Selection of Components and Regions for NDE in RPV.

Gert HEDNER
Swedish Nuclear Power Inspectorate, Stockholm, Sweden

ABSTRACT

To make sure that the RPV integrity is maintained, NDE is used. Present trend is to increase the amount and quality of NDE and to reduce the inspection intervals. The Swedish Nuclear Power Inspectorate and the Swedish nuclear facilities are making a joint study of how additional NDE should be directed to give maximum benefit.

BACKGROUND

The purpose of the paper is to present recent discussions in Sweden regarding the selection of components and regions for NDE in RPV. The basic aim of the NDE efforts is to make sure that the primary system barrier remains intact in spite of degradation from fatigue, corrosion, thermal aging, etc. The NDE efforts can be motivated from both a safety point of view and an efficiency point of view, but the present discussion relates only to the safety aspect.

The International Atomic Energy Agency (IAEA) has defined basic safety principles for NPP, one of which is the principle of "Defence in Depth" (IAEA Safety Series No. 75-INSAG-3). This principle identifies barriers preventing the release of radioactive material, and includes the defence of such barriers. The details of the inspection associated with this defence, i.e. selection of regions, inspection intervals, inspection methods and verification, are specified in national Codes, for instance the ASME, KTA, etc.

Although the principle of "Defence in Depth" is generally accepted, the implementation of the NDE required to defend the barriers varies significantly between codes. It is felt that because of the global impact of a failure of a RPV, it is desirable to have an international discussion and acceptance also for the principles of the implementation of NDE. The present study may hopefully serve as a starting point for such a discussion.

Table 1. Control group matrix.

FI \ CI	1	2	3	4	Extent of inspection
I	A	A	B	C	A = 75 %
II	A	B	C	C	B = 10 %
III	B	C	C	C	C = -

In the Swedish Code for Nuclear Components, each component in the piping system is assigned two indices, a Consequence Index and a Fracture Index (Nilsson et al, 1988). The Consequence Index (1 - 4, 1 is severe consequence) is assigned to a component according to the consequence to the nuclear system (core damage or damage to a barrier) if it fails and a single failure occurs in the safety systems. The Fracture Index I - III, I is high risk for failure) is assigned according to the probability that the component will fail. The extent of in-service inspection required is determined from a matrix shown in Table 1. If both indices are low, an extensive inspection is required. If the consequence is severe but the risk of failure is low, less extensive inspection is required.

BENEFITS, COSTS OF NDE

As with any activity, NDE of RPV is associated with benefits and costs. The benefits to the individual utility may be difficult to quantify, particularly in the short time perspective. The costs in terms of economy and dose to the personnel are easy to measure and may be substantial. Adding to these facts the observation that few defects requiring any action are normally detected during NDE of RPV, utilities argue that the benefits do not measure with the costs.

The risk of failure of the RPV has been evaluated elsewhere, and has been found to be very low, of the order 10^{-7} per reactor year. It may be worth while to consider briefly the consequences to be expected if a RPV should fail. The consequences could be separated into different cathegories:

- direct consequences to the utility and the environment
  - dose to the public
  - economical to the utility owners
- indirect consequences to the industry
  - regulatory changes
  - public acceptance of nucler power
  - political consequences.

It is possible that utilities tend to underestimate the indirect consequences. Although the direct costs for NDE may be substantial, the entire industry must share the responsibility to keep nuclear power safe everywhere in the world in the eyes of the public.

Irrespective of what level of cost and dose are considered acceptable, the benefits of the NDE effort should be maximized. In case an additional NDE effort is considered, it should be directed towards a component or a region where the benefit is greatest. This requires a comparison between the benefit at different regions and a discussion of consequences of failure and risk of failure.

CONSEQUENCE OF FAILURE

The present discussion is restricted to the direct consequences. If the RPV fails but all other barriers and safety systems remain intact, no radioactive release will occur. In that case the only immediate consequence will be economical. This is considered acceptable in the present context: a failure of the RPV is considered acceptable provided it does not affect the adjacent barriers.

The analyses carried out have revealed that the important parameters considering the consequences of a RPV failure were the location and the size of the opening in the RPV, and the possibility of loose parts of the vessel affecting the containment (missile effect). As an example a typical BWR of Swedish design was considered.

The <u>location</u> of an opening was considered to less severe if the opening was located above core level than below core level. The reason is that if the opening is above core level the cooling of the core puts less demand on the cooling systems.

The <u>size</u> of the opening was judged to have little significance if the mass flow was below 30 kg/s. Then the core cooling systems and the containment were not challenged. For mass flow above 16000 kg/s there are no analyzes available for the core cooling or the containment integrity. The major problem in this case is believed to be the reaction forces on the RPV and flow induced loads on the internals. For mass flows between 30 and 16000 kg/s the safety systems were considered adequate from a core cooling point of view. Notice that these numbers are plant specific, and can not be used as generic.

The missile effect was not considered to be significant, except for the top of the RPV where a nozzle, if it came loose, might hit the cupole and jeopardize containment tightness.

RISK OF FAILURE

Defects in the RPV material may be induced during manufacture or erection, or be created in service. Any defect which grows under service conditions poses a threat to the RPV barrier, be it pre-service or in-service induced. Some crack growth mechanisms are known.

