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Terms for describing new, advanced nuclear power plants

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FOREWORD

The development of new nuclear power plant designs spans a wide range of alternatives. Some represent only small extensions of existing designs, while others incorporate more significant modifications and departures from such designs. The new designs have frequently been described as advanced designs, next generation designs, evolutionary designs, or by more pseudo-technical terms such as passively safe designs, intrinsically safe designs, and deterministically safe designs. A precise explanation of the implication of the terms did not seem to exist, and different organizations have used the same terms with different meanings. Such inconsistencies may create confusion and result in credibility problems, and an effort to improve the understanding of widely used technical terms and to provide clarification regarding their proper usage, as well as similar related terms, is important.

The IAEA's Division of Nuclear Power and the Fuel Cycle (then the Division of Nuclear Power) took an initiative in this field some years ago when work was initiated in the area of "safety related terms" by its International Working Group on Advanced Technologies for Water Cooled Reactors. This activity drew on advice from reactor design organizations, research institutes and government organizations, and aimed at helping eliminate confusion and misuse of safety related terms in widespread use, clarifying technical thinking regarding these terms, and improving nuclear power acceptability by providing precisely described technical meanings to them. After discussion also in the International Working Groups for Gas Cooled Reactors and Fast Reactors, the work resulted in the publication in September 1991 of IAEA-TECDOC-626, entitled "Safety Related Terms for Advanced Nuclear Plants", which has become a widely used publication.

The present TECDOC has been prepared using the same approach to obtain advice from involved parties. Drafts of this report have been reviewed by the International Working Groups on Water Cooled Reactors, Fast Reactors and Gas Cooled Reactors, as well as by the IAEA's International Fusion Research Council (IFRC). The comments and suggestions received have been evaluated and utilized for producing the present TECDOC.

The IAEA staff member responsible for this publication was T. Pedersen of the Division of Nuclear Power and the Fuel Cycle.

EDITORIAL NOTE

CONTENTS

1. INTRODUCTION

Terms such as "evolutionary designs", "passive designs", and "innovative designs" have been widely used in describing advanced nuclear plant designs, generally without definition and sometimes with usages inconsistent with each other.

In view of the importance of communication to both the public and to the technical community in general and among the designers of different advanced reactor lines within the nuclear industry itself, consistency and international consensus are desirable with regard to the terms used to describe various categories of advanced designs. In 1991, a report entitled "Safety Related Terms for Advanced Nuclear Power Plants" was issued as IAEA-TECDOC-626, *and this TECDOC has become widely used. The terms considered in the present* publication refer primarily to the state of development of the designs and to the general amount, kind and duration of effort needed to bring them to realization. Although some relationship to safety in these terms is unavoidable since enhanced safety is a goal of virtually all current advanced reactor work, safety is not usually the main focus of these terms. Even so, the approach to the definition of the terms considered here follows that of TECDOC-626 to the extent applicable.

Many organizations and persons have made and continue to make proposals for improving and advancing nuclear technology. There is a very large spread in the degree of innovation in proposed design approaches and in the corresponding degree of technical maturity of the solutions being proposed. Although there is also a spread in design objectives ranging from improving performance, economics, and safety over what has already been achieved with current technology to expanding the field for application of nuclear energy, strong common threads include enhancement of safety, feedback of experience from operating plants, and incorporation of recent advancements in electronics, computers, and human factors. The terms described here are used to distinguish between designs at different points in this spread.

The designs considered are plant designs rather than reactor designs, since the reactor is only a part of the complete installation needed to produce economic, dependable, and safe nuclear energy.

The following terms are described in this report:

- Advanced design
- Evolutionary design
- Innovative design
- Next generation design
- Near-, mid- and long-term designs
- Future design
- Integral design
- Revolutionary design
- Passive, simplified, and forgiving designs
- Inherently safe design
- Deterministically safe design
- Catastrophe free design.

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, also by members of the nuclear community, rendering the terms more meaningful, and thereby improving communication within the technical community and with the public; and

- to help clarify these terms and thereby to achieve a better understanding of the time and effort needed to bring the various advanced designs into operation.

