Office for Nuclear Regulation

An agency of HSE

ONR GUIDE			
Heat Transport Systems			
Document Type:	Nuclear Safety Technical Assessment Guide		
Unique Document ID and Revision No:	NS-TAST-GD-037 – Revision 2		
Date Issued:	May 2013	**Review Date:**	May 2018
Approved by:	D Senior	Director Regulatory Standards	
Record Reference:	Trim Folder 1.1.3.776. (2016/315982)		
Revision commentary:	Fit for purpose review		

TABLE OF CONTENTS

1. INTRODUCTION

1.1. ONR has established its Safety Assessment Principles (SAPs) which apply to the assessment by ONR specialist inspectors of safety cases for nuclear facilities that may be operated by potential licensees, existing licensees, or other duty-holders. The principles presented in the SAPs are supported by a suite of guides to further assist ONR's inspectors in their technical assessment work in support of making regulatory judgements and decisions. This technical assessment guide is one of these guides.

2. PURPOSE AND SCOPE

2.1. This Assessment Guide is intended to support the Safety Assessment Principles [1] and to provide general guidance on the main issues to be addressed by nuclear inspectors in the assessment of safety submissions relating to the provisions for the transport of heat generated from a variety of sources, and transmitted through intermediate hot bodies to an ultimate heat sink. The Guide applies to all systems that contribute to the safe transport of heat, by absorbing heat, by accumulating heat, by conveying heat, by providing power or by supplying fluids to act as a medium for the transport of heat including applications in both power reactors and nuclear chemical plant.

2.2. The Guide is broadly applicable both to new plant throughout the design, construction and commissioning phases, and to existing operating plant originally built to standards applicable at the time of their design. Because of development in safety standards, existing plant may not comply in every respect with current standards. Where this is the case, other factors such as the age of the plant and projected lifetime may be taken in to account in demonstrating risk is as low as is reasonably practicable (ALARP). For power reactors, the Guide covers the heat transport role of the reactor coolant system (RCS), the transport of heat to the energy converter (e.g. turbo-generators) and finally the removal of residual heat to an ultimate heat sink, together with a range of auxiliary and intermediate heat transfer systems. For nuclear chemical plant, the Guide addresses the requirement to provide or remove heat from the relevant stages in the particular process to ensure that an energy balance is maintained and controlled at an acceptable level.

2.3. The Guide does not extend to the detailed design, categorisation, qualification or specification of individual components or systems, particularly in relation to their ability to perform their safety function. What it does do, is consider the duty identified for safety related components or systems, in the broad terms of the safety functional requirements intended by incorporation of a component or system into the overall design of heat transport systems for nuclear installations.

2.4. As for all guidance, inspectors should use their judgement and discretion in the depth and scope to which they employ this guidance. Comments on this guide, and suggestions for future revisions, should be recorded on the appropriate registry file.

3. SAPS ADDRESSED

ONR's SAPs and the WENRA reference levels were re-issued in 2014. This TAG will be updated to reflect these changes in due course and in the meantime inspectors need to check that they are using the correct versions of those publications during their assessments.

3.1. The following safety assessment principles in Ref. 1 are relevant to heat transport systems:

"(EHT.1) Heat transport systems should be designed so that heat can be removed or added as required.

(EHT.2) Sufficient coolant inventory and flow should be provided to maintain cooling within the safety limits for operational states and design basis fault conditions.

(EHT.3) A suitable and sufficient heat sink should be provided.

(EHT.4) Provisions should be made in the design to prevent failure of the heat transport system that could adversely affect the heat transfer process, or safeguards should be available to maintain the facility in a safe condition and prevent any release in excess of safe limits.

(EHT.5) The heat transport system should be designed to minimise radiological doses.

(ERC.1&3) The design and operation of the reactor should ensure the fundamental safety functions are delivered with an appropriate degree of confidence for permitted operating modes of the reactor. "

Specifically:

"There should be suitable and sufficient margins between the normal operational values of safety-related parameters and the values at which the physical barriers to release of fission products are challenged.