Fatigue occurs if stress (or strain) varies with time. The frequency of the variation may be low (Low Cycle Fatigue, LCF) or high (HCF), and the reason for the variation may be mechanical or thermal. During the design of the RPV the LCF mechanical and thermal loads anticipated during 40 years service were taken into account. If the design is sound it follows that few problems should be expected with LCF loads. HCF loads, however, were usually not given in the design specifications, and some defects which are attributed to thermal fatigue have been found (NUREG 0619). HCF vibration induced mechanical loads are probably a minor concern for the RPV.

Stress Corrosion Cracking (SCC) has occurred quite frequently in the stainless steel piping systems, and recently some cases have been found where the cladding of the RPV was affected (NRC IN 90-29). There exists some research results indicating that under unfavourable conditions the SCC growth in carbon steel may be rapid. Also numerous reports on SCC in nickel base alloys and weld material have been the cause of some concern. Research results have indicated that the growth rate of SCC depends on the quality of the water chemistry in the plant, and that chemical transients may be important.

Material degradation which does not appear as cracking may also occur, reducing the acceptable defect size. The only effect of this kind taken into account in the present study is the irradiation degradation of the RPV wall at the core region. Other types of material degradation, for instance excessive grinding on stainless steel causing an unfavourable change in the microstructure which makes the material corrosion sensitive, have not been included.

Design loads are specified, but there may also exist severe stresses which are not specified and are poorly known. One example is residual stresses in weldments, where the magnitude and distribution through thickness depend to a very large extent on the fine details of the weldning procedure.

Considering the fact that our knowledge of crack distributions, growth rates, driving forces and critical sizes of defects are statistical in nature and that there may exist unknown damage mechanisms, it appears logical to make the selection of inspection regions partly selective and partly random. The purpose of the selective part is to make use of the experience gained from similar components and vessels around the world. The purpose of the random part is to capture so far unknown damage mechanisms. The balance between the two parts may well change with time, with the random inspection dominating when the technology is still young and the selective inspection dominating as the technology becomes mature.

It is important to realize that only the defects and growth mechanisms that we know of can be used as a basis for our analysis of the risk of failure. Also requirements on inspection intervals and quality of the in-service inspection methods can only be made on the basis of known damage mechanisms. It follows that such requirements can be better founded as the experience and reserach base is growing.

DETERMINISTIC APPROACH

One approach taken was to try to expand the metod used for the piping inspection to the RPV. A Consequence Index was assigned to each region on the basis of only opening location, but it has turned out to be difficult to really discriminate between regions on rational grounds. A Fracture Index was also assigned to each region, based on fracture mechanics analyses and a general feeling for the design loads and the damage mechanisms considered appropriate. So far (February 1991) this effort has not been brought to an end, so no final judgment can be made.

PROBABILISTIC APPROACH

A probabilistic approach has recently been tested, (Berman et al, to be published). Using probabilistic fracture mechanics the probability for crack penetration through the vessel wall was estimated. The preservice crack distribution was estimated with an established distribution function, the Octavia distribution. The probability of inservice crack creation was taken to be 2.5 10^{-2} per reactor year based on available experience data for BWR RPVs. Inservice crack propagation due to fatigue was found to be insignificant, and crack propagation due to stress corrosion cracking was taken to be 6.3 mm/year once the cladding was penetrated. Mechanical and thermal loads were taken to be deterministic, but the fracture toughness was taken to be stochastic and three differnt (one Weibull and two lognormal) distributions were adapted to measured data.

Knowing that the consequences were different for small and large leak rates, an attempt was made to separate the cases of small and large opening. This made the crack length an important parameter. If the crack length was larger than approximately five times the wall thickness, a crack penetrating the wall would start to grow along the wall causing a large opening. This made the probability of a moderate leak rate small, the leak rate was either less than 30 kg/s or larger than 16000 kg/s. For the unit considered the analysis also indicated that the load case dominating the failure probability was a cold overpressurization during the initial startup procedure after the outage.

So far (February 1991) only two regions of the RPV, the core region and a steam outlet nozzle, are analyzed with this method. It has been found that for the unit considered the probability of large leak rate is between 10 and 1000 times higher for the steam outlet nozzle region than for the core region. Hopefully the methodology shall be capable of listing regions in the RPV in descending order of risk for severe consequence, and to make a rational selection of regions for NDE possible. It may also give a rational basis for determining the extent of NDE.

CONCLUSIONS

The study so far has shown that involving the concept of consequence in the analysis or RPV failure appears to be useful.

In particular for the unit investigated it was found that the consequence of a RPV failure may be either very small or very large, the moderate failure is less likely to occur.

Finally the probabilistic approach seems to be promising so far.

REFERENCES

IAEA Safety Series No. 75-INSAG-3 "Basic Safety Principles for Nuclear Power Plants." International Atomic Energy Agency, Vienna, 1988.

Nilsson, F., Skånberg, L., Bystedt, P., "New Swedish Regulations for Safety of Pressurized Components." Proceedings of the 9th International Conference on NDE in the Nuclear Industry, Tokyo, Japan, 25-28 April 1988.

Bergman, M., Brickstad, B., Dahlberg, L., Dillström, P., Nilsson, F.; "Application of probabilistic fracture mechanics to allocation of NDT for nuclear pressure vessels." To be published.

Snaider, R,. "BWR Feedwater Nozzle and Control Rod Drive Return Line Nozzle Cracking." NUREG 0619, April 1980.

NRC Information Notice No. 90-29, "Cracking of Cladding and its Heat-affected Zone in the Base-metal of a Reactor Vessel Head." USNRC, April, 1990.