The specific purpose of this TECDOC is to draw distinctions between design stages reflecting the maturities of designs[1]; e.g., whether of a developmental nature with some yet untested features or whether evolutionary in the sense of drawing primarily on experience with existing plants.

Many of the terms described in this report have been widely used in some countries, sometimes without sufficiently clear understanding of what they mean and what they imply. The intent of this TECDOC is **not to promote** wider use of these terms, but rather **to clarify** their meaning. Some of these terms have the potential of being misleading to non-experts and of conveying to the public undesirable implications not intended by the designers of advanced plants. The criterion for inclusion of each term in the definitions of this TECDOC has been whether the term is already in fairly common, widespread use, **not** whether such use is desirable. Some terms described here are not compatible with this criterion. They are therefore undesirable and their use should be avoided; when this is the case it is indicated in their description. Finally, it should be mentioned that description of some potentially useful terms not now widely used was intentionally omitted to avoid coining or promoting new terms, which, again, would increase rather than reduce potential misunderstanding.

The explanations of the terms for describing new, advanced nuclear power plants 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. Dictionary definitions tend to describe such public understandings in very broad and general terms; the descriptions here should conform to dictionary definitions but should include any elaboration, refinement, and specificity needed to make them applicable and useful for describing advanced nuclear power systems.

Another important criterion is clarity and ease of application; there should be no ambiguity, and anyone who understands a particular design should be able to determine, quickly and easily, whether or not it conforms to a description. This is more readily achieved by drawing distinctions on the basis of qualitative principles and approaches rather than on quantitative criteria or on judgements of degree to which some qualitative judgement criterion is attained.

The process of resolving differences resulting from historically different development goals and approaches and time scales in different countries, between varied interests, and between differing cultural understanding of words has been difficult. Compromise on an international

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[1]In the context of design maturity, a model for describing different phases of design development has been discussed, but the related terms were found to be of general nature and not specific for describing advanced designs. Therefore, the description of the design development phases has not been included in the main text, but is presented in Appendix B.

level was often required. This holds also for some of the technical comments and suggestions made by outside reviewers.

2. DESCRIPTION OF TERMS

The relationship between the development related terms described below is shown in Figure 1. Neglecting in the present context the important group of designs of operating plants, all currently proposed and future plant designs are advanced plant designs if they are of current interest and/or merit. Advanced designs can be further characterized, depending upon the major attribute of requiring, or not requiring, a prototype or a demonstration plant. Further subdivisions of these categories are defined, but except for the innovative designs, consensus terms could not be found for these subdivisions, given the desire to avoid coining new terms. The degree of innovation of designs in these subdivisions increases from small in the engineering-only category to unlimited in the innovative designs.

Advanced design

An advanced plant design is a design of current interest for which improvement over its predecessors and/or existing designs is expected. Advanced designs consist of evolutionary designs and designs requiring substantial development efforts[2]. The latter can range from moderate modifications of existing designs to entirely new design concepts. They differ from evolutionary designs in that a prototype or a demonstration plant is required, or that not sufficient work has been done to establish whether such a plant is required.

Evolutionary design

An evolutionary design is an advanced design that achieves improvements over existing designs through small to moderate modifications, with a strong emphasis on maintaining design proveness to minimize technological risks. The development of an evolutionary design requires at most engineering and confirmatory testing.

Innovative design

An innovative design is an advanced design which incorporates radical conceptual changes in design approaches or system configuration in comparison with existing practice. Substantial R&D, feasibility tests, and a prototype or demonstration plant are probably required.

Next generation design

This term can refer to designs for plants to be built in the future, or that represent substantial technological advancements, or both. Since this term can cover a wide spectrum, it is suggested that it be used with great care and only with a specific definition by the user.

