Non-destructive tests through gammagraphy:
« *a technical job as well as some necessary rigorous improvisation and astutes*[1] »

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Introduction

Non-destructive tests play a key role in industrial maintenance activities. The efficiency of these activities depends a lot on the results obtained. The reliability of these tests and their results therefore become an important link of the general reliability of all the technical systems involved in the running and the exploitation of a nuclear power plant.
The ageing of some materials and the application of new regulation requirements have increased the NDTS activities when the number of radiologists has remained relatively stable. The fact that shutdown operations mainly happen during certain periods of the year makes it very difficult to make available these *itinerant* workers [Doniol-Shaw et al., 1995] that belong to sub-contracting companies.
From a prevention point of view, in the last few years several incidents occurred during which operators doing non-destructive tests through gammagraphy were exposed [Abéla, 2001 ; Crouail, Rittore & Lefaure, 2001]. The analysis of these incidents have shown that human errors played an important part, but is it that easy ?
In a context in which non-destructive tests are more and more needed and when plant owners and deciders wish to reduce to a minimum the exposure of operators to ionising radiation, the managers of EDF radio-protection[2] and of its Laboratory Group[3], have decided to set up a work group[4] and to launch an ergonomical study so as to better understand what these activities imply. In this work group you find members of the Laboratory Group, of the EDF Risk Prevention Group[5], representatives of 2 nuclear-power plants, representatives of the sub-contracting companies and ergonomists.
The issue of the ergonomical study is to confront the a posteriori accident analyses with the descriptions of the real conditions of non-destructive tests through gammagraphy, taking into account individual, collective and organisational factors.
The aim of this paper is to present the first results of the ergonomical study currently being carried out, and more particularly the observations made in a first nuclear power plant during the summer of 2001[6]. We will more particularly emphasise the variations encountered during the operations, the skills used to solve the problems, the difficulties met and finally, dosimetry problems. We will put forward the idea that these activities are not as easy as one might think ! To do the industrial radiography under tight time constraints and with higher and higher quality exigencies, operators have to take many decisions in a context of strong uncertainties. Taking into account the great many different situations encountered (congestion of some areas, difficult accessibility, type of radiography, etc.) the operators use their technical skills while they also « *rigorously improvise* » to adjust to each situation.

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[1] The tem "***necessary rigorous improvisation and astutes***" is described in the parts 4.2.4 and more generally in 5.2. It corresponds to skills, which will complete technical competences. That kind of skills are fed by experiences They contribute to reliability and quality of the NDTs.
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[3] EDF Laboratory Group
[4] This work group is headed by Henri-Pierre Blandin, from the EDF Laboratory Group
[5] EDF Risk Prevention Group
[6] We wish to thank here the executives and the operators of CEP for their kind help, as well as the actors of the concerned power plant (occupational doctors, Head of the Risk Prevention department, Head of the Laboratory Group on-site, Head of Maintenance).

1 – The approach followed

This approach articulates around :

1.1 - An exploratory stage

Its aim is to characterise the present context of industrial radiographic tests. It is based on interviews with various actors (Laboratory group members, sub-contracting companies, equipment manufacturers, etc …). After this exploratory stage, scenarios or profiles of exposure situations should be characterised. These scenarios could include multi-causality, the organisation of the task, the type of control being carried out, or the geographical areas concerned, etc. This will enable us to choose real work situations that will then be analysed with a classical ergonomical approach.

1.2 – Analysis of the preparation stages the NDT interventions

Based on the exploratory study and on the identification of some characteristic scenarios, and on-site analysis of the preparation stage will be made. This will enable us to better understand how the different actors envisage the type of tests to be made, the conditions in which they will be made (accessibility, dosimetry, interfaces, etc.). This will enable us to make sure that the preparation is adapted to their representation of the task and allow them to preserve some manoeuvring margins. Planning, communication and preparation skills can then be emphasised.

Different elements could then be characterised :

- The co-ordination between the various services : planning department, Risk Prevention department, preparation engineering, task distribution services, general services, Laboratory Groups, sub-contractors etc.
- The taking into account of lessons learnt return of experience ;
- The different types of tests carried out ;
- The documents developed and made available by the sub-contractors ;
- The equipment required ;
- Etc.

