Operational indications and self-assessment checklist for internal audits in cyclotron facilities – an Italian experience

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Abstract. In this work the authors intend to provide useful operational indications to approach, with the best practice, the design of a cyclotron facility for the production of PET radioisotopes. Special attention is devoted to organizational and safety aspects. In order to prompt toward a systematic application of the proposed indications, the article presents them in form of a specific self-assessment checklist, consisting in a list of items which address the design process in all the different phases. This checklist represents a useful toolbox both in the design stage and subsequently for the development of internal audits.

KEYWORDS: nuclear medicine; occupational safety; radiation protection; radiopharmaceutical.

INTRODUCTION

Nowadays the use of radionuclides in the health sector is increasingly widespread in nuclear medicine applications, or in activities concerning the manufacture and use of radioactive sources for preparing radiopharmaceutical products.
The radioisotopes used in the imaging technique positron emission tomography (PET) are mainly produced artificially through the use of cyclotrons.
Handling, storage and disposal of unsealed radioactive substances can expose workers to a risk of both external radiation, which is the prevalent exposure pathway, and internal contamination. Therefore, the design of these environments requires features and equipment that minimize the risks from ionizing radiation and contamination of workers, work environment and equipment, as well as the dispersion of radioactive substances outside the facility, ensuring the protection of the population.
For this purpose, in the design stage it is essential to meet technical and organizational requirements, such as:

- careful organization of accesses and routes;
- correct spatial arrangement and organization of premises;
- adequate choice of coatings;
- appropriate ventilation system;
- use of special equipment, shielding and monitoring systems;
- adequate management and storage of solid and liquid waste and gaseous effluents;
- working procedures for activities involving risks from ionizing radiation.

In the later stages of the facility's life, a systematic evaluation of the compliance with these requirements is necessary to ensure a continuous quality improvement; this can be achieved through internal audits, which are useful to check the safety of activities carried out and to identify any necessary corrective actions [1].
Directive 2013/59/Euratom [2], which lays down basic safety standards for the protection against ionizing radiation, establishes clinical audit as "a systematic examination or review of medical radiological procedures which seeks to improve the quality and outcome of patient care through structured review". Since the use of ionizing radiation in medical facilities often favors promiscuous risk scenarios, in which the source that emits ionizing radiation could imply exposure of both the patient and the operator, internal audits can be useful also for occupational health and safety purposes.
In Italy a comprehensive guide for designing facilities where unsealed sources are handled has been issued in collaboration with one of the national regulatory authorities. In this document indications are provided to fulfill the national and international regulations and to guarantee workers' safety [3]. An accurate analysis of regulatory provisions and standards for good practice applicable in the field has been carried out in the paper "Review of operational indications on the design of facilities for radiopharmaceutical manufacturing in Italy" [4].

In order to prompt toward a systematic application of the proposed indications, making them a comparison model that can be easily consulted and used by the facilities concerned for internal audits, this article presents a specific self-assessment checklist for cyclotron facilities, consisting in a list of different sequential items.
The approach followed in the elaboration of the form includes a list of key points and four levels of applicability for every single indication. This checklist represents a useful toolbox to proceed, through a guided "audit" style, in the comparison between the design criteria possibly followed by a cyclotron facility and the "expected" ones, suggested from the technical document mentioned above, with the final goal of stimulating quality control and improvement of the adopted radiation protection strategy.

REFERENCES

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CYCLOTRON UNIT

M = MANDATORY
A = ADVISED
R = RECOMMENDED
E = EVALUATE IF NECESSARY ON THE BASIS OF THE CONSIDERATIONS OF THE RADIATION PROTECTION EXPERT AND THE ORGANIZATION OF THE ACTIVITIES

ROUTES FOR PERSONNEL / PATIENTS / RADIOACTIVE MATERIAL

PERSONNEL ROUTES			
M	Regulated and controlled access	**YES**	**NO**
M	Exit through a "filtering" area (personnel airlock)	**YES**	**NO**
HANDLING OF RADIOACTIVE MATERIAL			
A	Dedicated entrance/exit, with the minimal route from the radiopharmacy	**YES**	**NO**
M	Automated target-positioning system *otherwise* coding of specific procedure for the positioning of the solid target	**YES**	**NO**
M	Presence of shielded underground transfer lines for radionuclides from the cyclotron to the synthesis modules *otherwise* coding of specific procedure for manual transport in the case of solid targets	**YES**	**NO**
E	Possible lift for the transport of radionuclides produced by the cyclotron in solid form towards the radiopharmacy	**YES**	**NO**
HANDLING OF RADIOACTIVE WASTE			
A	Identification of short routes in low attendance area and times to minimize exposure of workers and population (coding of procedure)	**YES**	**NO**