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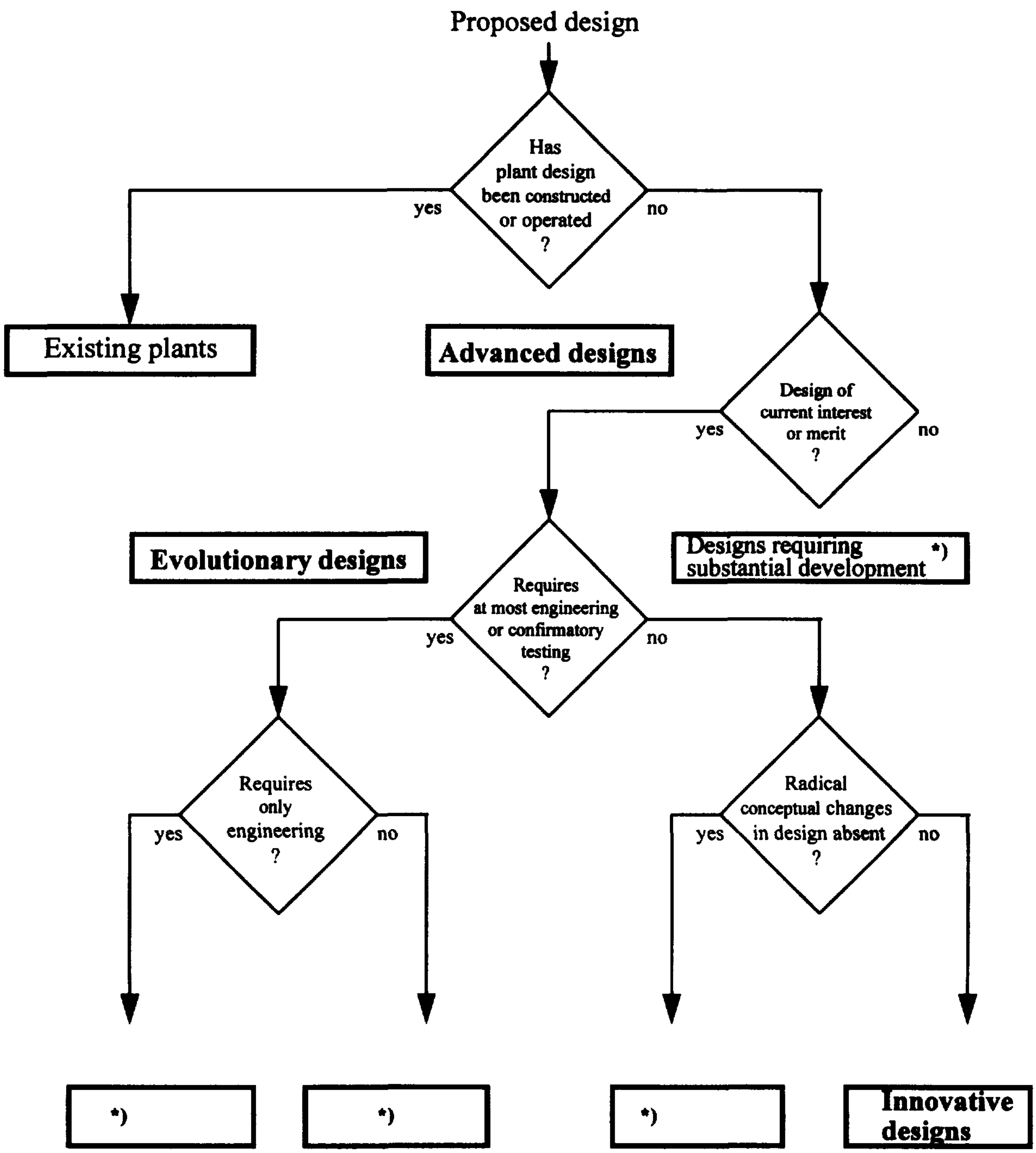
[2]When advanced designs are utilized for plant construction and the plant is placed in operation, the design will at some point cease to be advanced.



*) *No consensus could be found on suitable existing terms for these categories.*

FIG. 1. Relationship between design related terms.

Near-, mid- and long-term designs

Time references such as near-, mid- and long-term are usually applied to advanced designs. If the time scale implied by the use of these relative terms is not obvious from the context, it should be stated by the user.

Future design

The term "future design" refers to plants not yet built, whether of advanced design or not. It refers to time only.[3]

Integral design

The term "integral design" refers to a reactor system design in which the whole reactor primary circuit, including, for instance, pressurizer, coolant pumps, and steam generators/heat exchangers, as applicable, is enclosed in the reactor vessel. It is a purely technical term.

