New Policy for Body Contamination Control at the Tihange Nuclear Power Plant.

Report presented to the workshop
organized by ISOE/EC on 5,6,7 April 2000 in Tarragona

Report presented by Dr Thielemans and Mr. J. Fourez

Editors
CBMT: Dr Thielemans
ELECTRABEL: Messrs J. Fourez – B. Adriaens rev. 2 of 16/03/2000

New Policy for Body Contamination Control at the Tihange Nuclear Power Plant

SUMMARY

The Tihange Nuclear Power Plant goes through a performance boost.

The management of the Tihange Nuclear Power Plant has always sought to provide suitable and increasingly powerful means of radiological monitoring of the personnel working at the plant.
Especially, since the early eighties, Tihange has looked for improvement of systems checking internal and external contamination.

Two highly sensitive control devices placed at the entrance and exit points on site have enabled detection and management of contamination events much below the levels accepted elsewhere.

The Physical Control Department has recently been at the center of an R&D effort to create a new control concept: every exit of the area monitored features very thorough β *detection (both geometric and in sensitivity), associated to an equally thorough* γ *detection on the whole body.*

This concept was first used to boost detection and measurement performance regarding external contamination.
Then experience showed that systematic γ *detection at each exit of the area monitored would replace very well the internal contamination control held at the end of each work session on site.*

Through a brief historical presentation we will show how the new β - γ *gates have enabled us to push back the limitations of contamination control.*
We submit two reports validating the use of the new gates to measure internal and external contamination.
Last but not least, we will present a summary of contamination control procedures.

* * * * * * *

CHAPTER I
DETECTING CONTAMINATION AT THE TIHANGE NUCLEAR POWER PLANT

1. DETECTION PROBLEMS WITH "STANDARD" GATES

As early as 1983, the 3 Tihange nuclear plant units were fitted with standard gates manufactured in France and identical to those used by EDF: the Nardeux gates.
These gates measure total contamination by BETA emitters through proportional counters with a surface gas flow of 800 cm_. These include:

- 5 detectors covering the front of the body and 4 covering the back, placed in standard geometry (i.e. two parallel faces)
- 4 hand detectors placed in standard geometry (2 parallel faces) with grates and protective plastic sheet
- 2 foot detectors with grates and protective plastic sheet

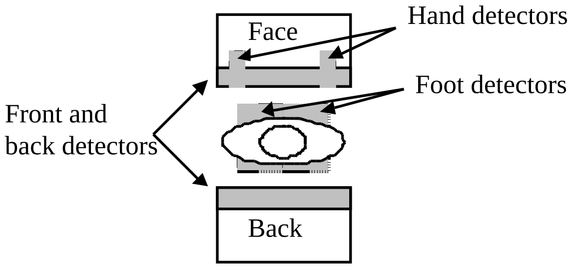
Such detectors have very good β sensitivity for the main types of energy found in PWR power plants (refer to table).

Isotope	Energy KeV	n % body (β 4 Pi)
C14 C0 60 Cl 36 Sr-Y 90	156 310 714 540 2270	2 11 16 17

Response of 4 Pi at 6 cm

However they have the following downsides:

- the position of the body between the 2 parallel faces is variable, according to body morphology and position



· the isotropic response is also variable, as it features dead angles (sides, arms, forearms, nails)

Moreover the final Quicky control, especially as regards γ radiation, still detected external contamination, highlighting an additional drawback of such gates: simply measuring β rays does not cover the measurement of all isotopes in a nuclear power plant.

Some isotopes are:
* weak β emitters, both in energy and transmission: this mainly applies to C0 58 (only 15% of transmission at 480 keV) but also partly to Co60 (only 310 keV of energy) ;
* no emitters at all: this applies to Mn54 and Cr51.

2. MEASURES AT THE TIHANGE NUCLEAR POWER PLANT

The thresholds have been set to energy levels representative of the isotope mix in nuclear power plants: Cl36 has been chosen as benchmark isotope (β radiation of 100% at 714 keV and a very long half-life).

From the very start, gate thresholds were set very low to achieve the best compromise: optimal detection with as little false alarms as possible. This procedure was very necessary indeed, as the end control at the Quicky was especially severe, as it was located outside the area monitored (lower BKG (background noise)) and fitted with γ detectors.

The thresholds have been gradually lowered through improved cloakroom configuration (gate positions, dirty linen bins, etc.). From the threshold of the old (Munchener) gates, set to a value of 1 Bq/cm_ reported to the detector surface (i.e. 800 Bq per body detector), the thresholds have been finally lowered to report to a standard surface of 100 cm_ (i.e. 100 Bq per detector and thus by a factor of 8 over several years).