The geometry of the core should be maintained within limits that enable the passage of sufficient coolant to remove heat from all parts of the core. Where appropriate, means should be provided to prevent any obstruction of the coolant flow that could lead to damage to the core as a result of overheating. In particular the overheating of fuel should be prevented where this would give rise to:

a) fuel geometry changes that have an adverse effect on heat transport;

b) failure of the primary coolant circuit.

The structural integrity limits for the core structure and its components (including the fuel) should ensure that their geometry will be suitably maintained."

3.2. For power reactor applications, the Reactor Cooling System (RCS) (see Table 1) and its associated systems (see Table 2) have the primary safety objective of ensuring that the fuel in the core is cooled by an appropriate coolant for all operational states and identified fault conditions. In addition, an intact RCS including its integral components and features, should act as a barrier to limit the loss of heat transport fluids and radioactive inventory from the system and particularly into the environment.

3.3. The heat transport systems important to safety are listed in Table 3. The majority of these are present to ensure that sources of heat generation are cooled sufficiently to ensure that plant and equipment continues to perform its design function and that the safety systems they serve are capable of performing their safety function under all operational and identified fault conditions. However, in addition to cooling, it may be necessary to provide trace heating to ensure sustained functioning of plant.

3.4. In the case of nuclear chemical plant, the heat transport systems are generally present to ensure that appropriate quantities of heat are supplied or abstracted to maintain the required process conditions, and ensure that the plant operates and performs its safety function in the necessary range of plant states considered in the design.

4. RELATIONSHIP TO LICENCE AND OTHER RELEVANT LEGISLATION

4.1. Licence Condition (LC) 14: Safety Documentation - The safety case for the plant, including the justification of heat transport aspects, is produced and assessed by the licensee under this condition, which also requires documentation to be submitted to HSE on request.

4.2. Licence Condition (LC) 15: Periodic Review - The adequacy of the safety case, including heat transport aspects, should be reviewed against the current operating conditions and statutory requirements to ensure that there has been no significant change (e.g. increase in fouling, tube plugging etc sufficient to invalidate the safety case).

4.3. Licence Condition (LC) 19: Construction or Installation of New Plant - The design of the heat transport system should be considered at an early stage, and appropriate testing should be carried out to ensure that the systems meet the design specification.

4.4. Licence Conditions (LC) 20 and 22: Modification to plant - Such modifications should be assessed to ensure that they do not impact adversely on the design heat transport capability of the plant.

4.5. Licence Condition (LC) 21: Commissioning - Appropriate commissioning tests should be carried out to ensure, for example, that design criteria have been met.

4.6. Licence Condition (LC) 23 and 24: Operating Rules and Instructions - These will be required, for example, in respect of availability of heat transport systems.

4.7. Licence Condition (LC) 25: Operational Records - These may include, for example, records of temperatures, pressures and flow rates of heat transport fluids.

4.8. Licence Condition (LC) 27: Safety Mechanisms, Devices and Circuits - The suitability and sufficiency of the heat transport systems should be assessed to comply with this condition.

4.9. Licence Condition (LC) 28: Examination, Inspection, Maintenance and Testing - It is expected that heat transport system components such as pumps, valves and heat transfer surfaces would form part of the licensee’s site-wide arrangements under this licence condition.

5. ADVICE TO ASSESSORS

5.1. General

1) It is particularly important in nuclear applications to ensure, so far as is practicable, that safety-related equipment will perform its function with an adequate reliability despite the potential for the occurrence of postulated faults and/or hazards. This objective may be assured by the adoption of a number of different plant and equipment provisions, together with the use of techniques to evaluate the adequacy of the specified measures.

2) In assessing the fitness for purpose of safety related plant, and particularly the ability to perform a safety function, it is necessary to first define the qualified operating envelope for equipment and the design limits for components. This data acts as constraints to the thermal design process and needs to be supported with evidence of strength dependent on the risk significance of the equipment and the demonstrated safety margins in the design. Where the equipment qualification is dependent on a number of factors, it is necessary to ensure that these are not each considered in isolation when analysing the anticipated normal and fault conditions. Further guidance on the engineering principles to apply is found in [1].

3) The assessment of the adequacy of heat transport systems is generally focused on the consideration of the transient response of the system in the event of a fault occurring from the most limiting operating condition that could reasonably be anticipated. Judgements on what constitutes a reasonable set of assumptions are based on consideration of the risk. This is discussed in T/AST/035. However, a demonstration of sound engineering principles should not rely solely on arguments relating to the anticipated likelihood of equipment failure.

