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SURVEILLANCE OF NUCLEAR POWER REACTORS.

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SURVEILLANCE OF NUCLEAR POWER REACTORS

SUMMARY

Surveillance of nuclear power reactors is now a necessity imposed by such regulatory documents as USNRC Regulatory Guide 1.133. In addition to regulatory requirements, however, nuclear reactor surveillance offers plant operators significant economic advantages insofar as a single day's outage is very costly.

The economic worth of a reactor surveillance system can be stated in terms of the improved plant availability provided through its capability to detect incidents before they occur and cause serious damage. Furthermore, the TMI accident has demonstrated the need for monitoring certain components to provide operators with clear information on their functional status.

In response to the above considerations, Framatome has developed a line of products which includes :

- pressure vessel leakage detection systems
- loose part detection systems
- component vibration monitoring systems
- crack detection and monitoring systems.

Some of the surveillance systems developed by Framatome are described in this paper.

The main components of a Nuclear Steam System Supply (NSSS) are shown in Figures 1 to 3. Drifting metallic parts may cause serious consequences in such areas as the bottom of steam generators (hot leg bottom head) or the top of reactors where the control rods are located.

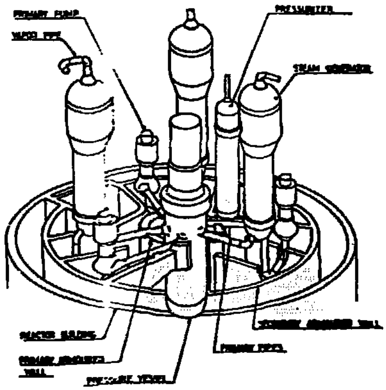


FIGURE 1: THREE-LOOP PWR GENERAL VIEW

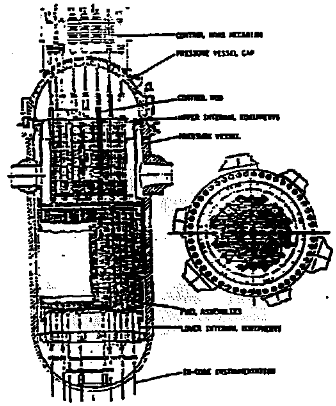


FIGURE 2: CORE OF NSSS

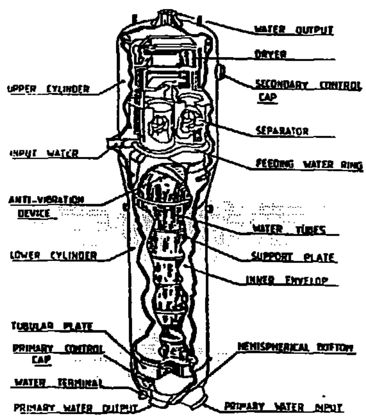


FIGURE 3: STEAM GENERATOR

The primary system pressure is 155 bars and leakage may be experienced in various areas such as the manhole cover seal of the steam generator bottom head, hot and cold sides. Crack propagation is possible wherever thermal fatigue can occur, and potential critical zones can be listed taking into account the difficulties related to the manufacturing process, welding between carbon steel and stainless steel, etc. Acoustic emission monitoring seems to be a good way of detecting and locating these particular incidents.

Abnormal vibration behavior of the core and internals can cause serious damage such as has been noticed on French and US reactors. The use of accelerometry and neutron noise measurement will be a great help to prevent these incidents.

ECONOMIC AND REGULATORY ASPECT OF INSERVICE MONITORING OF REACTORS.

When a reactor experiences an incident such as a loose part in the primary system, major economic consequences are obvious. Several months of shutdown have already been noticed on US and German reactors due to this specific incident. In France too, during the startup phase, loose parts were found which caused serious damage.

A reliable detection system (without false alert signals) can be very useful when it can detect very rapidly the existence of loose parts. Although there is no French regulation on this topic, one can refer to the US Regulatory Guide 1.133 which specifies the energy of metal impacts to be detected.

For leakage detection on PWRs, because the primary system is pressurized to 155 bars, leakage may occur in various zones. The US Nuclear Regulatory Commission (NRC) also gives indications concerning the threshold to be detected (1 gl/mn within one hour).

Abnormal vibration of the SENA reactor core barrel caused fatigue failure and subsequent shutdown for a year and a half. Neutron noise vibration surveillance could probably have seen useful to help avoid this particular incident.

On crack growth detection, it should also be noted that incidents may be possible due to the presence of defects left without repair in a structure and which may evolve due to fatigue conditions. No nuclear regulations appear to exist in this field because there is still a lack of confidence in current methods. Recent developments using sophisticated, totally digitized systems seem to give more reliable results.

