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Safety related terms for advanced nuclear plants

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FOREWORD

The drafting of this document grew out of an IAEA Technical Committee Meeting on "Definition and Understanding of Engineered Safety, Passive Safety and Related Terms" held in Västeras, Sweden, May 30-June 2, 1988. During that meeting, many papers dealing with these terms as applied to water cooled reactors (both light and heavy water) were presented and discussed, and an initial draft describing these terms was developed. In the hope that a better common understanding of these terms within and beyond the nuclear community would represent a positive contribution, the Agency convened a Consultants Meeting in Vienna in October 1988 to produce an improved, more extensive draft describing these terms and to develop an initial consensus supporting it within the water reactor community. This draft was then circulated for comment to organizations working in liquid metal reactor technology, gas cooled reactor technology, and nuclear fusion by the Agency, as well as to many additional organizations active in water reactors or in nuclear technology in general. A paper entitled 'Terminology for future nuclear power plants', presented by E. Lo Prato et al. at the International Workshop on the Safety of Nuclear Installations of the Next Generation and Beyond in Chicago in August 1989 (the proceedings of which were published as IAEA-TECDOC-550 in 1990), reviewed and commented on this report and presented a number of interesting proposals. During a second Consultants Meeting held in Vienna in December 1990, the document was redrafted in careful consideration of that paper and of the comments received. Since some of the comments represented misunderstandings and others were not consistent with each other or with criteria already established by the consultants after full and careful consideration, it was not possible to incorporate all suggestions received into the redrafted document.

The Agency would like to thank all individuals and institutions who have contributed to the preparation of the present document. The Agency would also like to thank all members of the Consultants Meetings, who met two times to prepare the final draft document, to review and incorporate comments received and who thus materially contributed to its successful completion. In particular, the very outstanding work of Mr. T. Pederson as a Chairman of the Technical Committee Meeting in Västeras and of the two editorial Consultants Meetings should be underlined.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

Safety related terms such as passive and inherent safety have been widely used, particularly with respect to advanced nuclear plants, generally without definition and sometimes with definitions inconsistent with each other.

In view of the importance of communication to both the public and to the technical community generally and among the designers of different advanced reactor lines within the nuclear industry itself, consistency and international consensus is desirable with regard to the terms used to describe various approaches to the development of advanced reactor types and - as far as applicable - to the possible improvement of current reactors.

Current power reactors mainly use a combination of inherent safety characteristics and engineered safety systems, whose function may be active or passive. In the past decade there have been many proposals for applying different technologies to reduce reliance on active systems. These new designs are expected to be effective in contributing through simplification to improved economics in terms of construction costs, operation and maintenance costs, ease of operation and reliable equipment and systems.

The terms considered in this document are in widespread current use without a universal consensus as to their meaning. Other safety related terms are already defined in national or international codes and standards as well as in IAEA's Nuclear Safety Standards Series (NUSS). Most of the terms in those codes and standards have been defined and used for regulatory purposes, generally for application to present reactor designs. There is no intention to duplicate the description of such regulatory terms here, but only to clarify the terms used for advanced nuclear plants.

Only a few terms, such as "active component" and "passive component" used both in the regulatory area and for advanced concepts are included.

The following terms are described in this paper:

- inherent safety characteristics
- passive component
- active component
- passive system
- active system
- fail-safe
- grace period
- foolproof
- fault-/error-tolerant
- simplified safety system
- transparent safety

The overall purpose of a detailed description and an improved international consensus on these terms is:

- to help eliminate confusion and misuse of the terms by members of the nuclear community, rendering the terms more meaningful, and thereby improving communication within the technical community;

- to help clarify technical thinking regarding safety terms used in connection with efforts to enhance safety and thereby to help bring about improvements in future designs; and

- to help future acceptance of nuclear power by giving precisely described technical meanings to terms commonly used in public discourse and in other technologies; meanings which correspond to that common usage, thereby enhancing the credibility of the nuclear (and perhaps other technical) communities with the public.