Because of the increasing number of external work crews and in order to make internal contamination control more systematic at the end of each work session, an additional measuring apparatus suited to detecting both internal and external contamination, a Helgelson Quicky, was placed in the access building as early as 1981. The aim of the external contamination measuring was to enable Tihange to take into account small amounts of residual external contamination in their interpretation of internal contamination.

These devices were used both at the arrival of people on site (employees carrying contamination sustained at another site frequently arrive in Tihange), and at the end of each work session, whenever internal contamination was suspected.

Tihange personnel operated them to detect internal contamination, and after one minute's measuring, these devices showed whether the employee thus measured exceeded one of the thresholds set for the main contaminants existing on site. The thresholds had been set to 1% ALI (annual limit of intake) of the main potential contaminants, taking into account a decay of 15 days. The employees were measured with their clothes on. Whenever they measured positive, the employees concerned were referred to the medical department for isotope identification and quantitative measurement, wearing pajamas and after having taken a shower.

The Quicky systems were indeed efficient in detecting internal contamination, but they had two weaknesses:

- they had some difficulty in measuring some isotopes with sufficient efficiency, in view of the control timing at the end of the work assignment;
- the fact that employees could very well leave the site at the end of the work assignment without submitting him/herself to the contamination check. When the obligation to submit to the Quicky control was checked, it was noted that such evasion of the compulsory control procedure was not exceptional at all!

These two weaknesses showed that internal contamination control had not yet become optimal.

Therefore there was a need to look for a means of detecting external contamination that would escape the above drawbacks.

3. CONCLUSIONS OF THE TIHANGE NUCLEAR POWER PLANT STUDY

This study, launched from early 1992, led to the following conclusions:

1) keep the total β measurement for the reasons below:

- it has the best detection sensitivity (yield in the order of 20%)
- it is the least sensitive to BKG
- it enables precision pinpointing of the contaminated area
- the number of detectors can be high in view of the average unit cost

2) improve this β measurement:

- set the distance of the body in relation to the detectors
- reduce the dead angles

3) add a <u>complementary</u> γ measurement:

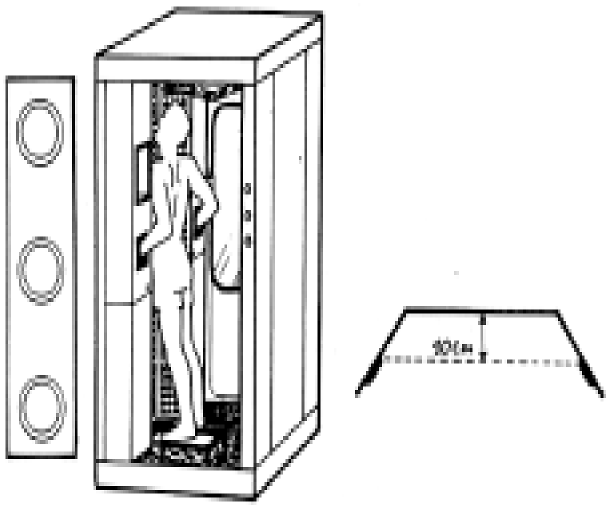
- cover the whole body (as there is detection of external contamination)
- ensure an isotropic response capable of covering the dead angles in β rays

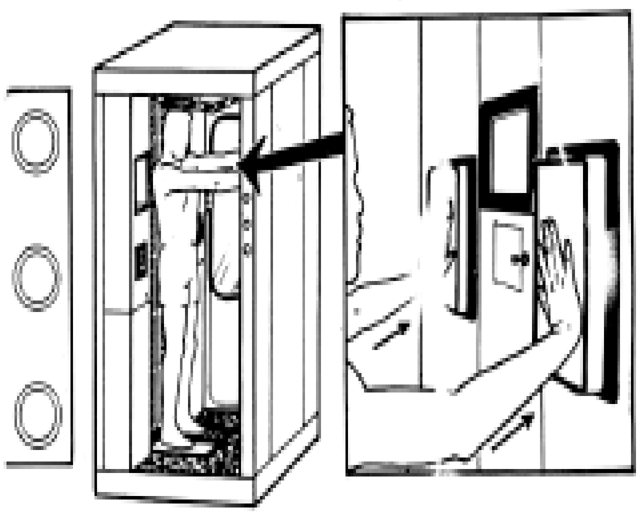
Following tests on 3 prototypes featuring a different design (1 French, 1 American et 1 British), Tihange opted for the IPM9 gate, manufactured by N.E. Technology, 20 units of which were ordered and taken into operation in the three nuclear plant units in late 1994.

