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Radiological Survey of a Uranium Pilot Plant for Rebuilding Purpose

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INTRODUCTION

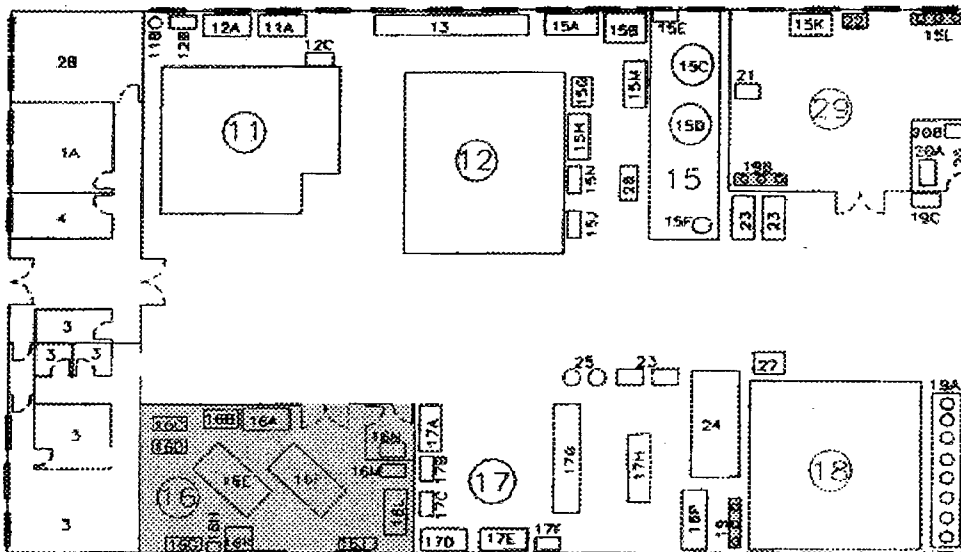
A Metallic Uranium Development Pilot Plant located at the Instituto de Pesquisas Energéticas e Nucleares (IPEN) facilities worked for several years with natural and depleted uranium casting salvage operations. Basically those operations consisted of chemical conversion of UF₄ powder into metallic uranium followed by metallurgical processes eventually obtaining metallic uranium ingots.

Changes in the process led to the necessity of rebuilding the pilot plant. For this job, it was necessary a radiological survey of the facility. This survey followed recommendations of regional radiation safety norms and regulations (CNEN 3.01) and international recommendations of ICRP 26 and Safety Series 9.

In this work survey steps will be presented, which includes workers dose rate measurements, direct and indirect surface contamination monitoring methods and air monitoring of the facility.

It was convenient to divide the plant in several sections for a better practical task. Figure below shows the plant layout:

PRODUÇÃO TECNICO CIENTÍFICA
DO IPEN
DEVOLVER NO BALCÃO DE
EMPRESTIMO



IPEN's Metallic Uranium Development Pilot Plant layout

It was selected for this work Section 16, Cutting and Pickling Laboratory, where surface contamination and dose rates values were generally higher than the others.

A general radiological survey was necessary for evaluation of essential health physics conditions before the beginning of decontamination procedures and rebuilding tasks. Decontamination procedures will not be cited here.

METHOD

Air monitoring point was chosen in agreement with worker's circulation in the area nowadays. It was studied the dispersion of nuclide particles considering inhalation risk. For sampling it was used a Millipore 0.3µ mesh filter coupled through a Eberline regulator air pump to a Emerson vacuum pump. Filter was positioned 1.70m height at point 16F. The rate of flow of the air sampling was 12.5 L/min and the period of time of collection was 3 hours.

Uranium concentration in the filter was determined by neutron activation analysis (NAA). Sample and uranium standard were irradiated for 2 minutes at IPEN's IEA-R1m reactor at a neutrons flux of 10¹¹ n.cm⁻².s⁻¹. After 1 minute decaying, gamma induced activity from ²³⁹U was measured by hyperpure germanium Canberra

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GX 20202 detector using VISPECT2 computer program for data processing.

Equivalent dose rate was measured using a portable Geiger-Müller detector, IPEN, PI 760 model considering worker as reference.

Surface contamination was evaluated by direct and indirect methods. A portable Geiger-Müller pancake type, Prólogo PSN 7013 model and a Ludlum 14C scintillation monitors were used for direct monitoring.