4) Consideration should be given to plans for commissioning. In particular, ONR would normally expect tests to be performed to demonstrate claims on novel aspects of the design and to validate models used in computer codes as part of the design substantiation.

5) In addition to this probabilistic treatment of the risk arising from the design of an installation, attention should be paid to the appropriate codes, standards and methods used in specifying the deterministic plant design.

6) A suitable design will usually employ the concepts of Defence in Depth [2]. This is provided by a combination of suitable diversity, redundancy, conservatism, engineering quality and inherent safety.

7) Finally, the safety of plant operators in both maintenance and fault conditions should be considered, particularly where manual operations may be required in response to anticipated fault conditions.

5.2. Identification of Heat Loads

1) A starting point in an assessment of the heat transport provisions at nuclear installations is the identification of all forms of heat load likely to affect a particular process. Consideration should be given to whether the following could be significant:

    1) Energy deposited by a flux of radioactive particles;
    2) Chemical energy released e.g. combustion or oxidation;
    3) Mechanical or electrical energy deposited in the equipment.

2) Particular attention should be given to ensuring adequate heat removal from equipment used in auxiliary systems. This includes reliable cooling of lubrication and shaft sealing systems as well as cooling for electrical equipment.

3) Compilation of a schedule of such heat loads may be useful in demonstrating the cooling requirement of a process and the level of cooling margin present in the measures provided to perform this function.

5.3. Maintaining Cooling Capability

1) Most often the process cooling medium is an appropriate fluid, which has the potential to leak from its containment and mix with the surroundings. The consequences of this occurrence need to be considered, in terms of possible adverse reactions with the surroundings generating additional heat, the system ability to maintain its cooling function and any possible radiological consequences.

2) Where the heat transport fluid is pressurised water or steam, successful cooling may depend on the fluid pressure being kept within an acceptable range related to saturation temperatures. It should be ensured that this range can be maintained by the pumps delivering feed water and by the valves controlling the discharge pressure and that the heat removal system can withstand the fluid pressures and temperatures generated. Particular care is needed to ensure that plant transients do not generate damaging shock waves by water hammer and that sufficient subcooling of fluid is maintained at the inlet to pumps to avoid cavitation on impeller surfaces.

3) Where there is doubt about the cooling capability of a faulted heat transport system, or its reliability, alternative measures should be provided to back-up the primary provision. In some circumstances where a particular heat transport system contributes fundamentally to plant safety, it may be prudent to provide back-up systems regardless of predicted plant reliability and performance. Particular examples of heat transport systems with important safety functions are discussed further in Appendix 1 and in the supporting references.

4) In cases where the heat transfer system is relied upon to meet a primary safety function within the Design Basis of the plant, there is likely to be a need to demonstrate a minimum level of redundancy and (where common-mode failure can not be discounted) diversity of equipment.

5.4. Monitoring Coolant Provision and Condition

1) Loss of coolant in a heat transport system has the potential to allow local temperatures to rise which may challenge a system safety function and may dramatically increase the risk from the plant. To guard against excess coolant loss, safety systems should include a means of monitoring coolant levels and/or direct leak detection to facilitate early detection of coolant loss. This needs to be associated with provision for isolation of affected plant where reasonably practical. The design of heat transport systems should ensure that nonessential parts of the systems can be isolated.

2) On detection of coolant loss, reserve supplies of coolant should be available to provide make-up or an alternative cooling provision. Such measures should be capable of responding in the time scales required to prevent rapid progression of a routine make-up requirement or a fault scenario. In some applications it may be necessary to provide separate safety systems to provide appropriate cooling provision in the short term and in the longer term. Sufficient stocks of coolant should be provided to ensure adequate cooling after all postulated faults within the design basis and adequate provision should be made to replenish stocks and ensure long-term heat removal.

3) Where routine leakage, let-down, by-pass, evaporative loss or overflow can occur, where practical provision needs to be made to collect the extraneous coolant, and measures taken to allow reuse if possible and safe storage if not. Where possible, coolant inventory

should be adequately monitored, in order to control the total quantity of coolant resident in a safety system.