BASIC PRINCIPLE OF INSERVICE SURVEILLANCE SYSTEM USING A.E. TECHNIQUES.

Metal/metal impact detection.

When a loose part strikes a component, it generates acoustic waves which spread through the structure. Detection of these waves can be performed in the low frequency range using accelerometers or in the high frequency range using A.E. transducers. Experimental surveys performed in labs and on plants have shown that the signal to noise ratio is higher when monitoring is performed in the high frequency range.

Figures 4 and 5 show some examples of impacts detected by accelerometers and acoustic emission transducers observed in the BUGEY 5 reactor.

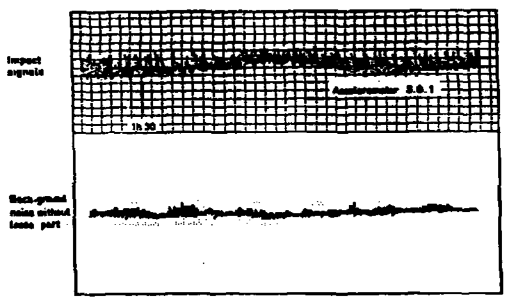


Figure : 4 – RECORDS OF IMPACTS IN STEAM GENERATOR BOTTOM HEAD DETECTED BY ACCELERCMETERS.

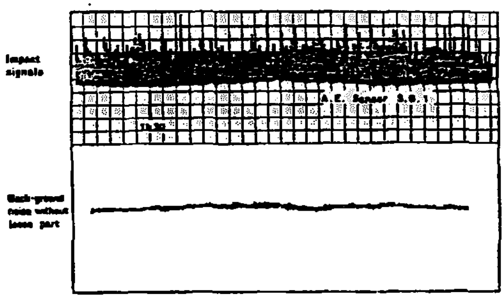


Figure : 5 _ RECORDS OF IMPACTS IN STEAM GENERATOR BOTTOM HEAD DETECTED BY ACOUSTIC EMISSION SENSORS.

Furthermore, it has been noticed that even working in the high frequency range, spurious signals caused by control rod movement, valve opening, etc. can be interpreted as metal/metal impacts. These observations have led us to a new concept for designing reliable equipment using spatial discrimination.

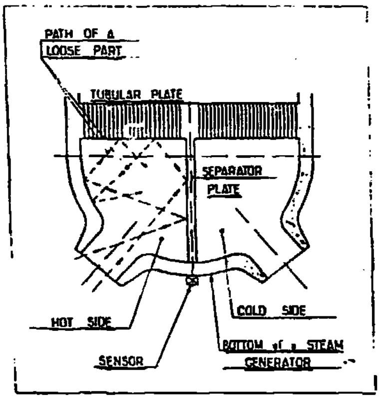


FIGURE 6 : HOT LEG STEAM GENERATOR BOTTOM HEAD.

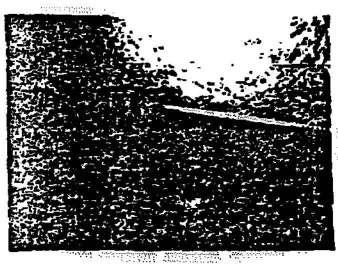


FIGURE 7 : IMPACTS AFTER HAVING A LOOSE PART INSIDE A STEAM GENERATOR BOTTOM HEAD.

The basic principle is to take into account the signal originating in a delimited zone to the exclusion of signals originating outside this zone.

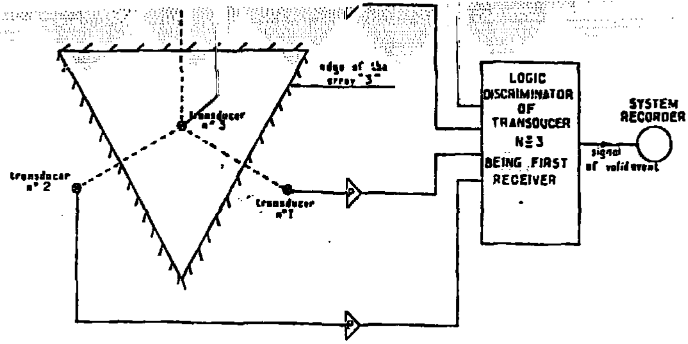


FIGURE 8 : SPATIAL DISCRIMINATION PRINCIPLE

By assuring that transducer n° 3 must receive "first", it can be seen easily in Figure 8 that the array system of 4 transducers gives a positive response if the impact is generated inside the triangle and gives no response for signals generated outside.

This is the principle of spatial discrimination which is used in the LOCAPAR system described below.

Leakage detection.

