

Annex 3

IAEA/WHO guideline on good manufacturing practices for investigational radiopharmaceutical products

Background

In view of the rapidly expanding field of molecular imaging and targeted radiopharmaceutical therapy, combined with the absence of dedicated guidance specific to the manufacture of investigational radiopharmaceuticals used in both early and late clinical trials, the World Health Organization (WHO), in partnership with the International Atomic Energy Agency (IAEA), has raised the urgency for the generation of a new *IAEA/WHO guideline on good manufacturing practices for investigational radiopharmaceutical products*.

The objective of this guideline is to meet current expectations and trends in good manufacturing practices specific to investigational radiopharmaceuticals used in clinical trials (that is, phase I, phase II and phase III trials) and to harmonize the text with the principles from other related international guidelines.

This text was developed in alignment with the *Good manufacturing practices; supplementary guidelines for the manufacture of investigational pharmaceutical products for clinical trials in humans (1)*. A draft working document was made available online for comments (2).

Contents

Background	171
1. Introduction	173
2. Scope	175
3. Glossary	175
4. Quality management	178
5. Quality risk management	179
6. Personnel	180
7. Documentation	181
7.1 Specifications	182
7.2 Manufacturing formulae and processing instructions	183
7.3 Batch manufacturing records	183



8. Premises	183
9. Equipment and utilities	185
10. Materials	185
10.1 Starting materials	185
10.2 Reference standards for analytical purposes	186
11. Production	186
11.1 Manufacturing operations	187
11.2 Packaging and labelling	188
12. Quality control	189
13. Qualification and validation	190
14. Complaints	192
15. Recalls	192
16. Returns	193
17. Shipping	193
18. Destruction	194
References	194

1. Introduction

- 1.1 Radiopharmaceuticals are rapidly re-emerging as clinically valuable tools used in the diagnosis and treatment of various types of disease. Molecular imaging agents offer unparalleled methodology not only to help elucidate the presence and the extent of disease but also to help characterize the disease, select specific patients for a particular therapy and evaluate a treatment response. Additionally, novel targeted radioligand therapies offer alternatives to patients for whom no other treatment options exist.
- 1.2 This rapid expansion has been accompanied by a set of challenges due to the complexity and unique nature of these agents. One of the main challenges associated with novel radiopharmaceutical development is how to define the proper balance with respect to the controls required when conducting early clinical studies of manufacture of investigational radiopharmaceuticals, and the subsequent implementation of additional controls as the radiopharmaceutical is developed further into pivotal phase III trials. Having inadequate manufacturing controls during early clinical evaluations either carries the risks of unnecessary patient harm or jeopardizes the validity of the collected study results. On the other hand, redundant manufacturing controls, particularly in the initial stages of development, carry the risk of slowing the pace of clinical development of potentially lifesaving therapies. This risk is further intensified by other factors such as the high costs and lengthy time associated with the actual clinical conduct of the study, the completion of the preclinical evaluation of the agent, and the low probability of successful marketing approval. In light of these challenges, a balanced approach with respect to manufacturing process controls is essential, as the degree of manufacturing process controls is correlated with the particular stage of radiopharmaceutical development, the nature of the agent itself, and the clinical study goals.
- 1.3 This guidance provides recommendations on the minimum standards that should be in place when preparing novel radiopharmaceuticals for phases I–III clinical investigations that do not have a marketing authorization.
- 1.4 Investigational radiopharmaceuticals are used for testing purposes, as a reference in a clinical trial for an unauthorized indication, and to gain further information about the authorized form.
- 1.5 Depending on the country, these products are sometimes not covered by legal and regulatory provisions in the areas of good manufacturing practices (GMP). The lack of both high-level GMP requirements and prior knowledge of the risk of contamination and cross-contamination

of products contributes to the risk of using them in human subjects. In addition, the risk may be further increased in cases of incomplete knowledge of the potency, human biodistribution, and toxicity of the investigational radiopharmaceuticals.

- 1.6 To minimize the risks and to ensure that the results of clinical trials are unaffected by inadequate safety, quality or efficacy arising from unsatisfactory production, investigational radiopharmaceuticals should be produced and managed in accordance with an effective quality management system and the recommendations contained in this guideline.
- 1.7 Procedures should be flexible to allow for changes whenever necessary through a properly controlled and traceable change management system, as knowledge of the process increases in accordance with the stages of development of the product.
- 1.8 Investigational radiopharmaceuticals should be produced in a manner that is compliant with GMP requirements that are specific to the particular stage of agent development.
- 1.9 As the clinical development of radiopharmaceutical progresses from phases I–II to the pivotal phase III and commercial stage, additional manufacturing process controls and analytical method validation should be implemented so as to ensure:
 - that subjects of clinical trials will be protected from poor-quality products due to unsatisfactory manufacturing;
 - that consistency exists between and within batches of the investigational radiopharmaceuticals;
 - that consistency exists between the investigational product and the future commercial product.
- 1.10 The selection of an appropriate dosage form for clinical trials is important. While it is accepted that the dosage form in early trials may be different from the anticipated final formulation (for example, different strength or different buffers, radiostabilizers and other excipients), in the pivotal phase III studies it should be equivalent to the projected commercial presentation in terms of the expected biodistribution profile. If there are significant differences between the investigational and commercial dosage forms, data should be submitted to the registration authorities to demonstrate that the final dosage form is equivalent, in terms of biodistribution and stability, to that used in the clinical trials.