TERMS TO BE AVOIDED

Revolutionary design

The term "revolutionary design" has sometimes been used to characterize an advanced design that is substantially different from evolutionary designs. It has essentially the same attributes as an innovative plant design, but since the word revolution may have a negative connotation, the use of this term should be avoided.

Passive, simplified and forgiving designs

These have been described in IAEA-TECDOC-626[4] at the component and system level. Unless it can be shown that these terms can validly be applied at the plant level, their use as plant descriptors should be avoided.

Inherently safe design

In accordance with the conclusions in IAEA-TECDOC-626, the unqualified use of the term "inherently safe" should be avoided for describing an entire nuclear power plant or its reactor.

Deterministically safe design

The term "deterministically safe" has sometimes been used for concepts in which all accident sequences leading to unacceptable consequences are described as having been eliminated by design measures. The use of this descriptor for an entire nuclear power plant, or its reactor, is discouraged since it implies absolute safety, which is impossible.

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[3]The term "future designs" has been used in a somewhat different meaning in some IAEA publications, e.g., in IAEA-TECDOC-801 on "Development of Safety Principles for the Design of Future Nuclear Power Plants" in which it denotes designs with enhanced safety characteristics.

[4]An excerpt of IAEA-TECDOC-626 is provided in Appendix A.

Catastrophe free design

The term "catastrophe free design" has sometimes been used for describing concepts for which it is claimed that all accident sequences that could potentially lead to unacceptable consequences, have been eliminated by design measures. The use of this descriptor is discouraged on essentially the same grounds as for the term "deterministically safe design".

3. DISCUSSION OF BACKGROUND OF TERMS

Nuclear power plant designs that are being developed span a wide range of alternatives; some represent very small extensions of present day designs, others incorporate more significant, but still rather moderate modifications, and still others depart very markedly from current designs, including on occasion radical innovations. Existing plants and established development programmes cover light water reactor (LWR), heavy water reactor (HWR), high temperature gas cooled reactor (HTGR), and liquid metal reactor (LMR) technologies; in addition, other basic concepts, such as the Molten Salt Reactors, have been developed in the past and could be of future interest.

3.1. ADVANCED DESIGNS

Designs which have already been built and operated can not be considered advanced designs, and terminology for existing plants is already well established and beyond the present scope. When considering future designs, it is also necessary to ask whether any candidate design is of current interest or merit. Among the many conceivable designs, there are some which have been previously developed (either wholly or partially) and then abandoned. Many of these have been conceived and considered but not found to be of sufficient interest for further development, and presumably some which remain to be conceived and evaluated. In the approach taken for this publication, none of these can currently be considered as Advanced Designs; that designation applies only to designs of current interest or merit which upon completion of their development are expected to incorporate improvements of varying degrees and kinds over existing plants.

Development programmes are not always successful in regard to full achievement of desired improvements. Only upon successful development, an advanced design would also be an improved design. Evolutionary designs involving a minimum of technological risks will normally be improved designs. Very innovative designs are subject to large development risks and may or may not become improved designs. Conversely, an improved design need not be an advanced design, since the term improved may also refer to improvements implemented in an existing plant.

At some point in time, designs that have been successfully developed, built, and operated can no longer be considered advanced. In other words, the term advanced is a relative term that may change with time. Similarly, when considering independent reactor developments in different countries, the term advanced design is relative because what has been implemented in one place may still be the subject of active development in another. For the question of precisely when in the development process an advanced design becomes an operating plant, the IAEA-PRIS[5] practice of accepting a plant as operating when it is first

[5]IAEA-PRIS refers to the IAEA Power Reactor Information System that contains general information on operating nuclear power plants as well as data on their performance.

connected to the electric grid or, in the case of heat-only plants, to its load has been adopted here.

