
Minimum technical requirements for siting of nuclear power plants with Generation IV nuclear reactors.

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Foreword

The procedures used to develop this document follow the recommendations of ISO/IEC Directives, Part1 and CEN/CENELEC guidelines.

Whilst certain details described in this document might be subject to various patent rights, however, given the non-commercial and voluntary character of the publication, CEN/CENELEC shall not be held responsible for identifying any or all such rights.

This document is intended for presentation to CEN/CENELEC committee responsible for nuclear technologies.

Introduction

Generation IV reactors, expected to become a foundational technology of any new nuclear power plant, are described by number of respective codes and standards.

This document is not intended to replace any of them but to add requirements for siting of newly planned nuclear power plants in order to meet enhanced requirements for public safety and improve public perception of such plants.

Whilst a great engineering effort is put into designing of the safety systems of the nuclear power plant, there always exist certain threats which can not be eliminated by technology only. These include, but are not limited to; armed conflicts, high-level terrorism, collateral damage, malevolent actions by the operator.

In such cases, a potential release of big amounts of highly radioactive isotopes would lead to contamination of large areas, rendering them uninhabitable and without economic use for very long time.

Therefore, this document is intended to lay down the basic requirements for siting of new nuclear power plants **underground**, in a manner which minimizes the risks of such release under any scenario to negligible values.

Increased costs of such an arrangement are expected to be offset by:

- unnecessary containment building,
- extended lifetime under tolerably lower availability and efficiency factors,
- in-situ decommissioning.

Minimum technical requirements for siting of nuclear power plants with Generation IV nuclear reactors.

1. Scope

This document defines the minimum technical requirements for selection of the nuclear power plant (NPP) localization and siting of the Generation IV (GEN IV) nuclear reactors. It does not address the details of reactor construction, maintenance, inspection and radiology protection.

Annex A details various concepts of a reactor placement.

The scope of this document is limited to the main components of the NPP and the placement of them within NPP's operational boundary, such that:

- are important in terms of nuclear safety,
- determine the functioning of the NPP's thermal cycle,
- define handling of radioactive fuel and materials.

2. Normative references

This standard references both EN- as well as ISO- norms related to the nuclear reactor technology. It reflects the intention for this document to become a common standard for both Organisations.

3. Terms and definitions.

The vocabulary used in this document follows definitions described in ISO 12749-5:2018(en).

4. Units of measurement

All measurements are in SI units, except for groups of products where trade custom or manufacturer recommends otherwise.

5. Management system

Project management system shall be implemented following requirements of IAEA.

6. Siting requirements.

6.1. General

Siting of an NPP exceeding designed or planned thermal power of **100 MWth** shall be preceded by population density analysis, comprising at least radius of **200 km** from NPP's operation boundary.

If population density within such perimeter, averaged over 3 years before the siting selection, exceeds **35 people/sq.km**, the reactors and Primary Heat Transport Systems (PHTS) shall be placed **underground** at a minimum depth of **300 m**.

Existing infrastructure and objects of previous mining activity are recommended place for siting of NPPs falling in the category regulated by this standard. Decommissioned salt mines, coal mines, metal ores mines as well as natural formations such as caves are to be considered. In lack of such, vertical and horizontal shafts shall be excavated leveraging standard mining techniques.

Every such localisation shall be subject of a geological study to assess stability, gas tightness, water ingress in the geological formation containing planned localisation.

The time scale of such a geological study shall be reasonable; not shorter than **100 years** but not exceeding 500 years.

Within this time period, selected formation should provide mechanical and hydraulic stability for the NPP under scenarios of:

- planned end-of-life decommissioning,
- natural residual radioactive decay,
- natural heat convection from residual heat generation,
- isotope transport by gaseous and liquid effluents,
- spontaneous criticality of the radioactive residuals,
- major nuclear accident with full core meltdown.

6.2. Design

The design of NPP configuration shall take under consideration complete life cycle of the power plant, from construction through refuelling and planned maintenance to decommissioning and long-term storage of the burnt-out radioactive fuel and irradiated materials.

6.2.1. Structures.

It is required that the whole primary heat transport circuit (PHTS) shall remain below the limiting depth of **300 m** under the surface. Therefore, the design shall provide for the heat transport to the surface realised by secondary- or tertiary- heat circuits via heat exchangers and vertical pipes. Plan for structures to support such piping systems with respect to the substantial role of hydrostatic pressure. In the construction phase, cranes and lifts of sufficient capacity shall be installed for vertical and horizontal transport of very heavy components.