- 1.11 The quality of investigational radiopharmaceuticals should be appropriate for the particular stage of development. For example, it should be feasible to apply only the critical manufacturing controls for agents in phase I and phase II trials, while the manufacture of investigational radiopharmaceuticals for phase III clinical studies should generally have the same degree of applied controls as for commercial manufactured products.
- 1.12 This document should be read in conjunction with other World Health Organization (WHO) GMP guidelines, including good clinical practices, good documentation practices and International Atomic Energy Agency (IAEA) radiation protection documents related to radiopharmaceuticals (3–9).

2. Scope

- 2.1 The recommendations in this guideline are applicable to investigational radiopharmaceutical products for human use.
- 2.2 The recommendations of this guideline do not apply to radiopharmaceuticals in phase IV (with marketing authorization) that already have regulatory authority approval for a certain indication but might be used to conduct a clinical study for a different indication. In those situations, the IAEA/WHO guideline on GMP for radiopharmaceutical products should be used (3).

3. Glossary

The definitions given below apply to the terms used in this guideline. They may have different meanings in other contexts.

active pharmaceutical ingredient. With respect to radiopharmaceutical preparations, the active pharmaceutical ingredient is the radioactive molecule that is responsible for the radiopharmaceutical mechanism of action. This active pharmaceutical ingredient may be in the form of the radionuclide by itself, if its use by itself is clinically indicated, or in the form of a radionuclide coupled to a non-radioactive ligand or vector molecule.

as low as reasonably achievable. This term is used to define the principle of underlying optimization of radiation protection for occupational workers and the public, including patients. This is practised based on the principles of time, distance and shielding, while placing an emphasis on creating adequate awareness among all stakeholders.

clinical trial. Any systematic study on (radio)pharmaceutical products in human subjects, whether in patients or other volunteers, in order to discover or verify the effects of, or identify any adverse reaction to, investigational products; and to study the absorption, distribution, metabolism and excretion of the products with the object of ascertaining their efficacy and safety.

Clinical trials are generally divided into phases I–IV, although phase IV studies usually do not apply to investigational radiopharmaceuticals, and thus are not mentioned further in this guideline. It is not always possible to draw clear distinctions between these phases, and different opinions about the details and methodology exist. However, the individual phases, based on their purposes as related to the clinical development of pharmaceutical products, can be briefly defined as follows:

- **Phase I.** These are the first trials for new radiopharmaceuticals (also called “first in human”), often carried out in healthy volunteers. Their purpose is to make a preliminary evaluation of safety, an initial pharmacokinetic and pharmacodynamic profile, and an initial safety assessment of the active ingredient and radiation dosimetry.
- **Phase II.** The purpose of studies in phase II is to determine activity and to assess short-term safety. The trials are performed in a limited number of subjects, but a greater number than in phase I, and aim to determine the optimal administered dose. In the case of therapeutic radiopharmaceuticals, they also aim to clarify the dose–response relationships in order to provide an optimal background for the design of extensive therapeutic trials.
- **Phase III.** This phase involves trials in large (and possibly varied) patient groups for the purpose of determining the short- and long-term safety and efficacy, and assessing the overall and relative diagnostic accuracy and therapeutic value of the intended radiopharmaceutical. Phase III studies are often multicentric. The pattern and profile of any frequent adverse reaction must be investigated and special features of the product must be explored (for example, clinically relevant drug interactions and factors leading to differences in effect, such as age). In general, the conditions under which the trials are conducted should be as close as possible to the normal conditions of use.

finished pharmaceutical product. With respect to radiopharmaceutical preparations, the finished pharmaceutical product is a combination of the active pharmaceutical ingredient and other components of the formulation such as diluents, radioprotectants and other formulation excipients. In some instances, the active pharmaceutical ingredient is co-produced concurrently with the

finished pharmaceutical product in a single seamless process. In other cases, the active pharmaceutical ingredient is synthesized first and then formulated further as a separate process to yield the finished pharmaceutical product. In all cases, the finished pharmaceutical product is created once the active pharmaceutical ingredient is formulated in the final formulation form.

good manufacturing practices for radiopharmaceutical products. Good manufacturing practices (GMP) for radiopharmaceutical products are a set of practices, using a traceable process, that ensure that radiopharmaceutical products are consistently produced and controlled to the quality standards appropriate for their intended use and designed to consistently yield the radiopharmaceutical product. GMP fall under the umbrella of the overall quality management system.

investigational radiopharmaceutical. Any radiopharmaceutical product (new compound or a commercial product) being evaluated in a clinical trial.

investigator. The person responsible for the trial and for protecting the rights, health and welfare of the subjects in the trial. The investigator must be an appropriately qualified person, legally allowed to practice medicine or dentistry.

manufacturing or production. For the purpose of this document, these terms are defined in the same way as in the *IAEA/WHO guideline on good manufacturing practices for radiopharmaceutical products* (3). They refer to all the operations performed leading up to the finished pharmaceutical product, including the purchase of starting materials, production, quality control, release and storage of radiopharmaceuticals.

monitor. A person appointed by the sponsor who is responsible for monitoring and reporting the progress of the trial and for the verification of data.

