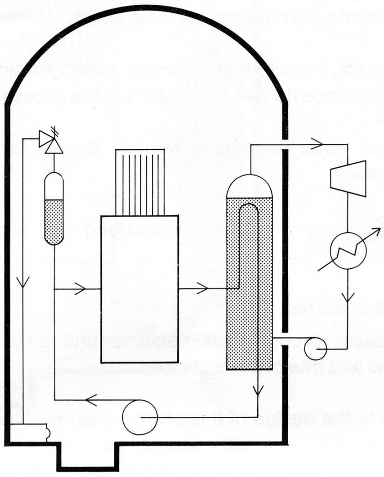
SAFETY NEWSLETTER

No. 156
THREE MILE ISLAND
LESSONS FOR THE CHEMICAL INDUSTRY



Do not neglect ancillary and packaged units

Do not connect a service line to a process line at a higher pressure

Measure directly what you want to know

Train operators in diagnosis

Learn from others' experience

Do not rely on regulations — do what you consider necessary for a safe plant

Pay as much attention to software as to hardware

Consider minor failures as well as major ones

Plan how to deal with public relations in an emergency

An Engineer's Casebook — Corrosion resistant alloy steels

ICI

IMPERIAL CHEMICAL INDUSTRIES LIMITED

PETROCHEMICALS DIVISION

THE LESSONS FROM THREE-MILE ISLAND FOR THE CHEMICAL INDUSTRY

Few incidents in recent years have caused more concern than the accident at Three Mile Island nuclear power station in 1979. Are there any lessons for the chemical industry? During the Autumn of 1981 groups of managers discussed this and this Newsletter is based on their conclusions.

Description of the Power Station

Figure 1 is a simplified diagram of a pressurised water reactor, the type used at Three Mile Island.

Heat is generated in the core by radioactive fission. The heat is removed by pumping primary water round and round. The water is kept under pressure so that it is not boiling. (It is called a pressurised water reactor to distinguish it from another sort, a boiling water reactor).

The primary water gives up its heat to the secondary water, which is boiled. The steam drives a turbine and is condensed and the condensate is recycled.

All the radioactive materials, including the primary water, are enclosed in a containment building so that they will be contained if there is a leak from the process.

There are no pressurised water reactors in the UK. Except for some experimental units, our reactors are cooled by gases.

In the following the sequence of events is described and at each step the lessons for the chemical industry are drawn.

Phase A — How the trouble started

The secondary water passes through a resin polisher unit to remove traces of impurities. There are several parallel paths and one of them choked.

Less attention was paid to the design of this off-the-shelf ancillary unit than to the design of the main radioactive equipment. Its reliability was not studied to the same extent. Its failure led to the incident.

There is a message for us here. Packaged units, ancillary units, off-plots and so on need as much detailed attention as the main stream, especially when their failure can cause a shut-down of the main stream.

To try to clear the choke the operators used instrument air. Its pressure was lower than that of the water so water got back in to the instrument air lines. There was a non-return valve in the line but it was faulty.