1.3 – Analysis of NDT interventions

This stage consists in attending « live » the tests being carried out, the preparation of which had already been analysed by us, so as to characterise the unavoidable divergences between a real work situation met on-site during shut-downs and the theoretical situation taken into account during the preparation. The management of these divergences by the operators and the organisation (real time co-ordination of the various actors involved : Laboratory Group, planning department, supervision, general services, etc.) will be the object of specific follow up. The difficulties encountered while the operations are being carried out will be characterised.

1.4 – Restitution

All these stages should enable us to draft a diagnosis of the existing situation and to suggest explanation links between the accidents or incidents encountered and their possible causes related to preparation or intervention. This diagnosis should unfold around the ALARA approach. It will be presented at all levels implied : national, on the site and to the sub-contracting companies.

2 – Social construction

This research/action is based on a social construction, which involves various actors in the project. Starting with national preoccupations, particular attention is given to the preoccupations of the sub-contracting companies, as well as to those of the power plant. The approach suggested leads to several levels of intervention: at national level via the workgroup, a sub-contracting level and at the level of the three nuclear plants chosen. The

modalities to accede to the different levels will be defined by the workgroup. The involvement of the Health and Safety Committees within the sub-contracting companies or the plants could be suggested.
A leaflet presenting this research/action has been developed to present its objectives and to remind the confidentiality engagements as far as industrial property is concerned, to show how to use the data from the exploratory stage and from the analyses of the activity. Each observation of the working activity will lead to a report that will be validated by the concerned person, so as to be used for research later on.

3 - A first representation of industrial gammagraphy activities

Although everyone admits the importance of the quality of tests, it is surprising to see how little known this activity is, that often takes place at night. It is often presented by most deciders as an easy job : it would ***only*** consist in placing the films cassette at the right spot and to expose it through a source. For the exposure time, you ***only*** had to go and look for it in the available documents. Nevertheless, it is a risky job since you have to use radioactive sources. Therefore, you ***only*** have to carefully follow the technical procedures concerning quality or safety and your mission would be fulfilled. We will demonstrate that this first level of representation remains simplistic and that it doesn't correspond at all to real situations. And yet, it is still this first level of representation that often prevails among deciders. This will lead to a certain way of organising the work, of certain procedures, planning of the operations, etc.

4 – First results observed

These first results are based on the observations stages carried out in a power plant in the South West of France, during a shutdown period. Prior to these observations a representation of the study and of the methodology used were given to the chosen sub-contractor ; the latter then had to agree to give free access to its company to ergonomists. The same study was presented, within the power plant, to the occupational doctor, the head of the Laboratory Group, the head of the Risk Prevention department in the plant and to the manager in charge of maintenance.
The results are based on the observation of the preparation stage shortly before the shutdown, and on the 5 work sites that followed.
Our presentation of the observations will start with the characterisation of the encountered variabilities due to the situation during the tests, followed by the skills used and the ***rigorous improvisation*** set up, then the difficulties met and end with problems related to dosimetry. We will then review the different stages of the work site : preparation, installation of the equipment, and the exposure of the tested part.
Various actors were interviewed :

- The Laboratory Group team on-site, whose role is to identify the elements requiring periodic tests, to prepare the giving of orders to sub-contractors, to make sure the tests are carried out properly during the shut-down, to take part in the interpretation of the obtained results, etc.
- The sub-contracting company that has a day team preparing the radiographic exposures and that take part in the meetings during the shutdown. And night teams made of shift supervisor who is responsible for all the tests carried out that night, a courier operator whose main task is to take the exposed films back to the laboratory, one or two developers and controllers. Usually controllers are working in pair : one with experience and an assistant.

4.1 – Preparation

In our study we differentiate the preparation prior to the shutdown and the preparation of the work site itself a few days or hours before the tests are carried out. It is to notice that for the site we observed, the organisation and the management of the non-destructive tests within the plant studied, were undergoing deep changes. In the months to come activities will be transferred from Laboratory Group to the maintenance department. Regardless to this, for this particular shut down very little preparation was done prior to the opening of the work site. Theoretically, two months before the shutdown, the Laboratory Group prepare the lockout requests that will appear in the planning of the shutdown. Any change in the planning of the tests during the shutdown must be the object of modifications in the lockout procedures and must be carefully followed up.
During the week before the beginning of the shutdown, a team belonging to the company that was going to carry out the non-destructive tests prepared these activities in close connection with the Laboratory Group people.