order. An instruction to process, package and ship a certain number of doses of an investigational radiopharmaceutical.

preparation or kit reconstitution. For the purpose of this document, these terms are defined in the same way as in the *IAEA/WHO guideline on good manufacturing practices for radiopharmaceutical products* (3). They refer to all the procedures carried out as per instructions from marketing authorization holders that involve addition of radionuclide solution approved by regulatory authorities to an approved cold kit.

product specification file. A reference file containing all the information necessary to draft the detailed written instructions on processing, packaging, labelling, quality control testing, batch release, storage conditions and shipping.

protocol. A document that gives the background, rationale and objectives of the trial and describes its design, methodology and organization, including statistical considerations and the conditions under which it is to be performed and managed. The protocol should be dated and signed by the investigator or institution involved and the sponsor, and can, in addition, function as a contract.

radiopharmaceutical product. For the purpose of this document, this term is defined in the same way as in the *IAEA/WHO guideline on good manufacturing practices for radiopharmaceutical products* (3), as any pharmaceutical product that, when ready for use, contains one or more radionuclides (radioactive isotopes) included for medicinal purposes.

retention sample. An additional sample of the final drug product that is collected and stored for the purpose of being analysed, should the need arise.

sponsor. An individual, company, institution or organization that takes responsibility for the initiation, management and financing of a clinical trial. When an investigator independently initiates and takes full responsibility for a trial, the investigator also then assumes the role of the sponsor.

4. Quality management

- 4.1 There should be a comprehensively designed, clearly defined, documented and correctly implemented quality management system in place. Senior management should assume the responsibility for this, as well as for the quality of the investigational product.
- 4.2 All parts of the quality management system should be adequately resourced and maintained.
- 4.3 The quality management system should incorporate GMP, which should be applied to all stages of the product life cycle, including the transfer of technology and the interface between the manufacture and the trial sites (for example, with regard to shipment, storage and labelling).
- 4.4 The quality management system should ensure that:
 - products are designed and developed in accordance with the requirements of this document and other associated guidelines, such as good clinical practices, good laboratory practices, good storage and distribution practices, and GMP for radiopharmaceuticals, as appropriate (3–6);
 - responsibilities are clearly specified in job descriptions;
 - operations are clearly specified in a written form;

- arrangements are made for the manufacture, supply and use of the correct starting and packaging materials;
- all necessary controls on starting materials, intermediate products, bulk products and other in-process controls are in place;
- calibrations and validations are carried out where necessary;
- the finished radiopharmaceutical product is correctly processed and quality controlled according to the defined procedures;
- there is an appropriate system for quality risk management;
- satisfactory arrangements exist to ensure, as far as possible, that the investigational radiopharmaceuticals are stored, distributed and subsequently handled so that their quality is maintained;
- deviations and changes are investigated and recorded with an appropriate level of root cause analysis done and appropriate corrective and preventive actions identified and taken.

4.5 For the manufacture of phase I and II radiopharmaceutical investigational products, the information on deviations, changes, out-of-specification investigations and corrective and preventative actions may be captured in a documentation system that is less regimented than the standard operating procedures and forms that are normally used during manufacture of commercial radiopharmaceutical products where the degree of variability and reliability of the process has been established and validated. This less regimented documentation system allows for manufacturer flexibility, which is essential for the manufacture of the novel agent, as this process is inherently subject to a higher degree of variability when compared to agents in later stages of pharmaceutical development. Regardless of the documentation system utilized, the relevant information must be adequately captured and be traceable.

5. Quality risk management

5.1 A quality risk management system should cover a systematic process for the assessment, control, communication and review of risks to the quality of the product and, ultimately, to the protection of the trial subjects and patients (7). Specific areas of quality risk assessment should include:

- sterility assurance;
- expiration time;
- method of sterilization;
- mass of the drug substance or ligand;

- physicochemical properties of the radionuclide or radiopharmaceutical;
- planned dosing schedule (single dose or multiple doses into the same study subject);
- route of administration;
- agent specific in vitro stability;
- the degree of clinical investigator supervision.

5.2 The quality risk management system should ensure that:

- the evaluation of the risk is based on scientific knowledge and experience with the process and product, and is ultimately linked to the protection of the patient;
- as the agent development continues, the basis of risk assessment is the transition from scientific knowledge and experience to process validation;
- procedures and records for quality risk management system are retained;
- the level of effort, formality and documentation of the quality risk management system process is commensurate with the level of risk.

5.3 The quality risk management system should be applied both proactively and retrospectively, when appropriate.

6. Personnel

- 6.1 There should be a sufficient number of appropriately qualified personnel available to carry out all the tasks for which the manufacturer of investigational products is responsible.
- 6.2 Individual responsibilities should be clearly defined, recorded as written descriptions and understood by all persons concerned.
- 6.3 A designated person, with experience in product development, clinical trial processes, and relevant guidelines on GMP and good clinical practices, should ensure that there are systems in place that meet the requirements of this guideline and other relevant GMP guidelines.
- 6.4 Personnel involved in the development, production and quality control of investigational products should be appropriately trained in relevant GMP and in the requirements specific to the manufacture of investigational radiopharmaceuticals.