4. THE IPM9 GATE FOR EXTERNAL CONTAMINATION CONTROL

4.1. Measuring Geometry

The IPM9 gate is derived from the β IPM8 gate, to which the manufacturer has added 10 γ detectors as well as lead shields. Like the IPM8 it is based on a two-stage counting requiring the employee to turn around at half-measure. This two-stage counting enables operators to set the distance of the body (a maximum of 10 cm per position sensor) in relation to the β detectors.





β **Measurement**

This is done through proportional counters with gas flow of 600 cm_ (300 x 200). This is their distribution:

- 3 x 6 body counters placed in a hexagon geometry
- 4 hand detectors placed in triangular geometry with protective plastic sheet
- 1 foot detector with protective plastic sheet
- 1 small object detector

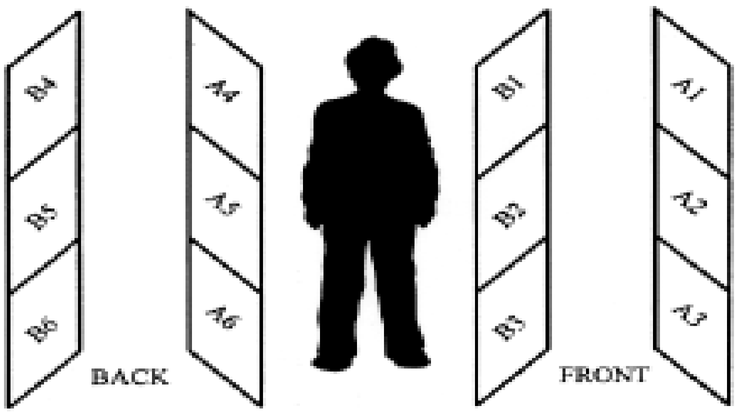
The detectors are protected by metal grates shaped as honeycombs to achieve maximum yield in β.

γ **Measurement**

This is done through plastic scintillators two inches thick and with a surface of 1800 cm_ (600 x 300). This is their distribution:

- 2 x 3 counters placed in rhombus geometry to cover the dead angles in β
- 2 hand detectors
- 1 foot detector
- 1 small object detector

Figure 6.16 – Gamma Detector Identification for Summing



4.2. Isotropic β Response

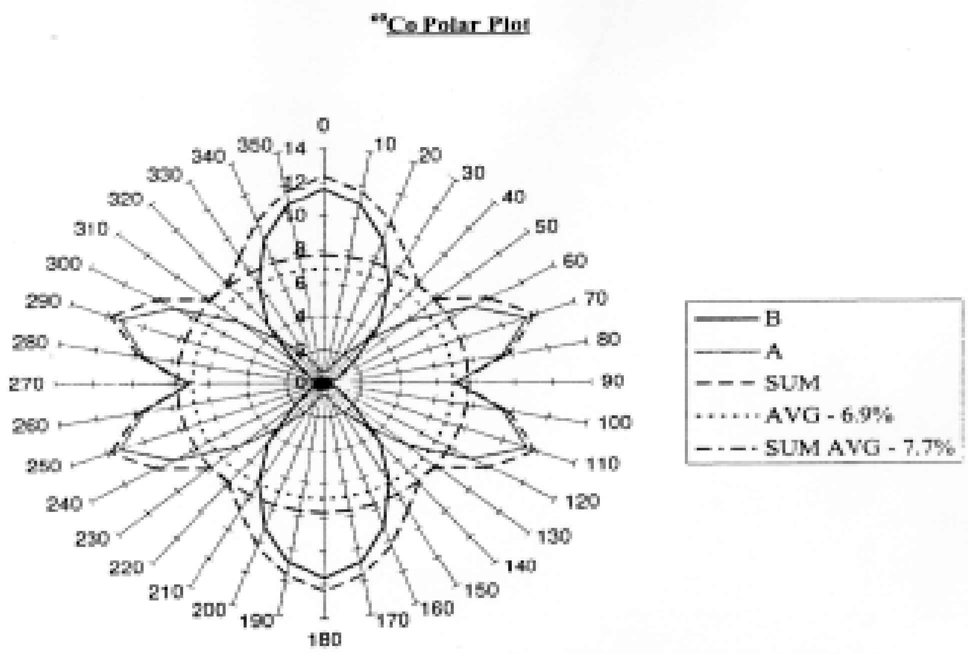
The β sensitivity of the detectors has been slightly improved.