3.2. EVOLUTIONARY DESIGNS AND DESIGNS REQUIRING SUBSTANTIAL DEVELOPMENT

The full spectrum of advanced plant designs or concepts for which current interest or merit can be identified, covers evolutionary designs as well as designs requiring substantial development efforts. A natural dividing line between these groups arises from the necessity of having a prototype or demonstration plant to bring a concept with much innovation to commercial maturity as such a plant represents the major part of the resources needed. Note that designs in both categories need engineering, and may also need R&D and confirmatory testing prior to freezing the design of either the first plant of a given line in the evolutionary category or of the prototype and/or demonstration plant for the second category. The amount of such R&D and confirmatory testing depends on the degree of both the innovation to be introduced and the related work already done, or the experience that can be built upon. This is particularly true for designs in the second category where it is entirely possible that all a concept needs is a demonstration plant, if development and confirmatory testing is essentially completed. At the other extreme, R&D, feasibility tests, confirmatory testing, prototype and/or demonstration plant are needed in addition to engineering. Figure 2 illustrates schematically the different tasks to be accomplished and their corresponding costs in qualitative terms as a function of the degree of departure from existing designs. In particular, it shows the jump in costs resulting from the need to build a reactor as part of the development programme.

When beginning the development of a plant design incorporating substantial new concepts or approaches, it is not always obvious whether a prototype and/or demonstration plant will be needed. Prior to a decision on such need, the design should be considered as part of the second category.

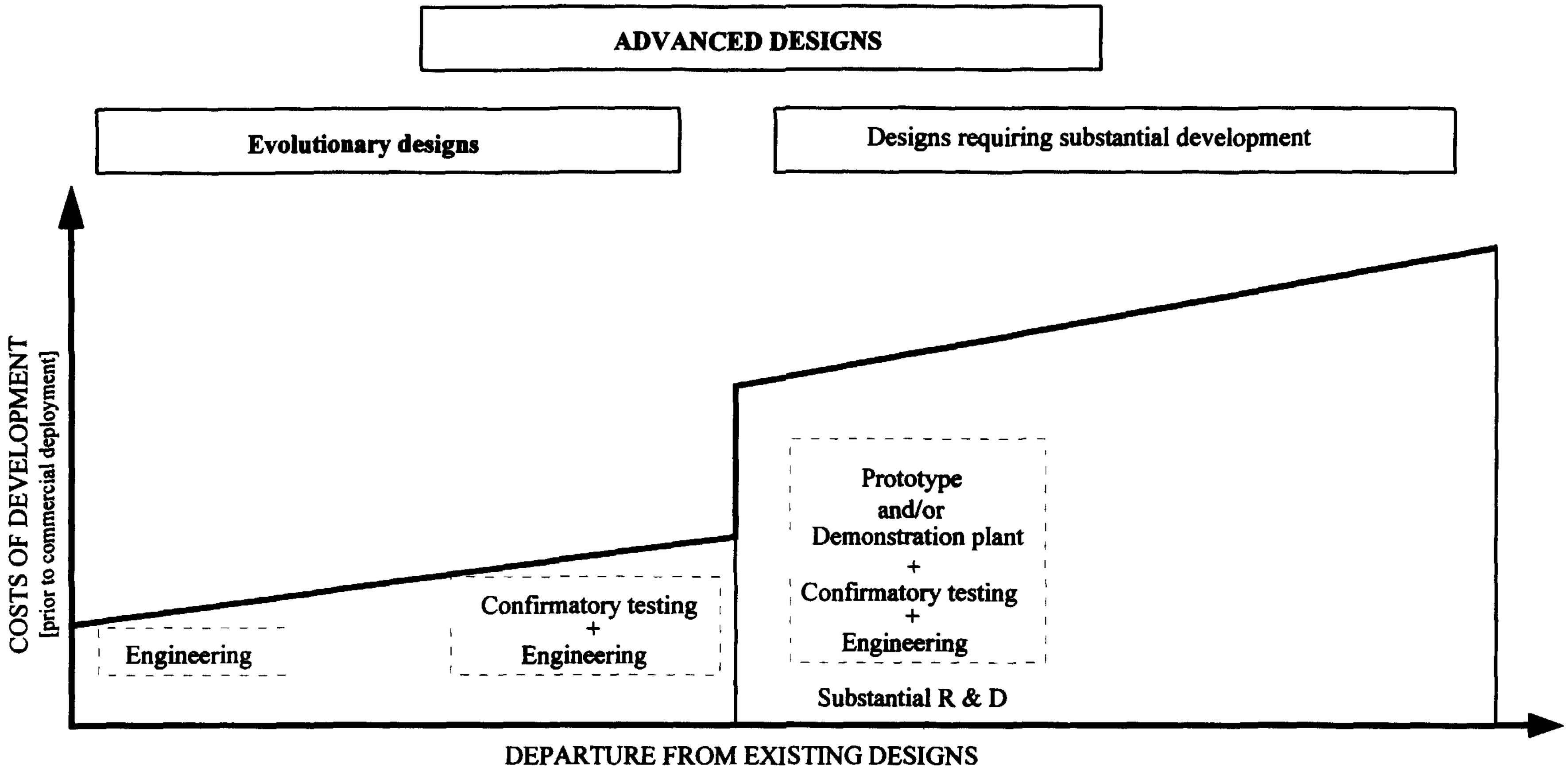
Evolutionary designs involve only moderate modifications or improvements of present day plant designs — with a strong emphasis on maintaining proven designs. In this way, commercial risks are minimized. If modifications and design changes are larger, with more departure from current designs, and with introduction of unproven features, risks increase correspondingly since less operating experience would be applicable.