For indirect method, dry smear test was applied by wiping 5 cm diameter paper discs into a 100cm² surface area. A scintillation counter Eberline SAC 4 was used for α and a Geiger-Müller pancake counter Eberline BC 4 for β counting.

It was taken a sample from the drain of the facility for radionuclide identification. Sample were measured using hyperpure germanium Eurisys EGNC 25-190-R detector by a period of 12 hours and it was used a VISPECT2 computer program for data processing.

RESULTS AND DISCUSSION

It was identified ²³⁴Th and ²³⁵U radionuclides, by gamma-ray spectrometry thus indicating the presence of ²³⁸U and small amounts of ²³⁵U (1,2). So, contamination is basically due to uranium compounds.

Uranium concentration determined in 2.256 m³ sampled air by NAA was 0.145 ± 0.002 µg. Taking into account that it was found basically ²³⁸U, total uranium activity was calculated using following equation:

$$A = \frac{m(\ln 2)N_A}{t_{1/2}M}$$

where:

A = activity in Bq

m = uranium concentration in grams

N_A = Avogadro's number, 6.02 X 10²³ atoms.mol⁻¹

$t_{1/2}$ = half life of ²³⁸U, 4.468 X 10⁹ years

M = molar mass of uranium, 238 g.mol⁻¹

Activity calculated was 1.8 mBq and considering air volume sampled, uranium total activity was 8 X 10⁻⁴ Bq.m⁻³. Derived air concentration limit (DAC) is 7 X 10⁻¹ Bq.m⁻³ for ²³⁸U nuclide in the more restrictive form (UO₂, U₃O₈) (3), as uranium concentration dispersed in air is about a thousand times lower than the most restrictive DAC, no special respiratory protective gears are necessary although care should be taken to prevent loose contamination dispersion during decontamination tasks.

Dose rate measurements were taken considering workers' exposure during decontamination tasks including devices transfer. Following tables show dose rate measurements at several points taken in section 16 (16, 16A and 16P).

Cutting and Pickling Laboratory

Point 16	Description	Surface	Dose rate ($\mu\text{Sv/h}$)
A	Bench	Wood, iron (porous)	0.4
B	Fume hood	Fiberglass, brick (porous)	2.0
C	Power saw 17"	Carbon steel (smooth)	20.0
D	Power saw 17"	Carbon steel (smooth)	30.0
E	Power-lathe	Carbon steel (smooth)	2.0
F	Power-lathe	Carbon steel (smooth)	2.0
G	Glove-box	Iron, Lucite (smooth)	0.3
H	Plane	Carbon steel (smooth)	0.5
I	Grinder	Steel (smooth)	BG
J	Inside cutter disk	Steel, Lucite (smooth)	60.0
K	Bench	Iron, wood	0.4
L	Cupboard	Painted steel (smooth)	BG
M	Cupboard	Painted steel (smooth)	BG
N	Power saw 21"	Carbon steel (smooth)	10.0
O	Entrance floor	Concrete (porous)	BG
P	Floor next power lathe	Concrete (porous)	BG
Q	Floor next power lathe	Concrete (porous)	BG
Point 16	Description	Surface	Dose rate ($\mu\text{Sv/h}$)
R	Floor next power saw	Concrete (porous)	BG
S	Drain next power saw	Concrete (porous)	15.0
T	Drain next grinder	Concrete (porous)	20.0
U	Floor next bench	Concrete (porous)	20.0
V	Glove-box floor	Concrete (porous)	BG
X	Clean washroom's floor	Concrete (porous)	BG
Z	Clean washroom's cupboard	Concrete (porous)	BG

Walls

Point 16A	Description	Surface	Dose rate ($\mu\text{Sv/h}$)
A	Entrance (next the door)	Concrete (porous)	2.0
B	Bench (next the window)	Concrete (porous)	2.0
C	Fume hood (next the window)	Concrete (porous)	2.0
D	Power saw	Concrete (porous)	2.0
E	Power saw	Concrete (porous)	2.0
F	Drain	Concrete (porous)	2.0
G	Glove-box	Concrete (porous)	2.0
H	Plane	Concrete (porous)	2.0
I		Concrete (porous)	2.0
J	Bench	Concrete (porous)	2.0
K	Cupboard	Concrete (porous)	2.0
L	Drain	Concrete (porous)	2.0
M	Clean washroom's door	Concrete (porous)	2.0
N	Clean washroom's cupboard	Concrete (porous)	2.0
O	Cutter disk	Concrete (porous)	2.0

