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Atmospheric Dispersion of Radionuclides Originating from Hypothetical Accidents and Normal Operation in Research Reactors and Medical Production Facilities

▪ Alessi M., INVAP S.E., S.C. de Bariloche, Argentina

malessi@invap.com.ar

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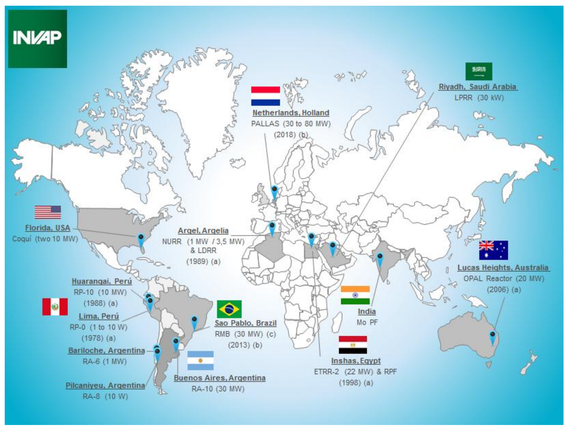
1. Abstract

Analytical and Commercial Atmospheric Transport Models (ATMs) are used at **INVAP** as an efficient tool for the design and optimization of Research Reactors, Medical Production Facilities (MIPF) and Fuel Elements Manufacturing Plants, already in operation in different countries.
INVAP has relevant experience related to the atmosphere radionuclide emission, monitoring and mitigation, at each stage of the design of nuclear facilities.
In this work, results of emission and dose in normal operation and different examples of hypothetical accidents, for Research Reactors and MIPFs, are presented. Mainly, the different contributions of the xenon released to the atmosphere are analyzed.

2. INVAP Experience

In Nuclear Technology, INVAP has earned relevant place among those international companies that supply nuclear projects such as the following:

- Multi-purpose (research) nuclear reactors.
- Medical Isotope Production Systems (MIPs): Facilities for the production, handling, and fractioning of radiopharmaceuticals and other labeled compounds.
- Equipment for the fabrication of fuel elements.
- Facilities for the safe dry storage of spent fuel elements.
- Equipment and services for Nuclear Power Plants.



INVAP in the Nuclear Scenario. (a) Date of reactor criticality. (b) Date of signing the contract. (c) INVAP will provide detailed engineering for the construction of a nuclear research reactor.

Huarangai, Perú
RP-10 (10 MW)

Lima, Perú
RP-0 (1 to 10 W)

Bariloche, Argentina
RA-6 (1 MW)

Pilcaniyeu, Argentina
RA-8 (10 W)

Coquí Radiopharma, Florida, USA

LPRR, Riyadh , Saudi Arabia

Ra-10, Buenos Aires, Argentina

OPAL Reactor, Lucas Heights, Australia

Inshas, Egypt
ETRR-2 (22 MW) & RPF

3. Safety Reports Analysis

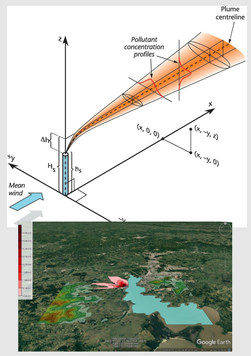
Framework (Regulatory Acceptance Criteria)

Safety Analysis

- Study of relevant systems/process, followed by failure probability analysis.
- Design (air systems, filters, points of release, stack dimensions, inventory).
- Site Conditions, (buildings, forestation, geographic's parameters), meteorological conditions (winds, climate, rain, etc), food production .
- Populations: distributions, habits, critical group.

Concentration Models

- Analytical Models



ATM: Gaussian Dispersion Models

Normal Operation

- Analytical Models
- Crom (Codigo de Criba para evaluaciÓn de iMpacto, CIEMAT Madrid)
- PC-CREAM (PC. Consequences of Releases to the Environment Assessment Methodology PHE)

Accidental Scenarios

- Analytical Models
- HotSpot (Health Physics Codes for the NARAC)
- Calpuff (Puff Air Dispersion Model EPA)
- RASCAL (Radiological Assessment Systems for Consequence Analysis NRC)

Dose Models

- Including: cloud-shine, inhalation, and deposition.