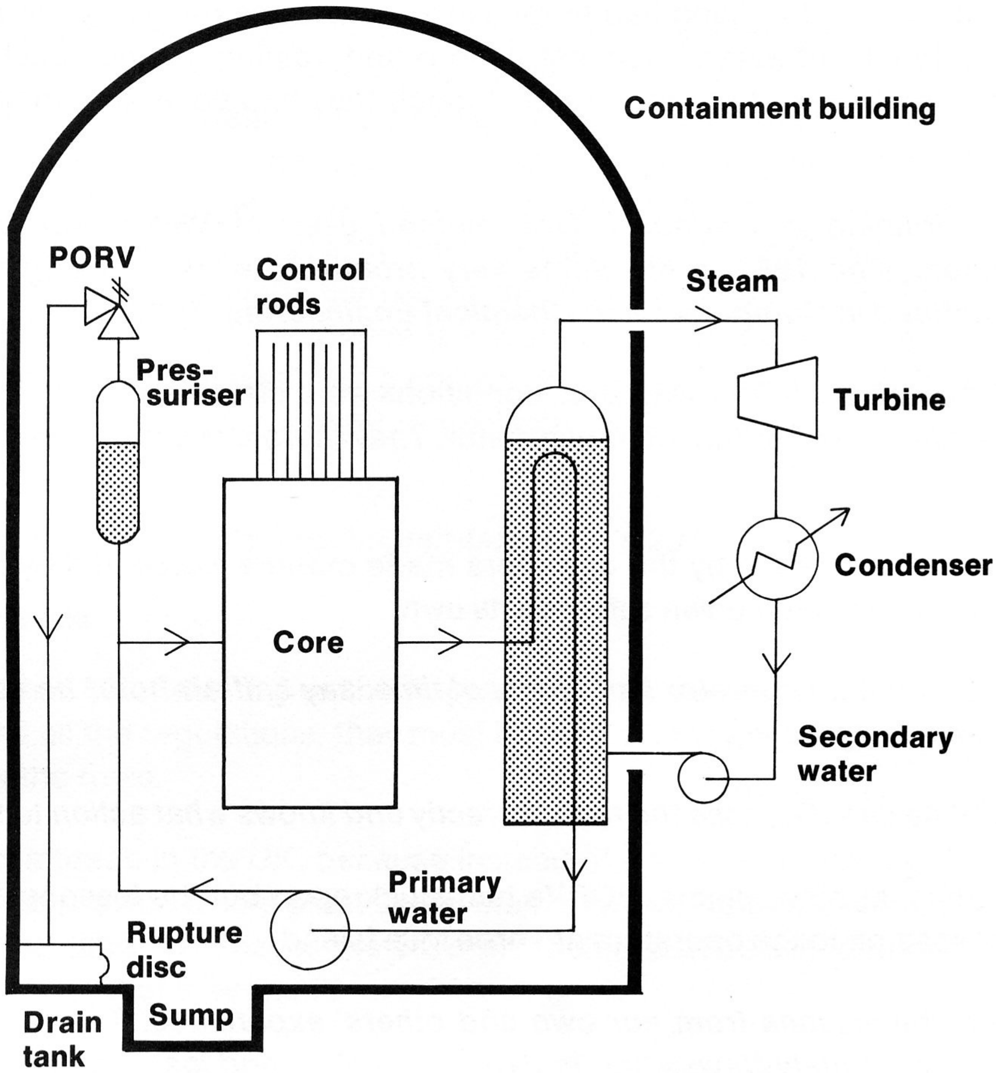
How often have we connected process equipment to service lines at a lower pressure and ended up with flammable gas in the nitrogen lines or oil in the compressed air lines? (See Newsletters 98/2 & 3 and 79/2(b).) The actual pressures in services lines are often lower than the nominal pressures.

Instrument air should never be used for line blowing.

The water in the instrument air lines caused several instrument failures and the turbine tripped. This stopped the removal of heat from the radioactive core. The production of heat by fission stopped automatically within a few minutes. (Silver rods drop down into the core. They absorb neutrons and stop radioactive fission). However the heat produced by radioactive decay (about 6% of the normal load) had to be removed. This caused the primary water to boil, the pilot operated relief valve (PORV) on the primary circuit lifted and pumps started up automatically to replace the water evaporated from the primary circuit.

Unfortunately the PORV stuck open.

Figure 1 A pressurised water reactor — simplified



Phase B — How the trouble got worse over the next 2 hours

The operators did not realise that the PORV was stuck open as a light on the panel told them that it was shut. However the light was not operated by the valve position but by the signal to the valve. The operators did not know this (or had forgotten).

Whenever possible instruments should measure directly what we want to know, not some other property from which it can be inferred. (See Newsletter 119/1).

If a direct measurement is impossible then the label on the panel should tell us what is measured, in this case, 'Signal to PORV' and not 'PORV Position'.

Several other readings should have suggested to the operators that the PORV was stuck open and that the water in the primary circuit was boiling:

The PORV exit line was hotter than usual (140°C instead of 90°C) but this was thought to be due to residual heat.

