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4S Safety Design Criteria

September 2012

TOSHIBA CORPORATION

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LIST OF ACRONYMS AND ABBREVIATIONS

4S	Super-Safe, Small and Simple
ANS	American Nuclear Society
ANSI	American National Standards Institute
CFR	Code of Federal Regulation
CACS	Containment Atmosphere Cleanup System
CHRS	Containment Heat Removal System
CRBR	Clinch River Breeder Reactor
DA	Design Approval
ECCS	Emergency Core Cooling System
EPS	Electric Power System
GDC	General Design Criteria or Criterion
HVAC	Heating, Ventilation, and Air Conditioning
LMR	Liquid Metal Reactor
LOCA	Loss of Coolant Accident
LWR	Light Water Reactor
NRC	United States Nuclear Regulatory Commission
PDC	Principal Design Criteria or Criterion
PRISM	Power Reactor Innovative Small Module
PS	Protection Systems
RCB	Reactor Coolant Boundary
RHRS	Residual Heat Removal System
RVACS	Reactor Vessel Auxiliary Cooling System
RV	Reactor Vessel
SSCs	Structures, Systems, and Components
S&HER	Structures and Equipment Heat Removal
TEDE	Total Effective Dose Equivalent
UPS	Uninterrupted Power Supply

1 INTRODUCTION

The regulations of §50.34 of Title 10 of the Code of Federal Regulations (10 CFR 50.34) requires applicant of the Principal Design Criteria (PDC) for license application. The PDC is defined as very important safety policy by 10 CFR 50 Appendix A [1] as follows:

" The principal design criteria establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety; that is, structures, systems, and components that provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public."

On the other hand, the General Design Criteria (GDC) established by 10 CFR 50 Appendix A is intended to be used for the light water reactor (LWR) and some of criteria are not applied to fast reactor. Thus Toshiba established the 4S PDC which is based on 10 CFR 50 Appendix A (LWR's GDC) by referring past license application in U.S such as CRBR (NUREG 0968) [2] and PRISM (NUREG 1368) [3]. In addition, ANS/ANSI 54.1 (1989 ver.) criteria [4] and result of study by NRC regarding passive safety design (SECY-94-067) [5] are also taken into account.

Toshiba has presented PDC to the United States Nuclear Regulatory Commission (NRC) staff on third pre-application meeting on the 4S [6] and previously submitted technical reports to the NRC. In this report, Development of 4S PDC and 4S PDC themselves are described. 4S PDC based on this report are to be reflected to safety analysis report on Design Approval (DA).

Section 2 describes the purpose and scope of this report. Section 3 presents the developing 4S principal design criteria. Section 4 summarizes the main conclusions of this report. Appendix A describes 4S PDC.

2 PURPOSE AND SCOPE

2.1 Purpose

The purpose of this report is twofold:

1. To indicate the concept and content of PDC for 4S design approval at NRC.

2. To obtain NRC feedback on the above items in order to identify and resolve any outstanding issues and facilitate the 4S Design Approval process.

2.2 Scope

The items to be covered in this technical report are as follows:

- PDC applied to 4S reactor and its defined concept

This technical report consists of following chapters to cover the scope mentioned above:

- Development of 4S PDC (Chapter 3),

- Conclusion (Chapter 4),

These items described above have been already explained in the third NRC Pre-review meeting [6]. This technical report intends to cover more detailed information than previous materials.

3 DEVELOPMENT OF 4S PRINCIPAL DESIGN CRITERIA

This chapter describes the procedure and review result of the principal design criteria for 4S.

3.1 Approach for Developing 4S Principal Design Criteria

As the 10 CFR 50 Appendix A describes, GDC [1] are intended to establish minimum requirements for the design of LWR plants:

"*The General Design Criteria are also considered to be generally applicable to other types of nuclear power units and are intended to provide guidance in establishing the principal design criteria for such other units*"

In order to adapt the 4S characteristics to GDC, the LMR-based Principal Design Criteria has been developed. The procedure is presented as follows.

A basic policy of the development of 4S PDC is maintained neither addition of LWR GDC nor deletion as much as possible. And the development of 4S PDC is considered past application for the fast reactor in the United States and the standard of LMR are considered.

LWR GDC were evaluated for applicability and completeness of 4S safety design. 4S design concept, Clinch River Breeder Reactor (CRBR) safety evaluation report [2], Power Reactor Innovative Small Module (PRISM) safety evaluation report [3] and ANS/ANSI 54.1 standard [4] were reflected to this evaluation. Moreover applicability of NRC accepted approach as for passive reactor [5] was considered in this evaluation. LMR GDC could be established by applying applicable, modified, inapplicable and new criteria. 4S PDC has been established based on evaluation results.

This procedure of developing PDC for 4S is shown in Figure 3-1.

3.2 Development of Principal Design Criteria

3.2.1 Evaluation of applicability and adequency

Evaluation of the applicability and adequacy of the GDC to the 4S reactor took into account past LMR licensing experience and LMR related standards, listed as follows:

(1) Principal design criteria accepted by the NRC for the CRBR and PRISM LMR.

(2) LMR standards related to general safety design criteria [4], and liquid metal fire protection [7].

(3) NRC accepted approach as for passive reactor and regulatory treatment of non-safety systems that provide defense in depth to passive features [5].

LWR-specific items are not applied to LMR described as follows:

- LWR design-basis LOCA (double-ended pipe rupture)
- High pressure reactor coolant boundary
- ECCS (Emergency Core Cooling System)
- Xenon buildup after shutdown
- Add boron (poison) to ECCS as a backup shutdown feature
- LWR torus and sumps as components of the containment heat removal system

LMR-specific items are selected as follows:

- Mitigate and prevent measures against sodium and sodium reaction product
- Sodium heating systems
- Sodium and cover gas purity control system
- Minimize fuel handling error

Passive safety system specific item is selected as follows:

- Treatment of non-safety system in passive reactor design

4S-specific item is selected as follows:

- Use of reflector as reactivity control system

3.2.2 The feature of developed PDC

4S PDC were established based on evaluation results. The basic structure is shown Figure 3-2. The structure of 4S PDC is same as LMR GDC. Applicable, main modified points or inapplicable of each criterion are shown in Figure 3-3.

LWR-specific items are not applied to LMR described as follows:

- Remove the LWR-specific reference such as LOCA and ECCS
- Replace reactor coolant pressure boundary by reactor coolant boundary
- Delete “including Xenon burnout”

- Delete “such as the torus, sumps, spray nozzles, and piping”

LMR-specific items are selected as follows:

- Proper account for sodium and sodium reaction product
- Add a PDC on Sodium heating system
- Add a PDC on Sodium and cover gas purity control
- Add statement to minimize potential of fuel handling error by design

Passive safety system specific item is selected as follows:

- Add a PDC and modifying some PDC on treatment of non-safety system in passive reactor design based on NRC recommendation

4S-specific item is selected as follows:

- Replace control rod by control element

Evaluation of each criterion is described in section 3.2.3.

3.2.3 Evaluation of acceptability of each criterion to 4S and developed PDC

LMR specific technical terms and inapplicable or modified points of each criterion of LWR GDC to 4S PDC are described in this section.

Intermediate coolant system: Those components such as heat exchangers, pumps, tanks and connecting piping which contain intermediate coolant and are necessary to transport reactor core heat from the reactor coolant system to the principal heat removal system. (Based on ANS/ANSI 54.1 [4])

Reactor coolant boundary: Those facilities which contain reactor coolant at normal operation and form coolant boundary under anticipated operational occurrences and accidents, whose failure leads to accident of leak of reactor coolant. The components combined reactor coolant boundary with reactor cover gas boundary form close-boundary against radioactive materials from reactor.

Reactor cover gas boundary: Those facilities except reactor coolant boundary which contain reactor cover gas and reactor coolant at normal operation and form boundary under anticipated operational occurrences and accidents, whose breakage leads to accident of leak of radioactive materials from reactor cover gas or reactor coolant.

Reactor residual heat removal system: The system which removes residual heat from the reactor and transports it to the ultimate heat sink. This system may use the normal heat transport system, a separate system, or a combination thereof. (Based on ANS/ANSI 54.1[4])

Inapplicable or modified points of each criterion LWR GDC to 4S PDC are described in this section as follows and these results are summarized in Table 3-1.

I. Overall Requirements

Criterion 4 is generally applicable except the LOCA which is non-practical event for LMR. In order to be consistent with NRC recommendation for the PRISM LMR [3], the statement "including loss of coolant accident" is replaced by "including effects of sodium, its aerosol and combustion products".

New criterion 6 is added. It is same as Criterion 3.1.4 in ANSI/ANS-54.1-1989 standard, "general safety design criteria for a liquid metal reactor nuclear power plant" [4]. This criterion applies to both sodium and sodium-potassium alloy (NaK) metal coolants. It is modified to apply to only sodium. It is added as PDC 6.