- 6.5 The personnel should also be trained appropriately to prevent radiation contamination and other associated risks.
- 6.6 Production and quality control operations should be carried out under the control of clearly identified responsible persons who are separately designated and independent from one another.
- 6.7 In the manufacture of investigational radiopharmaceuticals, the same operator may be qualified as either a production operator or a quality control operator, or both, and the training for a specific function should be documented. Normally, the same operator should not perform both manufacture and quality control testing of the same batch of investigational radiopharmaceuticals. In circumstances where this may not be possible (for example, in academic radiopharmacies with limited personnel that are not engaged in the manufacture of investigational radiopharmaceuticals for phase I–II clinical evaluations on a routine daily basis, and where the produced investigational agent use is limited to the inside of the same institution), the same trained operator may perform both production and quality control testing, but it must be ensured that the batch release is performed by another independent authorized person.
- 6.8 In the manufacture of investigational radiopharmaceuticals, it may be possible for an authorized person responsible for batch release to also participate in either the batch production or quality control of a particular batch of an investigational radiopharmaceutical. However, if this authorized person does participate in either production or quality control testing of the particular batch, they cannot be responsible for the release of this batch of investigational radiopharmaceutical.

7. Documentation

- 7.1 Good documentation is an essential part of a quality management system. The documents should be appropriately designed, prepared, reviewed and distributed. They should also be appropriate for their intended use.
- 7.2 The documents (such as standard operating procedures, batch records and official reports) should be approved, signed and dated by the appropriate responsible person or persons. No authorized document should be changed without the prior authorization and approval of the responsible persons.
- 7.3 The documentation requirements applied during the manufacture of phases I–II investigational radiopharmaceuticals may be less vigorous than the documentation requirements applied during the manufacture of

phase III investigational radiopharmaceuticals, but they would still need to be adequate to allow for traceability of the manufacturing process.

7.1 Specifications

- 7.4 Specifications (for starting materials, primary packaging materials, and intermediate, bulk and finished products), batch formulae and production instructions should be as precisely detailed as possible and should take into account the latest state of the art.
- 7.5 In developing specifications, attention should be paid to the characteristics that may affect the efficacy and safety of products, namely:
- sterility and bacterial endotoxins
 - radioactive strength
 - radiochemical purity
 - specific activity, if applicable
 - batch size that is intended for the trial, where applicable
 - in-use stability
 - preliminary storage conditions
 - shelf-life of the product
 - appearance of the finished pharmaceutical product
 - radionuclidic purity, if applicable
 - chemical purity, if applicable.
- 7.6 As a result of the development of an investigational radiopharmaceutical, specifications may be changed by following a documented procedure. Changes should be authorized by a responsible person. Each new version should take into account the latest data and information, current technology, and regulatory and pharmacopoeial requirements. There should be traceability to the previous version or versions. The reasons for any change should be recorded. The impact of the change on any ongoing clinical trial, product quality, stability, bioavailability or bioequivalence (where applicable) should be considered.
- 7.7 For phase II or III studies, information necessary to prepare the intended investigational radiopharmaceutical should be summarized in a product specification file, which contains reference to the relevant documentation (for example, standard operating procedures, qualification or validation protocols, analytical methods, stability data, or storage and shipment conditions) required to perform processing, packaging, quality control

testing, batch release, labelling, storage conditions or shipping of the desired product.

- 7.8 The product specification file should indicate who has been designated or trained as the designated responsible person or persons for the release of batches.
- 7.9 The product specification files should be continuously updated, whilst, at the same time, ensuring the appropriate traceability to any previous versions.

7.2 Manufacturing formulae and processing instructions

- 7.10 Detailed manufacturing formulae, processing and packaging instructions and records should be available. Where this is not possible, other clear, written instructions and written records should be available for every manufacturing operation or supply.
- 7.11 These records should be used when preparing the final version of the documents to be used in routine manufacture.
- 7.12 Batch records should be retained for at least five years after the termination or discontinuance of the clinical trial or after the approval of the investigational radiopharmaceutical.
- 7.13 Where the data are intended for inclusion in an application for marketing authorization purposes, the records should be maintained until the end of the life cycle of the product.

7.3 Batch manufacturing records

- 7.14 Processing, packaging and testing records should be kept in sufficient detail for the sequence of operations to be accurately traced. They should contain any relevant remarks that increase the existing knowledge of the product, allow and reflect changes and improvements in the manufacturing operations, and justify the procedures used.

8. Premises

- 8.1 The premises where investigational radiopharmaceutical products are manufactured should be located, designed, constructed and maintained to suit the operations to be carried out. The design of the laboratories used for the handling of radioactive materials should always consider the need for radiation protection and compliance with “as low as reasonably achievable” standards, and should exhibit a high level of cleanliness and controls to minimize possible microbial contamination (8–10).