Isotope	Energy KeV	n % body (β 4 Pi)
C14	156	2
C0 60	310	13
Cl 36	714	16
Sr-Y 90	540 2270	22

Response of 4 Pi at 5 cm

β measurement and contamination pinpointing are optimized by:

- two-stage measurement: the number of measuring channels has been doubled, i.e. there are 36 body detectors
- position sensor: the response has become more independent from position and morphology
- hexagon geometry: more constant isotropic response and reduction of dead angles (sides, arms, forearms, nails)
- adding adjacent channels: improving the “dead angle” situation



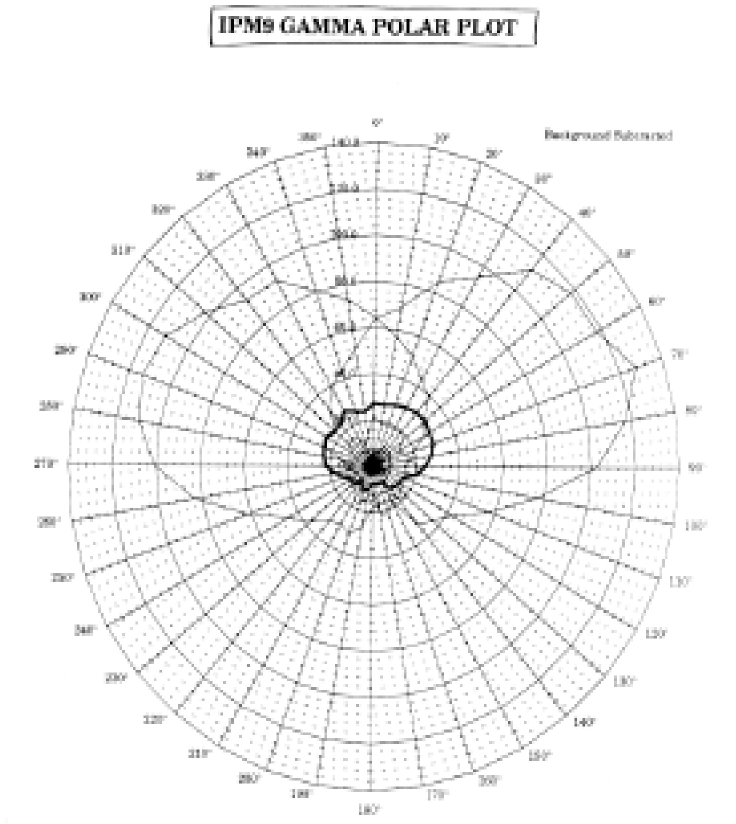
<u>Isotropic Response to γ</u>

The thick plastic scintillators have a good γ sensitivity to the main energies in PWR power plants.

Isotope	Energy KeV	N % body (γ 4 Pi)
Ba 133	356	11
Cs 137	662	7
C0 60	1173	12
	1333	

Response of 4 Pi, source placed at 5 cm of the β detectors.

The isotropic response shows the complementary cover of β geometry (the β "dead angles" are covered by a maximum γ detection). The addition of the response from the adjacent detectors also helps to reduce the "dead angles" in γ.



PS. This isotropic graph only covers a range of 180°. There should be a symmetrical replica to achieve a response over 360°.

To reduce the effect of BKG, γ detectors are wrapped into a 2 cm lead cover and the back of the gate is shielded with a 1 cm lead sheet. The gates are placed back-to-back to achieve mutual shielding and their siting should be optimized in relation to the preferential direction of the BKG (following the direction of the BR).

4.3. Thresholds and Alarms

4.3.1. Thresholds in β

The β thresholds have been mainly set to the same values as those of the Nardeux gates, i.e. 100 Bq/detector in C136 equivalent, but at 5 cm for the body.

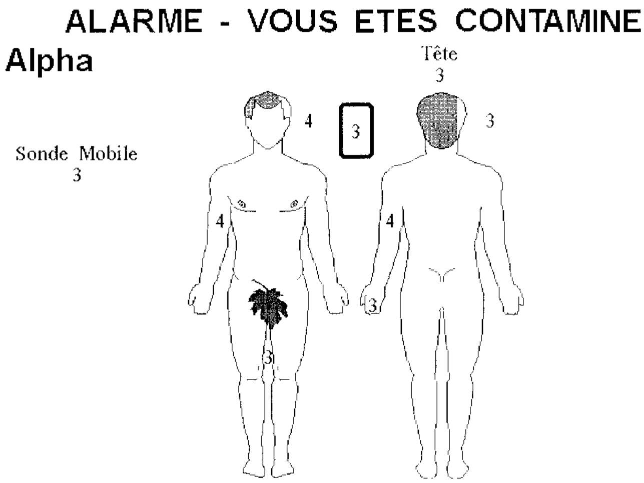
4.3.2. Thresholds in γ

The γ thresholds have been set to the predominant isotope in nuclear power stations, i.e. Co60.
They have been set to 10 Bq/cm_, i.e. 1000 Bq /detector for a reference surface of 100 cm_ (which practically equals a threshold of 141 cps).
The skin dose resulting from external contamination having this value, only involving γ rays and a typical contaminant mix for PWR plants, would have the same level as the skin dose due only to β rays.