New criterion 7 should be added. It reflects on the intent of the NRC accepted approach for treatment of non-safety systems used in passive plant designs described in SECY-94-084 [5]. The approach provides the advantage of integrating the design process with safety and performance analysis, and regulatory oversight through the life cycle of the project. This enhances an optimum safety-focused design and operation of the 4S reactor. It is added as PDC7.

II. Protection by Multiple Fission Product Barriers

Criterion 13 is general enough to apply to all reactor types with one exception. Due to low pressure system of LMR, "reactor coolant pressure boundary" is replaced by "reactor coolant boundary"

Criterion 14 is applicable to the 4S reactor with one exception, same as Criterion 13.

Criterion 15 is applicable to the 4S reactor with two exceptions. In order to be consistent with the NRC recommendation for the PRISM LMR [3], sodium heating systems is added to the list as systems in the criterion. Another exception is same as Criterion 13

Criterion 17 is applicable to the 4S reactor by considering following exceptions. (1)The passive safety system of 4S reactor is designed to operate without offsite power or safety grade onsite ac power. Design and performance requirements for the onsite ac power sources will be determined by using the approach for treating non-safety systems for passive plant designs described under criterion 7. (2) “coolant boundary” is used for LMR without the “pressure” qualifier. (3) “One of these circuit shall be designed to be available with in a few second following a loss of coolant accident to assure that core cooling, containment integrity, and other vital safety functions are maintained” is deleted because requirements for LOCA are not applied to LMR.

Criterion 19 is applicable to the 4S reactor with three exceptions; (1) “accident conditions including LOCA” in the first sentence is replaced by “accident conditions including those form sodium reactions”, and (2) change “rem” limit for whole body and thyroid to Sv and TEDE unit, (3) since sodium melts at 98 °C, which is not a “cold” temperature, the phrase “cold shutdown” at the end of item 2 of GDC 19 is replaced by ”any coolant temperature lower than hot shutdown.”.

III. Protection and Reactivity Control

Criterion 23 is applicable to the 4S reactor with one exception. The phrase “sodium and/or sodium reaction products” is added to the list of adverse environment.

Criterion 25 is applicable to the 4S reactor with two exceptions. (1)The phrase (rod ejection or dropout) is removed since rod ejection due to low pressure in reactor vessel and dropout are not possible for LMR; therefore, such a qualifier is not necessary. (2) “rod” is changed to “elements” because 4S uses the reflector for reactivity control.

Criterion 26 is applicable to the 4S reactor with three exceptions, (1) Xenon burnout is not a concern for LMR, (2) “rod” is changed to “elements” because 4S uses the reflector for reactivity control, and (3) “cold conditions” in last sentence is replaced by “the lowest temperature associated with any normal operating condition”.

Criterion 27 is applicable to the 4S reactor with two exceptions, (1) “in conjunction with poison addition by the emergency core cooling system” that is not used in LMR is removed, (2)”rod” is changed to “elements”.

Criterion 28 is acceptable with three exceptions: (1)“reactor coolant pressure boundary” is replaced by “reactor coolant boundary”, (2) since rod ejection, dropout and steam line rupture are not possible for LMR, they are replaced by “accidental withdrawal of control elements, (3) the word “water” in the last sentence is replaced by “sodium”.

IV. Fluid Systems

Criterion 30 is applicable to the 4S reactor with the recognition of LMR’s lower coolant pressure than LWR’s. Therefore the term “coolant pressure boundary” is replaced by “coolant boundary”.

Criterion 31 is applicable, similar to the previous criterion, (1) “coolant boundary” is used for LMR without the “pressure” qualifier. (2) In order to be consistent with the NRC recommendation for the PRISM reactor, the following degradation factors are added: “service degradation of material properties, creep, fatigue, stress rupture”, and the effect of “coolant chemistry”.

Criterion 32 is applicable to the 4S reactor except the “pressure” qualifier of the coolant boundary.

Criterion 33 is not applicable. The coolant pressure of LMR is much lower than that of LWRs. Reactor coolant makeup is not needed. As an alternative to GDC 33, the NRC suggested the use of LMR-specific criterion, such as that of Section 3.4.1 of ANSI/ANS-54.1-1989 standard.

Criterion 34 does not address innovative passive designs. An amendment to the criterion is shown in the 4S principal design criteria where requirements for innovative passive residual heat removal systems to retain the reliability level as redundant active systems are defined.

This criterion requires the residual heat removal system (RHRS) to have redundant components and to be able to perform its function with assuming either onsite or offsite electric power's single failure.. 4S Reactor Vessel Auxiliary Cooling System (RVACS) is a passive system that relies on natural circulation of the primary sodium and cooling air outside the guard vessel. A proposed change to GDC 34 has been implemented in the 4S PDC to accommodate RVACS as a single passive system, while preserving the high reliability associated with redundant active components and systems.

The NRC has addressed two issues related to the acceptance of RVACS of the PRISM LMR [3]. The first issue relates to the use of a system that deviates significantly from the active systems used in LWRs for which GDC 34 applies. The NRC considered this issue to be resolved only through regulatory policy decision.

The second one relates to the relatively high temperature that the reactor silo concrete might be exposed due to the elevated temperature of the reactor vessel (RV), if RVACS is the only available system. The RV elevated temperatures of PRISM are 607 °C as the best estimate value and 646 °C as the 95% confidence value, respectively [3].

To comply with the intent of GDC 34, the following proposed change has been added:

"For passive residual heat removal systems, the safety function shall be accomplished

(1) With an adequate margin to account for uncertainties in physical phenomena, and for degradation of flow paths and heat transfer, and

(2) Without adverse impact on the long term capability for heat removal."

The adverse impact in the second requirement could be degradation of the silo concrete, or other high-temperature-related degradation of the RHR components or structures.

Criterion 35 is LWR specific criterion and not applicable. This criterion is unnecessary for the LMR.

Criterion 36 is not applicable, since LMR does not require ECCS (see GDC35). However, to ensure high reliability of the residual heat removal system, the criterion has been redefined to address inspection of the residual heat removal system. This modified criterion is described under principal design criterion 36. We change PDC 36 on "inspection and monitoring of residual heat removal system"

Criterion 37 is not applicable. Since LMR does not require ECCS (see GDC35), it is not necessary to apply this GDC to 4S. However, to ensure high reliability of the residual heat removal system, the criterion is redefined to address inspection of the residual heat removal system. This modified criterion is shown under principal design criterion 37. We change PDC 37 on “testing of residual heat removal system”

Criterion 38 is applicable with three exceptions: (1) amended to allow containment heat removal by passive means, (2) performance of non-safety active support system (if appropriate) must satisfy PDC 7and (3) it replaced LOCA by postulated accident

Criterion 39 is applicable with three exceptions: (1) this criterion is modified to “Inspection and monitoring of containment heat removal system” and (2) added “and functional monitoring (for passive systems)” and (3) deleted “such as the torus, sumps, spray nozzles, and piping” because these designs are not applied to LMR.

Criterion 40 is applicable with one exception; “the associated cooling water system” in last sentence is modified “the associated cooling system” because these designs are not necessary to apply to LMR.

Criterion 41 is applicable with two exceptions: (1) The criterion is applicable and necessary to be modified to add sodium aerosol and (2) reaction product as result of postulated accidents and some leakage, chemical reaction and potential hydrogen generation from sodium-concrete interaction.

Criterion 44 is applicable with two exceptions: (1) “cooling water” is replaced by “Structural and equipment cooling” as suggested by the NRC during the PRISM reactor review and (2) “as necessary” in second sentence is added.

Criterion 45 is applicable with two exceptions: (1) “cooling water” is replaced by “Structural and equipment cooling” as suggested by the NRC during the PRISM reactor review and (2) “water” in first sentence is deleted.

Criterion 46 is applicable with two exception; (1) “cooling water” is replaced by “Structural and equipment cooling” as suggested by the NRC during the PRISM reactor review, (2) “and for loss-of –coolant” in last sentence is deleted.

New criterion 47 is added to address the measures required when using sodium as coolant, which has higher melting point than water. These are in response to recommendation by the NRC during the review of the PRISM reactor. The criterion is the same as that of ANSI/ANS-54-1-1989 section 3.1.7. It is added as PDC 47.

New criterion 48 is added to address the control of the purity of the reactor and intermediate coolant and cover gas systems to prevent chemical attack, fouling and plugging of passages, radioisotope concentration and to detect sodium-water interaction. The substitute criterion was suggested by the NRC during the PRISM reactor review. The criterion is the same as that of ANSI/ANS-54-1-1989 section 3.4.4. It is added as PDC48.

V. Reactor Containment

Criterion 50 is applicable to the 4S reactor with the following exceptions that is incorporated in the corresponding principal design criterion: (1) LOCA is replaced by “postulated accidents”, (2) “energy from metal water and other chemical reactions that may result from degradation but not failure of emergency core cooling functioning” is replaced by “fission products, potential sodium fire or aerosol formation, and potential exothermic reactions.”

