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EXPECTED DAMAGE STATES OF IN-DOOR COMPONENTS INDUCED BY BUILDING FAILURE

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ABSTRACT

This paper deals with a method to treat the relation of damage state of in-door components induced by a supporting building failure for the seismic PSA study of nuclear power plants. The author introduce the concepts of a damage state vector and a state conversion matrix. Elements of a state conversion matrix consist of two kind of values which obtained by a numerical response analysis and by a subjective judgement on damage records on previous earthquakes.

§1 INTRODUCTION

This concept was produced by the author during the drafting works on "Seismic PSA Modeling" for IAEA in September 1986.

Most of mechanical components in nuclear power plants are installed in a reactor building and other auxiually buildings. Therefore, if a supporting building would be damaged during a destructive earthquake, all components in that building may be damaged in some certain degree. This paper deals with the relation of such type of failure of in-door components including pipings and electrical components. But it should be noticed that those components may be failed or be damaged by the earthquake motions, even if the supporting building is no damaged.

Therefore, the way of establishing the relation of the degree of a building failure to damage of in-door components must be devided into two ways. Those procedures will be discussed in another papers which will be presented in the near future. Anyway, the damage relation of the structure to in-door components under severely damaged condition of a supporting building is estima.ed based on emphirical knowledge obtained in previous earthquakes. There are many records of such type of failures in countries where prefubricated reinforced concrete structure or maisonry structure are used[1][2][3].

On the other hand, if a supporting building will remain no or slightly damaged, the degree of damaging of components can be estimated by the ordinary response and failure analysis technique. The relation can be expressed as a conversion matrix shown latter, but it is expressed by a combined way of the numerical analysis with a subjective assessment.

§2 CONCEPT OF PRACTICE

Most of in-door components, such as mechanical components, electrical components, pipings are installed in building structures, like a reactor building and other auxiuslly building in nuclear power plants. Especially, the safety related items are in a reactor building and other limited auxiliary buildings. Therefore, if the damage state , or degree of damage of those buildings to various input ground accelerations is obtained, the expected damage state of these components can be estimated independently to the building design. If there is no failure on the building, the damage state of components may be estimated by ordinary response and failure analysis. If there is minor damage on the building, the response spectrum using for this analysis should be modified to that in the elasto-plastic region's one. Even if the building is damaged nearly to loose its restoring capacility, the behavior of components also may be estimate by ordinary analytical way. In this case, input ground acceleration to components may be lower than that in the undamaged building, however, the relative movement of separation of anchoring points may cause another type of failure to a multi-supported component like a piping system. And we should expect partial damage of the building in this state, but still the response of components is numerically analyzable.

The spoilation of the building occures and fragments of concreate causes missiles to components, then we should expect another failure mode. This phenomenon is a random one, and more stochastic to compare to former two modes of components failure. If the building is damaged or collapsing, most of failures of components have a stochastic nature, and its probability becomes very high.

The benefit using this concept is as follows:

i) The design groups are usually devided into building engineers and to component engineers, and they know the cause and mode of failures of their own items under a certain earthquake condition.

ii) For the daily practice of Seismic-PSA(PRA), the component engineer should treat enoumous number of items, on the other hand, the number of safety related buildings is very limited. This approach can reduce a number of the response analyses to that of the related buildings and it can avoid too many analyses on whole systems, like a reactor building-reactor vessel system, a reactor building-main pipings system and so on.

iii)The behavior or damage state is not necessary to be included in the Fault Tree Analysis. All basic events start from the failure of components, even they are not independent.

iv) By using FTA procedure for an internal event, there is a possibility to obtain the following state conversion matrix, which is refered from a basic event, obtained by the analysis in this article, to the top event such as core damage.

§3 ANALYTICAL PROCEDURE

As shown in Fig. 1, the various levels of PGA (peak ground acceleration), may be six levels, can be expressed by a probability vector L. This vector is converted to the damage state vector which is expressing the damage state in percentage share D by a conversion matrix B. This process is "Type 1" in the Fig. 1.

If necessary, this damage state vector D can be accompanied by the numerical vector to express the floor acceleration level or the floor response curve and the relative deformation of the building for multi-supported items. This vector may have two types; "Type 2/A" and "Type 2/B" as shown in Fig. 1. Type 2/A shows a stochastic characteristic or distribution of such values for each damage state. And Type 2/B shows only a mean value. Both also should be partially replaced by random failure indecies caused by structural failure of the building, for example, concrete missile penetration to a service fuel tank in a building which is partially failed.