A leak in any pressure vessel generates turbulence in the vicinity of the leak. This turbulence produces sound waves which spread through the surrounding structures. The sensors detect and transmit the increased background noise. A suitable band selection gives a good signal to noise ratio even for small leaks. Leakage rates of only several deciliters per hour can be detected.

- during the first cold hydrotest (preservice inspection)
- during normal operation
- during other periodic hydrotests in order to minimize radiation exposure to operators.

Studying modification of acoustic PSD monitored on reactor during plant operation without and with leakage, it can be seen that a good signal to noise ratio is obtained near 100 kHz. Figure 9 gives some results of RMS value of A.E. versus leakage parameters measured on primary piping.

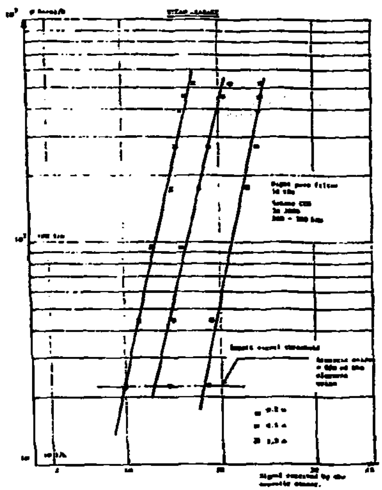


FIGURE 9 : RMS VALUE OF A.E. VERSUS LEAKAGE PARAMETERS

In the nuclear industry, plant availability is also greatly dependent on good performance of components such as relief and other types of valves. Since not enough attention has been paid in the past to the design and testing of such components, some incidents have been observed during implementation of the French nuclear program. A contributing factor to the accident at Three Mile Island was also a malfuctioning relief valve.

[illegible] in recent years :
residual heat relief valves and pressurizer relief and safety valves.

The residual heat relief valves protect the residual heat removal system from overpressure. They are set at 40 bars and the temperature of the system can reach 180° C.

The main problem encountered is that, since there are two relief valves in parallel and the fluid conveyed is generally water, the mobile disc swings and impacts the seat. This mode of operation can deteriorate the valve parts and, after closing, watertightness may not be assured.

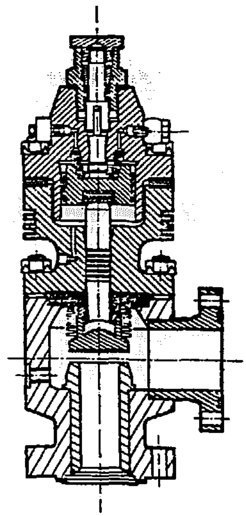


Figure 10: Residual Heat Relief Valve

The pressurizer valve system can be seen in Figure 11. Three relief valves (only one shown) are provided and three sets of valves including, in series one air-operated valve and one safety valve.

A water slug is provided upstream of each valve in order to assure hydrogen tightness between the primary system and the auxiliary systems. The pressure and temperature conditions of the primary system are 154 bars and 320° C, respectively.

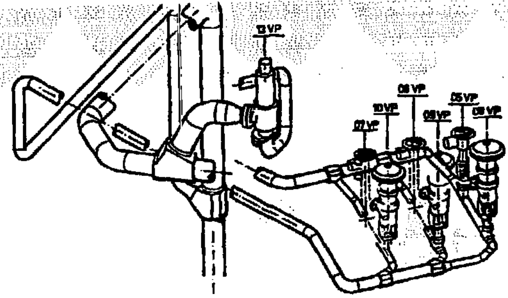


Figure 11 Pressurizer Valve Systems

Good leaktightness has to be assured for the air-operated valve, which is required to operate a great number of times.

DEVELOPMENT AND PRINCIPLE OF ACOUSTIC SURVEILLANCE.

Although some of the following objectives can be fulfilled with other kinds of instrumentation, acoustic apparatus was used to : first, provide a clear indication in the control room that a valve is operating and has not stuck open ; second, if it is closed, indicate that the leaktightness is still assured or otherwise give a quantitative indication of the leakage third, monitor whether valve chattering occurs.

Many tests were performed on test loop and on reactors during startup testing before an industrial type instrumentation system (DAMES) was designed and installed on site.

The principle of tests run on EDF and Framatome facilities was to install instrumentation on valves and piping and provide data to strip chart and magnetic tape recorders during the testing of relief and other valves.

Acoustic data were analyzed with Power Spectral Density (PSD) and Fast Fourier Transform (FFT) apparatus.

detected by an acoustic sensor attached to a residual heat relief valve during tests on EDF's facility at Chatou.