Criterion 51 is applicable to the 4S reactor with one exception. It is better to replace “ferritic” materials by “metallic” material to broaden the application to PDC.

Criterion 55 is applicable with two exceptions; (1) the word “pressure” is removed from “coolant pressure boundary”, and (2) reactor cover gas boundary is added to the coolant boundary.

Criterion 57 is applicable with two exceptions: (1) delete the word “pressure” characterizing the boundary, (2) add the cover gas boundary.

VI. Fuel and Radioactivity Control

Criterion 61 is applicable with one exception. The following sentence is added at the end of the criterion in response to the NRC recommendation during the PRISM reactor review: "The fuel handling and its interfacing systems is designed to minimize the potential for fuel handling errors that could result in fuel damage."

Criterion 64 is applicable with two exceptions; (1)The statement "spaces containing components for re-circulation of loss-of-coolant accident fluids"is deleted in the corresponding principal criterion since it does not apply to LMRs, (2) the word "pressure" is removed from "coolant pressure boundary".

The whole statement of PDC with modified history are shown in Appendix A.

Table 3-1(1/7) Summary of applicability of GDC to 4S

GDC Title	PDC No	Applicability 4S	Remark
I. Overall Requirements:			
1. Quality standards and records	1	Applicable	-
2. Design bases for protection against natural phenomena	2	Applicable	-
3. Fire protection.	3	Applicable	New criterion is added for sodium fire.
4. Environmental and dynamic effects design bases	4	One change	Replace "loss of coolant accidents" by "effects of sodium, its aerosol and combustion products"
5. Sharing of structures, systems, and components	5	Applicable	-
-	6	New criterion (Protection against sodium reactions)	Address potential effects of sodium reaction (ANSI/ANS-54.1, criterion 3.1.4 exclusion of NaK)
-	7	New criterion (Treatment of non-safety systems)	Allow for crediting of non-safety systems

Table 3-1(2/7) Summary of applicability of GDC to 4S

GDC Title	PDC No	Applicability 4S	Remark
II. Protection by Multiple Fission Product Barriers:			
10. Reactor design	10	Applicable	-
11. Reactor inherent protection	11	Applicable	-
12. Suppression of reactor power oscillations	12	Applicable	-
13. Instrumentation and control	13	One change	Replace "reactor coolant pressure boundary" by "reactor coolant boundary"
14. Reactor coolant pressure boundary	14	One change	Replace "reactor coolant pressure boundary" by "reactor coolant boundary"
15. Reactor coolant system design	15	Two changes	1)Add sodium heating system to the list of auxiliary systems 2)Replace "reactor coolant pressure boundary" by "reactor coolant boundary"
16. Containment design	16	Applicable	-
17. Electric power systems	17	Several changes	1)Change to allow use of non-safety ac power and power distribution if appropriate provided PDC 7 is applied. 2)Replace "reactor coolant pressure boundary" by "reactor coolant boundary" 3)Remove reference to LOCA, and the need for one of the electric power system to be available within a few seconds
18. Inspection and testing of electric power systems	18	Applicable	-
19. Control room	19	Three change	1)Replace LOCA by "those conditions resulting from sodium reactions" 2)Change rem limits for whole body and thyroid to Sv and TEDE units for consistency with latest PDC 19 3)Replace "cold shutdown" by "any coolant temperature lower than the hot shutdown"

Table 3-1(3/7) Summary of applicability of GDC to 4S

GDC Title	PDC No	Applicability 4S	Remark
III. Protection and Reactivity Control Systems:			
20. Protection system functions	20	Applicable	-
21. Protection system reliability and testability	21	Applicable	-
22. Protection system independence	22	Applicable	-
23. Protection system failure modes	23	One addition	Add sodium and/or sodium reaction products to the list of adverse environments
24. Separation of protection and control systems	24	Applicable	-
25. Protection system requirements for reactivity control malfunctions	25	Two changes	1)Remove "(not ejection or dropout)" 2)Replace "rods" by "elements"
26. Reactivity control system redundancy and capability	26	Three changes	1)Replace "rods" by "elements" 2)Remove "(including Xenon burnout)" 3)Replace cold conditions by the lowest temperature associated with any normal operating condition.
27. Combined reactivity control systems capability	27	Two changes	1)Remove "in conjunction with poison solution by the ECCS" 2)Replace "rods" by "control elements"
28. Reactivity limits	28	Three changes	1)Replace "reactor coolant pressure boundary" by "reactor coolant boundary" 2)Replace "rod ejection (unless prevented by positive means) rod dropout steam line rupture" by "accidental withdraw of control elements" 3)Replace "cold water addition" by "cold sodium addition"
29. Protection against anticipated operational occurrences	29	Applicable	-

Table 3-1(4/7) Summary of applicability of GDC to 4S

GDC Title	PDC No	Applicability 4S	Remark
IV. Fluid Systems:			
30. Quality of reactor coolant pressure boundary	30	One change	Replace “reactor coolant pressure boundary” by “reactor coolant boundary”
31. Fracture prevention of reactor coolant pressure boundary	31	Two changes	1)Replace “reactor coolant pressure boundary” by “reactor coolant boundary” 2)Add effect of high temperature and sodium chemistry on material properties and stress
32. Inspection of reactor coolant pressure boundary	32	One change	Replace “reactor coolant pressure boundary” by “reactor coolant boundary”
33. Reactor coolant makeup	33	Inapplicable	Replace with ANSI/ANS-54.1, Criterion 3.4.1 (Assurance of adequate coolant inventory)
34. Residual heat removal	34	Several changes	Amend to include requirements for passive residual heat removal systems
35. Emergency core cooling	-	ECCS Inapplicable	Delete criterion (LWR Specific ECCS)
36. Inspection of emergency core cooling system	36	ECCS Inapplicable	Change a PDC on “inspection and monitoring of residual heat removal system”
37. Testing of emergency core cooling system	37	ECCS Inapplicable	Change a PDC on “testing of residual heat removal system”
38. Containment heat removal	38	Several changes	1)Amend to allow containment heat removal by passive means 2)Performance of non-safety active support system (if appropriate) must satisfy PDC 7. 3)Replace LOCA by postulated accident
39. Inspection of containment heat removal system	39	Three changes	1)Change title to “Inspection and monitoring of containment heat removal system” 2)Add “and functional monitoring (for passive systems)” 3)Remove “such as the torus, sumps, spray nozzles, and piping”

Table 3-1(5/7) Summary of applicability of GDC to 4S

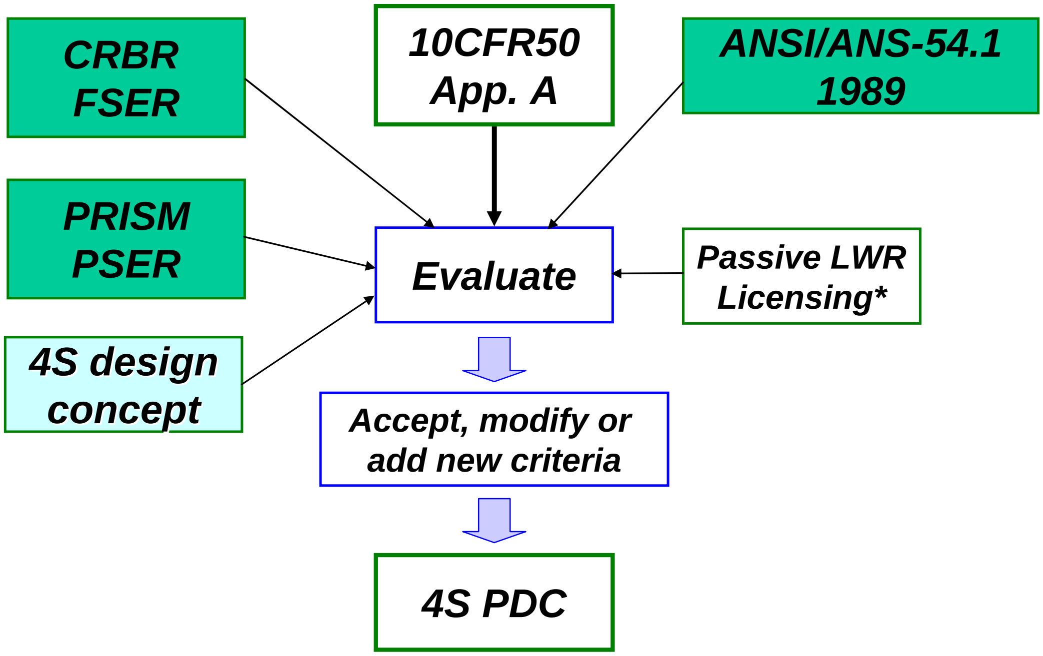
GDC Title	PDC No	Applicability 4S	Remark
IV. Fluid Systems (cont.) :			
40. Testing of containment heat removal system	40	One change	Replace "cooling water system" by "cooling system"
41. Containment atmosphere cleanup	41	Two changes	1)Add sodium aerosol and reaction products as products of postulated accidents 2)Add sodium leakage, chemical reactions, and potential hydrogen generation from sodium-concrete interaction
42. Inspection of containment atmosphere cleanup systems	42	Applicable	-
43. Testing of containment atmosphere cleanup systems	43	Applicable	-
44. Cooling water	44	Two changes	1)Change title to "Structural and Equipment Cooling" 2)Add "as necessary" to allow for not having the system if not needed
45. Inspection of cooling water system	45	One change	1)Change title to "Structural and Equipment Cooling," and remove reference to water in the text
46. Testing of cooling water system	46	Two changes	1)Change title to "Structural and equipment cooling" and remove reference to water in the text 2)Remove "for reactor shutdown and for LOCA accidents"
-	47	New criterion (Sodium heating systems)	Address measures required for usage of sodium which has high melting temperature (ANSI/ANS-54.1, criterion 3.1.7)
-	48	New criterion (Reactor and intermediate coolant and cover gas purity control)	Address measures to assure purity of cover gas and coolant (ANSI/ANS-54.1, criterion 3.4.4)

