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UCT

NUCLEAR VALVES AND THE LICENCING AUTHORITY : PROBLEMS AND PROGRAMS.

by

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Valve problems relevant to licencing authorities are discussed. It is suggested that the probability of valve failure should be given more emphasis in safety analysis. Problems of stress analysis, codes, seismic effects, malfunction and leakage are discussed and programmes aimed at solving future problems are outlined.

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1.0 The Licencing Authorities interest in Valves

Licencing authorities have an interest in nuclear valves for the following major reasons :

1.1 Valves constitute the largest number of any single item of equipment in a nuclear power plant. There are approximately 2500 valves in a 1000MW(e) station (1).

1.2 Each valve incorporates a penetration of the system involving problems of operation, maintenance and safety.

1.3 Leakage from bonnets and stems create radiation problems and lead to loss of coolant.

1.4 Errosion of valve trim material can introduce long-lived corrosion products into the primary heat transport system such as cobalt 60 from Stellite.

1.5 Large valve actuators pose seismic problems

1.6 Access to many valves is poor, increasing maintenance time and hence radiation dose.

1.7 Malfunction of some valves can cause Class 1 accidents.

1.8 Control and service lines to valves are vulnerable to damage and fire.

Licencing authorities grant site approval, construction, commissioning and operating licences. The main consideration in all these cases is clearly, safety.

Let us consider the implications of valve safety in construction and operation and examine some of the more important problems and programmes to solve them.

2.0 Safety in Design and Construction

2.1 Design based accidents - Consequences

As South Africa's first plant is being supplied by a French company, it is beneficial to briefly examine present French safety philosophy. In France, reactor safety assessments are based on examination of the integrity of the various barriers interposed between the fission products and the public e.g. fuel cladding, piping and valves, containment, etc. (2)

Traditionally, the design based accident (DBA) is a sudden pipe failure. The cause of the event is usually not specified, but its consequences studied in detail.

Examining the large valves in the primary system or injection system shows that catastrophic failure of the body or bonnet is quite similar to the pipe failure as far as the area of the break is concerned. Coupled with the complex shape and hence stresses in the valve, a DBA based on valve failure is credible and probably worth considering when the Safety Analysis Report is evaluated.

The analysis of the consequences of valve failure are similar to those of a pipe break and are outside the scope of this paper. However, the reliability of a valve is much lower than that of pipe, so the probability of a valve failure may be higher than for pipe breaks.

2.2 Design based accidents - Causes

The cause of a major structural failure in a valve body or bonnet is likely to be due to overstressing or loads exceeding the fracture toughness of the material.

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Evaluating stresses in a valve body is much more difficult than those in piping. The geometry is more complex, the material properties more variable and the loads imposed difficult to assess.

Valve bodies are often subject to extensive experimental stress analysis in addition to analytical stress analysis. Methods such as brittle coatings, strain gauges and photo-elasticity are used.

Obviously any stress analysis is the responsibility of the architect-engineer or valve manufacturer. But the licencing authority has a responsibility to assess the Certified Stress Reports and clearly must have a capability of review at a high level of competence.

The AEB has supported UCT work in fracture mechanics for some years and recently work in the significance of defects in welded components. There is also knowledge at UCT in gaskets, pressure, sealing closures and stem packing. With support and encouragement, these skills can provide you with a capability to review overseas designs.

2.3 Seismic Effects

After the recent Welkom "tremor" designers and builders are more conscious of seismic effects.

Valve actuators cause most of the seismic problems. These devices are often massive and located a long way from the pipe centre line so that huge bending forces can occur. Many manufacturers buy out their actuators and so they are often poorly integrated into the design.

Valves tested in seismic conditions are going to be costly. One method is to subject the valve and actuator to the amplitude and duration of a tape-recorded earthquake on a shake table. Although costs may not concern the licencing

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authority, the adequacy of such tests undoubtedly will.

2.4 Codes

1) National Standardization of Codes is not complete. For example, pressure vessels in South Africa are manufactured to ASME, BSS and ADM codes.

2) Codes undergo continuous and often drastic revisions. For example, ASME Nuclear Code Section 3, 1963 to 1971.

3) It takes a long time to become familiar with and to trust Code rules.

4) There is no international standardization of nuclear codes and divided opinion on the matter exists.