If a plant design appears to be very similar to an existing plant, it may still be called evolutionary since even a near-replica of a given design is usually fine tuned to include the most recent operating experience, and thus incorporates evolutionary changes.

3.3. RANGE OF EVOLUTIONARY DESIGNS

Evolutionary designs may be subdivided into two categories, depending on whether only engineering is required or whether both engineering and confirmatory testing are needed.

Given the desire to avoid coining new terms and the lack of international usage and consensus on terms to describe these two categories, no designations for them are shown in Figure 1.



[A prototype is normally a scaled down unit, whereas a demonstration plant is a more substantial plant that can be as large as full size.]

FIG. 2. Efforts and costs of development for advanced designs versus departure from existing designs.

In the US Advanced Light Water Reactor Program, the terms "evolutionary ALWRs" and "passive ALWRs" have been defined. In this context, however, "evolutionary" and "passive" are used as qualifiers for the basis under which licensing of these plants is being pursued in the USA. "Evolutionary" refers to plants to be licensed on the basis of active safety systems. "Passive" refers to plants to be licensed on the basis of passive safety systems. ("Hybrid" would be used for plants licensed on the basis of a combination of active and passive safety systems.)

Confirmatory testing to satisfy regulatory and investment protection concerns is expected to be minimal for the "evolutionary ALWRs" and extensive for the "passive ALWRs".

3.4. RANGE OF DESIGNS REQUIRING SUBSTANTIAL DEVELOPMENT

The range of designs for which substantial development efforts are still needed is much wider than for the category of evolutionary designs. For some concepts, development is almost completed, while for other concepts much work remains to be performed.

Again, given the stated desire to avoid coining new terms, only one category, "innovative design", is designated in Figure 1.

The key attribute of an innovative design, sometimes also called a novel design, is that it is based on radical conceptual changes in design approaches or system configuration in comparison with established practice. As the degree of innovation introduced may differ from concept to concept and since the judgement of which changes are radical conceptual changes is necessarily very subjective, a sharp and objective distinction between innovative designs and other designs needing substantial development is very difficult. Anyone describing reactor concepts of this kind needs to explain the terminology.

3.5. TIME RELATED TERMS

Although the terms "future design", "near-, mid- and long-term" designs are straightforward and not usually subject to misuse or misunderstanding, they are qualitative, and whoever uses them should give an appropriate indication of what time frame is meant, if it does not follow from the context.

Common use of the terminology "next generation" implies time or specific characteristics, or both. Applied to nuclear power plant designs, it can cover a wide spectrum ranging from modest modifications over their predecessors, to concepts with radical and fundamental changes that are far more ambitious than for evolutionary designs. On the other hand, the term is often used by industry for a new series of plants which may be only a decade apart as opposed to the much longer time usually needed for radically new concepts. Usage of the term next generation design[6] to describe both extremes is acceptable as long as the respective meaning follows from the context.