Damage state vector D can be converted by a matrix (or a complex matrix M) into a probability vector of failure of in-door components F as shown in Fig. 2. Both vectors D and F, damage state vectors of a building and a component are expressed by probabilistic one and the sum of values of each element must be unity. Therefore, those vector can be called either a damage-state vector or a damage state probability vector.

For Type 1 conversion, the conversion matrix M_1 from the damage state vector D to that of component F and the values of each array should have consistency to both probability vectors D and F. For lower level of the damage state of the building, their response and fragility analyses is necessary, unless the expert judgement would be introduced. For Type 2 conversion, again in lower levels of the building damage, their response and fragility analyses are necessary. After obtained a damage state vector of a component F by using a Type 2 conversion matrix M, the vector F must be normalized to a state probability vector. The operation (*) in Type 2 conversion in Fig. 2 includes this normalizing procedure.

§4 CONVERSION MATRIX

Here, the five damage states of a reactor building and an auxiliary building are assumed as followed;

i) shaking without any damage or plastic behavior,

ii) having minor damage on structural elements,

iii) being partially damaged,

iv) being damaged,

v) being completely collapsed, and these states are expressed as shown in the following section and Figs. 1 and 2.

The state of failure of the building is related to the expected state of damage of various kind of in-door components in them. To establish the scenario, which is necessary to find the combination or the route to calculate a value of PSA from an earthquake event to a core damage, we should know the damage relation of various items in the plant. How the state of forteen components to be afected is described by state transition charts and conversion matrices as shown in Figs. 3. ∿ 16. And these relations are expressed a series of conversion matrices with the charts. This conversion matrix is also called as a damage relation matrix. These relations can be developed to the whole scenario by connecting to the state vector of buildings D and and also to the following consequence of component's failure by another such matrix.

There is some ambiguity to compose a scenario. For example, the supporting building is shaken over the design basis earthquake of a component, it depends on the fragility characteristics whether or not it may fail without any damage of the building or may stand well. On the other hand, it is obvious that all components seem to be damaged or completely collapsed, if their supporting building is completely collapsed. In this article, the relation of components' failure to the consequence to core damage is not discussed.

§5 NOTATIONS AND VALUE OF ARRAY IN MATRIX AND VECTOR

The state vector of buildings D is expressed by "DG" as follow:

DG0: Only shaking and standing without any failure or non-linear behavior.

DG1: Shaking with non-linear behavior and some minor cracks are found after the event.

DG2: Shaking with extreme non-linear behavior and part of concrete may become fragments.

DG3: Shaking in non-predictable way, and many fragments are removed from the structure and it looses their stifness completely.

DG4: Completely collapse after shaking and no-shape remains as a structure.

Such state of a building causes some failure of in-door components in them. It's state is coded as follow (X,Y,A and so on is a digit):

00: No damage nor failure.

0X: Recoverable state without any repairing or the state which is not necessary to repair.

1Y: State with some failure, but not critical to reactor safety.

2Z: Nominally catastrophic state, but it might be not so serious.

3W: Failed by code definition, but it might be no significant change nor damage on elements of the component.

4U: Failed as catastrophic state, and that may be a "Faulted Condition", but some are on "Emergency Condition".

5V: Completely collapsed as a whole, and its exact state can not be identified, and that is "Faulted Condition" or more critical state.

And the second digit is as follow:

*A*5 : Most critical condition.

*B*6 < : Failure of additional components.

Less than 4 in the first digit means less critical condition compare to 5*V*. Those expression is not directly related the discussion in this article.

In a conversion matrix, definite occurence is designated by "1", and possible occurence is by "0.1", which is drawn by broken line in the figures (Fig.3 ∿ 16). Relation which is not necessary to be considered is designated by "99" instead of " ∞ ", which is expressed by →x mark in the figures. Value of each array or element of matrix may be extending a membership function for a fuzzy expression on the relation of "cause" to "result" in the figures based on knowledges obtained through previous earthquake observations as mentioned in previous sections. If the fuzzy state will be introduced, this value may be "0.8, 0.5, 0.3 and so on".

§6 CONCLUDING REMARKS

There is no definit analysis on the relation of building failure to that of in-door components so far to be in a seriously damaged building. An assumption made in a particular report on Seismic PSA is depending mainly on the subjective one of the analysist. But as shown in the figures, the relation is very variable, and it is depending on the design criteria and philosophy of buildings. We may write thick line based on our design criteria in a chart, but it is not common to that under another design criteria. Those in this region should be obtained by response and fragility analyses as previously discussed.