Any such test requires an exposure permit [cf. Abela, 2001] and a boundary map. They are prepared by the sub-contractor and transmitted to different services of the plant. The latter has them signed by the person in charge of the shutdown, during the morning meeting, so that the tests can be carried out.
In reality, the dynamic of the shutdowns and the hazard discovered during maintenance work engender many changes to the planning as a whole and more particularly to the test activities. This can mean changing teams, for example switching day and night teams, etc. It is important to know that operators come from various parts of France and can work in all the nuclear plants throughout France.
This leads to a great mobility and the teams are constantly reshuffled. From one shutdown to another, it is not often possible to keep the same people in the same team.

4.2 – The setting up of the work site

The equipment includes a gammagraph with the source (GAM), the control cable and its handle, cassettes containing the films to expose, markers identifying lead exposures, a system to fix the source, a blue revolving light to be left next to the source, an orange revolving light left near the three dimensional space, some area delimiting tape. To these traditional pieces of equipment you can add tension wires, straps, sello tape, etc.
Each team is given a file at the beginning of the night shift. In it they will find : the signed exposure permits, the lockout procedures, the map of the restricted area, the intervention orders (IO), the document allowing the transport of the sources (derogation DI82), the procedures, the circuits description (ISO), a prevention plan (PP) and the ALARA form, the quality plan (QP) and a telephone directory.

4.2.1 – Transport of equipment

In the concerned power plant, the radioactive sources are stored in a specially designed room, outside the controlled zone. This compels the operators to handling and they need a special permit to transfer the source towards the NDTS site. When NDTS are inside the controlled zone the derogation procedure (DI82) has to be taken in to account.
The rest of the equipment is stored in small premises in the BAN. All this equipment being fairly voluminous and heavy, particularly the Gammagraph (near 20 kg) and the film cassettes, the team of two operators (one with experience and an assistant) use a trolley for the transport. This trolley is without closed sides, which can explain why some pieces of equipment can fall. Furthermore the storage room being upstairs, the trolley has to be unloaded and re-loaded which leads to handling and posture risks for the operators (cf. photo 1). At the end, the trolley is parked in a corner and the equipment is carried by hand, for example in case of crinoline ladders passages, which are not easy to negotiate.

4.2.2 – Variabilities in situation

The different observations enabled us to show evidence of the great diversity of the elements linked to the situation, even more often, the problems of accessibility. Indeed, the premises are often small or heavily crowded. They can be well-lit or in semi-darkness. In some cases it could be in atmospheres conveying high doses, which requires the setting up of biological protections. One has to notice that, in some cases, the scaffoldings or biological protections can hinder the operators when they set up the equipment and the film. In such a context, the identification of the welding that has to be tested can take time. It appears that the reading of the “piping map” (ISO) can sometimes be quite difficult, even for experienced controllers.

4.2.3 – Defining a three-dimensional restricted area

This seems to be something quite easy to do. It is not. Indeed, according to the configuration of the space to define in three dimensions, to the number of possible entrances, to the presence of full slabs or of floor grating, this activity can take more or less time. Most of the time this is done by the assistant and based on the boundary map given by the Risk Prevention service. Since some other activities still go on, even at night, it is not always easy to block out all the entrances. Negotiations can take place with the Risk Prevention people to agree on the best delimitation. This is not always easy to implement. For example when the only solution consists in fixing the tapes with sello tape, the walls or the cables raceways have to be cleaned beforehand and must regularly check whether the tape still sticks (cf. photo 2). During our observations the boundary tape fell down ; it has been checked by the operators and replaced.