The purpose of this document is to present a better technical description of these terms and to achieve a better understanding and consensus on their meaning and proper use.

Many of the terms described in this document have been widely used in some countries, sometimes without adequate understanding of what they mean and what they imply. The intent of this document is <u>not to promote</u> wider use of these terms, but rather <u>to clarify</u> their meaning. Many of these terms have the potential of being misleading to nonexperts and of conveying to the public undesirable implications not intended by the designers of advanced plants. The criterion for inclusion of each term in this document has been whether the term is already in fairly common, widespread use, <u>not</u> whether such use is desirable. The alternative of declining to address certain terms considered by some to be undesirable (if consensus could be reached on which terms these would be) was considered but rejected. The omission of terms here would not help eliminate their use, while their inclusion and discussion could help to make such use more technically valid and meaningful and in some cases to limit or reduce such use significantly. Finally it should be mentioned that description of some potentially useful terms not now used was purposely omitted to avoid coining or promoting new safety-related terms.

The process of resolving differences between the varied interests and cultural understanding of words has been difficult. Compromise on an international level was often required.

2. BACKGROUND DISCUSSION OF SAFETY CONCEPTS

2.1 Criteria for Description of Terms

In developing and drafting these descriptions of the various advanced-plant safety related terms, a number of criteria were established and used. The descriptions should conform to the broad, general, common-sense understanding of each term by the public as well as by the technical community. Application of the terms should be in agreement with the public's common, everyday experience with non-nuclear sources of accidents such as automobiles, aircraft, fires, etc. Since many of these terms are also used in nonnuclear technologies (e.g., the chemical industry) which are perceived by the public as sources of danger, but which unlike automobiles and aircraft are poorly understood, the descriptions should be consistent with reasonable usages in such other technologies. Dictionary definitions tend to describe such public understandings in very broad and general terms; the descriptions here should not contradict dictionary definitions but should include any elaboration, refinement, and specificity needed to make them applicable and useful for advanced nuclear power systems.

Another important criterion is clarity and ease of application; there should be no ambiguity and it should be quickly and easily determinable by anyone who understands a particular component or system whether or not it conforms to a description. "Easily determinable" means a qualitative description rather than a quantitative criterion. Meeting a quantitative criterion requires analysis, assumptions, computer programs, etc., and therefore becomes dependent on the details and subject to the uncertainties of just how the quantitative criterion is claimed to be met. Finally, each description must be able to pass a "sanity test;" i.e., not to lead to ridiculous results such as allowing either the Three Mile Island or the Chernobyl plants to be described as inherently safe, based only on information available prior to their accidents.

2.2 Explanation of Various Concepts

1) Inherent* Safety refers to the achievement of safety through the elimination or exclusion of inherent hazards through the fundamental conceptual design choices made for the nuclear plant. Potential inherent hazards in a nuclear power plant include radioactive fission products and their associated decay heat, excess reactivity and its associated potential for power excursions, and energy releases due to high temperatures, high pressures and energetic chemical reactions.
Elimination of all these hazards is required to make a nuclear power plant inherently safe. For practical power reactor sizes this appears to be impossible. Therefore the unqualified use of "inherently safe" should be avoided for an entire nuclear power plant or its reactor.

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* Intrinsic is considered to be synonymous with inherent.

2) On the other hand, a reactor design in which one of the inherent hazards is eliminated is inherently safe with respect to the eliminated hazard. An inherent safety characteristic* is a fundamental property of a design concept that results from the basic choices in the materials used or in other aspects of the design which assures that a particular potential hazard can not become a safety concern in any way.

   No changes of any kind, such as internally or externally caused changes of physical configuration can possibly lead to an unsafe condition. For example, a plant in which no combustible materials are employed would be inherently safe against fire, regardless of whatever else may happen during an accident.

   As described, inherent safety is equivalent to absolute safety; i.e., an inherent safety characteristic is not subject to failure of any kind. Stated another way, an inherent safety feature represents conclusive, or deterministic safety, not probabilistic safety.