MINIMUM REQUIREMENT OF PREMISES

COLD AREA **Areas and premises not susceptible to contamination**			
M	"Cold" changing rooms for staff adjacent to the filtering area (separation of man / woman or, alternatively, procedures and systems that guarantee privacy; equipped with lockers)	**YES**	**NO**
FILTERING AREA (PERSONNEL AIRLOCK) **Area that must be provided before accessing (or leaving) the areas with risk of contamination**			
M	"Hot" changing rooms for staff (equipped with lockers for work clothes and drums for the collection of contaminated clothing) (separation of man / woman or, alternatively, procedures and systems that guarantee privacy)	**YES**	**NO**
M	Area equipped for any decontamination operations	**YES**	**NO**
HOT AREA **Areas and premises where there is a risk of external exposure and contamination**			
M	Cyclotron vault	**YES**	**NO**
M	Utility room for the cyclotron (heat exchanger, electronics, etc.)	**YES**	**NO**
M	Control room for the cyclotron	**YES**	**NO**
A	Dedicated toilets	**YES**	**NO**

E	Temporary storage of radioactive waste (solid waste)	**YES**	**NO**
E	Temporary storage of radioactive waste (liquid waste tanks and dedicated measuring system)	**YES**	**NO**
M	Janitorial room (including decontamination supplies)	**YES**	**NO**
E	Radiopharmacy laboratory	**YES**	**NO**
E	Quality Control laboratory	**YES**	**NO**
E	Packing room for all finished products that must be prepared for shipping	**YES**	**NO**
E	Room where the products can be stored for subsequent use within the facility or for marketing	**YES**	**NO**
E	Shipping room with regulated access for external operators	**YES**	**NO**

CHARACTERISTICS AND REQUIREMENTS OF PREMISES AND SYSTEMS

	WALLS AND SURFACES		
M	The floor of the work spaces must be made of smooth material, without interstices, roughness or imperfections that can trap the contaminant, resistant to corrosion by any chemical agents used, waterproof and, as far as possible, without interruption	**YES**	**NO**
A	Coding of a procedure for periodic evaluation of the state of conservation of these coatings and of the need for renovation	**YES**	**NO**
M	Surfaces of walls must be easily decontaminated and, as far as possible, without interruption	**YES**	**NO**
M	The joint of the floor with the walls must be rounded, with a rise on the walls of about 20 cm	**YES**	**NO**
M	Work surfaces, where radionuclides are used or stored (benches, tables and chairs), must be finished with a material which is hard, non-porous, waterproof, washable and resistant to heat, stains and chemicals and must have raised edges	**YES**	**NO**
M	The floor of the cyclotron vault must be designed in such a way as to withstand high loads	**YES**	**NO**
A	Floor equipped with drains for water, if possible connected to a collection system in order to control the concentration of radioactivity in the water before it is released into the sewer	**YES**	**NO**
A	Ducts that cross the wall to the passage of cables or pipes must be angled or S-shaped and positioned in the lower part of the walls	**YES**	**NO**
A	Pipes of the transmission lines of radionuclides must be made of plastic and inserted inside ducts large enough to allow easy replacement	**YES**	**NO**
A	Coding of a procedure for periodic evaluation/replacement of pipes of the transmission lines	**YES**	**NO**
	SAFETY AND CONTROL SYSTEMS		
	"COLD" CHANGING ROOM:		
M	lockers for personal clothes	**YES**	**NO**
	"FILTERING" AREA WITH "HOT" CHANGING ROOM:		
M	lockers for working clothes	**YES**	**NO**
	hand – foot – clothing contamination monitor	**YES**	**NO**
	sink with controlled drain	**YES**	**NO**
	shower with controlled drain for a possible decontamination	**YES**	**NO**
	container for contaminated clothes	**YES**	**NO**
	"FILTERING" AREA:		