5) Where coolant is recycled, the licensee should ensure that plant is provided to maintain the condition of the coolant within specified limits of performance. These limits should be identified by the licensee, documented and included in the procedures developed to ensure that the nuclear facility functions within specification.

6. APPENDIX 1 - TECHNICAL GUIDANCE

6.1. General

1) The assessor is advised that the following sections should be considered in the assessment of the heat transport aspects of a safety case. The safety aspects described may not be totally comprehensive and may not be applicable in all circumstances. The assessor will need to utilise expertise, experience, appropriate advice and engineering judgement in the consideration of each particular safety case.

2) In order to limit potential releases of radioactivity to workers and the public to as low as is reasonably practicable from a nuclear installation, it is necessary to set appropriate design limits to provide defence in depth against an intolerable radioactive release. A subset of these limits will be controlled via the arrangements under LC 23. In general terms, this requires provisions to prevent:

   i) overheating of the fuel elements or an excess of alternative sources of process heat, chemical heating or nuclear heating;

   ii) loss of integrity of any primary barriers or pressure containment;

   iii) loss of integrity of any intermediate barriers or additional containment provisions.

   iv) loss of safety significant equipment.

3) In deciding what constitutes a tolerable potential release of radioactivity to workers and the public, guidance should be obtained from the SAPs, and particularly T/AST/030.

4) To reduce the risk of an unacceptable release of radioactivity to workers and the public, it is likely that the design of heat transport systems will need to possess a number of important features which are intended to improve system reliability and enhance the safety functional performance of the plant. These characteristics are likely to include the following:

   i) appropriate level of inherent system and functional reliability;
   ii) satisfactory performance against the single failure criterion;
   iii) inclusion of appropriate levels of redundancy into the safety system;
   iv) incorporation of diverse equipment into redundant trains where possible to reduce the potential effects of common-cause failures;
   v) segregation of redundant trains of equipment where possible;
   vi) ensure functional independence where necessary;
   vii) inclusion of principles of a fail-safe design;
   viii) provision of auxiliary safety system back-up;
   ix) appropriate safety categorisation/classification of plant and equipment;
   x) employ robust provisions for faults and hazards;
   xi) the use of proven components.

5) These aspects of safety system functional performance are covered in detail in other Assessment Guides.

6) In order to assess the adequacy of heat transport provisions, it is necessary to identify potential heat sources and sinks within the system boundary. Heat loads and design temperature limits should be considered. Consideration of heat flows within a system should address the necessary range of commissioning, operational and identified fault conditions which might make demands on the heat transport systems. It may also be prudent, at an early stage, to consider any particular heat transport requirements relating to decommissioning of the facility.

7) The operating parameters need to be constrained to ensure a suitably stable flow distribution and the local velocities must be low enough to avoid excessive hydrodynamic excitation of the structures and flow-induced corrosion. This is particularly true of heat-transfer surfaces, where the requirement for a high power density tends to result in small margins to these limits.

8) Where a quantitative assessment of the heat flows within a system is required, it should be ensured that the system capabilities are specified on the basis of a suitably pessimistic consideration, with appropriate allowances for uncertainties included in the calculation.

9) Where claims of diversity are made between system components, care should be exercised to ensure that the intended benefits are realised and not undermined by practical compromises required to deploy suboptimal equipment or arrangements.

10) Consideration should be given to the benefits of functional isolation and physical separation of redundant subsystems.

11) In many locations of safety significance on a nuclear installation (e.g. the main control room) the local environmental conditions are controlled by the heating ventilation and air-conditioning control system (HVAC). This system controls the air supply to a location and may be required to extract heat generated by plant and instrumentation. In a fault or accident scenario, rejection of this heat to an ultimate heat sink may be important for long-term functioning of a range of safety systems. For locations of primary safety significance, the heat transport function of the HVAC will need to have a high level of reliability.

12) Consideration of system operability and maintainability needs to include facilities for venting and draining of the coolant and safe isolation of components to facilitate maintenance or to mitigate faults.

13) Arrangements for inspection and testing and for the calibration of instrumentation used to monitor the system should be in accordance with the safety categorisation of the system.