3) When an inherent hazard has not been eliminated, engineered safety systems, structures, or components are provided in a design to make its use acceptable without undue risk Such provisions generally aim to prevent, mitigate, or contain potential accidents. Although an objective in their design is to make them highly reliable, they remain in principle subject to failure (however low the probability of such failure), unlike inherent safety characteristics.

4) The concepts of active and passive safety describe the manner in which engineered safety systems, structures, or components function and are distinguished from each other by determining whether there exists any reliance on external mechanical and/or electrical power, signals or forces. The absence of such reliance in passive safety means that the reliance is instead placed on natural laws, properties of materials and internally stored energy. Some potential causes of failure of active systems, such as lack of human action or power failure, do not exist when passive safety is provided. However, it is important to note that passive devices remain subject to other kinds of failure, such as those resulting from mechanical or structural failure or willful human interference. Therefore, passive safety is not synonymous with inherent safety or absolute reliability.

5) The concept of passivity as described can be considered in terms of several degrees or categories, which are described and discussed in Appendix A. Safety systems may be classified into the higher categories of passivity when all their components needed for safety are passive. Systems relying on no external power supply but using a dedicated, internal power source (e.g., a battery) to supply an active component are not subject to normal, externally caused failures and are included in the lowest category of passivity. This kind of system has active and passive characteristics at different times, for example, the active opening of a valve initiates subsequent passive operation by natural convection.

Explanatory and supporting comments on the development of the concepts of inherent and passive safety as presented above are given in Appendix B.

6) Fail-safe refers to the behaviour, after a failure (either internal or external) of a component or system. When a given failure nevertheless leads directly to a safe condition, the component or system is fail-safe with respect to that failure. If the failure leads to safety only indirectly, as through activation of a redundant system, the criterion for fail-safe is not met.

   In principle, the concept of fail-safe is meaningful only in the context of a stated kind of failure and situation, since systems can be vulnerable to many kinds of failures and under different situations be fail-safe with respect to some of these and not fail-safe with respect to others.

7) The term grace period is used to describe the ability of a plant to remain in a safe condition for a substantial period of time after an incident or accident, without need for any human intervention. The calculation of a value for the grace period of a particular plant requires both the definition of the accidents to be considered and a numerical limit for allowable external radiation dose for such accidents during the grace period. The accidents and the dose limit calculation are necessarily specific to the plant design, the site, and the regime under which licensing takes place. These are not further described, since the present objective is to describe only the general concepts underlying the various terms.

   The term walkaway safe has also been used in contexts similar to those of the grace period. Although this term was never intended to imply that plant staff may actually walk away after an incident, the potential for such misunderstanding exists. By specifying the duration of a grace period, the length of time during which a plant may be said to be walkaway safe is given. The use of the term walkaway safe is unnecessary and its use should be avoided.

8) Since operations may in the worst case involve human error or misguided action to initiate upset conditions or failure to take obvious prescribed actions during an emergency, another word describing safety with respect to human action or inaction, foolproof, is often used. Foolproofness is the achievement of safety regardless of any faulty but well-intentioned human actions or inactions; for example, through simplification and good ergonomics practice.

9) The terms forgiving, error-tolerant or preferably fault-tolerant are relative terms sometimes used to describe the degree to which human inaction (or erroneous action) can be tolerated. Fault-tolerant is also similarly used with regard to mechanical or electrical faults or malfunctions. As relative terms, they may validly be used only in comparing two specific designs; any statement that a given design by itself is "fault-tolerant" or "forgiving" is meaningless and should be avoided. The degree of tolerance to operator inaction is

usually associated with dynamic characteristics, such as large thermal inertia or wide operating margins with respect to safety limits, which provide more time before corrective action is needed.

10) Designing for safety through simplification avoids complexity by using a minimum number of components to achieve the safety function and to rely as little as possible on support systems. This should minimize operator errors and the need for maintenance actions and testing. Adoption of simplified safety function may imply sharper distinctions between the safety missions such as protecting the fuel integrity and preventing the release of radioactivity to the environment.