Design minimum one fast-closing barrier on each vertical shaft to isolate the PHTS with reactor island from upper levels of the NPP. Design gravity-actuated, normally-closed closure systems.

Position the reactor vessel near the bottom of the vertical shaft, with a core catcher underneath.

By depths exceeding 1000 m, design at least one heat exchanger station on vertical pipes to maintain hydrostatic pressure growth under **10 MPa**.

6.2.2. Components and systems.

During design stage take into consideration the requirement of the vertical and horizontal transport of very heavy items in confined spaces. The heaviest items of the power plant are; reactor vessel, heat exchangers, generator stator and turbine casings. It is, therefore, recommended to design a few smaller units instead of a single large one, to meet the thermal output of the reactor.

Evaluate the possibility of fabrication and assembly of the heaviest components at place of installation.

Consider backpressure turbines in place of condensing units.

Consider pump-free, thermal convection driven flows in the primary circuits.

Consider non-motorised, flow-, pressure-, or gravity- actuated valves in the primary circuits.

Analyse the possibility of installing the entire turbine island on the surface with respect to technical and economic aspects.

6.2.3. Refuelling and maintenance

At the design stage, consider possibility of the robotic refuelling. In this respect, Open Pool Reactors might be a preferred choice.

Foresee a place for storage of burnt-out fuel in direct proximity of the nuclear island.

Select all rotating machinery under criterion of long intervals between scheduled maintenance before mechanical/thermal efficiency considerations.

Design all components and systems for automatic, fail-safe, fully redundant mode of operation. Consider redundancy for **50 years** of the plant operation, without the necessity of replacement of the components but by switching over to the standby units.

6.2.4. Decommissioning.

It is recommended that all irradiated components of the NPP remain in-situ along with burn-out fuel, without the necessity of surface transport of any highly radioactive materials from the NPP. These include parts and components of the reactor and PHTS.

The barrier above the nuclear island shall be firmly closed, with the possibility of opening for required regular inspections at least **once per year**, during the period of **50 years after** decommissioning date.

Measure heat generation, heat convection, radioactive decay constantly throughout this period.

Design a shutdown cooling system, preferably as closed system based on thermal convection, fully enclosed under the limiting depth of **300m** below surface.

6.2.5. Long-term shutdown state.

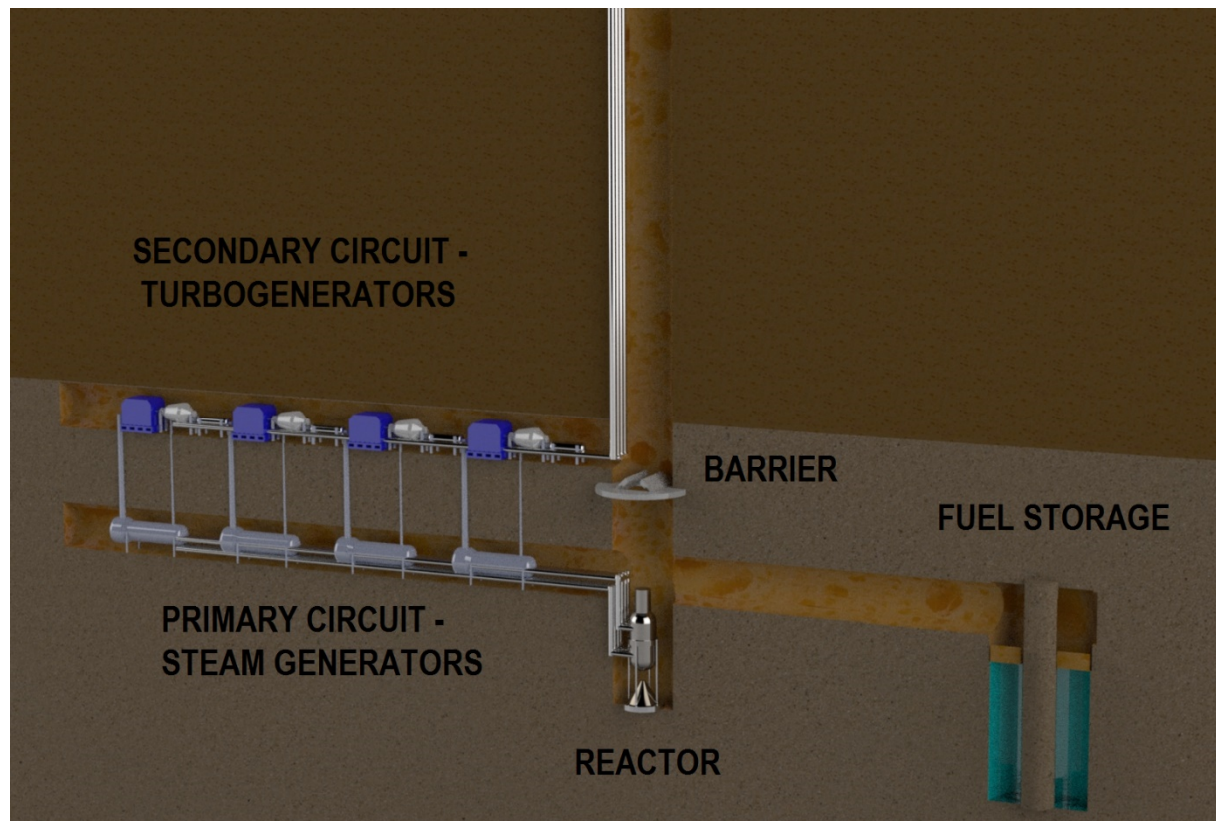
For the time **beyond 50 years** following plant decommissioning, a passive system of heat transport shall be designed for the burnt-out fuel and reactor core to prevent development of natural criticality in the radioactive residuals. Such system shall be operator-free and based on natural heat convection with heat sink located under the level of the vertical barrier.