4.3.3. Alarms

The user interface goes through a flat PC screen (color VGA).

The contaminated areas are shown in red on 2 human figures (front and back).
The number at the center of this area indicates the factor by which the threshold is exceeded.
This provides information on the efficiency of possible decontamination (refer to diagrams)



ALARM – YOU ARE CONTAMINATED

Through a keyboard and the entry of a password, the RP operator has access to the last alarm condition (display of the two figures) as well as to the measure results from each detector.

A printed report can be obtained for each control or for the positive controls only.

5. THE IPM9 GATE FOR INTERNAL CONTAMINATION CONTROL

As we have just seen the IPM9 was acquired to look for external contamination at the exit of the area monitored.

Given that these systems are fitted with γ detectors, it would seem obvious that they might detect internal contamination.

This part seeks to quantify their ability to detect internal contamination. This quantification was done on an empirical basis.

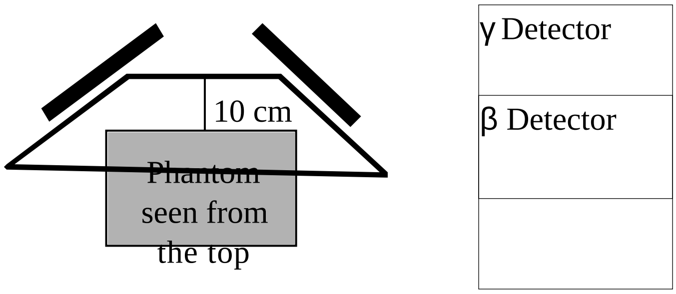
5.1. Quantifying Performance

5.1.1. Description of the Phantom

The phantom used is CANBERRA’s MC-II, made of a chunk of Plexiglas designed to simulate internal contamination, either of the thyroid (THY), either of the lungs (LUNG), or of the gastrointestinal tract (TGI), or for non clearly pinpointed internal contamination, called ”whole body” (WHOLE BODY). It is used for calibration of the ACCUSCAN anthropogammameter of the medical department.

CANBERRA has done testing to show that this phantom accurately simulates “standard’” man as understood by the ICRP (1.70 m and 70 kg).

The phantom is placed on its support, directly in the place of the user, hand and foot sensors being disabled. The phantom lies in the very center of the IPM9 at the maximum distance allowed by the body proximity sensor, i.e. 10 cm.



5.1.2. The radioactive Sources used to define the Energy Response Graph

Source Selection Criteria

Before entering into any other consideration, we should obviously see to it that all sources are γ ray emitters.

Energy is the first criterion, as it is important that the sources picked are representative of the energy types in PWR plants. According to the libraries used by the chemistry and radiological protection departments, the energy range to scan starts at 59 keV with the Am-241 and it ends at 1917 keV with the Y-93. The sources selected should therefore be distributed uniformly along this energy range.

As we want to estimate energy-related yields (see above), such sources necessarily have to be mono-energetic or have a main spectrum with limited energy width. This is our second criterion.

For greater ease and precision source half-life should not be less than a day. This is the third criterion.

Ideally the sources should have close geometries.

Moreover their diameter shall be less than 28 mm and they shall have a maximum height of 100 mm to allow their insertion into the phantom.

Their activity should be sufficient to yield enough counting statistics. We should take into account the fact that, for low energy sources, detector yields are low.

The last criterion – not the least essential for that – is that we should, if possible, seek sources available at Tihange.

In view of the above criteria, we have chosen the following radio-isotopes [14][15]: Am-241, Ce-141, Ba-133, Cs-137 and Co-60.

Historically we should note that Ce-141 was added after the first tests to obtain measuring points between Am-241 and Ba-133. Indeed, in this energy range the nature of the energy-related yield graphs is such that an additional point of measurement had to be added after the first tests.

Characteristics of the Sources used

Most sources used have a calibration certificate from DAMRI (Département des Applications et de la Métrologie des Rayonnements Ionisants, in Gif-sur-Yvette in France).