14) The general expectation is that where manual operation of plant is required, that there will be a provision for this to occur remotely; from the plant control room or an alternative control point.

6.2. Power Reactors

1) The design of the Reactor Coolant System (RCS) should be such that no postulated internal or external initiating event could give rise to serious plant conditions that could affect the integrity of the fuel cladding or the pressure boundary of the System [4].

2) The design should be so laid out that no external event or internal hazard considered in the design (such as a pipe break or a flood) has the potential to prevent the system from performing its intended safety functions. In particular, for safety Class 1 and 2 systems [1][4], the capability of the system and its components should be maintained under the most severe seismic conditions considered in the design. Moreover, the system should be so designed that no single failure could prevent the fulfilment of its intended safety function or those of other systems [4].

3) Specific considerations for the assessment of the consequences of hazards are found in T/AST/014. For the purposes of this TAG, it is important to note that system design should include sufficient segregation of redundant cooling trains and sufficient diversity to reduce the likelihood of common-mode failure of the heat removal system to an acceptable level.

4) The main source of heat within a nuclear power reactor results from the nuclear reaction taking place within the reactor core. After a reactor is shutdown decay heat continues to be produced at a decreasing rate, but in many designs, the maintenance of coolant conditions is necessary to ensure adequate control of the nuclear processes and to ensure that the reactor remains shutdown.

5) In addition, heat can be supplied from a range of other sources including heat created by mechanical work, heat supplied by chemical reactions, heat supplied by nuclear reactions outside the core (e.g. fuel route).

6) For power reactors (with a few exceptions such as boiling water reactors (BWR)) the primary means of heat removal from the reactor coolant system is the heat exchanger (called either a boiler or steam generator depending on the design), which transfers heat from the primary to the secondary circuit – where the energy is utilised. To maintain a stable process for converting the feed water into steam, active control of boiler feed flow rates is generally required and in some designs, measures are required to adjust spatial flow distribution.

7) The feed flow to the boiler must be sufficiently high to ensure that parts of the tube bundle designed to remain wet are not damaged by drying out, while the flow must not be so large as to transport water droplets to parts of the plant where they could cause damage or carry activity to the turbine hall.

8) The system must include provision for the management of particulate deposited on flow surfaces and the potential affects of this on heat transfer and flow distribution.

9) Ultimately, all heat not utilised to generate power or absorbed by the surroundings, needs to be exchanged with a final heat sink to prevent unacceptable temperature rises in the plant. The general requirement for this heat sink is that it has a sufficiently large capacity not to be significantly affected by the absorption of heat from the relevant processes so that its thermal properties and conditions remain essentially independent of the particular or related nuclear process. Such a heat sink is usually referred to as an ultimate heat sink (UHS). Two common forms of UHS are: substantial bodies of water (rivers, lakes or the sea) and also the atmosphere.

10) The role of the UHS is essential in maintaining the heat flows under adequate control. For this reason it is sometimes considered necessary for nuclear safety reasons, to make a redundant provision for heat transfer to an ultimate sink by using both water cooled and air cooled safety systems. Natural phenomena and human-induced events need to be accounted for in making this consideration [3], including a full range of external hazards.

5.3 Light Water Reactor (LWR) Reactor Types

1) For the LWR reactors (pressurised water reactor (PWR) and BWR) the primary coolant is pressurised to avoid a phase change and to achieve a high power density. It follows that a major loss of coolant accidents has the potential to result in rapid loss of primary coolant and a marked reduction in the efficiency with which heat is removed from the fuel. A complex system of coolant injection is therefore required together with a secondary containment building to contain activity released with the coolant.
2) Where a breach in the primary circuit pressure retaining boundary occurs, the environment within the reactor containment may be heated significantly. Under these conditions, systems are required to assist in the removal of the excess heat from the containment and to limit the containment pressure. In the event of fuel overheating, there may also be a requirement to limit the concentration of hydrogen gas in the containment atmosphere to tolerable levels.
3) In the event of the need to recirculate cooling water from the containment building sump, care needs to be taken to ensure that there is sufficient provision to remove fibrous material (such as insulation) from the coolant flow. Small quantities of this material entrained into the reactor core can significantly restrict coolant flow and heat removal.
4) In the event of a severe accident, where corium escapes into the containment building, it may also be necessary to flood the containment-building sump to minimise damage to the concrete base mat and the release of carbon dioxide resulting from core-concrete interaction.
5) Such a role may be provided by local water spray systems and fan coolers, but ultimately there is a need to provide an ultimate heat sink for heat generated in the containment building in severe accident conditions.
6) During refuelling, the normal heat removal by the main steam system is often not available (particularly if the pressure vessel head is open) and heat is removed from the reactor core using a residual heat removal system. This operating state requires particular attention to ensure that adequate levels of system resilience are preserved.