A	interlock system that prevents the simultaneous opening of the two access doors, provided with a mushroom switch for emergency opening	**YES**	**NO**
	RADIOPHARMACY:		
R	doors with viewing panel	**YES**	**NO**
R	at least 3 m^2 of free surface available per person	**YES**	**NO**
A	administration room positioned near the radiopharmacy for the passage of the radiopharmaceutical through material airlock *otherwise* provision of a lift *otherwise* conding of a procedure that regulates the transport of the radiopharmaceutical by operators ensuring short routes	**YES**	**NO**
E	supply of mobile shielding	**YES**	**NO**
	CYCLOTRON VAULT:		
M	access to the vault via an angled maze with multiple turns or through a shielding door	**YES**	**NO**
A	floor functioning effectively as a basin with drain channels directed to a containment system	**YES**	**NO**
M	after filtration, the air is discharged through stack of a height that ensures sufficient dilution of the gaseous effluents in the atmosphere	**YES**	**NO**
M	device for monitoring and sampling the effluents, placed inside the exhaust air duct, downstream of the filtration systems	**YES**	**NO**
E	detection systems for the presence of people inside the cyclotron vault	**YES**	**NO**
A	audio / video communication system between the cyclotron vault and the control room	**YES**	**NO**
A	sequence of power cut-off switches according to a coded procedure of timed patrol	**YES**	**NO**
M	control system allowing the cyclotron to start only after verification of all safety conditions	**YES**	**NO**
M	indicator light at the access door to the vault indicating the cyclotron's operating status and door closing	**YES**	**NO**
M	environmental radiation monitoring systems inside the cyclotron vault, the technical rooms, and the packaging room, equipped with an alarm system	**YES**	**NO**
M	safety systems preventing access to the cyclotron vault during the operational phase and, subsequently, until the level of exposure are below appropriate safety constraints	**YES**	**NO**
M	audible and visual signals to indicate: • that the timed patrol inside the cyclotron vault has been completed • that the cyclotron is ready for operation (usually an intermittent signal) • the closing of the doors of the vault • that the cyclotron is in operation (usually this is a continuous low intensity signal that remains active throughout the operation) • exceeding the pre-alarm and alarm dose rate thresholds set for the cyclotron vault • exceeding the pre-alarm and alarm thresholds in the air extracted form the cyclotron vault • evacuation in the event of an emergency • other possible risk situations detectable by means of suitable sensors (flooding, release of cryogens, gas, etc.)	**YES**	**NO**

M	emergency buttons both inside and outside the cyclotron vault (inside it is advisable to position them also near the floor): their actuation causes the door to stop closing or, if it were already closed, to reopen and stop the operations	**YES**	**NO**
M	photoelectric cells positioned inside the cyclotron vault which, if intercepted, stop the closing of the door	**YES**	**NO**
A	double safety wire to stop the closing system when pressed or severed	**YES**	**NO**
M	manual emergency opening system, which can be activated in the event of an electrical blackout	**YES**	**NO**
A	in case of radioactive release, the monitoring system of emissions through the exhaust pipes must: • close the exhaust air ducts from the premises • close the air delivery ducts in the premises • activate an alarm signal • allow the release of the air of the premises only after the time necessary for the decay below the constraints of radioactivity concentration	**YES**	**NO**
R	audible and visual alarms to indicate possible risk situations	**YES**	**NO**
M	coding of control procedures of all security systems	**YES**	**NO**
E	provisions for security of radioactive material	**YES**	**NO**
	VENTILATION		
M	the air flow must be directed from the areas with lower potential contamination to the areas with higher potential contamination, keeping the latter with negative pressure compared to the former, in compliance with the GMP guidelines [5]	**YES**	**NO**
M	adequate filtering systems for the air introduced into the premises	**YES**	**NO**
M	the air must be expelled through high efficiency filters appropriate to the nature and quantity of the effluent [6]	**YES**	**NO**
M	coding of a procedure for periodic replacement of filters	**YES**	**NO**
M	number of air changes in the premises according to the Italian technical standard UNI 10491 [7] or to recent and specific international technical standards [8]	**YES**	**NO**
A	dedicated extraction system for the air of the premises composed of prefilters, active carbon (specific for radioisotopes) and absolute filters (possibly ULPA filters)	**YES**	**NO**
A	filter container made of sealed steel and suitable for external maintenance in protected conditions	**YES**	**NO**
	RADIOPHARMACY:		
M	access to the radiopharmaceutical preparation area through a filtering area (personnel airlock) with interlocking doors, set in depression with respect to both the hot area and the corridor	**YES**	**NO**
M	conditions of overpressure in the radiopharmaceutical preparation area	**YES**	**NO**
M	in case of radiopharmaceutical preparation, presence of a class A laminar flow hood placed in a class B room, or an isolator that guarantees a sterile environment, placed in a grade D zone, according to the Italian Standards of Good Manufacturing of radiopharmaceuticals in nuclear medicine [9]	**YES**	**NO**
M	material airlocks equipped with a ventilation system suitable to guarantee a classification of the environment of the same degree of the area dedicated to the preparation of radiopharmaceuticals	**YES**	**NO**
	CYCLOTRON VAULT:		

M	ventilation system activated immediately after shutdown and connected to a detection system to control any accidental releases into the environment	**YES**	**NO**
M	number of air changes suited to the use and the safety systems implemented	**YES**	**NO**
M	air flow designed so that the cyclotron vault has the lowest pressure in the building (refer to the Italian technical standard UNI 10491 [7] or to recent and specific international technical standards [8])	**YES**	**NO**
A	damper delivery and exhaust air ducts, connected to a radiation monitoring system so that the shutters are closed and the expulsion fan is turned off in case of an emergency	**YES**	**NO**
M	systems for environmental radiation monitoring	**YES**	**NO**