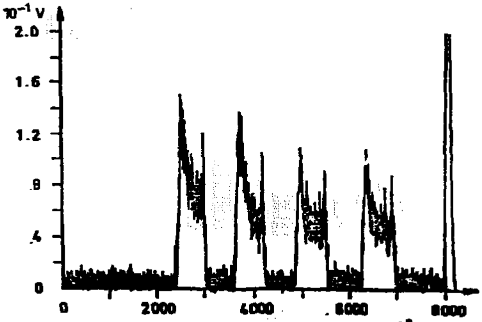


Figure 12: RMS value of noise detected by acoustic sensor during valve opening

After four openings followed by four correct closing operations, the background noise remains at the same level, indicating proper functioning and good leaktightness.

Figure 13 shows another example of valve functioning. Here, after four satisfactory operations, chattering occurred due to instabilities and hydraulic coupling between the fluid and the moving parts of the relief valve. After closing it can however be noticed that leaktightness is assured, because no significant increase of the acoustic background noise can be seen.

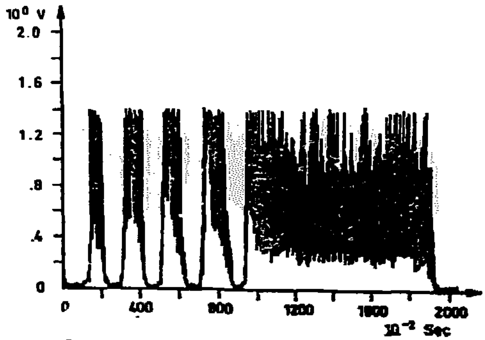


Figure 13 Valve chattering detected by acoustic sensor

Figure 14 shows an example of valve opening followed by incorrect closing, indicating leakage. The leakage is apparent because the background noise did not return to its previous value after valve operation.

Figure 14 Valve opening followed by incorrect closing

Many tests on facilities and reactors showed that water and steam leakage can be detected using acoustic sensors attached to piping or a valve body.

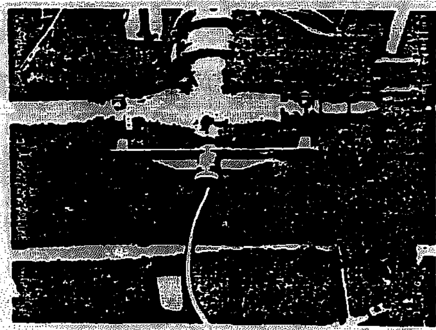


FIGURE 15 : INSTRUMENTATION INSTALLED ON A REACTOR

Crack growth surveillance

During crack growth in a stressed material, energy is released and acoustic stress waves are generated in a large frequency band. Some relationships exist between A.E. records and fracture mechanics theory.

For example, Figure 16 shows the large increase of burst noticed on a fatigue test performed on a specimen which is representative of a tube penetration in the bottom head of the pressure vessel. Before failure of the penetration weld near 37 580 cycles acoustic monitoring predicts a failure near 29 000 cycles. This unexpected failure was related to a piece of the machine itself. After repair of the fatigue machine and starting the test again, the specimen broke near 37 000 cycles.

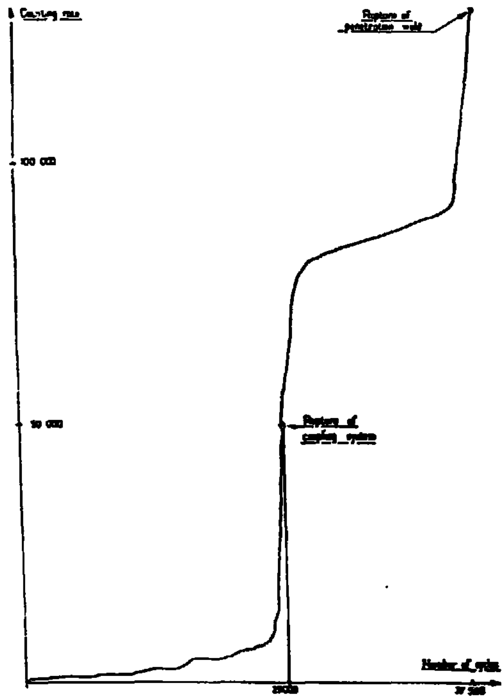


FIGURE 16 : FATIGUE TEST COUNTING RATE DURING THE RUPTURE PHASE

Various R and D programs in cooperation with University of Lyon (INSA) and CGR (Compagnie Générale de Radiologie), founded by EDF and the DGRST (Direction Générale de la Recherche Scientifique et Technique) are presently conducted with the objective of understanding the fundamental mechanism linked to stress waves generation when a crack grows or when a plastic zone is developed.

The differents alloys used in the construction of Framatome NSSSs have been studied and their acoustic signature behavior recorded during tensile and fatigue tests. Figures 17 and 18 show some examples of these results obtained with conventional A.E. instrumentation.