Table 3-1(6/7) Summary of applicability of GDC to 4S

GDC Title	PDC No	Applicability 4S	Remark
V. Reactor Containment:			
50. Containment design basis	50	Two changes	1)Replace LOCA by postulated accident 2)Replace “metal-water and other chemical reactions” by “fission products, potential sodium fire or aerosol formation, and exothermic chemical reactions
51. Fracture prevention of containment pressure boundary	51	One change	Replace “ferritic” materials by “metallic” materials to broaden the application of the PDC
52. Capability for containment leakage rate testing	52	Applicable	-
53. Provisions for containment testing and inspection	53	Applicable	-
54. Systems penetrating containment	54	Applicable	-
55. Reactor coolant pressure boundary penetrating containment	55	Two changes	1)Replace “reactor coolant pressure” by “reactor coolant” 2)Add the reactor cover gas boundary as part of the primary coolant boundary
56. Primary containment isolation	56	Applicable	-
57. Closed systems isolation valves	57	Two changes	1)Replace “reactor coolant pressure” by “reactor coolant” 2)Add the reactor cover gas boundary as part of the primary coolant boundary

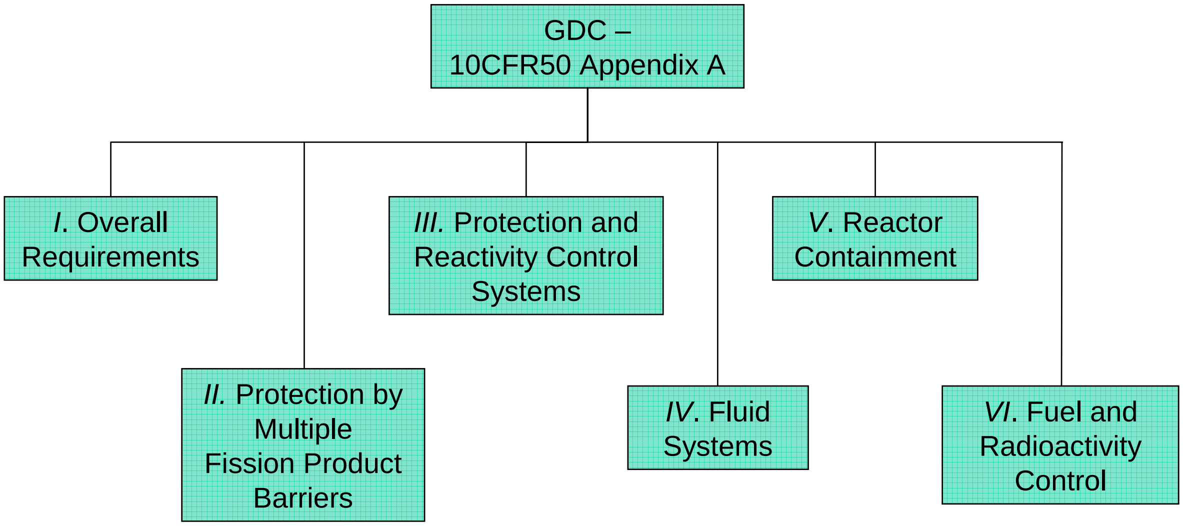
Table 3-1(7/7) Summary of applicability of GDC to 4S

GDC Title	PDC No	Applicability 4S	Remark
VI Fuel and Radioactivity Control:			
60. Control of releases of radioactive materials to the environment	60	Applicable	-
61. Fuel storage and handling and radioactivity control	61	One change	Add statement to minimize potential of fuel handling error by design
62. Prevention of criticality in fuel storage and handling	62	Applicable	-
63. Monitoring fuel and waste storage	63	Applicable	-
64. Monitoring radioactivity releases	64	Two change	1)Remove reference to LOCA 2)Replace “reactor coolant pressure boundary” by “reactor coolant boundary”

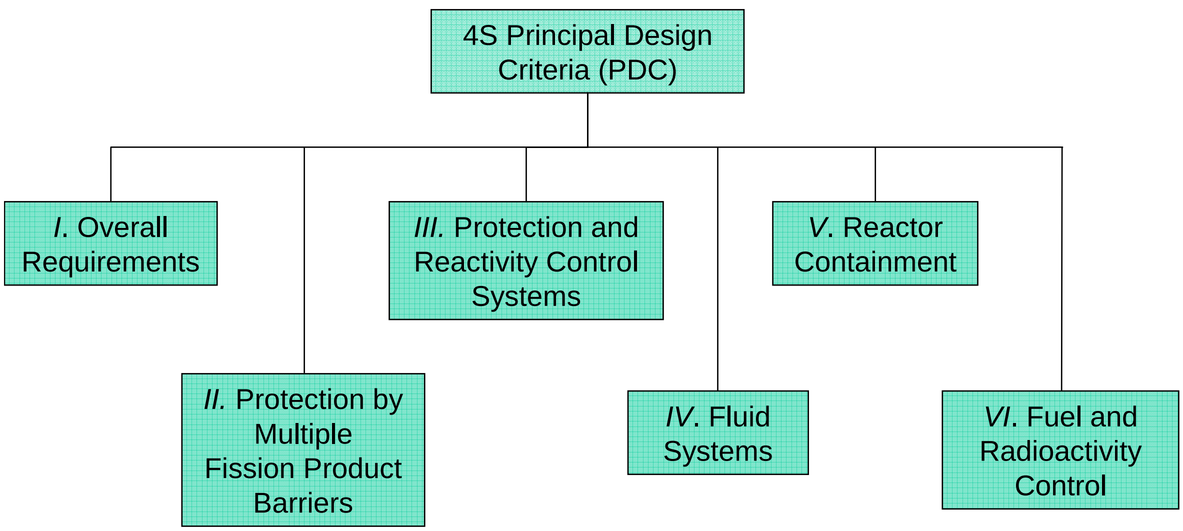


* US Nuclear Society, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-safety systems in Passive Plant Design," SECY-94-084, March 28, 1994.