- 8.2 In cases where the same facility and equipment are used to prepare different radiopharmaceuticals, including investigational radiopharmaceuticals, the layout and design of premises should aim to minimize the risk of errors and mix-ups and permit effective cleaning and maintenance in order to avoid contamination, cross-contamination and, in general, any adverse effect on the quality of the products.
- 8.3 General technical requirements for the premises involved in the routine production of radiopharmaceuticals also apply in the case of investigational radiopharmaceuticals. For instance, drains should be avoided wherever possible and should not be present in cleanrooms. Where drains are required, these should be appropriately designed: sinks should be excluded from clean areas, and access points to technical areas (for example, rooms to access the rear of hot cells) should be configured in a way that minimizes entrance of maintenance and technical personnel to the production (clean) areas.
- 8.4 The heating, ventilation and air-conditioning system and pressure cascade for the different areas should be appropriately designed and maintained to minimize the risk of product contamination, and to protect personnel from the risk of radiation exposure. Pressure differentials should be monitored in areas of the facility where relative pressure differentials need to be maintained (such as cleanrooms where the quality of air is controlled) (11).
- 8.5 The facility must be equipped with appropriate radiation monitoring systems suitable for routine radioactive contamination monitoring for both areas and operators.
- 8.6 The appropriate controls should be in place to promote containment of radioactive gases and vapours. The premises must be equipped with an appropriate radioactive gas emission monitoring system.
- 8.7 Radioactive gases should be removed through separate air handling units fitted with the appropriate filters before being exhausted. These should be regularly checked for performance. The recirculation of potentially radiation-contaminated air should not be allowed.
- 8.8 A dedicated area and dedicated equipment should be used for the manufacture of any investigational radiopharmaceutical product involving human blood or plasma.
- 8.9 Quality control laboratories should be segregated from production areas.

- 8.10 The premises must be equipped with appropriately designed radioactive decontamination areas where operator decontamination may be carried out in compliance with approved protocols. At a minimum, these areas should be equipped with handwashing and eye washing stations.
- 8.11 The facility must be equipped with appropriately designed radioactive waste storage areas.

9. Equipment and utilities

- 9.1 Equipment and utilities should be selected, located, constructed and maintained to suit the operations to be carried out.
- 9.2 Equipment and utilities should be qualified for their intended use. This may include user requirement specifications, design qualification (if applicable), installation qualification, operational qualification and performance qualification. Equipment and devices, as appropriate, should be calibrated and maintained.
- 9.3 Equipment maintenance, qualification and calibration operations should be recorded and records should be maintained.
- 9.4 Computerized systems, such as those controlling equipment, should be verified to ensure they are reliable and fit for the intended purpose (12).
- 9.5 The dose calibrator (also known as the activity meter) should be qualified using suitable reference standards. If such a reference standard recognized by a national authority is not available, dose calibrator manufacturer recommendations or published literature may be used when deciding upon the appropriate dial setting.

10. Materials

10.1 Starting materials

- 10.1 The consistency of the production of investigational radiopharmaceutical products may be influenced by the quality of the starting materials. Their physical, chemical and, when appropriate, microbiological properties should therefore be defined, documented in their specifications, and controlled.
- 10.2 Specifications for precursors for radiolabelling should be as comprehensive as possible, given the current state of knowledge. They should include, for example, identity, purity or certification of origin (if applicable) and any

other parameter or characteristic required to make the material suitable for its intended use.

- 10.3 Detailed information on the quality of precursors for radiolabelling and excipients (as well as of packaging materials) should be available.
- 10.4 Starting materials should be accepted by performing in-house testing. During the manufacture of investigational radiopharmaceuticals for phase I–II clinical trials, the in-house testing may also be in the form of a review of the certificate of analysis supplied by the reliable material supplier, to confirm compliance with the specification set by the investigational agent manufacturer. For positron emission tomography (PET) radiopharmaceuticals, the acceptance of materials based on review of the certificate of analysis may also apply to the phase III stage, as long as the final product release testing adequately confirms that materials of correct quality were used. For the manufacture of cold kit products, generators and therapeutic radiopharmaceuticals in phase III stages, additional physical tests (such as material identity confirmation) may need to be performed by the radiopharmaceutical manufacturer as part of the material acceptance process, in addition to a review of the certificate of analysis.

10.2 Reference standards for analytical purposes

- 10.5 Reference standards from reputable sources (such as qualified vendors) should be used, if available.
- 10.6 If not available from any source, the reference substance or substances for the precursor for radiolabelling should be prepared, fully characterized and released as reference materials by the producer of the investigational pharmaceutical product.

11. Production

- 11.1 Investigational radiopharmaceuticals intended for use in clinical trials should be manufactured at a facility that is specified in the investigational agent regulatory application.
- 11.2 Where activities are outsourced to contract facilities, the contract must then clearly state, inter alia, the responsibilities of each party, compliance with GMP or this guideline, and that the product or products to be manufactured or controlled are intended for use in clinical trials. Close cooperation between the contracting parties is essential.

- 11.3 Access to restricted areas should be by authorized and trained personnel only.
- 11.4 Processes should be designed to minimize the risk of contamination, cross-contamination and mix-ups. The following measures may be adopted to minimize these risks:
- procedures for clearing the room of previous product materials;
 - processing and filling in segregated areas;
 - avoiding the manufacture of different products at the same time, either in the same dedicated space or by the same personnel;
 - performing manufacturing area decontamination and visual prechecks;
 - using manufacturing closed systems (such as automated systems), whenever possible;
 - using preassembled kit (cassettes), whenever possible.
- 11.5 The stability and shelf-life of the finished product should be defined following the execution of a suitable written protocol.
- 11.6 The expiration dates and times for radiopharmaceuticals should be based on the results of an adequate number of stability studies.