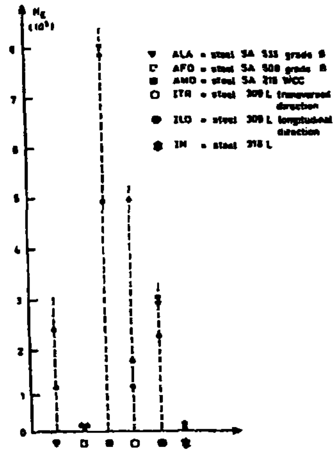


Figure. 17 _ STATISTICAL STUDIES OF A.E. SIGNALS OF VARIOUS KIND OF STEEL USED IN NUCLEAR COMPONENTS

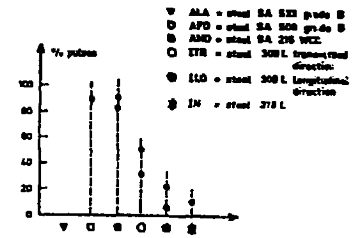


Figure. 18 _ STATISTICAL STUDIES OF A.E. SIGNALS OF VARIOUS KIND OF STEEL USED IN NUCLEAR COMPONENTS.

When using A.E. surveillance on a critical zone for reactors during full power operation, the main problem is to record data which are connected to the particular point at which we are looking at and not to take into account signals such as acoustic or R.F. interference. In general, localization of A.E. sources needs to be also more accurate as in the case of metal/metal impacts. Conventional instrumentation commercially available today was tested and found unreliable. New apparatus such as the HYPERLOC II system are being developed using digitization of the A.E. signals in connection with sophisticated software.

Figure 19 gives some examples of digitized A.E. signals. Before being taken into consideration for further processing (triangulation or quantification) each signals is compared to a reference level (Figure 20) which in this particular example is the averaged signal obtained during specimen tests.

EPROUVETTE n° 9

Date et heure de l'événement n°5	19 07 11 56 11
Nombre de cycle	83048
Charge lors de l'événement	5.33 Tonnes
Différence de temps d'arrivée	6.1 Microsecondes

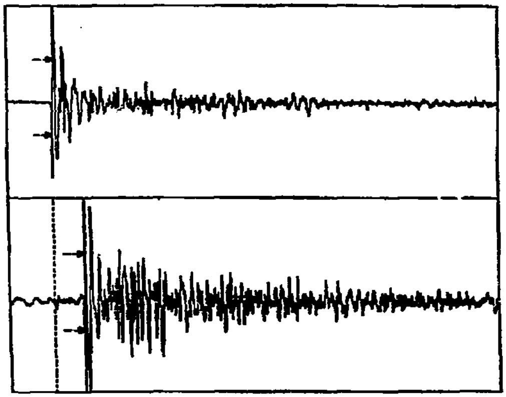


Figure : 19 - DIGITIZED ACOUSTIC EMISSION SIGNALS
TOTAL SCALE : 100 MICROSECONDES

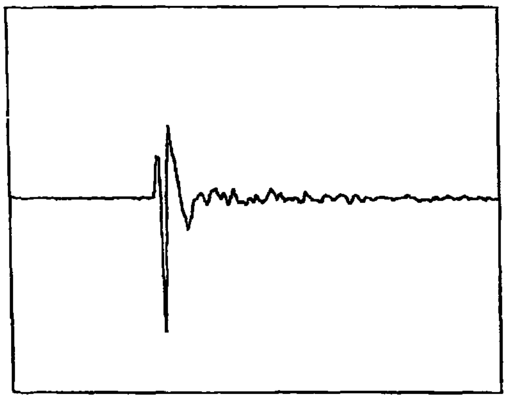


Figure : 20 - A.E. SIGNAL STANDARD FOR ACOUSTIC SURVEILLANCE OF FATIGUE CRACK PROPAGATION IN STAINLESS STEEL
TOTAL SCALE : 25 MICROSECONDES .

When a crack grows, the acoustic source of the stress wave is mainly a "DIRAC" function and only the beginning of the signal is of great importance. The end of the signal is mainly due to the waves propagating in the structure. This leads us to design and use more higher frequency transducers than it is usually done for crack growth surveillance.

CORE AND INTERNALS VIBRATION MONITORING.

A comprehensive joint program called SAFRAN was implanted in 1971 by Framatome and the CEA to study vibration behavior of PWR internals. Several measurement runs have been performed on site jointly with the CEA and EDF to enable comparison of laboratory and on-site results. The vibration measurements used sensors located inside and outside the pressure vessel as well as accelerometers and strain gages during hot functional tests of the reactor.

Measurements using accelerometers located on the top and bottom of the reactor vessel and measurement of ex-core neutron noise were performed on various reactors at different power levels.All these results were input to a data bank used to characterize the normal vibration behavior of PWRs built by Framatome.