   For example,"In France no binding Code requirements exist in the field of steel pressure vessel design and construction, with the argument that technical progress should not be hindered ....." (3)

   Most valves, however, are designed to the ASME Nuclear Codes, Section 3. The choice of component class in this Code is at the designer's discretion and can require an intimate knowledge of the function and safety implications to evaluate the choice. Designers are required to provide certified Stress Reports on all Class I valves and Certified Design Specification Reports for all 3 class of valves.

   Having worked closely with a large nuclear valve manufacturer for some years, I know some of the difficulties associated with design to Codes. We try to introduce familiarity with Codes to our Senior students but in practice time prevents much study in depth. As Codes are likely to assume greater importance in nuclear plants in the future, this matter should be given some priority.

2.6 Quality Assurance

QA is a disciplined approach by management to the procurement of (a) adequate design and (b) adequate supply, installation, inspection, testing, etc. By insisting upon adequate QA at all stages, the licencing authority can make a positive contribution. It is, after all, the licencing authority's duty to approve all designs and materials and manufacture and installation. Such a task can only be done if good QA systems are used by the contractors and utility.

3.0 Safety in Operation

Recent operating experience has identified valve performance, particularly the problems of improper operation and leakage, to be a major safety related problem (4).

3.1 Valve malfunction

Gross malfunctions such as yoke fractures, actuator failure or stem seizure are increasing. U.S. Nuclear Regulatory Commission data for 1967 - 1971 showed only 2,5 gross valve failures per plant year. This rate increased to 8,1 in the period 1973 - 74.

Assuming an average of 1500 valves per reactor and 8000 operating hours per year, the gross failure rate, $\lambda = 0,6 \times 10^{-6}$ failures per hour.

This actual failure rate experienced by a population of about 60 reactors appears to be most favourable when compared with non-nuclear failure rate data. However, the comparison can be misleading as this failure rate only refers to gross malfunctions which could affect reactor safety.

By comparison, Table 1 from unpublished data shows failure data for control valves which includes all causes of malfunction.

Data such as this is an input to failure Modes and Effects studies which in turn assist Fault Tree Analyses for overall safety assessments.

I'm sure you are familiar with this in your safety assessment work. I might mention operators are beginning to extend this work to assess life cycle costs and establish maintainability strategy, i.e. the optimum mix of corrective and preventative maintenance.

3.2 Valve Leakage

Until a few years ago valve design was a most empiric exercise; much had remained the same since Ferranti patented his first steam stop valve in 1904. (5)

The two main areas of leakage are the body to bonnet joint and the valve stem seal.

The first usually employs gasket seals or so-called pressure seals. The latter are usually restricted to the larger sizes.

Strangely enough, the mundane matter of gasket design is only now being solved.

Two years ago I gave a paper to the ASME on spiral wound gaskets giving test results and drawing attention to the present inadequate and non-conservative Code design rules (6). The Pressure Vessel Research Committee has now set up a task force to investigate this matter. (7).

Concerning pressure activated seals, there is some work going on in South Africa. We recently hydrostatically tested a vessel with a pressure activated seal. The sealing fluid is ammonia at 36 MPa (5200 lb/m^2) with a sealing diameter of 700mm.

To meet stringent stem leak tight requirements for nuclear valves, designers merely increased the number of packing rings. Some designers incorporate a lantern ring and leak off connection to collect leakage from the primary packing. This is a simple matter for the valve manufacturer. For the operator it means a whole new system to collect, store, filter and inject leakage into the main system.

I have been involved with laboratory studies aimed at understanding the mechanisms of stem leakage. Numerous tests both cold and at temperature show there is a strong relationship between axial packing stress and leakage.

One answer to reduce leakage is the provision of what is called "live load" on the packing. If the packing is maintained under a high rate spring load, small settlement and compaction is accommodated and leakage drastically reduced.

"Live loads" are widely used in Canadian power reactors, but are not generally available from valve suppliers.

Stems are also sealed with diaphragms and bellows. These provide zero leakage under normal operation. At present, bellows sealed valves are restricted to sizes less than 100 mm, but no doubt this size limit will increase in the future. Life is limited by fatigue to about 5000 cycles.

3.3 Consequences of Leakage

Why all the emphasis on leakage?