The barriers in the vertical shafts shall be plugged with concrete of minimum **10 m** thickness.

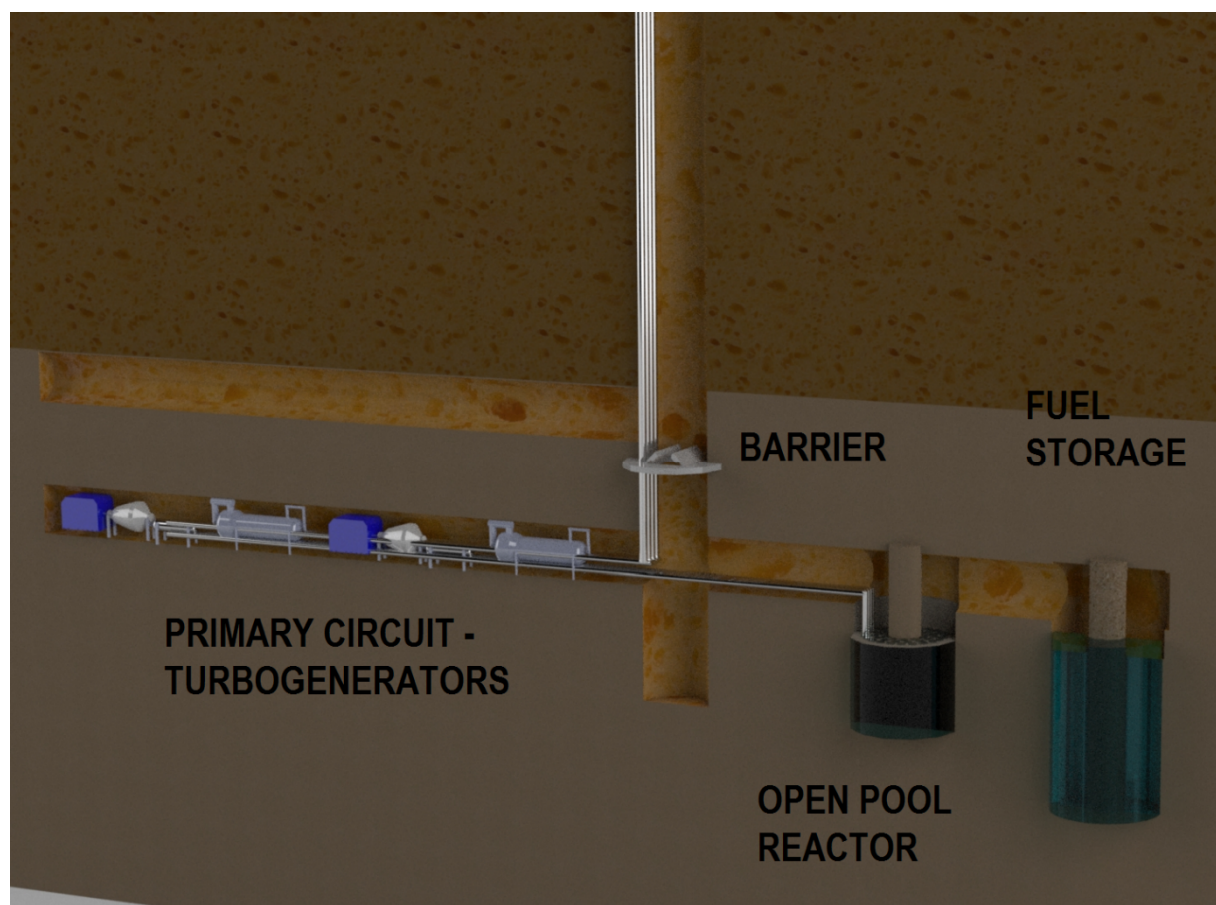
If any vertically open cavity exists less than 10 m above the reactor island and components of PHTS, it shall also be filled with concrete to form a **minimum 10 m** barrier of solid layer beyond said components.