Following BUGEY 2 hot functional tests, dimension measurements of the internals hold down spring led us to suspect that vibration levels could change with time. Consequently, regular neutron noise measurements were performed during the initial fuel cycle. The results for BUGEY 2 were compared with those previously obtained for FESSENHEIM 1 and 2, and with those from the SAFRAN program (theoretical and experimental laboratory results obtained on a 1/8th scale mock-up).

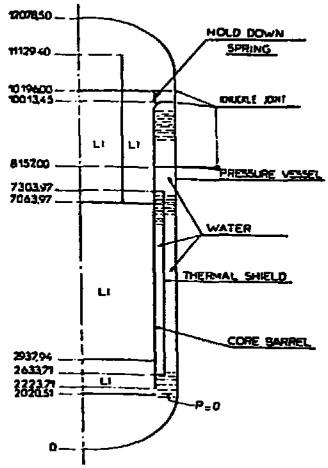


FIGURE 21 : MODEL OF INTERNALS USED FOR CALCULATION OF VIBRATION BEHAVIOUR.

EXPERIMENTAL FIELD STUDY.

The experimental study of internals and pressure vessel vibrations was performed on the FESSENHEIM 1 and BUGEY 5 reactors using external and internal accelerometers as well as strain gages /9/.

Figure 22 is an example of results from on-site measurement runs on BUGEY 5. All the results were used to describe the vibration behavior of internals and are used as a data bank for analysis and interpretation of ex-core neutron noise signals. (On some reactors ex-core and in-core neutron noise measurements were also performed).

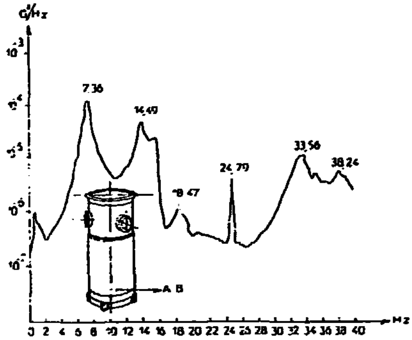


FIGURE 22 : BUGEY 5 - HOT FUNCTIONAL TESTS CONDITIONS. ACCELEROMETER AB LOCATED AT THE BOTTOM OF THE CORE BARREL.

Results obtained or the BUGEY 2 reactor.

Some examples of results recorded on the Bugey 2 unit are given in Figures 23a, 23b and 23c.