4.2.4 – Skills

According to the surroundings of the element to test (for example when there are scaffoldings, solenoid valves, etc… the installation of the films cassette and of the guide tube of projection can become a tricky job. So as to set up the exposure procedures, operators must use their technical knowledge in radiography (presence of filter, focal distance, exposure time, etc.) but also use ***many astute trick we call « rigorous improvisation ».*** These trick concern the fixation of the films cassette and of the guiding tube in a sometimes overcrowded environment, still respecting the standards of the trade so as to keep quality. Various means are then used, sello tape without which nothing could be done, sandows, straps, etc. (cf. photo 3). In the case when one exposure follows another in a high dose flow, you must be able to remove the film easily and rapidly. Therefore it has to be fixed, but not too much ! The cassette containing the film must mould the shape of pipes, sometimes you have to fold its edges without deforming it too much lest it should be exposed to daylight, etc.
This meticulous and rigorous improvisation are the object of many verifications, for example on the centring of the film, on the setting up of the lead markers that will identify the exposure, on the focal distance, etc. A good co-ordination between the controller and his/her assistant is then very important and they have to communicate a lot (cf. photo 4).
Finally, very often the controllers cannot see directly what they do because of elements in the way (when a cassette has to be placed behind a pipe, for example). Feelings like touching are omnipresent, as well as guiding through gestures made by the second operator. The choice of the place for the ejection flex and of the crank-handle used to eject is the result of compromising : you must protect yourself from the source and at the same time facilitate visual control of the area, and all this while avoiding bending the flex too much. The setting up of the films and of the guiding tube is therefore time consuming, for example for one minute exposure time this can take nearly 20 minutes.

4.2.5 – Difficulties

Beyond the difficulties already mentioned, it seems important to us to emphasise those related to the transport and the handling of the equipment, with the risk of falling, risks for the back. To this you can add off-balance postures when you fix the guiding tube of the films, sometimes inside a duct (cf. photo 5), or when you have to lie down on the ground with contamination risks due to dust (cf. photo 6 and 7).

4.2.6 – Dosimetry

When the elements to be tested are located in a high flow dose area, all the difficulties encountered when setting up the films or the ejection flex are going to lengthen the exposure times.
Co-ordinations with other services to measure the actual dose flows, to set up scaffoldings, biological protections, etc… are then preponderant.

4.3 – The exposure of the film

The exposure of the film is therefore only one of the links of the test and its duration varies according to the type of test and can last from one minute to several hours.

4.3.1 – Skills

The controller will try to take into account the precise data from the procedures, as well as the variable elements mentioned here above : the real focal distance, etc. The calculation of the exposure time is done by help of what is indicated in the procedures, but it will be repeated several times before and during the exposure. Operators say that different formulae have to be used and tried out. According to the results on the first film, the controller is going to increase or decrease, in situ, the exposure time. We stress here the importance of communication in situ between the controller and the person that develops the films. We have noticed the efforts made by the controllers to try and put the developer in « *situation* », and this over the phone. While the controller is waiting for the development of a film he has just exposed, he experiences a strong feeling of uncertainty, when he doesn't know if the results will be good, whether he can start another site, etc.

Obtaining a « good picture » depends on different parameters on which the operators have more or less control, which even reinforces this feeling of uncertainty. One can mention, at cassette preparation level, the importance of well choosing the sensitivity of the film, the differences in the quickness of the films depending on the lot bought, the film being positioned straight in the cassette, a well assorted cassette (3 films, filters, blockages, etc.), or no orientation mistake for the luminous marking of the film. As for the handling of the film cassette, one has to avoid : folding it, dropping it as well as any shock, rain or water making spots, the storage near a radioactive source, or a heat source, etc. During the exposure it is important to make sure that the film is correctly placed on the welding so that it is « visible », as well as all the different identifying markers. Any blockage of the source will lengthen the exposure time and alter the quality of the film. Finally, at the end of the chain, the development can also pose problems : the film can be « *eaten up* » by the machine, the adjustment of the machine can be upset (temperature, chemical composition, etc.), or mistakes can be made when trying to fine tune the intensity.

4.3.2 – Difficulties

During the exposure of the film, the main concern is how to manage the uncertainty of the result while waiting for it. Work rhythms change then. If a film has to be re-done the pressure on the operator increases, and even more if it is difficult to position the cassette or if the atmosphere presents a high dose debit. While observing we noticed several times that operators had difficulties in reaching their interlocutor (developer, lockout service, control room), either because the area was too noisy near the phone, or the phone was out of order or the lines engaged. These communication problems increase the uncertainty described here above.

4.3.3 – Dosimetry

All the actors know the risks when the film is being exposed ; the sources can have an important activity, 60 or 100 Curies (units still used by radiologists). At first the controllers try to place the ejection crank behind a wall or some re-inforced part so as to be protected during the exposure. When the source is ejected, the operators make measurements with a radiation meter (at the beginning of the exposure). It is to be noticed that under these conditions the GAM indicators of radioactivity are not very clear : you can only see them when you are very close to the meter and with good lighting. Besides, since most of the time the gammagraph is on the floor, visibility is not optimum. What more, in presence of contamination risks the gammagraph can be protected by a plastic film (and so is the ejection flex and the guiding tube).