Figure 3-1 Procedure of developing PDC for 4S



General Design Criteria (GDC) stracture



4S PDC structure

Figure 3-2 4S PDC structure

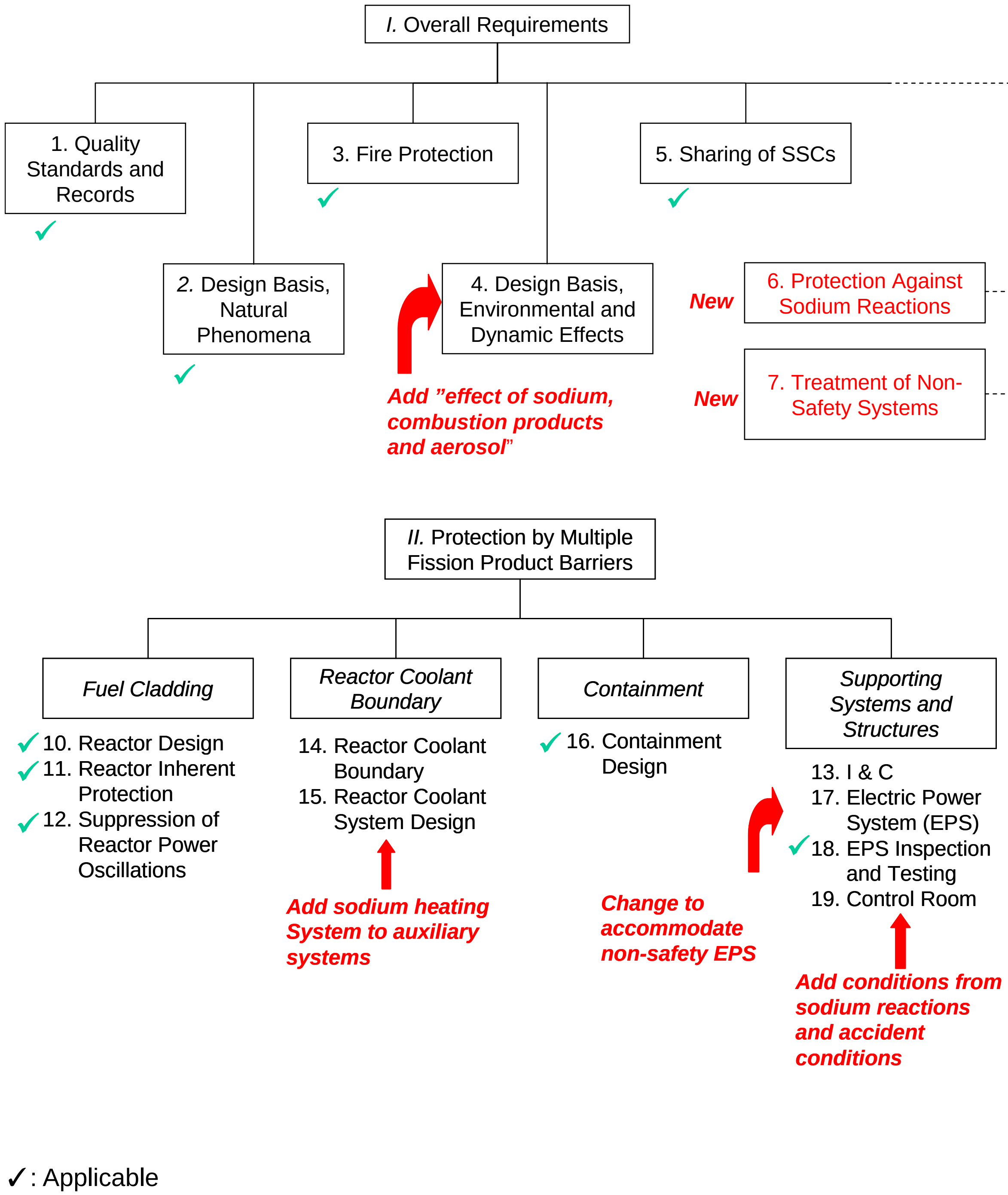


Figure 3-3 4S PDC-Changes from 10 CFR 50 Appendix A

III. Protection and Reactivity Control Systems

Protection Systems (PS)

- ✓ 20. PS Functions
- ✓ 21. PS Reliability and Testability
- ✓ 22. PS Independence
- 23. PS Failure Modes
- ✓ 24. Separation of PS and Control Systems
- 25 *PS Requirements for Reactivity Control Malfunction

Add "sodium and sodium reaction products" to adverse environment

Reactivity Control Systems

- 26 *Reactivity Control System Redundancy and Capability
- 27 *Combined Reactivity Control Systems Capability
- 28 * § Reactivity Limits

Protection and Reactivity Control Systems

- ✓ 29. Protection against Anticipated Operational Occurrences

*** Change control rod to control element**

§ Change rod ejection and rod dropout to accidental control element motion

IV. Fluid Systems

Assuring Adequate Core Coolant Inventory

- 30. Quality of Reactor Coolant Boundary (RCB)
- 31. Fracture Prevention of RCB
- 32. Inspection of RCB
- 33. Assurance of Adequate Coolant Inventory — **Replace**

Core Heat Removal

- 34. Residual Heat Removal System (RHRS)
- 35. (ECCS, N/A)
- 36. Inspection and monitoring of RHRS
- 37. Testing of RHRS

Containment Heat Removal

- 38. Containment Heat Removal System (CHRS)
- 39. Inspection and monitoring of CHRS
- 40. Testing of CHRS

Containment Atmosphere Cleanup

- 41. Containment Atmosphere Cleanup System (CACS)
- ✓ 42. Inspection of CACS
- ✓ 43. Testing of CACS

Structures and Equipment Heat removal (S&EHR)

- 44. S&EHR System
- 45. Inspection of S&HER System
- 46. Testing of S&EHR System
- **New** 47. Sodium Heating System
- **New** 48. Reactor and Intermediate Coolant and Cover Gas Purity Control

Figure 3-3 (cont.) 4S PDC-Changes from 10 CFR 50 Appendix A

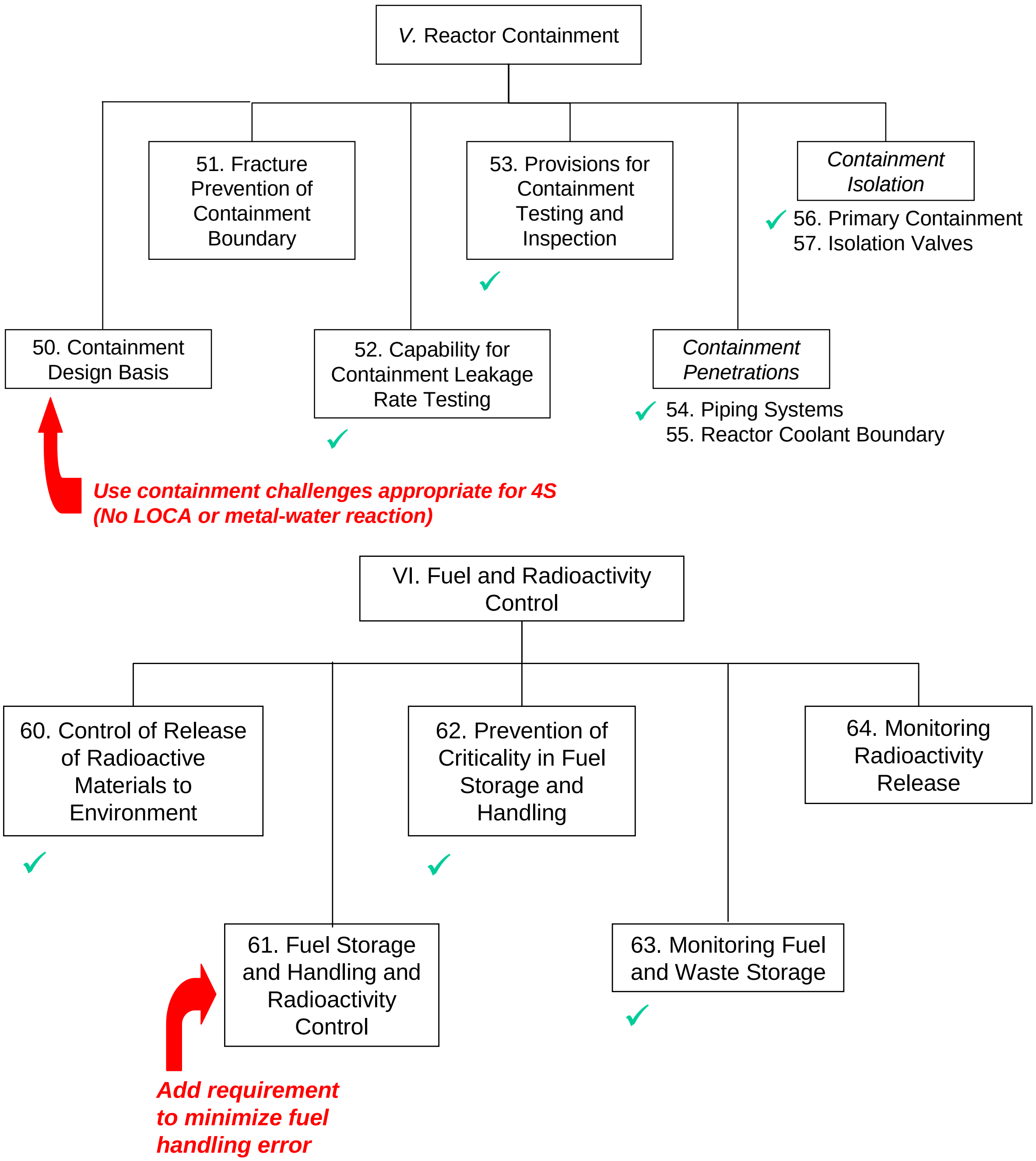


Figure 3-3 (cont.) 4S PDC-Changes from 10 CFR 50 Appendix A

4. CONCLUSION

The 4S PDC was established based on GDC for LWR and LMR; ANS54.1 1984, the safety evaluation report for CRBR; NUREG-0968, and the safety evaluation report for PRISM; NUREG-1338. In addition, SECY-94-084 “Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Design,” was taken into consideration.

The PDC consists of 23 criteria equivalent to the GDC, 31 criteria with modification or addition from the GDC, one criterion removed from the GDC, and 4 criteria newly added to the GDC.

PDC and the conformance of 4S safety design is planned to be explained prior to license application.. The PDC would be checked by employing the new ANS/ANSI 54.1 standards for SFR design criteria that is currently in progress at ANS WG.

5. REFERENCES

1. U,S. Nuclear Regulatory Commission, "Appendix A to Part 50--General Design Criteria for Nuclear Power Plants," Last revised August 02, 2006.

2. U.S. Nuclear Regulatory Commission, "Safety Evaluation Report Related to the Construction of the Clinch River Breeder Reactor Plant," NUREG-0968, Volume 1, March 1983.