The pressure and temperature of the primary water were lower than usual.

There was a high level in the containment building sump.

The primary water circulation pumps were vibrating.

On the other hand the level in the pressuriser was high, as it was raised by bubbles of steam.

The operators chose to believe the PORV position lights and the pressuriser level and ignore or explain away the other readings, probably because:-

(i) They did not really understand how the temperature and pressure in the primary circuit depended on each other and when boiling would occur.

(ii) Their instructions and training had emphasised that it was dangerous to allow the primary circuit to get too full of water. Their instructions and training had not told them what to do if there was a small leak of primary water (though they had covered a major leak such as a pipe break).

*Operators need training in diagnosis. One method used at Wilton was described in **The Chemical Engineer**, Feb 1981, p 66. Some very promising work on using computers to aid diagnosis is described in **Computers and Chemical Engineering, 1980, Vol 4, p 143.***

The operators thought the PORV was shut, conditions were clearly wrong and their training had emphasised the danger of adding too much water. *They therefore shut down the make-up water pumps*.

Note that the only action taken by the operators made matters worse. If they had done nothing the system would have cooled down safely on its own.

We used to think that if an operator had plenty of time, say half-an-hour, he could be trusted to act correctly in an emergency.

This is true only if he can diagnose the fault correctly and knows what action to take.

On other occasions, at other plants, PORVs had stuck open but the lessons of these incidents had not been passed on to the operators at Three Mile Island.

We should learn the lessons from our own and others' experience. The cost of the incidents described in a typical Safety Newsletter, in damage to plant and lost production, is hundreds of thousands of pounds. You get the descriptions free. They are the best bargain you will ever have. Do you make full use of them?

Phase C — How the damage occurred

With the make-up water isolated the level in the primary circuit fell. The top of the radioactive core was uncovered. The steam reacted with the zirconium cans which protect the uranium and hydrogen was formed.

Meanwhile the steam which was discharging through the PORV was condensing in a drain tank, overflowing into the containment building sump and was being automatically pumped outside the containment building.

Changes in design could have minimised these consequences but the lessons are not of general interest.

It was 2 hours before damage started. Correct diagnosis at any time during that 2 hours would have allowed a full recovery. But the operators had made their diagnosis and stuck to it although the evidence against it was overwhelming. They had a 'mind-set'. Newsletters 155/2 and 109/1 & 2 described other accidents caused by mind-sets.

We are much more likely to develop a mind-set when we are under strain, as the following quotation shows:

"Most people, when faced with a problem, tend to grab the first solution that occurs to them and rest content with it. Rare, indeed, is the individual who keeps trying to find other solutions to his problem. This is especially evident when a person feels under pressure...

And once a judgement is arrived at, we tend to persevere in it even when the evidence is overwhelming that we are wrong. Once an explanation is articulated, it is difficult to revise or drop it in the face of a contradictory evidence...

Many interesting psychological experiments have demonstrated the fixating power of premature judgements. In one experiment, colour slides of familiar objects, such as fire hydrant, were projected upon a screen and people were asked to try to identify the objects while they were still out of focus. Gradually the focus was improved through several stages. The striking finding was this: If an individual wrongly identified an object while it was far out of focus, he frequently still could not identify it correctly when it was brought sufficiently into focus so that another person who had not seen the blurred vision could easily identify it. What this indicates is that considerably more effort and evidence is necessary to overcome an incorrect judgement, hypothesis or belief than it is to establish a correct one. A person who is in the habit of jumping to conclusions frequently closes his mind to new information, and limited awareness hampers creative solutions."

E Raudsepp, Hydrocarbon Processing, September 1981, p 291.

Some General Lessons

The reports on Three Mile Island give the impression that many of those concerned believed that if they followed all the regulations, they must be safe. All they needed to do to achieve a safe plant was to follow the rules.