5.4 Gas Cooled Reactors

1) The concrete pressure vessels of the gas cooled reactors have particular cooling requirements because concrete degrades at elevated temperatures and therefore the surface of the vessel needs to be cooled during normal operation and fault conditions. A gas-tight steel liner which provides a seal for primary coolant retention and layers of foil insulate the vessel from the primary circuit gas. During operating and fault conditions a separate heat transport system is provided to maintain the liner temperature within acceptable limits.
2) Similarly, the vessel design includes steel penetrations for entry of pipework and instrumentation as well as for refuelling. These penetrations need to be adequately cooled to avoid loss of RCS integrity.
3) In the short term, faults can be mitigated by tripping the reactor and allowing the heat generated in the core to be stored in the graphite, but post-trip cooling needs to be established urgently both to ensure that the fuel remains within its design limits and to ensure that the core does not return to power as a result of the rising moderator temperature. Heat can be removed by natural circulation of gas within a pressurised RCS and by forced cooling otherwise.

4) Gas cooled reactor boilers have a role of fundamental importance in removing heat from the primary circuit. The importance of this role is reflected in the high level of reliability required for this function and the provision of both diverse and redundant boiler feed systems.

5) It is necessary to ensure that hot gas from the core outlet does not reach the bottom of the boilers and the lower core support structures as these are not designed for sustained high-temperature operation. It is therefore important to isolate boilers that are not in service to ensure that they do not act as a flow path for hot gas.

5.7 Nuclear Chemical Plant

1) For nuclear chemical plants, many of the safety requirements discussed in the preceding general text and that on power reactors may also apply, although the specific plant provisions to achieve a safety function may be quite different.

2) On nuclear chemical plant, the supply or abstraction of heat from the process is the primary function of the heat transport provisions. There may be a variety of mechanisms whereby heat can be produced or accumulated at a number of points in a process during operation and identified fault conditions, and these need to be considered in the design and assessment of heat transport systems for such plant.

3) For each process involved at a nuclear chemical facility, potential heat sources and sinks should be identified and recorded in a schedule of heat loads for the plant. The potential for exothermic chemical reactions should be considered and controlled by design as far as is reasonably practical. The list translates to a requirement for adequate heat transport systems to maintain the heat loads under control within the design temperature limits at all points in the process. Passive heat transport systems (e.g. radiation or natural convection) are preferable to active systems (e.g. forced convection).

4) In assessing the heat loads, the potential for release of internal energy, accumulated in the reactants or stored material should be included in the heat transport calculations. Where the potential exists for large quantities of additional heat being available from a source, appropriate measures should be considered to ensure that potential heat liberation is reduced to acceptable levels within the capacity of the heat transport systems provided.

5) Where heat-generating nuclear materials are intended to be stored, a record of the items retained in the store and the cooling requirements of the stored material needs to be maintained. The quantity and arrangement of such material also needs to be considered in relation to the heat transport systems provided to ensure that temperature limits are maintained within acceptable levels, bearing in mind that it may be difficult to isolate a storage facility or its safety systems. The systems provided should have the capability to ensure acceptable temperatures throughout the material retained in the store, for all operational and identified fault conditions for the complete duration of the anticipated storage period.

6) Prior to plant modification or decommissioning activities being undertaken on a nuclear chemical facility, a re-evaluation of the potential heat loads should be undertaken to ensure that the provisions for safe and adequately controlled heat transport will remain sufficient throughout the process to be undertaken.

7. REFERENCES

1. Safety Assessment Principles for Nuclear Plants (2006).
2. IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles, (2006).