11) Transparent safety is obvious or easily understandable safety and normally follows from inherent safety characteristics and from simple, straightforward design concepts. Since it is a relative term necessarily dependent on the knowledge, experience, and intelligence of the person trying to understand the safety concept, the highest degree of transparency is associated with easy understanding by the layman rather than by the expert.

3. DESCRIPTION OF TERMS

1) Inherent safety characteristic
Safety achieved by the elimination of a specified hazard by means of the choice of material and design concept.

2) Passive Component
A component which does not need any external input to operate.

3) Active component
Any component that is not passive is active.

4) Passive system
Either a system which is composed entirely of passive components and structures or a system which uses active components in a very limited way* to initiate subsequent passive operation.

5) Active system
Any system that is not passive is active.

6) Fail-safe
The term describes the behaviour of a component or system, following a failure (either internal or external). If a given failure leads directly to a safe condition, the component or system is fail-safe with respect to that failure.

7) Grace period
The grace period is the period of time during which a safety function is ensured without the necessity of personnel action in the event of an incident/accident.

8) Foolproof
Safe against human error or misguided human action.

9) Fault-/error-tolerant (also called forgivingness)
The term fault-/error-tolerant, also called forgivingness, describes the degree to which equipment faults/human inaction (or erroneous action) can be tolerated.

10) Simplified safety system
A system designed with a minimum number of components to achieve the related safety function and relying as little as possible on support systems.

11) Transparent safety
Safety which is obvious or easily understandable; this normally follows from simple, straightforward design concepts or from inherent safety characteristics.

* For elaboration of limitations, please see Appendix A.

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Appendix A

RANGE OF POSSIBILITIES FROM PASSIVE TO ACTIVE

When deliberating over the distinctions between active and passive functions and within these two categories, it was realized that a spectrum of possibilities exists. This commentary is offered to qualitatively address this difficult question.

For components and systems (but not structures) having safety functions, there must be at least two states corresponding to the normal function and to the safety function. Then, to change from the normal to the safety state:

- there must be "intelligence" such as a signal or parametric change to initiate action;
- there must be power and potential difference or motive force to change states; and
- there must be the means to continue to operate in the second state.

A component or system can be called passive when all three of these considerations are satisfied in a self-contained manner. Conversely, it is considered active if external inputs are needed.

There are, however, other considerations that must be taken into account because passive has a connotation of superior performance that cannot be accepted without evaluation and justification.

These other considerations include:

- reliability and availability in the short term, the long term and under adverse conditions;
- longevity; the equivalent of shelf life, against corrosion or deformation by creep etc;
- the requirements for testing or demonstration; and
- simplification and man-machine interaction.

From these considerations some broad categories of passivity can be drawn for qualitative evaluation and classification. The following categories can be considered as passive:

<u>Category A</u>

This category is characterized by:

- no signal inputs of "intelligence", no external power sources or forces,
- no moving mechanical parts,
- no moving working fluid.

(The no-motion requirement does not extend to unavoidable changes in geometry such as thermal expansion.)

Examples of safety features included in this category are:

- physical barriers against the release of fission products, such as nuclear fuel cladding and pressure boundary systems;
- hardened building structures for the protection of a plant against seismic and or other external events;

- core cooling systems relying only on heat radiation and/or conduction from nuclear fuel to outer structural parts, with the reactor in hot shutdown; and
- static components of safety related passive systems (e.g., tubes, pressurizers, accumulators, surge tanks), as well as structural parts (e.g., supports, shields).

Category B

This category is characterized by:

- no signal inputs of "intelligence", no external power sources or forces,
- no moving mechanical parts, but
- moving working fluids.

The fluid movement is only due to thermal-hydraulic conditions occuring when the safety function is activated. No distinction is made among fluids of different nature (e.g., borated water and air) although the nature of the moving fluid may be significant for the availability of the function performed within this category.