PC-CREAM
HotSpot
CALPUFF View™ Puff Air Dispersion Model
RASCAL

4. Research Reactors

Study Case: Research Reactor 3.5 MW

In Normal Operation, Ar-41 is the principal radionuclide released to the atmosphere with a release rate of:

5.83 E+04 Bq/s.

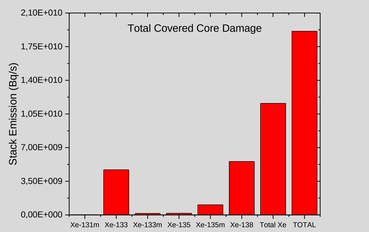
Examples of the hypothetical accidental scenarios:

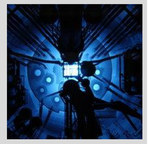
- ***Total Core Damage (covered):*** with the reactor in normal operation (at power of 3.5 MW), this scenario considers the occurrence of an initiating event followed by multiple failures in the safety systems, such that the end state could be up to 100% of core melted under water.
- ***Total Core Damage (uncovered):*** In this case the model describes fusion of 100 % of uncovered core. This accident is produced when the reactor is in normal operation.
- ***Cask fall (Partial Core Damage):*** This accident occurs during the maneuver that is done to move the cask for irradiated elements. The cask has an approximate weight of 3 tn and when it is moved over the reactor pool it may fall over the core causing its mechanical damage.
- ***Partial Core Damage (covered):*** This accident has been modeled within the context of a seismic initiating event followed by: (i) a seismically induced failure of the anchorage of small components located inside the reactor pool or, (ii) a structural failure of the reactor building causing debris to fall in the pool.
- ***Molybdenum Plates Fusion:*** This scenario is considered as a possible outcome of a human error during handling of irradiated targets and the fusion in air of up to eight irradiated Mo-99 plates is considered.

4.1 Results

- Total Core Damage (covered and uncovered) (21 Fuel Assembly, 6 operations days + 1 stop day):

Xenon Contribution	Total Core Damage (covered) (decay 1 min)	Total Core Damage (uncovered) (decay 1 min)
	Stack Emission (Bq/s)	Stack Emission (Bq/s)
Xe-131m	2.17 E+07	1.09 E+09
Xe-133	4.69 E+09	2.34 E+11
Xe-133m	1.54 E+08	7.71 E+09
Xe-135	1.74 E+08	8.68 E+09
Xe-135m	1.05 E+09	5.25 E+10
Xe-138	5.55 E+09	2.78 E+11
Total Xe	**1.16 E+10 (61%)**	**5.82 E+11 (61 %)**
TOTAL (all radionuclides)	**1.91E+10**	**9.62E+11**





Core Research Reactor

- Cask fall, Partial Core Damage and Molybdenum Plates Fusion

Typical Accidental Scenarios	Xenon Release Rate (Bq/s)	Total (all radionuclides) (Bq/s)
Cask fall (35 % core damage) (decay 7 hs)	2.49 E+09	2.49 E+09
Partial core damage (covered) (1FA STd - 19 plates)	5.69 E+08	9.25 E+08
Molybdenum Plates Fusion (8 plates - decay 60 min)	2.51 E+09	5.48 E+09

5. MIPs

Study Case: Medical Production Facility 1000 Ci per week

In Normal Operation, xenon emission is:

Radionuclide	Emission [Bq s^{-1}] (per process - 6 hs)	Activity (Ci)
Xe-133	3.43 E+07	20
Xe-135	7.71 E+07	45

Maximum Annual Dose to the public: 0.2 mSv per year.
Dose Limit: 1 mSv.

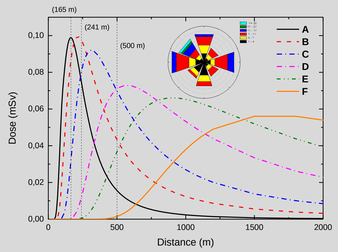
Dissolution Cell

Examples of one hypothetical accidental scenarios:

- ***Dissolver Breakage in Molybdenum Dissolution Cell***

Radionuclide	Release Fraction in air (%)
Noble Gases (Kr, Xe)	100
Iodine / Bromine	1
Aerosols (Cs, Rb, Ru, Sb, Sr, y Te)	0.02

Radionuclide	Activity (Bq)
Xe131M	6.77 E+11
Xe133	3.21 E+13
Xe133M	1.59 E+12
Xe135	2.61 E+13
Xe135M	3.35 E+12



Contributions	Maximum Dose (Case A) (to 165 m) Dose (mSv)
Total	9.89 E-02
Gases Nobles (emission 100 %)	9.77 E-02
Iodine y Bromine (emission 1%)	1.06 E-03
Aerosols (emission 0.02 %)	1.42 E-04

Dose to the public, as a function of the distance from the release point (wind rose 1 to 22 Kt).
A to F Pasquill atmospheric condition (full inventory), in this case, the Dose limit is 5 mSv.

6. Observations

- For all the study case, in a research reactor of 3.5 MW and MIPs (1000 Ci per week), the WOSMIP limit of 5 E+09 Bq/day is exceeded.
- But from Safety point of view, public Doses are below the regulatory limits.

Disclaimer: The views expressed on this poster are those of the author and do not necessarily reflect the view of the CTBTO