In Japan, "failure" of a eactor building may be upto a state "DG2" according to our design criteria, but in some countries it means a drop of its pre-fabricated roof to the floor as mentioned in a previous chapter, that is "DG3" or "DG4". If we try to write a scenario, we establish a common understanding on the design and construction situation of the country.

Based on such discussion, various alternative ways to express it may be found, and the purpose of this paper is a trial of expressing the relation of the state of a supporting building to a component. All figures from Fig. 3 to Fig. 14 in this article show necessary relations and try to cover most of significant items to the reactor safety.

§7 REFERENCE

(1) SHIBATA, Heki: On Damages of Industrial Facilities by Romanian Earthquake, *J. of Inst. of Ind. Sci., Univ. of Tokyo*, Vol.29, No.10 (Oct. 1977) p.503 (in Japanese).

(2) China Academy of Building Research: The Manmoth Tangshan Earthquake of 1976 --- Building Damage Photo Album, (1986), China Academic Publishers, p.114 and others.

(3) Inst. of Geology, State Seismological Bureau: The Photo Album of Eight Strong Earthquake Disastors in China, (1983), Seismological Press, Chart 29 and others.

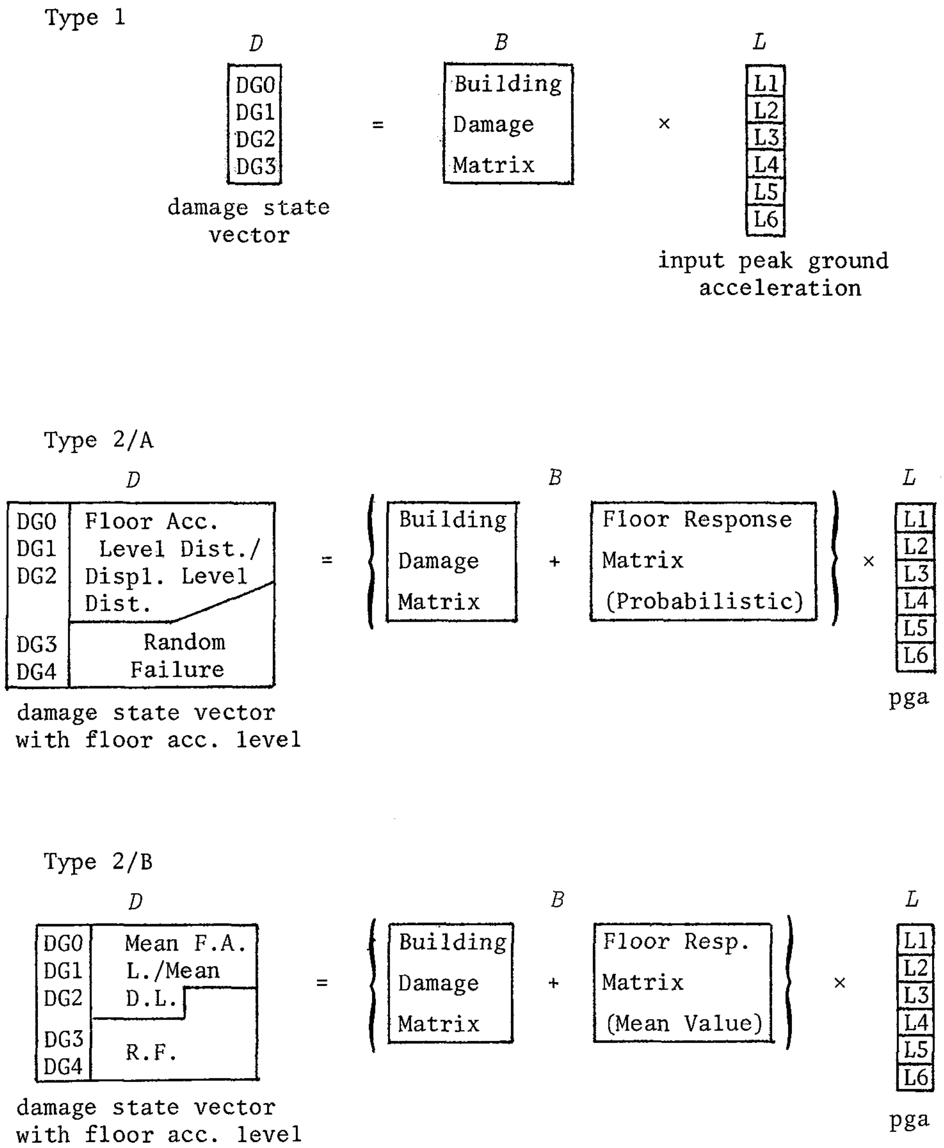
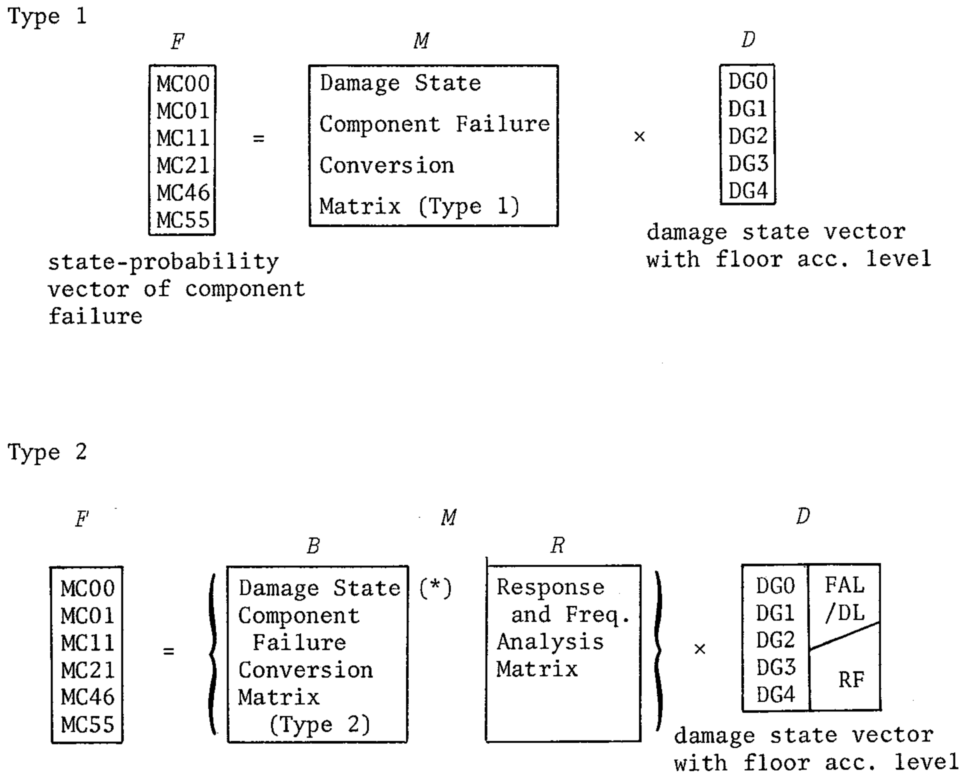