Power saw 21"

Point 16P	Description	Surface	Dose rate (μSv/h)
A	Body	Painted steel (smooth)	BG
B	Bench	Painted steel (smooth)	0.4
C	Engine	Painted iron (smooth)	0.4
D	Power saw's front floor	Concrete (porous)	0.4
E	Engine's back floor	Concrete (porous)	0.4
F	Power saw's back floor	Concrete (porous)	0.4
G	Drain's wall	Concrete (porous)	0.6
H	Drain's	Concrete (porous)	0.4
I	Engine's cover	Painted iron (smooth)	0.3

It can be observed that dose rate measurements varies from 0.2 μSv/h (background - BG) up to 60.0 μSv/h. Each decontamination step will not take all day long, all month for one worker so, by the values measured and, attending the CNEN NE 3.01 recommendations, no restriction measures are required concerning time of exposure.

Usually, from a practical point of view the first thing to be done for direct monitoring of large areas, is to determine points which counting readings are high, using for this a pancake monitor (4). After this, a scintillation monitor can be used at specific points for activity determination. Direct monitoring superficial activity values calculated from PSN 7013 readings considered β and γ emissions while for Ludlum 14C readings, α emissions. Superficial activity values for direct monitoring were calculated using following equation (5):

$$A_s = \frac{N - N_0}{E_i \cdot E_s \cdot W \cdot 60}$$

where:

A_s = superficial activity in Bq.cm²

N = instrument reading in cpm

N_0 = background reading in cpm, PSN 7013 - 150; Ludlum 14 C - 0

E_i = instrument efficiency, PSN 7013 - 0.32; Ludlum 14 C - 0.13

E_s = source emission efficiency, PSN 7013 - 0.5; Ludlum 14 C - 0.25

W = detector area, PSN 7013 - 15.5 cm²; Ludlum 14 C - 81 cm²

Minimum detectable activity can be calculated using following equation (6):

$$MDA = \frac{2.71 + 4.65\sqrt{BG}}{E_i \cdot E_s}$$

where:

MDA = Minimum detectable activity in dpm

BG = background counting in cpm

Superficial activity calculated values for points 16, 16A and 16P are shown in the following tables:

Cutting and Pickling Laboratory

Point 16	A_s (Bq.cm ⁻²) PSN 7013 (β, γ)	A_s (Bq.cm ⁻²) Ludlum 14C (α)	Point 16	A_s (Bq.cm ⁻²) PSN 7013 (β, γ)	A_s (Bq.cm ⁻²) Ludlum 14C (α)
A	27.51	1.27	M	18.03	2.53
B	62.3	5.70	N	315.3	23.42
C	188.80	12.66	O	< MDA	0.16
D	220.43	13.93	P	2.85	0.13
E	68.63	6.33	Q	2.85	0.13
F	93.93	7.60	R	62.30	3.80
G	11.70	3.17	S	62.30	4.43
H	8.54	2.53	T	125.55	6.33
I	43.33	1.90	U	125.55	6.33
J	315.30	24.06	V	5.38	0.13
K	9.17	2.53	X	< MDA	< MDA
L	< MDA	0.13	Z	< MDA	< MDA

Walls

Point 16A	A_s (Bq.cm ⁻²) PSN 7013 (β, γ)	A_s (Bq.cm ⁻²) Ludlum 14C (α)	Point 16A	A_s (Bq.cm ⁻²) PSN 7013 (β, γ)	A_s (Bq.cm ⁻²) Ludlum 14C (α)
A	< MDA	< MDA	I	< MDA	< MDA
B	< MDA	< MDA	J	< MDA	< MDA
C	< MDA	< MDA	K	< MDA	< MDA
D	< MDA	< MDA	L	< MDA	< MDA
E	< MDA	< MDA	M	< MDA	< MDA
F	< MDA	< MDA	N	< MDA	< MDA
G	< MDA	< MDA	O	< MDA	< MDA
H	< MDA	< MDA			

Power saw 21"