During the exposure, operators concentrate on the number of revolutions required to eject the source. They keep wondering : « *are you sure to have had 13 revolutions ? Is the source really out ? Has it been withdrawn properly ?* »
During our observations the operators did not have any revolution clock, they were counting mentally, knowing that 13 revolutions only take a few seconds. The operator ejecting the source relies then on his own feelings. In two cases an operator felt he had to « force » and then thought the source was blocked ; but in fact he was able to withdraw it and eject it again. This uncertainty about the position of the source adds to those described above and can even cause tension. What strikes us is the discrepancy between the duration of work on one site and the time the source is being ejected. For example for a 4 hours work session on site, with 6 films exposed, the source was only ejected 6 times for a duration of 1 minute. This means that the exposure risk was only there for 6 minutes in 4 hours of work. And yet, no specific information or signal is there to remind the controllers or the people working nearby, when risks are really encountered. The restricted area is in place whether the source is ejected or not.
For the operators, dosimeters with an alarm can be interesting but will not be efficient in noisy surroundings ; systems producing vibrations could re-inforce the alarm. A visual or noise indication, at the foot of the source and linked to a detection beacon could be interesting. But in high dose atmospheres these systems would work non-stop. In all cases the different systems or devices has to be resistant to the hard conditions of working site life ! The question is therefore still raised.
We must mention here that while we were observing, one operator was slightly contaminated on a shoulder while carrying the ejection flex. This was found out at the BAN safety gate. He only had to change his work-suit.

5 – Discussion

This workshop gave us the opportunity to formalise the first results of our study. They have to be taken at their face value and will be completed during the second observation phase programmed for the end of 2001. Based on the first stage, here is what we suggest to discuss.

5.1 – From human error to organisational reliability

Abéla [2001] emphasises that since 1997, 8 incidents occurred during gammagraphic tests carried in French nuclear power plants and they cause irradiation lower than 26 msv. Crouail & al. [2001], reviewing the Institut Curie data bank, analysed 20 accidents that happened between 1978 and 1998. They noticed that most incidents caused low irradiation. Nevertheless these could potentially have been much more serious. These authors identified three types of causes ; malfunctioning of equipment, human factors and breaching of the law. They state that human factors represent 46 % of the accident causes, the malfunctioning of equipment 29 % and breaching of the law 25 %.
When one reviews accident reports from power plant prevention services [Lefebvrève, 2001], the following formulations can be found : « *the operator forgot to …, through carelessness the operator didn't withdraw the source to safe position, or the three dimensional danger area had not been clearly defined, etc …* ». These reports are focused on the operator that becomes *guilty* and they strongly under-estimate the multicausal dimension related to the occurrence of incidents.
Based on our observations we can emphasise the fact that it is quite difficult to isolate one variable from another. Indeed we have here variables that interlock into one another and that have equivalent « weight ». The management of uncertainty and the time pressure play a vital role in the occurrence of incidents, especially since the work is carried out at night, when vigilance is lower anyway. The difficulties increase because of the hardship of manual handling and of some postures.

As de Terssac and Leplat [1990] remind us, error is always human since technique is developed by man ; we could add that this is also true for work organisation, which is also set up by man. At the same time, an error is never only man's fault since technical and organisational conditions are always at its origin. Wisner [1991] stresses that it is wrong to say that only operators make errors. It is now necessary to switch from the analysis of the mere operator, or faulty actor to the analysis of the whole system in which the latter evolves [Keyser, 1991]. From this view point, the analysis of accidents or incidents related to gammagraphic tests take little into consideration this imbrication.

It seems to us that we have to pass from analyses centred on the reliability – or not, of people to organisational reliability [Perrows, 1984 ; Hale & Glandon , 1987 ; Reason, 1990 ; Senders & Moray, 1991 ; Llory, 1996 ; Bourrier, 1999 ; Garrigou & Carballeda, to be published]. Beyond this broadening towards the organisational aspect, it is necessary to exploit what operators tell you about their accident so as to build up a *recollection bank* and to make it available to all concerned. Amalberti [1998] emphasises that a lot can be learnt from errors and he considers this as an indicator of the learning process. Weick [1987] thinks that the development of an oral culture of transmission through tales, enables members of an organisation to exchange quickly all kind of experiences, good or bad and therefore increase the awareness of workers about some problems. The understanding of the activity seems vital to us in order to feed these exchanges. In a prevention logic, radiological risks cannot be separated from more classical risks, or cannot bypass the knowledge of the task itself.