11.1 Manufacturing operations

- 11.7 As process knowledge of an investigational radiopharmaceutical is often not comparable with that of a radiopharmaceutical used for standard clinical care, process validation may not always be complete during the development phase of products; thus, critical quality attributes, process parameters and in-process controls should be identified, based on risk management principles and experience with analogous products, if available.
- 11.8 The necessary instructions for production should be defined and may be adapted based on the experience gained during radiopharmaceutical development itself.
- 11.9 For sterile investigational products, the controls to assure sterility of the final drug product should be no less than for licensed products (10). However, sterility verification studies (for example, bacteristasis or fungistasis) may not need to be conducted prior to pivotal phase III studies.

11.2 Packaging and labelling

11.10 At least the following information should be listed on the primary packaging container label (3):

- name of the product and batch number
- name of the manufacturer
- route of administration
- amount of activity at calibration date and time in appropriate units
- volume
- where relevant, the international symbol for radioactivity
- cautionary statements (for example, “For clinical investigational use only”);
- the study or trial number.

Note: Reporting information about activity (“strength”) on the primary label may not always be possible due to radiation protection reasons. In this case, the information may be reported on the secondary packaging label.

11.11 In the absence of regulatory authority requirements, the following minimum information may be listed on the secondary packaging container label, in addition to any information listed on the primary packaging:

- the finished pharmaceutical product formulation composition
- excipient information
- storage instructions
- address of the manufacturer, study sponsor, or investigator, as appropriate
- radioactive concentration at calibration date and time, if applicable
- end-of-synthesis date and time
- expiration date and time
- specific activity or mass.

11.12 The packaging must ensure that the investigational product remains in good condition during transport and storage. Any opening of or tampering with the outer packaging during transport should be readily discernible.

12. Quality control

- 12.1 Quality control should cover the sampling and testing of both the starting materials and the radiopharmaceutical final drug products, ensuring that materials are not released for use until their quality has been determined to conform to the predefined acceptance specifications.
- 12.2 As processes may not be standardized or fully validated, testing takes on more importance in ensuring that each batch meets the approved specification at the time of testing.
- 12.3 The release of a batch of an investigational radiopharmaceutical product should only occur after the designated responsible person has certified that the product meets the relevant batch release requirements. At a minimum, these requirements should include the following:
 - a review and approval of batch records, including control reports, in-process test reports, changes, deviations and release reports demonstrating compliance with the product specification file, the order and protocol;
 - verification of appropriate production conditions;
 - verification of the quality of starting materials (for example, status of approval, certificate of analysis);
 - verification of the validation status of facilities, equipment, processes and methods, as appropriate;
 - verification of conditions of storage and shipment, if applicable;
 - verification of successful completion of quality control tests required for batch release.
- 12.4 Due to the inherent rapid radioactive decay of radiopharmaceuticals containing radionuclides with relatively short half-lives, these products may be released and administered prior to completion of all quality control testing. Under these circumstances, the required pre-release and post-release testing should be clearly defined and documented.
- 12.5 Sampling procedures should consider the nature and the characteristics of the material being sampled (for example, a small batch size or its radioactive content) to make sure that the samples are representative of the entire batch of radiopharmaceuticals.
- 12.6 Quality control samples should be prepared, handled and stored in a way that ensures the adequate identification and segregation of the test samples to avoid mix-ups and cross-contamination.

- 12.7 In the event that a finished radiopharmaceutical product batch fails to meet a release acceptance specification (that is, an out-of-specification event occurs), an investigation should be conducted and documented. During the investigation, the affected batch should be segregated and quarantined to prevent release. If the investigation confirms the out-of-specification result, the finished radiopharmaceutical product should be rejected. A confirmed out-of-specification event that is detected during post-release testing requires an immediate notification to the end clinician who has the drug product in their possession. A batch of finished radiopharmaceutical product involved in an out-of-specification event may be released only if (a) the investigation reveals clear evidence that the obtained result is invalid; and (b) confirmatory testing results confirm the absence of non-compliance with the acceptance specifications. Final disposition confirming or invalidating the out-of-specification event should be notified to the clinician as quickly as possible.
- 12.8 Retention samples from every batch of a particular investigational radiopharmaceutical product should only be collected if they can be used to obtain meaningful testing data in the future. However, the collection of the retention samples is not required. The duration of storage of retention samples should be based on the ability to collect valid test data from using the sample.

13. Qualification and validation

- 13.1 The extent of qualification and validation activities should be in accordance with a risk-based approach, considering the complexity and critical aspects of the intended radiopharmaceutical production.
- 13.2 The extent of qualification and validation required for the manufacture of investigational radiopharmaceuticals in phase I–II trials may be less than for the manufacture of investigational radiopharmaceuticals in pivotal phase III trials. Nevertheless, the critical characteristics of the investigational radiopharmaceutical should always be addressed. For example, critical manufacturing step in-process control parameters, such as reaction temperatures or transfer of the activities, may need to be defined and monitored at any stage of development; on the other hand, the validation of less critical controls, such as bioburden sample collection or determination of maximum in-process holding times, may not be required during phases I–II.
- 13.3 The facilities and equipment need to be properly maintained and calibrated at any stage of development.