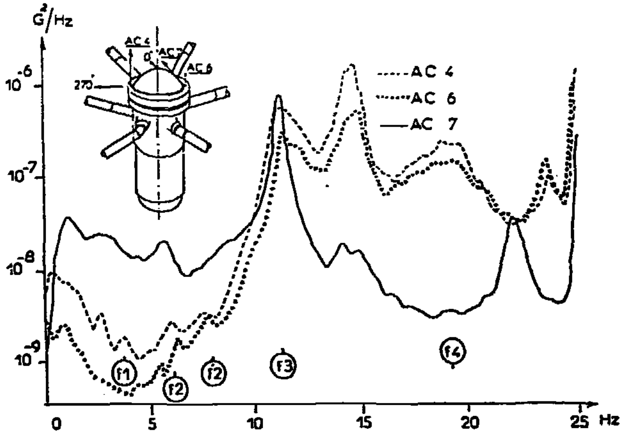


FIGURE 23 a : BUGEY 2 - APSD OF ACCELEROMETERS LOCATED ON TOP COVER HEAD - 2/21/79 - 100 % FP

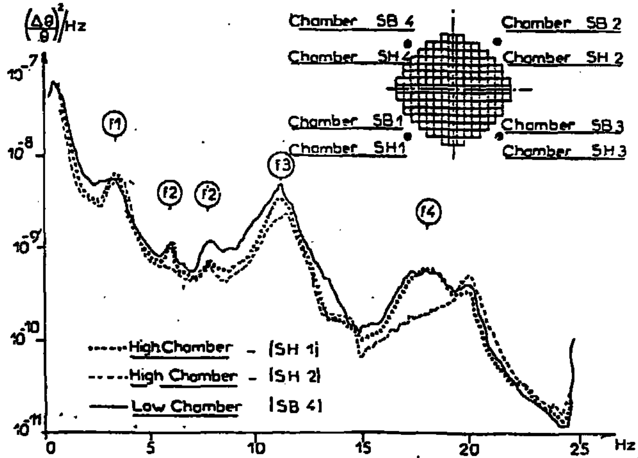


FIGURE 23 b : BUGEY 2 - APSD OF EX-CORE CHAMBERS - 2/21/79 - 100 % FP

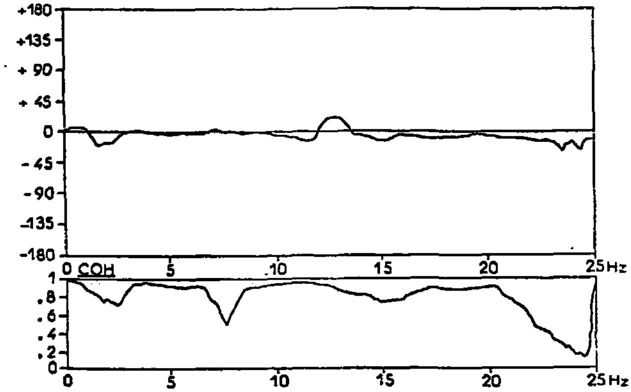


FIGURE 23 c : BUGEY 2 - COHERENCE AND PHASE SPECTRUM OF CHAMBERS SB1 AND SH1

Vibration analysis of the reactors built by Framatome during the past few years, which utilize accelerometers and neutron noise signals, provides experimental confirmation of resonant frequencies and modes of internals predicted by the SAFRAN program.

The comparison of results and time change analysis from ex-core neutron noise signals of Bugey 2 reactor during the first fuel cycle highlight the difficulties of interpretation. It was seen that the two main modes, free rocking and free rocking with contact of radial guides, may exist individually or coexist simultaneously.

ACTUAL CASES OBSERVED ON REACTORS AND MONITORING SYSTEMS DEVELOPED FOR REACTORS.

Loose parts detected by A.E.

Figure 24 shows acoustic signals recorded on the Blayais 1 PWR.

Figure 25 shows the corresponding loose parts found in the pressure vessel after plant shutdown and removal of pressure vessel top head.

The weight of the loose parts was 150 g which corresponds to an energy well below the threshold recommended by Regulatory Guide 1.133

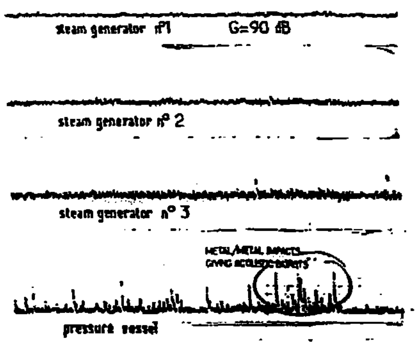
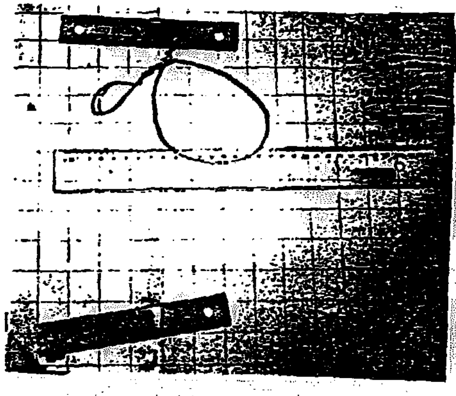


FIGURE 24 : METAL/METAL IMPACT SIGNALS - LOOSE PARTS IN THE PRESSURE VESSEL.



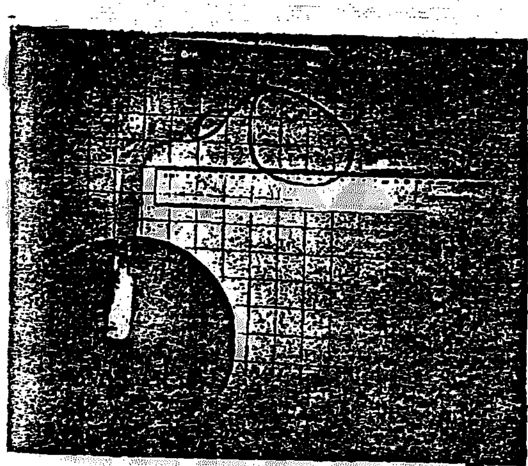


FIGURE 25 : LOOSE PARTS FOUND IN BLAYAIS REACTOR AT THE END OF HYDRO-TEST.

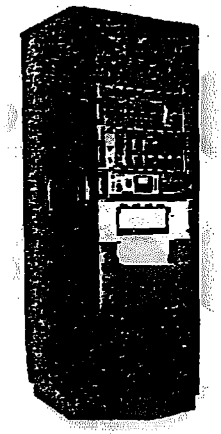


FIGURE 26 : LOCAPAR - LOOSE PART DETECTING SYSTEM - FRONT VIEW.

Leakage detected on plants by A.E.

Two types of leakage are considered :

- leakage of primary system to secondary or auxiliary systems (valve tightness).
- leakage of primary system to containment building.