We get less of this attitude in the UK, because instead of a lot of detailed regulations we have a general obligation to provide a safe plant and system of work. Nevertheless signs of this attitude appear from time to time. Whenever the HSE are being particularly demanding someone is tempted to say 'Just do what they want'.

We should do, as we always have done, whatever we consider necessary to protect our employees and our investment and as a result we shall do more than the Law requires. It is our responsibility to decide how far to go. This responsibility cannot be passed on to an Inspector or writer of regulations.

Many recommendations have been made for improvements to the Three Mile Island design. To quote the Kemeny Report (Further Reading, item 5, p 24), "While many of the proposed 'fixes' seem totally appropriate, they do not come to grips with what we consider to be the basic problem. We have stated that fundamental changes must occur in organisations, procedures, and, above all, in the attitudes of people. No amount of technical 'fixes' will cure this underlying problem".

Similarly in the chemical industry safety is achieved by good design and, equally important, by good software, that is, good instructions, training, methods of working, checking and so on.

There was so much concern with major failures such as a complete break of a primary water circulation pipe, that smaller but more probable incidents were ignored. There was a belief that if large-break accidents could be controlled, there was no need to worry about less important accidents.

Similarly in the chemical industry most in juries and damage are not due to major failures of equipment. We should consider minor failures as well as major ones.

At Three Mile Island, much went wrong, but no one was injured. (However, because Three Mile Island is shut down more coal has to be mined and burning it will cause more pollution; the mining and the pollution may cause extra deaths, perhaps two per year). The incident showed how safe nuclear power stations are. But nevertheless it has seriously damaged the reputation of the nuclear industry in the US and has set back the nuclear power programme.

"Some of those who briefed the press lacked the technical expertise to explain the events and seemed to be cut off from those who could have provided the expertise". (Further reading, item 5, p 18).

When something goes wrong, as it will from time to time, have you thought out how you will handle the public relations?

Further Reading

1 G L Brooks and E Siddall, "An Analysis of the Three Mile Island Accident", CNS First Annual Conference, Montreal, 18 June, 1980 (17 pages).

This is the best short account that I have read.

2 H W Lewis, "The Safety of Fission Reactors", Science, March 1980, p33 (13 pages).

3 W J Lanouette, "The Kemeny Commission Report", The Bulletin of the Atomic Scientists, January 1980, p 20 (12 pages).

4 A Schneider, "Three Mile Island: The Chemical Engineering Aspects", Loss Prevention, Volume 14, 1981, p96 (8 pages).

More detailed accounts are given in the following

5 "Report of the President's Commission on the Accident at Three Mile Island" (The Kemeny Report), Pergamon Press, 1979 (201 pages).

6 "TMI-2 Lessons Learned Task Force Final Report", Report No NUREG-0585, US Nuclear Regulatory Commission, 1979 (57 pages).

7 "Investigation into the March 28, 1979 Three Mile Island Accident by the Office of Inspection and Enforcement (Investigation Report No 50-320/79-10)", US Nuclear Regulatory Commission, 1979 (42 mm thick).

8 "Accident at the Three-Mile Island Nuclear Power Plant: Oversight hearings before a task force of the Subcommittee on Energy and the Environment of the Committee on Interior and Insular Affairs of the House of Representatives", Serial No 96-8, 1979.

ASKING THE WRONG QUESTION

Three Mile Island shows how experts can produce the wrong answer because they are asked the wrong question.

When the water level in the reactor fell, hydrogen was produced by reaction between the steam and the zirconium cladding around the uranium. A hydrogen bubble formed in the reactor.

Radiation causes water to split into hydrogen and oxygen. Could enough oxygen form to make a hydrogen/oxygen explosion possible? Several independent organisations were asked and they all estimated that enough oxygen would form in a few days. The Nuclear Regulatory Commission (NRC) released this information to the press.

When NRC's operating expert heard of this, he said, without making any calculations, that it was "nuts". His reason? A trace of hydrogen is normally added to the water to combine with any oxygen formed and convert it back to water. With a large excess of hydrogen present the conversion of oxygen back to water would be greater than usual. The experts had been asked at what rate oxygen would form and had answered this question. They had not been asked if it would be converted back to water.