3. U.S. Nuclear Regulatory Commission, "Pre-application Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor," Final Report, NUREG-1368, February 1994.

4. American Nuclear Society, "General Design Criteria for a Liquid Metal Reactor Nuclear Power Plant," ANSI/ANS-54.1-1989, April 1989.

5. US Nuclear Regulatory Commission, "Policy and Technical Issues Associated with the Regulatory Treatment of Non-Safety Systems in Passive Plant Design," SECY-94-084, March 28, 1994.

6. ADAMS: ML081400095, "4S reactor Third pre-application review meeting with NRC," May 2008.

7. American Nuclear Society, "Liquid Metal Fire Protection in LMR Plants," ANSI/ANS54.8-1988, November 1988.

Appendix A

4S Principle Design Criteria

- ***Italic style : Original GDC expression***
- **Underline style: Added PDC expression**
- ***Cancellation line: Deleted expression***

Principal Design Criteria

I. Overall Requirements

Criterion 1--Quality standards and records. *Structures, systems, and components important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized codes and standards are used, they shall be identified and evaluated to determine their applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function. A quality assurance program shall be established and implemented in order to provide adequate assurance that these structures, systems, and components will satisfactorily perform their safety functions. Appropriate records of the design, fabrication, erection, and testing of structures, systems, and components important to safety shall be maintained by or under the control of the nuclear power unit licensee throughout the life of the unit.*

Criterion 2--Design bases for protection against natural phenomena. *Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena and (3) the importance of the safety functions to be performed.*

Criterion 3--Fire protection. *Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.*

Criterion 4--Environmental and dynamic effects design bases. *Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including* ~~*loss-of-coolant accidents.*~~ effects of sodium, its aerosol and combustion products. *These structures, systems, and components shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit. However, dynamic effects associated with postulated pipe ruptures in nuclear power units may be excluded from the design basis when analyses reviewed and approved by the Commission demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping.*

Criterion 5--Sharing of structures, systems, and components. *Structures, systems, and components important to safety shall not be shared among nuclear power units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units.*

Criterion 6--Protection Against Sodium Reactions. Structures, systems, and components containing sodium shall be designed and located to limit the consequences of chemical reactions resulting from sodium leak. Special features such as inerted enclosures shall be provided as appropriate for radioactive sodium systems. Two barriers shall be provided between reactor coolant and fluids not compatible with sodium unless the consequences of failure of a single barrier can be shown to be acceptable. Fire control systems and means to detect sodium or sodium reaction products shall be provided to limit and control the extent of reaction as necessary to assure that the nuclear safety functions of structures, systems and components are maintained. Means shall be provided to limit the release of radioactive sodium reaction products to the environment as necessary to avoid undue risk to the public health and safety. Materials which might come in contact with sodium shall be chosen to limit the adverse effects of possible chemical reactions or microstructural changes. In areas where sodium chemical reactions are possible, structures, systems and components shall be designed and located so that the potential for loss of a nuclear safety function by sodium aerosols or reaction products is acceptably low. Means shall be provided as appropriate to limit possible contacts between sodium and water. The effects of possible interaction between sodium and concrete shall be considered in the design. If necessary to prevent loss of any plant nuclear safety function, the sodium-steam generator system shall be designed to detect sodium water reactions and limit the effects of the energy and reaction products released by such reactions.

Criterion 7--Treatment of Non-Safety Systems. Non-safety active systems may be used to reduce the challenges to the passive safety features that provide core cooling, residual heat removal or control of radioactive release following postulated accidents, or to enhance the safety functions of these features. Such non-safety systems shall meet the following requirements: (1) Adverse interactions between the non-safety active systems and the passive safety features are identified and minimized to the extent practical, and (2) reliability and availability goals of the non-safety systems are defined commensurate with their safety importance.

II. Protection by Multiple Fission Product Barriers

Criterion 10--Reactor design. *The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.*

Criterion 11--Reactor inherent protection. *The reactor core and associated coolant systems shall be designed so that in the power operating range the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity*

Criterion 12--Suppression of reactor power oscillations. *The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.*

Criterion 13--Instrumentation and control. *Instrumentation shall be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions as appropriate to assure adequate safety, including those variables and systems that can affect the fission process, the integrity of the reactor core, the reactor coolant ~~pressure~~ boundary, and the containment and its associated systems. Appropriate controls shall be provided to maintain these variables and systems within prescribed operating ranges.*

Criterion 14--Reactor coolant ~~pressure~~ boundary. *The reactor coolant ~~pressure~~ boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.*

Criterion 15--Reactor coolant system design. *The reactor coolant system and associated auxiliary, control,* <u>sodium heating systems</u> *and protection systems shall be designed with sufficient margin to assure that the design conditions of the reactor coolant ~~pressure~~ boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.*

Criterion 16--Containment design. *Reactor containment and associated systems shall be provided to establish an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment and to assure that the containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.*

Criterion 17--Electric power systems. <u>Non-safety systems that meet Criterion 7 may use non-safety electric power sources and distribution systems provided these sources and distribution systems meet the requirements of Criterion 7, namely; (1) They have reliability and availability goals commensurate with their safety importance, (2) they do not have an adverse impact on systems, structures, and components important to safety, in particular; (a) They do not degrade the safety grade DC or Uninterrupted Power Supply (UPS) systems, (b) they are available in time to prevent adverse effects that may result form: (i) Long shutdown at elevated coolant and reactor vessel temperatures, (ii) loss of control room habitability system, and (iii) loss of heating, ventilation, and air conditioning system (HVAC) that may adversely impact the instrumentation performance.</u>

An onsite electric power system and an offsite electric power system shall be provided, <u>if necessary</u> *to permit functioning of structures, systems, and components important to safety. The safety function for each system (assuming the other system is not functioning) shall be to provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant ~~pressure~~ boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents.*

The onsite electric power supplies, including the batteries, and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure.

Electric power from the transmission network to the onsite electric distribution system shall be supplied by two physically independent circuits (not necessarily on separate rights of way) designed and located so as to minimize to the extent practical the likelihood of their simultaneous failure under operating and postulated accident and environmental conditions. A switchyard common to both circuits is acceptable. Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite alternating current power supplies and the other offsite electric power circuit, to assure that specified acceptable fuel design limits and design conditions of the reactor coolant ~~pressure~~ boundary are not exceeded. ~~One of these circuits shall be designed to be available with in a few second following a loss-of coolant accident to assure that core cooling, containment integrity, and other vital safety functions are maintained.~~

Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power generated by the nuclear power unit, the loss of power from the transmission network, or the loss of power from the onsite electric power supplies.

Criterion 18--Inspection and testing of electric power systems. Electric power systems important to safety shall be designed to permit appropriate periodic inspection and testing of important areas and features, such as wiring, insulation, connections, and switchboards, to assess the continuity of the systems and the condition of their components. The systems shall be designed with a capability to test periodically (1) the operability and functional performance of the components of the systems, such as onsite power sources, relays, switches, and buses, and (2) the operability of the systems as a whole and, under conditions as close to design as practical, the full operation sequence that brings the systems into operation, including operation of applicable portions of the protection system, and the transfer of power among the nuclear power unit, the offsite power system, and the onsite power system

Criterion 19--Control room. A control room shall be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions, including ~~loss-of-coolant accidents~~ those conditions resulting from sodium reactions. Adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of ~~5 rem whole body, or its equivalent to any part of the body,~~ 0.05 Sv (5 rem) total effective dose equivalent (TEDE) as defined in 10CFR § 50.2, for the duration of the accident. Equipment at appropriate locations outside the control room shall be provided (1) with a design capability for prompt hot shutdown of the reactor, including necessary instrumentation and controls to maintain the unit in a safe condition during hot shutdown, and (2) ~~with a potential capability for subsequent cold shutdown of the reactor through the use of suitable procedures.~~ with a design capability for subsequent control of the reactor at any coolant temperature lower than the hot shutdown. ~~Applicants for and holders of construction permits and operating licenses under this part who apply on or after January 10, 1997, applicants for design approvals or certifications under part 52 of this chapter who apply on or after January 10, 1997, applicants for and holders of combined licenses or manufacturing~~

~~*licenses under part 52 of this chapter who do not reference a standard design approval or certification, or holders of operating licenses using an alternative source term under § 50.67, shall meet the requirements of this criterion, except that with regard to control roomaccess and occupancy, adequate radiation protection shall be provided to ensure that radiation exposures shall not exceed 0.05 Sv (5 rem) total effective dose equivalent (TEDE) as defined in § 50.2 for the duration of the accident.*~~

III. Protection and Reactivity Control Systems

Criterion 20--Protection system functions. *The protection system shall be designed (1) to initiate automatically the operation of appropriate systems including the reactivity control systems, to assure that specified acceptable fuel design limits are not exceeded as a result of anticipated operational occurrences and (2) to sense accident conditions and to initiate the operation of systems and components important to safety.*