5.2 – The status of skills and of rigorous improvisation

Taylorian tradition on the organisation of work separates design from execution. In this logic, on the base of knowledge issued from « hard » sciences, it would be possible to foresee, predict, in an exhaustive way, the different states in which a system can be. Most of the time these situations have been pre-defined by referring to situations called nominal, and this by underestimating situations when the system is in degraded mode and by ignoring the variations met. To the pre-defined situations engineers and managers associate regulations and prescriptions. In this context, the underlying hypothesis is that operators only have to « execute » and to strictly follow recommendations to respect safety, reliability and efficiency [Leplat, 1998].
Although recommendations and instructions are indispensable tools to regulate work, they are not enough [Llory, 1996]. Indeed, difficulties are numerous ; they can be found in implicit instructions that don't explicitly tell you what work is really expected [de Terssac, 1992]. They cannot foresee everything because of the difficulties to take into account the variability of situations and the necessary co-ordination between safety activities and production activities.

From their experience, operators are going to use skills, rigorous improvisation, catachresis, relying on strategies anticipating the unwanted events [Baumont, 1992 ; Garrigou et al., 1998 ; Clot, 1999]. Very often these rigorous improvisations are perceived by supervisors ***as something lacking seriousness or rationality*** ; they then keep back from the work. They only appear when they are caught in the wrong, for example in case of incidents or quality problems. These skills are vital, they are part of the job culture and guarantee the reliability and the quality of the operations. It seemed important to us to acknowledge these skills and to articulate them, to discuss them with the work procedures so as to enrich their content. This makes us wonder about what is being done by organisations about these skills.

The same question is raised about safety issues. Traditionally, safety experts and managers consider that most of the safety is ensured on the one hand, through the existence of a coherent and complete set of written procedures, recommendations, instructions and, on the other hand, through the strict observance of the latter by the workers [Llory & Llory, 1994]. In this logic, an efficient safety campaign implies « *repeating again and again the main risk prevention measures and reminding the staff about the appropriate behaviours* » (extracted from an APAVE promotional campaign for their new set of safety posters, in 1999). We will show that is not sufficient.
Based on studies carried out in work situations, Cru and Dejours [1983] have characterised cautiousness skills they define as attitudes, behaviours, operating methods that increase safety. Llory & Llory [1994] stresses that these cautiousness skills put into concrete form the prescribed safety requests, complete and re-inforce them : « *They are made of a set of techniques, tactics, strategies that refer to safety in work conditions* ».
Just like for the trade skills, cautiousness skills remain little known and not very accessible to the management. Sometimes it is even difficult for them to pass from one group to another.

On a more general level the question of the transmission among the teams of these trade skills, as well as cautiousness skill is raised, so as to manage, for example, the situations with strong uncertainty. Our observations have shown clearly that the nuclear world is not the ideal place to transfer experience from experts in industrial radiography to beginners since one cannot allow the slightest error. Finally the question of the organisation of initial training for controllers is raised, as well as that of their capability to adjust to real situations. Training situations, which would enable simulations based on real activity scenarios would contribute to re-organise technical knowledge and improve the development of skills *as rigorous improvisations or cautiousness skills*.
Of course, if these issues are important for nuclear industry, they are also relevant to other high-risk industries [Croft & Lefaure, 2000]. These different viewpoints will be explored in the continuation of our study.