Point 16P	A_s (Bq.cm ⁻²) PSN 7013 (β, γ)	A_s (Bq.cm ⁻²) Ludlum 14C (α)	Point 16P	A_s (Bq.cm ⁻²) PSN 7013 (β, γ)	A_s (Bq.cm ⁻²) Ludlum 14C (α)
A	6.64	0.22	F	62.30	2.53
B	252.05	12.66	G	49.65	1.27
C	62.30	3.80	H	252.05	12.66
D	315.30	15.83	I	43.33	2.34
E	62.30	3.17			

$MDA_{PSN 7013} = 1.55Bq$; $MDA_{Ludlum 14C} = 0.09 Bq$

As a Geiger-Müller monitor, PSN 7013 contamination values are higher than Ludlum's scintillation monitor due to its capability for detecting β , γ and α emissions without distinguishing them, while Ludlum can detect only α emissions, without any external influence at that point of measurement. Otherwise Ruesink and others (7) have used beta/gamma emissions to evaluate the levels attained by their decontamination task, only superficial activity values by Ludlum's measure will be considered here. They also used radiological control limits considering porosity of the surfaces. Attending CNEN 3.01 recommendations the kind of surface will not be considered here to limit contamination levels. It can be observed that all values are below contamination derived limit for restrict areas (30 Bq.cm⁻²). Maximum activity per square centimeter from direct method of surface contamination monitoring, considering alpha emission, was 24 Bq.

As direct monitoring can not distinguish removable from fixed contamination, wipe tests were made at

the same points. Superficial activity from indirect monitoring was calculated using following equation:

$$A_{st} = \frac{N - N_0}{E_i \cdot E_s \cdot 60} \times \frac{F}{S}$$

where:

A_{st} = superficial activity from indirect monitoring in Bq.cm²

N = instrument reading in cpm

N_0 = background reading in cpm,

E_i = instrument efficiency, SAC 4 - 0.84; BC 4 - 0.52

E_s = source emission efficiency, SAC 4 - 0.25; BC 4 - 0.5

F = removing factor, 10%

S = wiped area, 100 cm²

Following tables show superficial activity from indirect monitoring:

Cutting and Pickling Laboratory

Point 16	A_{st} (Bq.cm ⁻²) SAC 4 (α)	A_{st} (Bq.cm ⁻²) BC 4 (β)	Point 16	A_{st} (Bq.cm ⁻²) SAC 4 (α)	A_{st} (Bq.cm ⁻²) BC 4 (β)
A	0.77	0.65	M	0.87	1.75
B	0.11	< MDA	N	11.0	44.10
C	9.65	35.8	O	0.06	< MDA
D	7.19	30.4	P	0.15	< MDA
E	6.33	74.8	Q	0.10	< MDA
F	5.22	26.2	R	0.60	< MDA
G	2.01	2.88	S	0.48	0.94
H	0.22	< MDA	T	3.16	8.74
I	0.54	< MDA	U	7.40	20.50
J	16.2	22.9	V	0.31	< MDA
K	0.72	2.37	X	0.10	< MDA
L	0.13	< MDA	Z	0.05	< MDA

Walls

Point 16A	A_{st} (Bq.cm ⁻²) SAC 4 (α)	A_{st} (Bq.cm ⁻²) BC 4 (β)	Point 16A	A_{st} (Bq.cm ⁻²) SAC 4 (α)	A_{st} (Bq.cm ⁻²) BC 4 (β)
A	0.08	< MDA	I	0.07	< MDA
B	0.05	< MDA	J	0.02	< MDA
C	0.24	< MDA	K	0.29	< MDA
D	0.13	< MDA	L	0.29	0.84
E	0.17	< MDA	M	0.03	< MDA
F	0.28	< MDA	N	0.03	< MDA
G	0.15	< MDA	O	0.05	< MDA
H	0.15	< MDA			

Power saw 21"

Point 16P	A_{s1} (Bq.cm ⁻²) SAC 4 (α)	A_{s2} (Bq.cm ⁻²) BC 4 (β)	Point 16P	A_{s1} (Bq.cm ⁻²) SAC 4 (α)	A_{s2} (Bq.cm ⁻²) BC 4 (β)
A	3.45	12.7	F	4.13	44.5
B	14.6	42.0	G	0.90	2.96
C	2.23	8.36	H	3.08	4.45
D	1.81	2.97	I	1.76	4.23
E	1.32	3.63			