Criterion 21--Protection system reliability and testability. *The protection system shall be designed for high functional reliability and in-service testability commensurate with the safety functions to be performed. Redundancy and independence designed into the protection system shall be sufficient to assure that (1) no single failure results in loss of the protection function and (2) removal from service of any component or channel does not result in loss of the required minimum redundancy unless the acceptable reliability of operation of the protection system can be otherwise demonstrated. The protection system shall be designed to permit periodic testing of its functioning when the reactor is in operation, including a capability to test channels independently to determine failures and losses of redundancy that may have occurred.*

Criterion 22--Protection system independence. *The protection system shall be designed to assure that the effects of natural phenomena, and of normal operating, maintenance, testing, and postulated accident conditions on redundant channels do not result in loss of the protection function, or shall be demonstrated to be acceptable on some other defined basis. Design techniques, such as functional diversity or diversity in component design and principles of operation, shall be used to the extent practical to prevent loss of the protection function.*

Criterion 23--Protection system failure modes. *The protection system shall be designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis if conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument* *air), or postulated adverse environments (e.g., extreme heat or cold, fire, pressure, steam, water,* sodium and/or sodium reaction products, *and radiation) are experienced.*

Criterion 24--Separation of protection and control systems. *The protection system shall be separated from control systems to the extent that failure of any single control system component or channel, or failure or removal from service of any single protection system component or channel which is common to the control and protection systems leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system. Interconnection of the protection and control systems shall be limited so as to assure that safety is not significantly impaired*

Criterion 25--Protection system requirements for reactivity control malfunctions. *The protection system shall be designed to assure that specified acceptable fuel design limits are not exceeded for any single malfunction of the reactivity control systems, such as accidental withdrawal ~~(not ejection or dropout)~~ of control ~~rods~~* elements

Criterion 26--Reactivity control system redundancy and capability. *Two independent reactivity control systems of different design principles shall be provided. One of the systems shall use control ~~rods~~* elements*, preferably including a positive means for inserting the control ~~rods~~* elements*, and shall be capable of reliably controlling reactivity changes to assure that under conditions of normal operation, including anticipated operational occurrences, and with appropriate margin for malfunctions such as stuck ~~rods~~* elements*, specified acceptable fuel design limits are not exceeded. The second reactivity control system shall be capable of reliably controlling the rate of reactivity changes resulting from planned, normal power changes ~~(including xenon burnout)~~ to assure acceptable fuel design limits are not exceeded. One of the systems shall be capable of holding the reactor core subcritical under ~~cold conditions~~* the lowest temperature associated with any normal operating condition..

Criterion 27--Combined reactivity control systems capability. *The reactivity control systems shall be designed to have a combined capability, ~~in conjunction with poison addition by the emergency core cooling system,~~ of reliably controlling reactivity changes to assure that under postulated accident conditions and with appropriate margin for stuck ~~rods~~* control elements *the capability to cool the core is maintained.*

Criterion 28--Reactivity limits. *The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the* *effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant ~~pressure~~ boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures or other reactor ~~pressure~~ vessel internals to impair significantly the capability to cool the core. These postulated reactivity accidents shall include consideration of ~~rod ejection (unless prevented by positive means), rod dropout~~, ~~steam line rupture,~~* accidental withdraw of control element(s), *changes in reactor coolant temperature and pressure, and cold ~~water~~* sodium *addition.*

Criterion 29--Protection against anticipated operational occurrences. *The protection and reactivity control systems shall be designed to assure an extremely high probability of accomplishing their safety functions in the event of anticipated operational occurrences.*

IV. Fluid Systems

Criterion 30--Quality of reactor coolant ~~pressure~~ boundary. *Components which are part of the reactor coolant ~~pressure~~ boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.*

Criterion 31--Fracture prevention of reactor coolant ~~pressure~~ boundary. *The reactor coolant ~~pressure~~ boundary shall be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated accident conditions (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures*, service degradation of material properties, creep, fatigue, stress rupture *and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation* and coolant chemistry *on material properties, (3) residual, steady state and transient stresses, and (4) size of flaws.*

Criterion 32--Inspection of reactor coolant ~~pressure~~ boundary. *Components which are part of the reactor coolant ~~pressure~~ boundary shall be designed to permit (1) periodic inspection and testing of important areas and features to assess their structural and leaktight integrity, and (2) an appropriate material surveillance program for the reactor ~~pressure~~ vessel.*

~~***Criterion 33--Reactor coolant makeup.*** *A system to supply reactor coolant makeup for protection against small breaks in the reactor coolant pressure boundary shall be provided. The system safety function shall be to assure that specified acceptable fuel design limits are not exceeded as a result of reactor coolant loss due to leakage from the reactor coolant pressure boundary and rupture of small piping or other small components which are part of the boundary. The system shall be designed to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished using the piping, pumps, and valves used to maintain coolant inventory during normal reactor operation.*~~

Criterion 33--Assurance of adequate coolant inventory. The reactor coolant boundary and associated components, control and protection systems shall be designed to limit loss of reactor coolant so that an inventory adequate to perform the nuclear safety function of the reactor residual heat removal system is maintained under normal operation, including anticipated operational occurrences, and postulated accident conditions, assuming a failure of a single active component.

Criterion 34--Residual heat removal. *A system to remove residual heat shall be provided. The system safety function shall be to transfer fission product decay heat and other residual heat from the reactor core* under all shutdown conditions, including following a postulated accidents, *at a rate such that specified acceptable fuel design limits and the design conditions of the reactor coolant* ~~*pressure*~~ *boundary are not exceeded.*

A passive boundary shall separate reactor coolant from the working fluid of the reactor residual heat removal system. *Suitable redundancy in components and features, and suitable interconnections, leak detection, and isolation capabilities shall be provided* ~~*to assure that for*~~ For residual heat removal systems using active components, the system safety function shall be accomplished with *onsite electric power system operation (assuming offsite power is not available) and* ~~*for*~~ with *offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.* For passive residual heat removal systems, the safety function shall be accomplished (1) with an adequate margin to account for uncertainties in physical phenomena, and for degradation of flow paths and heat transfer, and (2) without adverse impact on the long term capability for heat removal.

~~***Criterion 35--Emergency core cooling.*** *A system to provide abundant emergency core cooling shall be provided. The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to*~~

~~*assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.*~~

***Criterion 36--Inspection* and monitoring *of ~~emergency core cooling~~* residual heat removal system.** *The ~~emergency core cooling~~* residual heat removal *system shall be designed to permit appropriate periodic inspection of important components, such as ~~spray rings in the reactor pressure vessel, water injection nozzles,~~* heat exchangers *and ~~piping~~,* inlet and outlet of ultimate heat sink, and functional monitoring (for passive systems) *to assure the integrity and capability of the system.*

Criterion 37--Testing of ~~emergency core cooling~~* residual heat removal *system. *The ~~emergency core cooling~~* residual heat removal *system shall be designed to permit ~~appropriate~~ periodic pressure and functional testing*, as appropriate, *to assure (1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the system, and (3) the operability of the system as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the system into operation, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources. ~~and the operation of the associated cooling water system.~~*

Criterion 38--Containment heat removal. *A*n active or passive *system to remove heat from the reactor containment shall be provided. The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any ~~loss-of-coolant~~* postulated *accident and maintain them at acceptably low levels.*For an active containment heat removal system, s*uitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.* For a passive containment heat removal system, the safety function shall be accomplished (1) with an adequate margin to account for uncertainties in physical phenomena, and for degradation of flow paths and heat transfer, and (2) without adverse impact on the long term capability for heat removal. A non-safety support system may be used provided that it complies with PDC 7.