Examples of safety features included in this category are:

- reactor shutdown/emergency cooling systems based on injection of borated water produced by the disturbance of a hydrostatic equilibrium between the pressure boundary and an external water pool;
- reactor emergency cooling systems based on air or water natural circulation in heat exchangers immersed in water pools (inside containment) to which the decay heat is directly transferred;
- containment cooling systems based on natural circulation of air flowing around the containment walls, with intake and exhaust through a stack or in tubes covering the inner walls of silos of underground reactors; and
- fluidic gates between process systems, such as "surge lines" of PWRs.

Category C

This category is characterized by:

- no signal inputs of "intelligence", no external power sources or forces; but
- moving mechanical parts, whether or not moving working fluids are also present.

The fluid motion is characterized as in category B; mechanical movements are due to imbalances within the system (e.g., static pressure in check and relief valves, hydrostatic pressure in accumulators) and forces directly exerted by the process. Examples of safety features included in this category are:

- emergency injection systems consisting of accumulators or storage tanks and discharge lines equipped with check valves;
- overpressure protection and/or emergency cooling devices of pressure boundary systems based on fluid release through relief valves;

- filtered venting systems of containments activated by rupture disks; and
- mechanical actuators, such as check valves and spring-loaded relief valves, as well as some trip mechanisms (e.g., temperature, pressure and level actuators).

Category D

This category addresses the intermediary zone between active and passive where the execution of the safety function is made through passive methods as described in the previous categories except that internal intelligence is not available to initiate the process. In these cases an external signal is permitted to trigger the passive process. To recognize this departure, this category is refered to as "passive execution/active initiation".

Since some desirable characteristics usually associated with passive systems (such as freedom from external sources of supply and from required human actuation) are still to be ensured, additional criteria such as the following are generally imposed on the initiation process:

- Energy must only be obtained from stored sources such as batteries or compressed or elevated fluids, excluding continuously generated power such as normal AC power from continuously rotating or reciprocating machinery;
- Active components are limited to controls, instrumentation and valves, but valves used to initiate safety system operation must be single-action relying on stored energy; and
- manual initiation is excluded.

Example of safety systems which may be included in this category are:

- emergency core cooling/injection systems, based on gravity driven or compressed nitrogen driven fluid circulation, initiated by fail-safe logic actuating battery-powered electric or electro-pneumatic valves;
- emergency core cooling systems, based on gravity-driven flow of water, activated by valves which break open on demand (if a suitable qualification process of the actuators can be identified); and
- emergency reactor shutdown systems based on gravity driven, or static pressure driven control rods, activated by fail-safe trip logic.

Concluding Points

The spectrum of possibilities from passive to active may well have additional categories. However, all passive systems must be essentially self-contained or self-supported; the more self-contained, the higher the degree of passivity. Other possibilities range to fully active, where all basic functions are supplied externally.

It should be emphasized that passivity is not synonymous with reliability or availability, even less with assured adequacy of the safety feature, though several factors potentially adverse to performance can be more easily counteracted through passive design. On the other hand active designs employing variable controls permit much more precise accomplishment of safety functions; this may be particularly desirable under accident management conditions.

A safety feature ranking in a lower passivity category is not necessarily less desirable than one in a higher category designed to perform the same function; the difference in categorization signifies only a difference in the extent of application of the passive safety principle.

Appendix B

EXPLANATORY AND SUPPORTING COMMENTS

The consultants' formulation of the description of inherent safety was aided by a comprehensive document on this subject by Trevor A. Kletz of the United Kingdom (1). This document deals with safety in the chemical industry, rather than in nuclear plants, is well-written and compelling, and the concepts presented are receiving wide acceptance in that industry. Although Kletz never explicitly defines inherent safety, the present approach to inherent safety and inherent safety characteristics represents the application of Kletz's concepts to nuclear plants in a concise way. Reading the Kletz document is strongly recommended as a means of achieving a fuller understanding of the implications of inherent safety. It should, however, be emphasized that the use of these inherent safety concepts in nuclear reactor technology is not new; for example, in 1961 the inherent safety features of a pressurized water reactor were described in a manner fully in accordance with Kletz and the descriptions given here (2).