Leakage violates one of the main safety principles : that of providing barriers and containment to radioactive material. Loss of primary coolant can be expensive (even condensate costs 10 cents/l today) but more seriously it distributes radioactive fission products from defective fuel and radioactive corrosion products around the reactor building. (While the fission

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product problem can be reduced by removing defective fuel, the corrosion product is a function of initial design and choice of materials.

Cobalt is by far the most dangerous material to have in the primary system. Table 2 shows that its radiation fields are many orders of magnitude greater than other materials. It is no coincidence that it is used in radiotherapy.

Operators may take pride in an all-stainless steel clad reactor vessel and piping but there are large areas of alloy steam generator surface and the ubiquitious hard facing on valves.

Table 3 shows the cobalt concentration in typical out of core materials.

Table 4 shows estimated release rates of cobalt into the system.

The figures speak for themselves. A stellite surface releases almost 200 times as much cobalt into the coolant as an Inconel-600 surface. Clearly cobalt alloys should be treated with caution.

Why the concern with cobalt and radiation fields?

As the licencing authority, your concern for radiation exposure includes the plant operators. High radiation fields are often a symptom of leakage which necessitates maintenance and in turn leads to personnel exposure. Routine maintenance and special repairs account for nearly 50% of the total exposure of a nuclear plant, so this is obviously an area of considerable concern.

Rather than decreasing as plants achieve maturity, radiation exposure to the operators has been increasing. In Main Yankee, for instance, where I witnessed inservice inspection in 1974, the average monthly exposures are shown in Table 5. (8).

A man rem will cost about R7000 in 1982-3 when Koeberg comes on line. Unless maintenance exposure is curtailed it will not only become an item of operating expense but will also deplete the pool of artisans in the Cape Town area.

At present these expensive men are sent into the containment to repack valve seals armed with primitive corkscrews and wire tools. In cramped and awkward positions they have to remove rock-hard compacted packings. Performance is poor. As an example, 40 small valves took 21 man hours/valve to repack and incurred a dose of 1 man-rem per valve in one reactor. In 1984 rands this would cost over R250 000.

4.0 PROGRAMMES

Table 6 lists programmes of interest to licencing authorities and indicates possible assistance that UCT can offer.

CONTROL VALVE FAILURE DATA
(DATA BASE: $2{,}5 \times 10^6$ h)

MAINTENANCE ACTION	OCCURENCE	$\lambda \times 10^{-6}$/h
REPLACE DIAPHRAGM	37	15
ADJUST PACKING	21	8,4
TIGHTEN BONNET	6	2,4
REPACK	31	12
REPLACE GASKET	6	2,4
LAP OR RENEW TRIM	20	8
REPLACE BODY	2	0,8
	123	49

OVERALL FAILURE RATE $\lambda = 4{,}9 \times 10^{-5}$/h

TABLE 1

RADIONUCLIDES IN ACTIVATED CORROSION PRODUCTS

NUCLIDE	HALF LIFE	RELATIVE γ-RAY POWER*	PARENT
Co-60	5.3 y	1500	Co-59
Co-58	71 d	1	Ni-58
Cr-51	28 d	0,4	Cr-50
Mn-54	303 d	0,06	Fe-54
Fe-59	45 d	0,07	Fe-58

* RELATIVE MeV/s BASED ON Co-58 FOR GIVEN OF NATURAL ELEMENT IRRADIATED TO SATURATION IN EQUAL FAST & THERMAL NEUTRON FLUXES

TABLE 2

COBALT CONCENTRATION IN OUT-CORE MATERIALS

MATERIAL	USE	% MASS Co
CARBON STEEL	PIPE, VALVES	0,015
INCONEL-600	STEAM GENERATOR TUBES	0,03
STELLITE	VALVE TRIM, PUMP WEAR SURFACES	55

TABLE 3

ESTIMATED Co RELEASE RATES

MATERIAL	RATE ($g/cm^2 s \times 10^{10}$)	TYPICAL AREA (cm^2)	Co RELEASE ($\mu g/s$)
CARBON STEEL	1,0	—	—
INCONEL-600	< 0,1	2×10^8	<0,6
STELLITE	1,0	4×10^2 *	0,02

* AREA IN ONE 24 INCH VALVE

CORROSION RATES FOR PH 10 H_2O, 270°C, LiOH or NaOH

TABLE 4.