Criterion 39--Inspection* and monitoring *of containment heat removal system. *The containment heat removal system shall be designed to permit appropriate periodic inspection of* *important components,* ~~*such as the torus, sumps, spray nozzles, and piping*~~ and functional monitoring (for passive systems) *to assure the integrity and capability of the system.*

Criterion 40--Testing of containment heat removal system. *The containment heat removal system shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the system, and (3) the operability of the system as a whole, and under conditions as close to the design as practical the performance of the full operational sequence that brings the system into operation, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of the associated cooling* ~~*water*~~ *system.*

Criterion 41--Containment atmosphere cleanup. *Systems to control fission products, hydrogen, oxygen,* sodium aerosol or combustion products, *and other substances which may be released into the reactor containment shall be provided as necessary to reduce, consistent with the functioning of other associated systems, the concentration and quality of fission products released to the environment following postulated accidents, and to control the concentration of hydrogen or oxygen and other substances in the containment atmosphere following postulated accidents to assure that containment integrity is maintained.* Such systems should consider the effects of sodium leakage and its potential reaction with oxygen and potential for hydrogen generation when in contact with concrete. *Each system shall have suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) its safety function can be accomplished, assuming a single failure.*

Criterion 42--Inspection of containment atmosphere cleanup systems. *The containment atmosphere cleanup systems shall be designed to permit appropriate periodic inspection of important components, such as filter frames, ducts, and piping to assure the integrity and capability of the systems.*

Criterion 43--Testing of containment atmosphere cleanup systems. *The containment atmosphere cleanup systems shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the systems such as fans, filters, dampers, pumps, and valves and (3) the operability of the systems as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the systems into operation, including operation of applicable portions of the protection* *system, the transfer between normal and emergency power sources, and the operation of associated systems.*

Criterion 44--~~Cooling water~~* Structural and equipment cooling*. *A system to transfer heat from structures, systems, and components important to safety, to an ultimate heat sink shall be provided. The system safety function shall be to transfer the combined heat load of these structures, systems, and components under normal operating and accident conditions* as necessary*. Suitable redundancy in components and features, and suitable interconnections, leak detection, and isolation capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.*

Criterion 45--Inspection of ~~cooling water~~ **structural and equipment cooling** ***system.*** *The cooling ~~water~~ system shall be designed to permit appropriate periodic inspection of important components, such as heat exchangers and piping, to assure the integrity and capability of the system.*

Criterion 46--Testing of ~~cooling water~~ **structural and equipment cooling** ***system.*** *The cooling ~~water~~ system shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the structural and leaktight integrity of its components, (2) the operability and the performance of the active components of the system, and (3) the operability of the system as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the system into operation for reactor shutdown ~~and for loss-of-coolant accidents~~, including operation of applicable portions of the protection system and the transfer between normal and emergency power sources.*

Criterion 47--Sodium Heating Systems. Heating systems shall be provided as necessary for nuclear safety-related systems and components which contain, or could be required to contain sodium or sodium aerosol. These heating systems and their controls shall be appropriately designed to assure that the temperature distribution and rate of change of temperature in systems and components containing sodium or sodium aerosol are maintained within design limits assuming a single failure. The heating system shall be designed such that its failure will not prevent other systems and components from performing their nuclear safety functions.

Criterion 48--Reactor and Intermediate Coolant and Cover Gas Purity Control. Systems shall be provided as necessary to monitor and maintain reactor and intermediate coolant and cover gas purity within specified design limits. These limits shall be based on consideration of (1) chemical attack, (2) fouling and plugging of passages, (3) radioisotope concentrations, and (4) detection of sodium water reactions.

V. Reactor Containment Systems

Criterion 50--Containment design basis. *The reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from ~~any loss-of-coolant accident~~* postulated accidents*. This margin shall reflect consideration of (1) the effects of potential energy sources which have not been included in the determination of the peak conditions, such as energy in steam generators ~~and as required by § 50.44 energy from metal-water and other chemical reactions that may result from degradation but not total failure of emergency core cooling functioning,~~* fission products, potential sodium fire or aerosol formation, and potential exothermic chemical reactions, *(2) the limited experience and experimental data available for defining accident phenomena and containment responses, and (3) the conservatism of the calculational model and input parameters.*

Criterion 51--Fracture prevention of containment pressure boundary. *The reactor containment boundary shall be designed with sufficient margin to assure that under operating, maintenance, testing, and postulated accident conditions (1) its ~~ferritic~~* metallic *materials behave in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the containment boundary material during operation, maintenance, testing, and postulated accident conditions, and the uncertainties in determining (1) material properties, (2) residual, steady state, and transient stresses, and (3) size of flaws.*

Criterion 52—Capability for containment leakage rate testing**.** *The reactor containment and other equipment which may be subjected to containment test conditions shall be designed so that periodic integrated leakage rate testing can be conducted at containment design pressure.*

Criterion 53--Provisions for containment testing and inspection. *The reactor containment shall be designed to permit (1) appropriate periodic inspection of all important areas, such as penetrations, (2) an appropriate surveillance program, and (3) periodic testing at containment design pressure of the leaktightness of penetrations which have resilient seals and expansion bellows.*

Criterion 54--Piping systems penetrating containment. *Piping systems penetrating primary reactor containment shall be provided with leak detection, isolation, and containment capabilities having redundancy, reliability, and performance capabilities which reflect the importance to safety of isolating these piping systems. Such the piping systems shall be designed with a capability to test periodically the operability of the isolation valves and associated apparatus and to determine if valve leakage is within acceptable limits.*

Criterion 55--Reactor coolant ~~pressure~~ boundary penetrating containment. *Each line that is part of the reactor coolant ~~pressure boundary~~* <u>or reactor cover gas boundaries</u> *and that penetrates primary reactor containment shall be provided with containment isolation valves as follows, unless it can be demonstrated that the containment isolation provisions for a specific class of lines, such as instrument lines, are acceptable on some other defined basis: (1) One locked closed isolation valve inside and one locked closed isolation valve outside containment; or (2) One automatic isolation valve inside and one locked closed isolation valve outside containment; or (3) One locked closed isolation valve inside and one automatic isolation valve outside containment. A simple check valve may not be used as the automatic isolation valve outside containment; or (4) One automatic isolation valve inside and one automatic isolation valve outside containment. A simple check valve may not be used as the automatic isolation valve outside containment. Isolation valves outside containment shall be located as close to containment as practical and upon loss of actuating power, automatic isolation valves shall be designed to take the position that provides greater safety. Other appropriate requirements to minimize the probability or consequences of an accidental rupture of these lines or of lines connected to them shall be provided as necessary to assure adequate safety. Determination of the appropriateness of these requirements, such as higher quality in design, fabrication, and testing, additional provisions for inservice inspection, protection against more severe natural phenomena, and additional isolation valves and containment, shall include consideration of the population density, use characteristics, and physical characteristics of the site environs.*

Criterion 56--Primary containment isolation. *Each line that connects directly to the containment atmosphere and penetrates primary reactor containment shall be provided with containment isolation valves as follows, unless it can be demonstrated that the containment isolation provisions for a specific class of lines, such as instrument lines, are acceptable on some other defined basis: (1) One locked closed isolation valve inside and one locked closed isolation valve outside containment; or (2) One automatic isolation valve inside and one locked* *closed isolation valve outside containment; or (3) One locked closed isolation valve inside and one automatic isolation valve outside containment. A simple check valve may not be used as the automatic isolation valve outside containment; or (4) One automatic isolation valve inside and one automatic isolation valve outside containment. A simple check valve may not be used as the automatic isolation valve outside containment. Isolation valves outside containment shall be located as close to the containment as practical and upon loss of actuating power, automatic isolation valves shall be designed to take the position that provides greater safety.*

Criterion 57--Closed system isolation valves. *Each line that penetrates primary reactor containment and is neither part of the reactor coolant ~~pressure boundary~~* or cover gas boundaries *nor connected directly to the containment atmosphere shall have at least one containment isolation valve which shall be either automatic, or locked closed, or capable of remote manual operation. This valve shall be outside containment and located as close to the containment as practical. A simple check valve may not be used as the automatic isolation valve.*

VI. Fuel and Radioactivity Control Systems

Criterion 60--Control of releases of radioactive materials to the environment. *The nuclear power unit design shall include means to control suitably the release of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced during normal reactor operation, including anticipated operational occurrences. Sufficient holdup capacity shall be provided for retention of gaseous and liquid effluents containing radioactive materials, particularly where unfavorable site environmental conditions can be expected to impose unusual operational limitations upon the release of such effluents to the environment.*

Criterion 61--Fuel storage and handling and radioactivity control. *The fuel storage and handling, radioactive waste, and other systems which may contain radioactivity shall be designed to assure adequate safety under normal and postulated accident conditions. These systems shall be designed (1) with a capability to permit appropriate periodic inspection and testing of components important to safety, (2) with suitable shielding for radiation protection, (3) with appropriate containment, confinement, and filtering systems, (4) with a residual heat removal capability having reliability and testability that reflects the importance to safety of decay heat and other residual heat removal, and (5) to prevent significant reduction in fuel storage coolant inventory under accident conditions.* The fuel handling and its interfacing systems shall be designed to minimize the potential for fuel handling errors that could result in fuel damage.

Criterion 62--Prevention of criticality in fuel storage and handling. *Criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations.*

Criterion 63--Monitoring fuel and waste storage. *Appropriate systems shall be provided in fuel storage and radioactive waste systems and associated handling areas (1) to detect conditions that may result in loss of residual heat removal capability and excessive radiation levels and (2) to initiate appropriate safety actions.*

Criterion 64--Monitoring radioactivity releases. *Means shall be provided for monitoring the reactor containment atmosphere, ~~spaces containing components for recirculation of loss-of-coolant accident fluids~~, effluent discharge paths, and the plant environs for radioactivity that may be released from normal operations, including anticipated operational occurrences, and from postulated accidents. (1) Further details relating to the type, size, and orientation of postulated breaks in specific components of the reactor coolant ~~pressure~~ boundary are under development. (2) Single failures of passive components in electric systems should be assumed in designing against a single failure. The conditions under which a single failure of a passive component in a fluid system should be considered in designing the system against a single failure are under development.*