$MDA_{SAC4} = 0.01$ Bq; $MDA_{BC4} = 0.59$ Bq

As already mentioned, BC-4 counter is a pancake type so, not only β emission can be count but, γ and α emissions too. Thus, calculated values of activity are higher than calculated readings from SAC-4's. Activities calculated from SAC-4 counting are the ones those will be considered as removable contamination. By indirect method of surface contamination evaluation, maximum value is 16.0 Bq/cm². Surface contamination values were not the same for direct and indirect methods, showing that most of contamination is fixed.

CONCLUSION

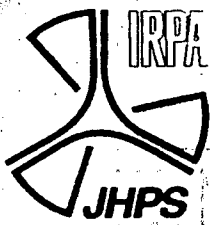
It was noted from this radiological survey that even though health physics restriction measures had been adopted, a low level and widespread contamination eventually occurred through all over the restricted area of the facility. Health physics conditions for the workers during decontamination processes must be directed considering that the contaminants are uranium compounds. Although the concentration in air is low, loose contamination is present, so care should be taken to avoid intakes during the tasks. Only in a few points dose rates values measured are above derived limits, so health physics measures that will be adopted includes the use of personal dosimeters and a very simple protective clothing, like overalls, protective gloves, caps and shoe covers. In some decontamination tasks however, when risk of spills occurs, then protective glasses and appropriate masks and filters will be required.

All procedures for local decontamination must be planned previously, taking into account the variety of contaminated materials at the site and the facts already mentioned. After decontamination tasks, another survey should be performed to evaluate if some points still need to be decontaminated more deeply taking into account the health physics principles, after that, the facility will be ready for rebuilding tasks.

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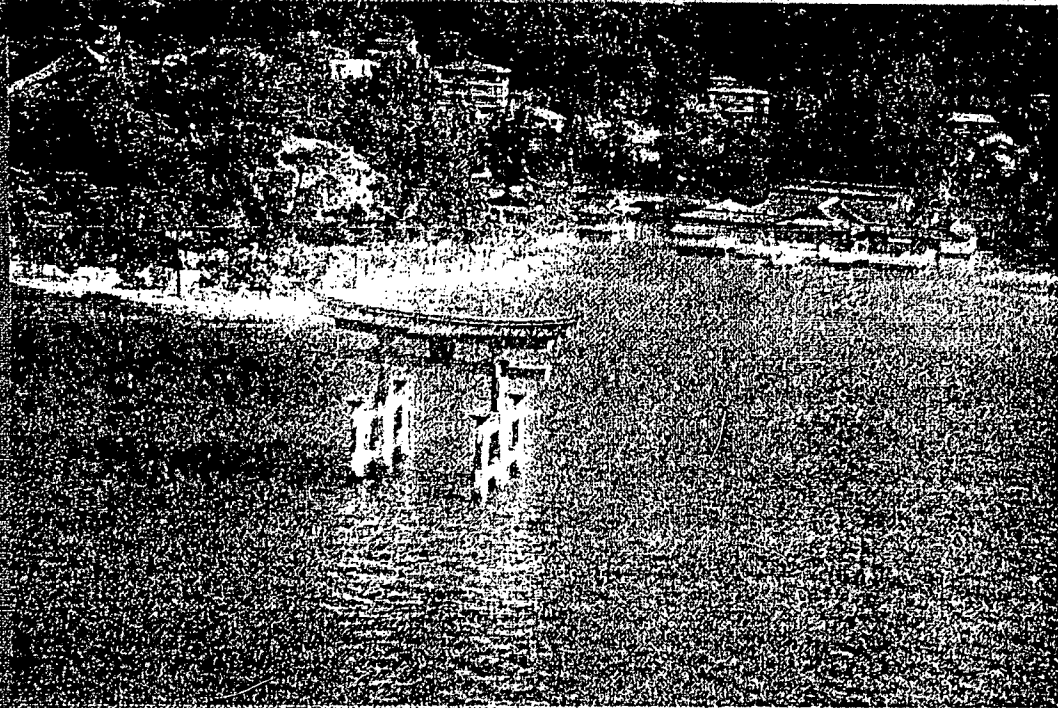


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