3.6. INTEGRAL DESIGN

As the term "integral design" is a purely technical term, there is no need for further discussion.

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[6]In this context it may be noted that the term "new generation" has sometimes also been used to describe new, improved designs, denoting advanced designs to be built in the future.

3.7. TERMS TO BE AVOIDED

Revolutionary design

The term "revolutionary design" has been used in connection with many innovative designs, almost synonymous with them. Although revolutionary can be a positive acknowledgement of new ideas and new thinking, it may have pejorative connotations, and therefore its use is discouraged.

The term revolutionary has also been used in contrast to evolutionary. This usage of revolutionary is also not encouraged since the second category includes concepts that have a long history of development, and some even without innovative features; therefore, these do not appear to fit the term revolutionary.

Passive, simplified, and forgiving designs

The terms "passive, simplified, and forgiving" have been described in IAEA-TECDOC-626 at the component and system level, as can be seen from the excerpt in Appendix A. Unless it can be shown that these terms can validly be applied at the plant level, their use as plant descriptors should be avoided.

Inherently safe design

The term "inherently safe" is also discussed in the excerpt of the TECDOC, and in accordance with the conclusions there, the unqualified use of the term "inherently safe" should be avoided for describing an entire nuclear plant or its reactor.

Deterministically safe design

The term "deterministically safe" indicates that required or desired safety can be conclusively proven as achievable when **all** accident sequences, even those of very low probability, have been taken into account and adequate measures have been taken to prevent them or to protect against their consequences. The crux of the matter lies in the word "all". If certain postulated, low probability accident sequences can validly be excluded from the word "all", one could probably accept the term deterministically safe. Since such complete exclusion seems difficult to defend in all cases, the use of this term is discouraged.

Also, it may cause confusion since use of deterministic methods constitutes an important element of established licensing practice. In fact, all operating nuclear power plants can be said to be deterministically safe within their licensing basis.

Catastrophe free design

When the term "catastrophe free design" is used, it seems to be synonymous with "deterministically safe design" with the implication that nothing severe can happen to the system on account of its design features. As this implies absolute safety, the use of this descriptor is discouraged.

Besides, the potential use of this term for a specific design would automatically be taken as a confirmation that other designs are far from being "catastrophe free". Hence, it appears imperative that this descriptor **be not used.**

Appendix A

EXCERPTS FROM IAEA-TECDOC-626, "SAFETY RELATED TERMS FOR ADVANCED NUCLEAR PLANTS"

2. BACKGROUND DISCUSSION OF SAFETY CONCEPTS

Explanation of various concepts

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.

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 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.

3. DESCRIPTION OF TERMS

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

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.

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.

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.

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*"Intrinsic" is considered to be synonymous with "inherent".

Appendix B

DESCRIPTION OF DESIGN DEVELOPMENT PHASES

During the development of this report it was suggested also to come to a common understanding of the terms describing the typical phases or stages of design development for a plant from conception until its completion. Although in all cases, the work to be done is more or less similar as dictated by the technical requirements, the practice in the different countries varies widely in the way the work is broken down in phases or stages and the terms used for their descriptions. Such a breakdown is also strongly influenced by the way R&D, testing and licensing are sequenced into the project.

The design and licensing status are important indicators of the engineering status of a plant design; i.e., of its readiness for deployment. An indiscriminate use of various terms to describe design status and differing licensing milestones can lead to confusion and can prevent a clear understanding of the real status. To approach this problem, a classification model based on practice in some European countries was reviewed. This is shown in Fig. B1. In this model, the design status is assessed against a set of often used milestones with five broad, typical phases. These are:

- Concept description:
- Conceptual design;
- Basic design;
- Detailed design; and
- Site specific design & engineering,

with typical activities included in each phase shown on the figure.

In view of the different practices in different countries it was concluded that a consensus on this terminology and scope may be difficult to achieve. Figure B1 addresses engineering activities only. Achieving a consensus on a corresponding terminology for R&D, testing and licensing, will probably also be difficult, and therefore, no attempts were made to include these aspects.