ANNEX A. EXEMPLARY CONFIGURATIONS

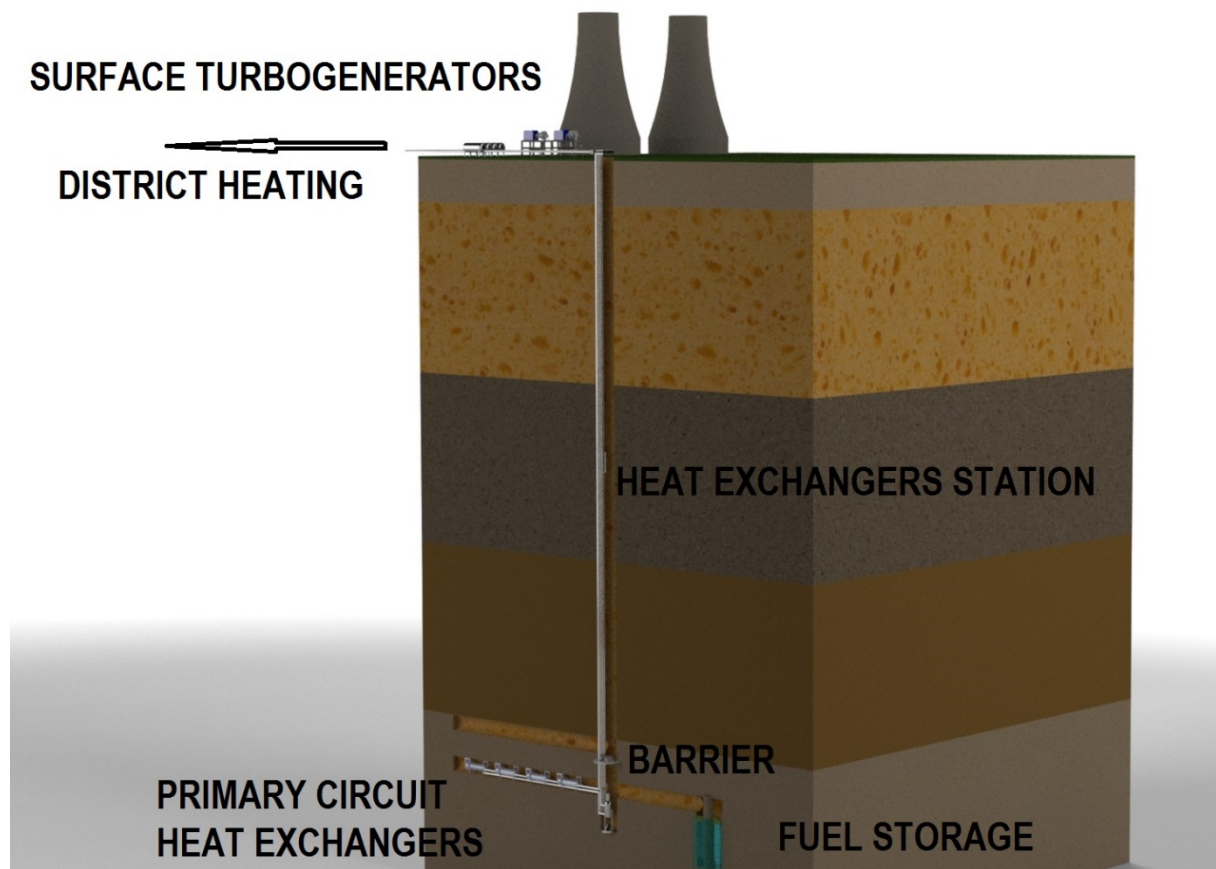
This Annex presents certain possible configuration of the NPP with nuclear island located entirely underground. Other configurations can be designed providing that they conform to the requirements of this standard.



Configuration 1 : Reactor and Steam Generators in PHTS



Configuration 2: Reactor, Steam Generators and Turbogenerators in PHTS



Configuration 3: Reactor, Heat Exchangers in PHTS; Turbogenerators on the surface