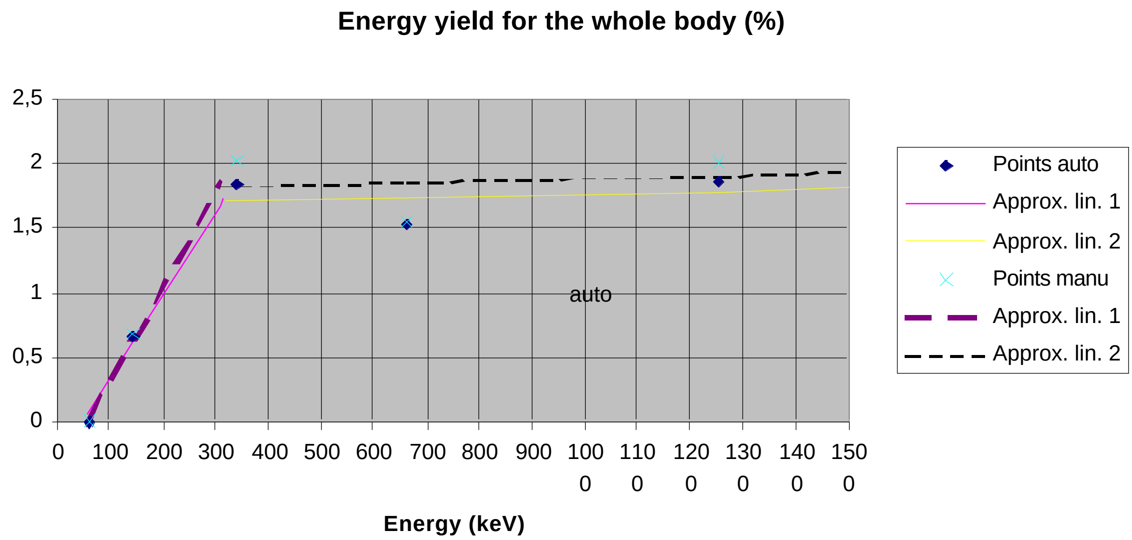
In any case the chemistry laboratory at the Tihange plant checked source purity and activity.

In order to establish the yield graph, a weighting was done to have each source represented by a single energy and a single level of emission levels. These values are listed in the table below.

Radio-isotope	Peak energy (keV)	Emission levels
Am-241	59.5	36%
Ce-141	145.4	48%
Ba-133	322.0	94%
Cs-137	661.6	85%
Co-60	1252.8	200%

On the basis of the results obtained with these sources and taking into account the conservative hypotheses set out in the next paragraph, and on the basis of manufacturer data, we have been able to determine the energy response graph.

Example of an energy-related yield graph obtained:



The straight line equations thus obtained shall be used to determine the yield for each energy and each geometry for later calculations.

5.1.3. Conservative Hypotheses

The methodology used in this paper is largely based on the principles of the nuclear industry. Indeed we have sought to pick a maximum of unfavorable hypotheses: this is the conservative method.

We have chosen the following unfavorable hypotheses.

- During the measurements, the phantom was placed as far as possible from the detectors, i.e. at the detection limit of the proximity detectors. The reduction of the radiation by air is thus at a maximum and the solid angle from which the detector sees the source is as limited as it can get.
- During the contamination checks made in automatic mode, the IPM9 adds up, two by two, all the measures from adjacent detectors to have a better picture of the sources placed just in between two detectors. This add-up system was disabled during all tests.
- For the calculation of the detectable ALI percentages, we have not added up the “hits” from the various peaks of a same isotope: we have calculated detectable ALI fragments on a peak by peak basis.
- Tests have been executed both in automatic and in manual mode. The minimum of the two yields was chosen.
- Detection limits have been estimated for the various source positions: thyroid, lungs, digestive tract and the whole body. This is the maximum alarm threshold – i.e. the yield minimum – used for comparisons with the ALI.

5.1.4. Calculation of the detectable AIL Percentages

For each peak of the isotopes of a standard library, we calculate, for each source position (thyroid, lungs, digestive tract and the whole body) the alarm threshold for the IPM9. This limit is an activity threshold above which the gate will move into alarm status. It is defined as follows:

$$\text{Alarm threshold (Bq)} = \frac{\text{IPM9 threshold (in hits per second)}}{\text{Energy - related yield} * \text{peak emission intensity}}$$

The library has been designed to include all isotopes conceivably present in contamination events, internal or external, at PWR power plants. It contains, among others, all isotopes from the standard contamination mix as defined by EDF (Electricité de France).