For the description of the characteristics which distinguish passive from active components given in this paper, two alternative approaches were proposed and discussed: the concept of "no external mechanical and/or electrical power, signals or forces" and the concept of "no moving parts". The initial draft from the Västeras meeting had utilized the latter concept, but with an accompanying footnoted statement indicating the existence of possible exceptions such as "rupture discs, check valves, safety valves, injectors and some solid state electronic devices". During the discussion of these alternate approaches, agreement was reached that rupture discs should be considered passive in spite of the "moving part", but that similar acceptance of check valves, for instance, was difficult for some members of the group, primarily because of the feeling that check valves may not be sufficiently reliable. Further discussion tended toward the view that the distinguishing feature for passivity should be based on the principle of operation, rather than on judgements of reliability. Quality of design, engineering, materials, manufacture, operations, maintenance, etc., all affect reliability, and it is thus possible to achieve high reliability (or suffer low reliability) with either passive or active components. The "no external inputs" concept was therefore preferred, as it required no ill-defined statement regarding exceptions.

During subsequent discussion of passive vs. active systems, the concept of a series of different degrees of passivity was developed. This series covers a spectrum ranging from "no moving parts, no moving fluids" at one extreme to a system meeting the criteria for passive, after an active initiation. After further discussion, the series of different degrees of passivity as described in Appendix A was accepted. In that appendix, the "actively-actuated" systems are the lowest category of passive.

References

1. Trevor A. Kletz, "CHEAPER, SAFER PLANTS or Wealth and Safety at Work--Notes on Inherently Safer and Simpler Plants", 2nd Edition, 1985, available from the Institution of Chemical Engineers, 165-171 Railway Terrace, Rugby, Warwickshire CV21 2HQ, United Kingdom.
2. Technical Safety Evaluation of the N.S. Savannah, European Atomic Energy Community, Brussels, October 1961, p. 21-22.

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Attachment

LIST OF PAPERS PRESENTED AT THE TECHNICAL COMMITTEE MEETING ON DEFINITION AND UNDERSTANDING OF ENGINEERED SAFETY, PASSIVE SAFETY AND RELATED TERMS

Västeras, Sweden, 30 May – 2 June 1988

Development of safety terms for both qualitative understanding and a quantitative application
R.E. Touzet

Advanced reactor concepts and safety
J.J. Lipsett

Safety category and inherent safety for water-cooled reactor
Zhang Senru

Thoughts about safety concepts and definition of safety terms in Federal Republic of Germany
P.-J. Meyer

Definition of some terms related to nuclear reactor safety and some discussions on passive cooling of reactor core under certain operational states
V. Venkat Raj

Formulating definitions of safety-related terms
M. Aritomi, K. Tominaga

Definitions of safety-related terms
M. Aritomi, K. Tominaga

Definitions for new safety features and their consequences
L. Noviello, S. Reynaud

Passive safety versus traditional safety concepts, goals, potentials and implications
T. Pedersen, T. Oehlin

Discussion of suggested definitions of terms describing passive safety
T. Pedersen

Implications of passive safety based on historical industrial experience
C.W. Forsberg

A discussion of defintions and usage of terms implying highly desirable nuclear safety characteristics
P.M. Lang

Basic theses and terms of concepts of light-water reactors with improved safety in the USSR
V.A. Voznesensky, V.G. Fyodorov

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Consultancy to Achieve Harmonization and Transparency in the Use of Terms and Defintions to Describe the Passive Features of Advanced Reactors
3-6 December 1990, VIC, Vienna

Consultants Meeting on Description of Passive Safety Related Terms
3-5 October 1988, VIC, Vienna

Technical Committee Meeting on Definition and Understanding of Engineered Safety, Passive Safety and Related Terms
Västeras, Sweden, 30 May - 2 June 1988