete.

One of the safety issues in this context is the quality of the copper canisters. After a canister is filled with nuclear waste its lid has to be welded onto the body. This process is fully remote controlled. The weld might be a weak point since different defects can occur in it. At least 35 mm of intact copper must protect the nuclear fuel. That is why the weld is investigated by four different testing methods: ultrasonic, radiographic, eddy current and visual testing [2], where the two first methods enable one to investigate the interior of the specimen while the latter two search for defects on and close to the surface. If one of these four testing methods detects a defect, further investigations and measurements will be done in order to decide whether the defect is acceptable or the canister has to be rejected. The latter case should be avoided since the canisters are very expensive in relation to the application of the testing methods. The tests are non destructive which means that a specimen does not have to be destroyed in order to test it. Non-destructive methods ensure that the tests can be repeated if necessary.

Our main goal is to study how evidence uncertainties can be taken into account in reliability reasoning. This means combining information gathered from different sources while paying attention to its quality and dependencies. In the case of final disposal canisters the task is to examine and determine the probability of accepting a defected canister. VTT has done some studies related to this subject in collaboration with Posiva, but offered it now also as this course case in order to get fresh insights. Thus, one of our objectives is to understand VTT's approaches and solutions and also to find potential

weaknesses in them. Also, the problem shall be defined and described by a consistent methodology in order to be able to find and validate usable approaches using methods of probability and reliability theory.

2 Methods and material

The framework for this project is nuclear waste management, and therefore our work and reporting needs to meet the standards of Posiva. This means transparent and traceable reasoning. In order to do this, we must find a taxonomy that is suitable for taking account the uncertainties in the evidence. One possible alternative is to create our own suitable taxonomy. When we have discussed about the quality of the evidence, our approach and work can ultimately be divided into two parts:

1. understanding the processes of welding and testing thoroughly
2. choose a proper methodology and create our application for the specific problem.

Our work is fundamentally an iterative process in which the complexity of our application and the knowledge from the welding and testing procedures increase hand in hand. The aforementioned two parts join together via the data. Thus it is very important to take care that the data used is suitable for the method chosen. When we have reached our final model for the case, it's reliability and performance, if possible, will be tested for example with Monte Carlo -simulation.

Next, we will discuss more about the two main parts of our work.

2.1 Study of the welding and testing processes

Meetings with our contact persons from Posiva and VTT and preliminary literature review has given us plenty of information about the processes of welding and testing. Nevertheless, a really precise understanding of the techniques and procedures used is essential for the construction and validation of our application. For example, every part of the process, where human error can have a major influence on the results, must be noticed and handled if possible. Of course, understanding the welding process is in minor role compared to the understanding of the testing process.

Essential part of our work is to determine the type and quality of the data we are given. Posiva has already preliminary POD-curves (probability of detection) for all the four tests. These curves represent the probability of detecting

a defect as a function of the size of the defect. The POD-curves are the important part of the initial information that is used in the application, that is why understanding their construction is crucial. Also, special attention to the possible dependencies in the data must be paid.

Information on the procedures is publicly available in Posiva's web page [1]. If some factors remain unclear, we have the possibility to consult our contact persons for detailed information. The Institute for Energy of the European Commission's Joint Research Centre (JRC) [3] has developed methods that are used for qualification in industry. Another possible source of information are the regulations of Radiation and Nuclear Safety Authority (Säteilyturvakeskus, STUK) [4] that must be fulfilled.

2.2 Creating the application

A very strong candidate to be used as the methodology for our application is the framework of Bayesian Belief Network (BBN) [5]. It introduces a well defined mathematical theory, which allows us to perform probabilistic reasoning in cases where we need to combine possibly dependent information from multiple sources. Managing the possible uncertainties in the evidence is easy with the BBN-approach, because the evidence can be represented as probability distribution functions. In addition, the update of *priori* distributions is easy as new information from tests is gathered.

3 Schedule and task allocation

During the time period from the project plan to the mid-term report (weeks 10–15) our goal is to establish a good understanding of our primary goals, data and mathematical tools we are going to use. The final inference model may not necessarily be built entirely before the mid-term since there is still time left after that, but we should still have at least the first version of the model in our hands. During the latter period of our work (weeks 16–19), this model may be improved by taking into account more things that cause uncertainty and failures in the welding and the final disposal process as a whole. The schedule is presented in table 1.

The first version of the model shall at least fix whether we are using the Bayesian approach or something else. It shall also describe one way of combining the information from the four different testing methods. It is worth noting that this is a major question in the whole building process of the reasoning model, so it must be dealt with great care. The way of handling this issue in the first model may not be the final one and may be adjusted later.

Table 1: The schedule for the project

	January				February				March					April				May	
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Action																			
Literature			X	X	X	X	X	X	X	X									
Model Building									X	X	X	X	X	X	X	X	X	X	X
Working with Reports								X	X					X	X			X	
Events																			
First Meeting			X																
Meeting with VTT				X											X				
Meeting with Posiva					X														
Project Plan									X										
Mid-Term Report															X				
Final Report																			X

Nevertheless, this is a thing that remains to be seen, but the importance of considering different ways of handling the information is stressed here.

During the project the plan is to allocate the tasks so that two people concentrate on the data we are using, and the other two are working on the mathematical tools that are used to exploit the data. The initial idea is that members Tuovila and Backlund are the ones concentrating on the data, and members Piironen and Wolf the ones studying the mathematical methods. The goal is to utilize the expertise of the both groups to combine all the information into the final model. The workload of writing the reports and the presentations for the seminar meetings is shared as equally as possible into reasonable tasks according to the expertise areas.

4 Risks of Project

The risks of this project are presented in table 2. All the risks that are specified here are very general and apply to most project works in groups. The most specific one is the risk related to the ambiguous starting point. This might cause that the requirements of VTT for the project are not met. However, the scope will become clearer when we start building the actual model. Other results of realized risks might be difficulties with the schedule, or with the personal workload. It is not in sight that any of the team members would be unmotivated or not co-operative, so team can be seen solid. Sharing tasks and working in sub-groups of two people will be the solutions to avoid too heavy personal workload or schedule difficulties.

Table 2: The risks of the project

Issue	Probability	Importance	Action
Ambiguous starting point	High	High	Regular negotiations with VTT
Personal workload	Medium	Medium	Working in smaller subgroups of two people
BBN is not applicable	Low	High	Valuable finding: case cannot be modeled as intended
Team member quits	Low	Medium	Motivated group members

References

[1] Posiva web-pages `http://www.posiva.fi/en/` (29.2.2012)

[2] Jan-Erik Holmberg, Pirkko Kuusela:
Analysis of Probability of Defects in the Disposal Canisters
Posiva Working Report 2011-36

[3] The European Commission's Joint Research Centre `http://ec.europa.eu/dgs/jrcindex.cfm` (29.2.2012)

[4] Radiation and Nuclear Safety Authority of Finland `http://www.stuk.fi/en_GB/` (29.2.2012)

[5] Judea Pearl: *Causality: Models, Reasoning, and Inference*, Cambridge University Press, 2000