We remind you that the gate threshold was set at 141 cps (the external contamination threshold equal to 1000 Bq of C060).

The peak emission intensity is therefore a constant for each peak of each isotope.
The energy-related yield is obtained through linear regression equations and it is a function of energy.

For each peak four alarm thresholds are calculated for the IPM9 matching the four possible and different positions of the source.

We then choose a conservative hypothesis: we use the maximum of these four thresholds for comparison with the different ALI values, which really amounts to the minimum yields, as:

- The maximum of these four limits is compared to the various ALI values (both regarding inhalation and ingestion) of the different isotopes and for each library.
- The detection threshold can then be expressed in "ALI %" for inhalation and ingestion.

5.1.5. Capacity of the IPM9 Gate to detect internal Contamination

The Quicky recording threshold was set at 1% of ALI, which took into account an average time between two measurements (noted as T) of thirty days.

This threshold is based on the equation of ICRP 54:

$$RL = \frac{1}{10} \quad ALI \quad \frac{T}{365}$$

ICRP 54 considers that if one carries out, for instance, twelve measurements per year (monthly check), the person concerned may not receive more than a twelfth of the ALI. Measurements are to be recorded, according to ICRP 54 standards, if they exceed 10% of one twelfth of ALI and the case has to be investigated if the measurement exceeds 30% of one twelfth of ALI.

However this equation seems absurd if carried to extremes. One might infer from it that the closer the checks are to each other in time (which would further personnel safety) the lower the recording limit will be and vice-versa.

If we take a one-day interval, the recording level shall be 1/3650 of ALI!

This approach does not seem to be very sensible, as all businesses or organizations needing to monitor contamination will have an interest in extending the intervals between checks, which will allow the operation of lower performance detection systems as the thresholds will be higher then. They also have an interest in long intervals since they will thus lose less money and time in controlling, and moreover they will be able to purchase lower-cost low-performance devices.

We have decided to keep the recording threshold at 1% of ALI. It is obviously better to look for 1% of ALI at each exit from the area monitored (i.e. about four hours after the person concerned entered it) than to look for 1% of ALI at the end of the current work assignment (i.e. on average 30 days after the first entry into the said area).

In this absolutely vast library we observe that only one isotope - Ce-144 – has an IPM9 alarm threshold for internal contamination that is above 1% of ALI, whether in inhalation or ingestion.

The case of Cerium 144

This isotope, a fission product, has only been detectable during some transient operations (e.g. reactor start-up) at a concentration of about 30 MBq/t during a week.

This phenomenon can probably be explained by the fact that it enters into a solution during such transients. Indeed, once it has become soluble, it can be found either in the circuit samples or on demineralizer resins. A few days after the transient the isotope would revert to its former state of insolubility: it will then be found in circuit samples, or on filters or demineralizer resins, or anywhere in the circuits. In the latter case it would no longer be detected.

When it appears the other fission products like I-131, I-133 and Xe-133 will have respective concentrations of about 5, 40 and 50 MBq/t.

In the improbable case that somebody would solely be contaminated by Ce-144, this event would only be detectable from a threshold equal to 36% of ALI for inhalation and one of 4% of ALI for ingestion..

It is also useful to remind ourselves that even the Quicky failed to detect Ce-144.

5.1.6. Conclusions about the Detection of internal Contamination

Our aim was to establish whether IPM9 was capable of detecting internal contamination at least as well as the Quicky. **The answer is affirmative, even more so since the tests involved more than ten times the number of isotopes recorded in the Quicky library.**

5.2. Practical Validation of internal Contamination Detection

You have heard how the physical control department was able to validate theoretically the use of IPM9 gates for detecting internal contamination.

Let us also add that we wanted to check in practice whether internal contamination was really detected with enough sensitivity.
This explains why Quicky controls at the end of each work session were kept as formerly, as the Quicky system was deemed to be the only official instrument for the detection of internal contamination.

We have analyzed the measurements made with the Quicky between March 1995 (when the IMP9 gates for γ detection entered into service) and November 1997, i.e. a period including 7

unit outages, one of which was a steam generator replacement; we found that no internal contamination discovered by the Quicky had not been detected by the IPM9 systems.
During this period, the number of people who worked in the area monitored was:

- in 1995: 3518
- in 1996: 2764
- in 1997: 1915

Convinced by theoretical validation and practical experience, we decided in May 1998 to discontinue the end-of-work check carried out with the Quicky.