Successful applications have been introduced in both cases.

On the Fessenheim 1 plant, a leakage of 9 l/h between pressure vessel and top cover head has been detected.

The MACOUMAT 3 is a computerized system which can monitor leakage and vibrations on reactor structures. Figures 27 and 28 give a block diagram and the view of the front panel of this system.

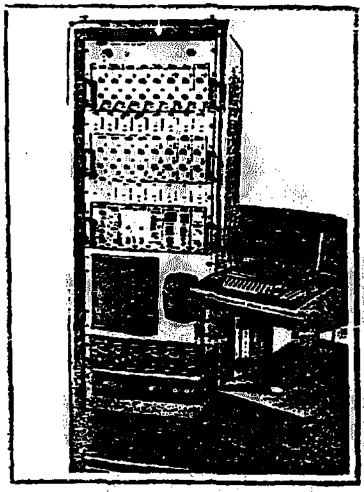


FIGURE 27 : MACOUMAT 3 - ACOUSTIC AND VIBRATION MONITORING FOR NUCLEAR REACTORS.

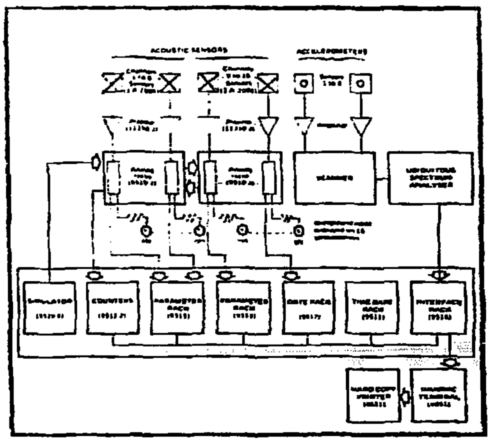


FIGURE 28 : MACOUMAT 3 - Block Diagram.

Crack growth detection on plants.

A.E. techniques have been successfully used on the Bugey 5 reactor for monitoring noise in a steam generator bottom head where special instrumentation was installed. During service, and with flow rate environment, crack growth spread and after 3 days the break occurred. Figure 29a, b and c shows some recorded data and the corresponding pieces of metal after plant shutdown (as time passes signal appears more frequently and with a higher amplitude).

RECORDING OF LOOSE PARTS DETECTION IN BUGEY 5 STEAM GENERATOR CHANNEL HEAD

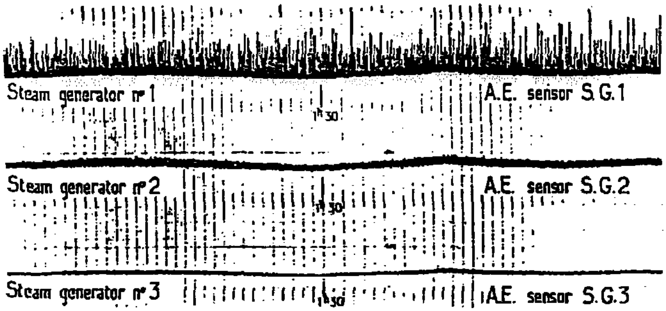


FIGURE 29 a : SIGNALS DURING BUGEY 5 HYDROTEST - 3 PUMPS IN ROTATION.

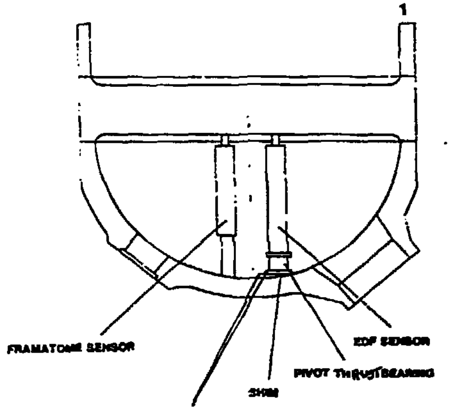


FIGURE 29 b : SPECIAL INSTRUMENTATION INSTALLED IN STEAM GENERATOR DURING HYDROTEST.

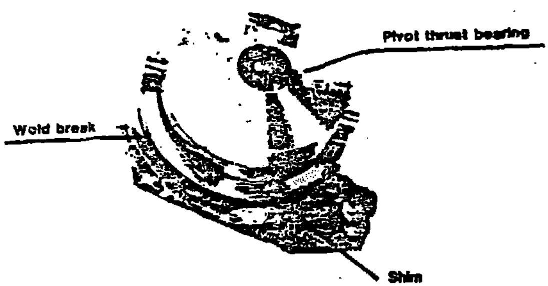


FIGURE 29 c : SHIM FAILURE

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