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Photos

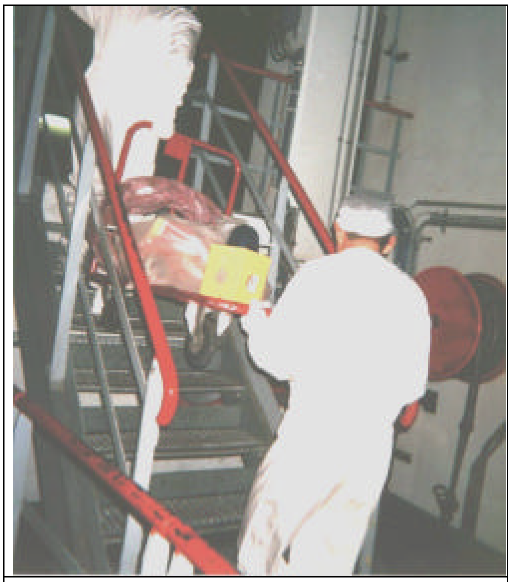

Photo n°1

Photo n°2

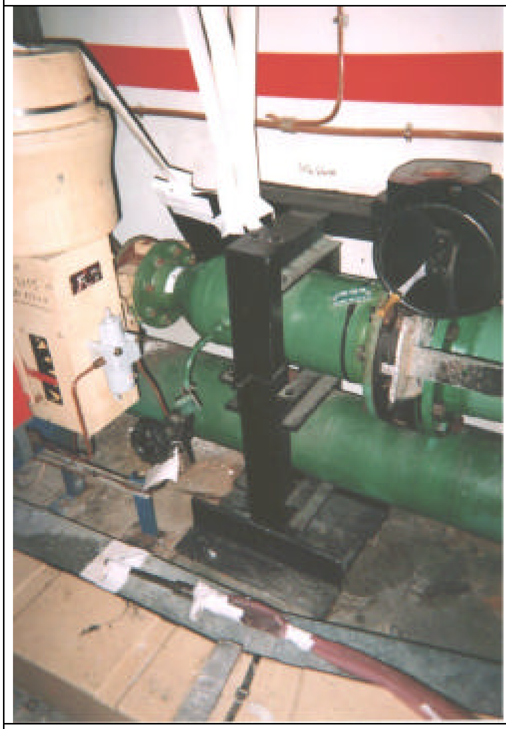

Photo n°3

Photo n°4

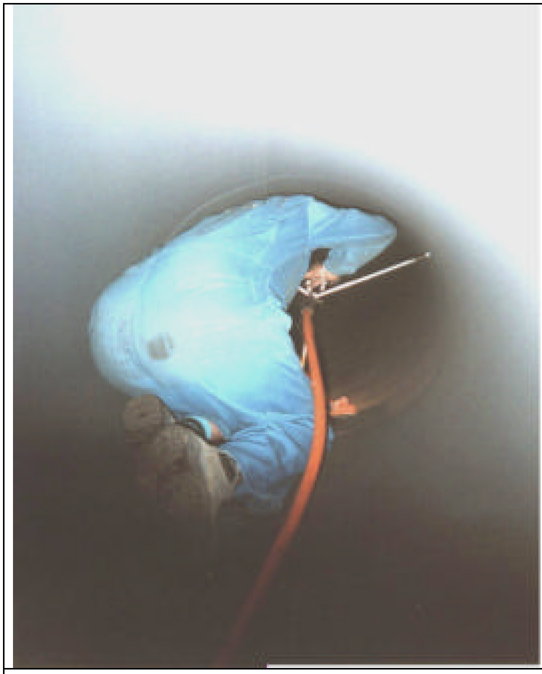
Photo n°5


Photo n°6

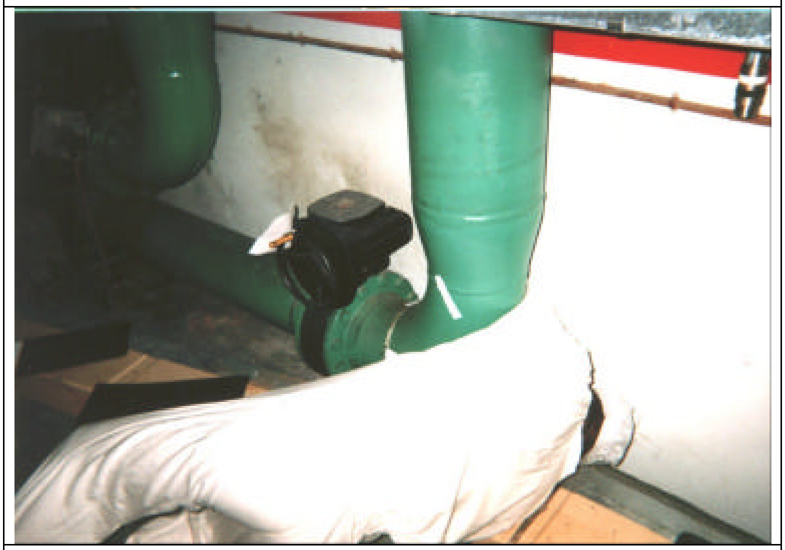
Photo n°7