- 13.4 Equipment should be qualified for its intended use. At a minimum, the equipment should be verified to be in conformance with the preventive maintenance and operational qualification requirements of the equipment manufacturer, as well as the performance qualification requirements of the investigational radiopharmaceutical manufacturer, as applicable.
- 13.5 The validation of aseptic investigational radiopharmaceutical production procedures presents special problems, as the batch size is often very small and the number of units filled may be not adequate for a full validation protocol. Thus, the validation of aseptic procedures needs to be supported by an operator and process validation via a media fill test, which consists of conducting a process simulation using broad spectrum bacterial growth media to demonstrate that the aseptic processing, controls and production environment are capable of producing a sterile product. The successful completion of media fill testing is a prerequisite for the clinical production of investigational radiopharmaceuticals at any stage of development.
- 13.6 Manufacturing process validation should only be carried out after all of the critical requirements (for example, media fill testing, relevant standard operating procedures for operator training, and preventive maintenance and operational qualification of equipment) have been completed. The validation batches campaign should include an adequate number of batches of the intended radiopharmaceutical(s). The number of batches and the batch size range should be predetermined as part of a risk assessment performed prior to process validation. In general, the completion of a minimum of three consecutive batches aimed for validation and stability studies is sufficient for the purposes of completing manufacturing process validation in phase I trials. However, the number of batches produced may need to be increased in certain situations. For example, more validation and stability runs may be required when the manufacturer is trying to qualify multiple suppliers of a particular critical component (such as radionuclide provided by multiple suppliers).
- 13.7 Defined, documented and reproducible analytical methods aimed to establish chemical, radiochemical and radionuclidic purity, as well as identity, specific activity (if applicable) and impurities content, should be established before any manufacture for human subjects begins. However, analytical method validation protocols fully compliant with the International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use (ICH) standards (13) for validation may be generated and implemented as part of the transition into pivotal phase III trials.

- 13.8 Compendial analytical methods applied by the investigational radiopharmaceutical manufacturer that are described in relevant pharmacopeia do not require validation but may require verification prior to the initiation of manufacture for pivotal phase III trials. For example, the compendial endotoxin testing method may not require full analytical method validation as described in relevant ICH guidances but may require the verification via conduct of specific inhibition and enhancement studies of the finished pharmaceutical product.
- 13.9 General principles on validation of analytical procedures may be followed (13); however, the unique nature of radioactivity should be considered and specific adaptations should be made, where required.

14. Complaints

- 14.1 There should be a written procedure describing the management of complaints. The procedure should provide a clear and concise description of responsibilities, actions that may need to be undertaken, communication pathways and structure, traceability and reporting requirements in the event that a complaint is received.
- 14.2 Any complaint concerning a product defect should be recorded with all the original details and thoroughly investigated.
- 14.3 Where necessary, the appropriate follow-up action, possibly including product recall, should be taken after the investigation and evaluation of the complaint.
- 14.4 All decisions made and measures taken as a result of a complaint should be recorded and referenced to the corresponding batch records.
- 14.5 Any potential impact on the trial or on the product development should be investigated in order to determine the cause and take any necessary corrective action.

15. Recalls

- 15.1 There should be a written procedure describing the management of a recall of an investigational radiopharmaceutical. The procedure should provide a clear and concise description of responsibilities, actions that may need to be undertaken, communication pathways and structure, traceability and reporting requirements in the event a product recall is initiated.

- 15.2 The recall of a product should be documented and inventory records should be kept.
- 15.3 Multiple project-specific and product recall procedures may need to be implemented for various radiopharmaceuticals in order to reflect the requirements for a specific project. For example, the product recall requirements for a manufacturer that supplies investigational agents to the clinic within the same institution or hospital may differ significantly from the manufacturer that works with a pharmaceutical company sponsor and distributes the manufactured product to multiple external clinics. In all cases, the exact requirements need to be clearly defined and the staff need to be trained on those specific requirements.

16. Returns

- 16.1 Investigational radiopharmaceuticals should be returned under the agreed conditions defined by the sponsor, specified in written procedures and approved by authorized staff members.
- 16.2 Return processes should be in accordance with the handling of radioactivity and radiation protection rules.
- 16.3 Inventory records of returned products should be kept.
- 16.4 Returned radiopharmaceuticals should not be reused.
- 16.5 Since the return of radioactive products is often not practical, the main purpose of recall procedures for radiopharmaceutical products should be to prevent their use, rather than an actual return. If necessary, the return of radioactive products should be carried out in accordance with national and, where applicable, international transport regulations (14).

17. Shipping

- 17.1 The shipping of investigational radiopharmaceuticals should be carried out in accordance with written procedures laid down in the protocol or shipping order given by the sponsor.
- 17.2 Shipping processes should also be in accordance with international and local rules (14).
- 17.3 The shipment should be accompanied by a printed form, including the relevant information related to the investigational radiopharmaceutical (for example, the same information included in the secondary packaging label).

18. Destruction

- 18.1 The activity of the active principle of investigational radiopharmaceuticals decreases following the decay law and half-life of the radionuclide; thus, usually there is no need for product destruction.
- 18.2 Should the product be destroyed, however, international and local rules on handling radioactivity and radiation protection should be followed. A dated certificate of, or receipt for, destruction should be provided to the sponsor. These documents should clearly identify or allow traceability of the batches and patient numbers involved and the actual quantities destroyed.