CHAPTER II
ORGANIZATION OF CONTAMINATION CONTROL

1. Dealing with Contamination Cases

As we have said, employees with a suspected internal contamination are immediately dealt with by the medical department.
A doctor and a nurse are on call at home, which allows round-the-clock intervention..

Initially, if external contamination beyond IPM9 thresholds persists, the nurse goes to the decontamination room (available in each unit) in an attempt to secure as thorough a decontamination as possible.
The results of the last IPM9 check are noted, including measurements in c/s, β and γ on each of the detectors, in front and back position. This information will be useful for the interpretation of the anthropogammametric measurements.

The employee then goes to the medical department, where an anthropogammametry is done. During this procedure the employee is in pajamas, as experience has shown that contaminated underwear is no exception..

The device used is an Accuscan with hyperpure germanium. The procedure is executed with the subject lying down, to allow the system to scan the whole body (routine geometry), as well as to make fixed measurements of the thyroid, the thorax or the abdomen. During the scanning process the distribution of activity in the anterior-posterior axis may assist in pinpointing the contamination.

The spectrum is analyzed by using several isotope libraries. In the exceptional cases where peaks are not identified, the energy and gross activity readings will allow a manual search. Contaminant identification enables us to interpret more finely the measurements from the detectors of β and γ rays on the IPM9.

2. Distinction between internal and external Contamination

One of the difficulties encountered is the distinction between internal contamination and residual external contamination. In cooperation with Physical Control, we use the results of the measurements recorded on the IPM9 for β and γ rays as well as a comparison between anthropogammametric measurements in prone position and in supine position in an attempt to make such distinction.
However the interpretation of anthropogammametrics remains a difficult matter during the first day(s), and subject to interpretation. The fortunately limited number of internal contamination cases has not allowed us to acquire much experience in this field.

3. Follow-up of significant internal Contamination

In the rare cases of significant internal contamination we provide regular anthropogammametric follow-up of the employee affected and we assess the dose received. To this end, we use Canberra's "CINDY" software to calculate the initial intake based on various measurements and according to three different methods, i.e. the method of the lesser squares, the ratio of averages and the slope average.

The software gives the intake values calculated through these three methods, as well as a comparison between the various measurements done and the calculated activity at these various measurement moments.

At a second stage, once we have chosen the initial intake value the software automatically calculates the committed dose as well as the dose received in one year, by using models that are generally those of ICRP. It is also possible to modify various parameters (like particle diameter, time of presence in the various compartments, the distribution between the various compartments).

4. Summary of the detected Cases of internal Contamination

Between January 1995 and November 1999, a period covering 11 unit outages, 2 of which with steam generator replacement and 1 with vessel head replacement, 25 internal contamination incidents were registered; 35 employees from Electrabel or subcontractors were detected as carriers of internal contamination.

As one might suppose the number of cases per year depends at least in part on the number and the scope of the unit outages, as evidenced by table 2.

Let us also point out that activity values indicated are gross initial measurements, where all activity measured is deemed to be due to internal contamination.

Table 2: Number of contamination incidents and employees concerned

Year	Incidents	Contaminated personnel	Number of outages
1995	10	16	3 (including 1 steam generator replacement)
1996	2	2	3
1997	3	4	1
1998	5	7	3 (including 1 steam generator replacement)
1999	5	6	1 (vessel head replacement)
TOTAL	25	35	11

Table 3 shows the frequency with which we found the various isotopes identified as well as the number of cases where they represent the isotope affecting ALI% most. We are not greatly surprised to see the front stage role played by cobalts, especially $_{60}Co$.

Table 3: Frequency of isotope detection and isotope contributing most to ALI%

Isotope	Number of cases	Maximum contribution in ALI%
$_{51}Cr$	5	0
$_{95}Zr$	3	0
$_{95}Nb$	10	1
$_{58}Co$	25	8
$_{54}Mn$	7	0
$_{60}Co$	26	23
$_{59}Fe$	1	1
$_{133}Xe$	2	1
$_{135}Xe$	2	1

Finally, when looking into the importance of the contamination incidents recorded, it is seen that the cases encountered all involve light contamination.
As we consider all measured activity as due to internal contamination and by adding up the ALI% of the various contaminants, we have found a single case where the level had moved beyond 1% of ALI (1.4% of ALI).

Table 4: ALI% (sum of the contribution of the various contaminants)

ALI%	Number of cases
<1/1000	8
1/1000 à < 3/1000	18
3/1000 à <1/100	6
>1/100	1 (1.4% of ALI)

Note: two contamination cases could not be included in this table as they were solely linked to ${}_{133}Xe$ and ${}_{135}Xe$ which have no ALI value.

* * * * * * *