3. IAEA Safety Standards Series No. SSR-2/1, Safety of Nuclear Power Plants: Design Specific Safety Requirements, (2012).
4. IAEA Safety Standards Series. NS-G-1.9, Design of the Reactor Coolant System and Associated Systems in Nuclear Power Plants - Safety Guide, (2004).
5. 10-CFR-50 - Code of Federal Regulations - USA Code for NPP Design Compliance.
6. WENRA Reactor Safety Reference Levels, January 2008.

Table 1

MAIN POWER REACTOR COOLANT SYSTEM COMPONENTS

The following listings give typical examples of the main components and equipment comprising the reactor coolant systems for various reactor types.

PWR

(a) Reactor vessel and primary circuit, with the closure head assembly;

(b) Reactor vessel internals (other than fuel assemblies and core support structures) necessary for the proper flow of the primary coolant, such as the core barrel;

(c) Reactor coolant side (tube side) of the steam generators;

(d) Reactor coolant pumps including the first stage seals;

(e) Pipes that, together with the tube side of the steam generators and the reactor coolant pumps, constitute the coolant loops:

- a hot leg between the reactor vessel and the steam generator of each loop,
- a crossover leg between the steam generator and the pump of each loop,
- a cold leg between the pump of each loop and the reactor vessel;

(f) Pressuriser with its relief valves, safety valves and piping connecting it to the coolant loop piping;

(g) Pipes bypassing the steam generators and the reactor coolant pumps and used for measuring the temperature of each loop;

(h) Reactor vessel appurtenances such as control rod drive mechanism pressure housing;

(i) Auxiliary systems connected to a loop up to and including the isolating devices;

(j) Components such as valve actuators and pump drives associated with (a)-(i).

MAGNOX/AGR

(a) Reactor vessel and primary circuit, with all internal insulations, external removable closures and fuelling machine when connected to a channel;

(b) Primary coolant pressure retaining parts of reactor vessel penetrations provided for the transfer of feed steam and services through the pressure boundary;

(c) Reactor coolant circulators and seals;

(d) Gas baffle assembly including core supporting structure;

(e) Reactor core channel extensions provided to segregate core inlet and outlet gas (guide tubes);

(f) Reactor moderator and associated equipment;

(g) Connections to the gas processing plant and secondary shutdown, reactor auxiliary and instrumentation systems up to and including the isolating devices;

(h) Reactor coolant safety relief valves and their connections to the reactor pressure vessel;

(i) Main boilers, reheaters and decay heat removal boilers located within the pressure boundary;

(j) Components such as valve actuators and pump drives associated with (a)-(h).

Table 2

REACTOR COOLANT SYSTEM - ASSOCIATED SYSTEMS

Associated Systems

(1) Systems directly associated with the RCS and which perform functions such as:

- emergency core cooling (by pumped or passive means);

- residual heat removal;

- reactor coolant chemical and inventory control including reactor coolant clean up;

- transfer of mass and heat and conversion to steam by the main stream and feedwater system or emergency feedwater system (for direct cycle designs this is limited to those portions of the systems not included in the RCS);

- transfer of heat by intermediate cooling loops from systems containing reactor coolant to the ultimate heat sink.

- containment cooling systems.

- transfer of heat from moderator.

(2) The systems connected to the RCS or to those systems listed in (1) above such as:

- drain lines (including seal leakage lines);

- safety or relief valve discharge lines up to and including any associated equipment;

- instrument lines;
- sample lines;
- surge lines;
- fill and vent lines;
- relief tanks.

Table 3

HEAT TRANSPORT SYSTEMS CONNECTED TO AN ULTIMATE HEAT SINK

(1) Circulation of sea water once through heat exchangers.

(2) Circulation of fresh water (or stored water) once through heat exchangers.

(3) Recirculation of water through a spray pond.

(4) Recirculation of water from a lake or reservoir or large pond.

(5) Evaporation of heat in steam generators.

(6) Dry cooling towers.

(7) Wet cooling towers with make-up facility, or wet/dry tower combinations.

(8) Conduction, convection or radiation from structures.

(9) Condensing systems.

(10) Spray systems.

(11) Forced convection through heat exchangers.

(12) Containment cooling systems.

(13) RPV cooling systems (external).

(14) Trace heating provisions (e.g. frost protection).