References

1. Good manufacturing practices: supplementary guidelines for the manufacture of investigational pharmaceutical products for clinical trials in humans. In: WHO Expert Committee on Specifications for Pharmaceutical Preparations: thirty-fourth report. WHO Technical Report Series No. 863, Annex 7. Geneva: World Health Organization; 1996 (<https://apps.who.int/iris/handle/10665/41849>, accessed 16 August 2022).
2. WHO good manufacturing practices for investigational products. In: WHO Expert Committee on Specifications for Pharmaceutical Preparations: fifty-sixth report. WHO Technical Report Series No. 1044, Annex 7. Geneva: World Health Organization; 2022.
3. International Atomic Energy Agency and World Health Organization guideline on good manufacturing practices for radiopharmaceutical products. In: WHO Expert Committee on Specifications for Pharmaceutical Preparations: fifty-fourth report. WHO Technical Report Series No. 1025, Annex 2. Geneva: World Health Organization; 2020 (<https://apps.who.int/iris/handle/10665/331814>, accessed 16 August 2022).
4. Handbook for good clinical research practice (GCP): guidance for implementation. Geneva: World Health Organization; 2005 (<https://apps.who.int/iris/handle/10665/43392>, accessed 30 August 2022).
5. Handbook: Good laboratory practice: quality practices for regulated non-clinical research and development. Geneva: World Health Organization; 2001 (<https://apps.who.int/iris/handle/10665/66894>, accessed 12 September 2022).
6. Good storage and distribution practices for medical products. In: WHO Expert Committee on Specifications for Pharmaceutical Preparations: fifty-fourth report. WHO Technical Report Series No. 1025, Annex 7. Geneva: World Health Organization; 2020 (<https://apps.who.int/iris/handle/10665/331814>, accessed 16 August 2022).
7. WHO guidelines on quality risk management. In: WHO Expert Committee on Specifications for Pharmaceutical Preparations: forty-seventh report. WHO Technical Report Series No. 981, Annex 2. Geneva: World Health Organization; 2013 (<https://apps.who.int/iris/handle/10665/81144>, accessed 16 August 2022).
8. Radiation protection and safety of radiation sources: international basic safety standards. General Safety Requirements, Part 3. Vienna: International Atomic Energy Agency; 2014 (https://www-pub.iaea.org/MTCD/publications/PDF/Pub1578_web-57265295.pdf, accessed 16 August 2022).

9. Radiation protection and safety in medical uses of ionizing radiation. IAEA Safety Standards Series No. SSG-46. Vienna: International Atomic Energy Agency; 2018 (<https://www.iaea.org/publications/11102/radiation-protection-and-safety-in-medical-uses-of-ionizing-radiation>, accessed 16 August 2022).
10. WHO good manufacturing practices for sterile pharmaceutical products. In: WHO Expert Committee on Specifications for Pharmaceutical Preparations: forty-fifth report. WHO Technical Report Series No. 961, Annex 6. Geneva: World Health Organization; 2011 (<https://apps.who.int/iris/handle/10665/44079>, accessed 16 August 2022).
11. ISO 14644:2019. Cleanrooms and associated controlled environments – Part 3: Test methods. International Organization for Standardization; 2019.
12. WHO good manufacturing practices: guidelines on validation. Appendix 5: Validation of computerized systems. In: WHO Expert Committee on Specifications for Pharmaceutical Preparations: fifty-third report. WHO Technical Report Series No. 1019, Annex 3. Geneva: World Health Organization; 2019 (<https://apps.who.int/iris/handle/10665/312316>, accessed 13 September 2022).
13. Validation of analytical procedures: text and methodology. Topic Q2 (R1). Geneva: International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use (ICH); 2005 (<https://database.ich.org/sites/default/files/Q2%28R1%29%20Guideline.pdf>, accessed 17 August 2022).
14. IAEA safety standards for protecting people and the environment. Regulations for the safe transport of radioactive material, 2018 edition. Specific Safety Requirements No. SSR-6 (Rev. 1). Vienna: International Atomic Energy Agency; 2018 (https://www-pub.iaea.org/MTCD/Publications/PDF/PUB1798_web.pdf, accessed 17 August 2022).

Further reading

- International Ethical Guidelines for Health-related Research Involving Humans Prepared by the Council for International Organizations of Medical Sciences (CIOMS) in collaboration with the World Health Organization (WHO), Geneva, 2016. Geneva: CIOMS; 2016 (<https://cioms.ch/wp-content/uploads/2017/01/WEB-CIOMS-EthicalGuidelines.pdf>, accessed 17 August 2022).
- The International Pharmacopoeia. Geneva: World Health Organization; updated regularly (<https://www.who.int/teams/health-product-and-policy-standards/standards-and-specifications/norms-and-standards-for-pharmaceuticals/pharmacopoeia>, accessed 12 September 2022).
- EudraLex – Volume 4 – Good Manufacturing Practice (GMP) guidelines. EU Commission Directives 91/356/EEC, as amended by Directive 2003/94/EC and 91/412/EEC (https://health.ec.europa.eu/medicinal-products/eudralex/eudralex-volume-4_en, accessed 17 August 2022).
- WHO good manufacturing practices for pharmaceutical products: main principles. In: WHO Expert Committee on Specifications for Pharmaceutical Preparations: forty-eight report. WHO Technical Report Series No. 986, Annex 2. Geneva: World Health Organization; 2014 (<https://apps.who.int/iris/handle/10665/112733>, accessed 17 August 2022).