MR E H FRANK

Many readers will be sorry to learn that Harland Frank (see Who's Who in Safety in Newsletter 103), author of most of our Engineer's Casebook articles, died on 31st December at the age of 59. He was an outstanding engineer; not only did he possess a sound grasp of engineering principles and the ability to apply them but he was also an expert craftsman. All who worked with him know that there was no one quite like him. During the last few years he had several periods of ill-health; they did not reduce his enthusiasm, but on doctor's orders he retired at the end of 1980.

In the last few years before he retired he was persuaded to put some of his experience on record, in the Safety Newsletters, in the Plant Engineer's Handbook, and in a short-lived publication called The Terotechnologist. Young engineers in the Company can learn much from these publications which contain some of the life-blood of a master engineer.

For more information on any item in this newsletter please 'phone P.2845 or write to us at Wilton. If you do not see this Newsletter regularly and would like your own copy, please ask us to add your name to the circulation list.

February 1982

An Engineer's Casebook No 56
CORROSION RESISTANT ALLOY STEELS

Frequently, when there is a corrosion problem on a plant, the first suggestion is 'let's replace it in stainless steel!' Many successful applications for stainless steels do exist around our plants, but problems do occur for various reasons.

Some examples drawn from ten years' experience on one of our Works at Wilton are set out below:-

1 Incorrect specification for stainless steels

(a) The original ICI designation for an 18/10/Mo/Ti stainless steel was M153 Class ZA (equivalent of BS 970 Part 4, Grade 320-517). This steel grade is now only available to special order and is superseded by BS 970 Part 4, Grade 316-512. In making this selection as an alternative it is well to note that this grade has slightly inferior physical properties.

(b) A 25/5 ferritic alloy steel pipe failed drastically through embrittlement of the steel. This was caused by formation of a phase in the steel when subjected to a temperature in excess of 700°C. (Recommended design maximum 350°C.)

2 Operating conditions higher than design

(a) A condenser originally designed for cooling water (shell side) with 18/8/Ti tubes at 60°C was operated at 110°C. The condenser tubes suffered stress corrosion cracking in tube plate crevices within 5 years of start up and required complete replacement with Sandvic 3RE60 grade stainless steel.

(b) A distillation column was to be injected with a small quantity of concentrated acid by an injection pump. Correct recognition of the need to use an injection nozzle was made, but localised gas turbulence in the column caused the acid to contact the vessel wall before dilution was possible; rapid corrosion of the shell wall occurred.

(c) A steam traced 88% phosphoric acid line in 316L stainless steel failed within 6 months when maintenance of an adjacent process pump had disturbed the tracing spacer between the main line and the tracer. A small hot spot occurred causing rapid localised corrosion.

3 Incorrect grade of stainless steel used

A steam jacketed acid main (acid temperature 170°C) was jacketed by reduced IP steam at 170°C. When a major steam escape from a storage tank vent was investigated, one 4 inch pipe section on the internal acid line was found to be fabricated from type 304, not 316L stainless steel as specified and had completely corroded before collapsing under the steam pressure.

These examples show some of the problems, many of which could have been avoided by careful consideration of the application for which the stainless steel was to be used. One of the examples (No 3) shows what can happen if an incorrect material grade is used.

To avoid such incidents in the future, the following questions should be asked before deciding on a particular grade of stainless steel.

What is the expected life for the equipment and its replacement frequency?

Is the material readily available and can it be readily fabricated?

What is the risk of failure of the equipment?

Will the performance of the alloy be affected by precise process conditions, or are there any other factors during the life of the equipment which could affect the alloy performance?

It will also be necessary to balance plant life, initial and replacement costs as prices for stainless steel range from £1100/tonne (321 grade) to £21 000/tonne (Hastelloy C). The most expensive may not be the best for your application. Finally, having decided on the right stainless steel for the job, make sure that it is what is actually supplied and used for the job!

P Nicholls