Even though it was found that a consensus would be difficult to achieve, it was generally acknowledged that establishing a model that can be used on an international level to indicate, in an easily understandable way, the status of development for a particular design, or its maturity for deployment, could be useful.

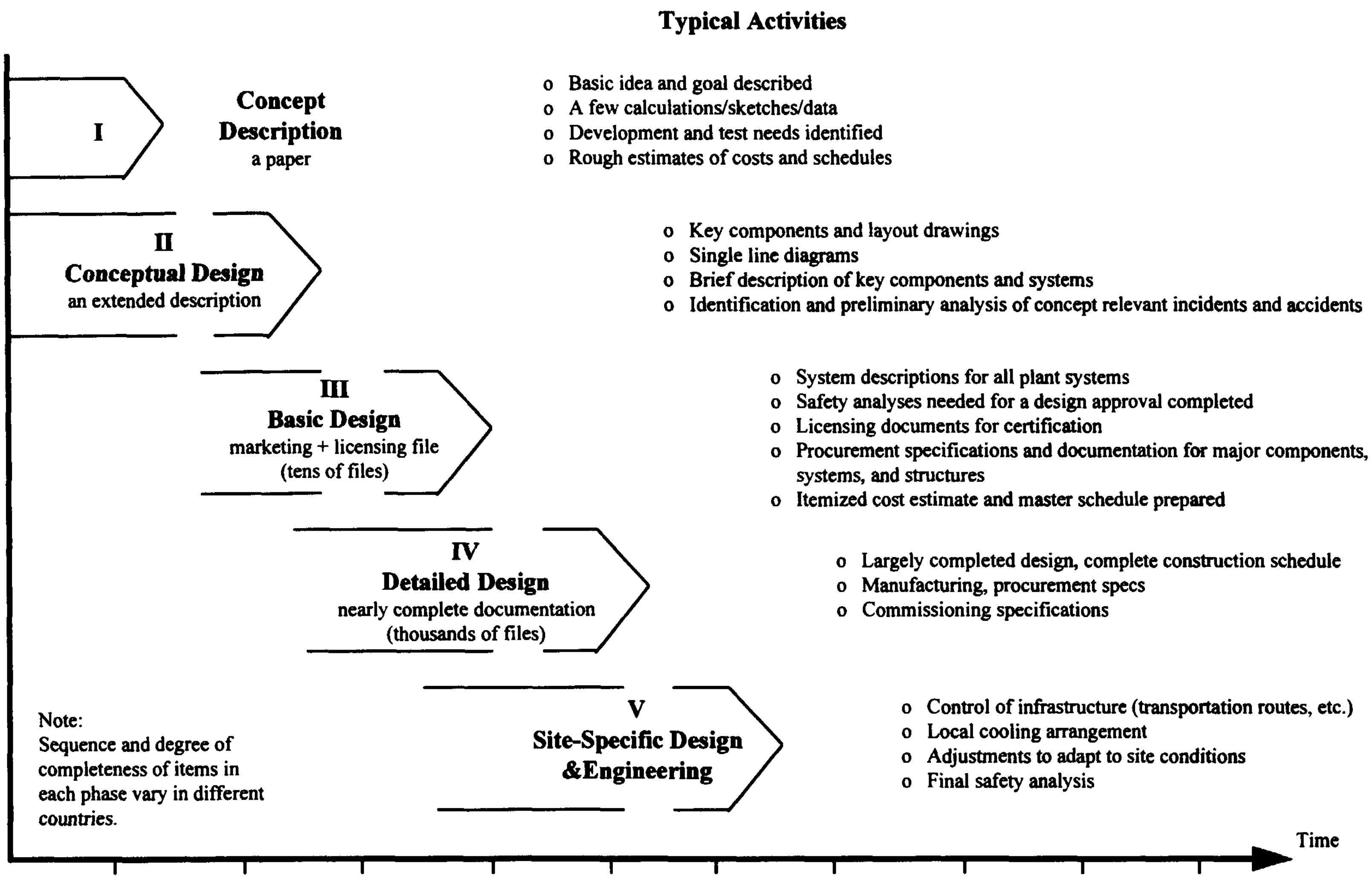

FIG. B1. Phases and corresponding activities during design development (excluding major testing).

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