Fig. 1 Schematic Relations Input Peak Ground Acceleration Vector to Damage State Vector



The meaning (*) is explained in the text

Fig. 2 Schematic Relations of Damage State Vector to State-probability Vector of Component Failure

Reactor Building except C/V

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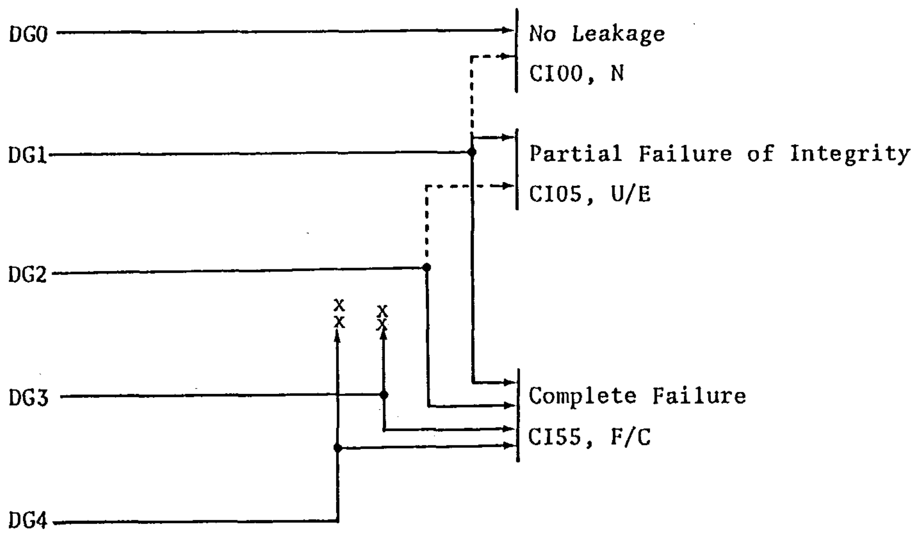
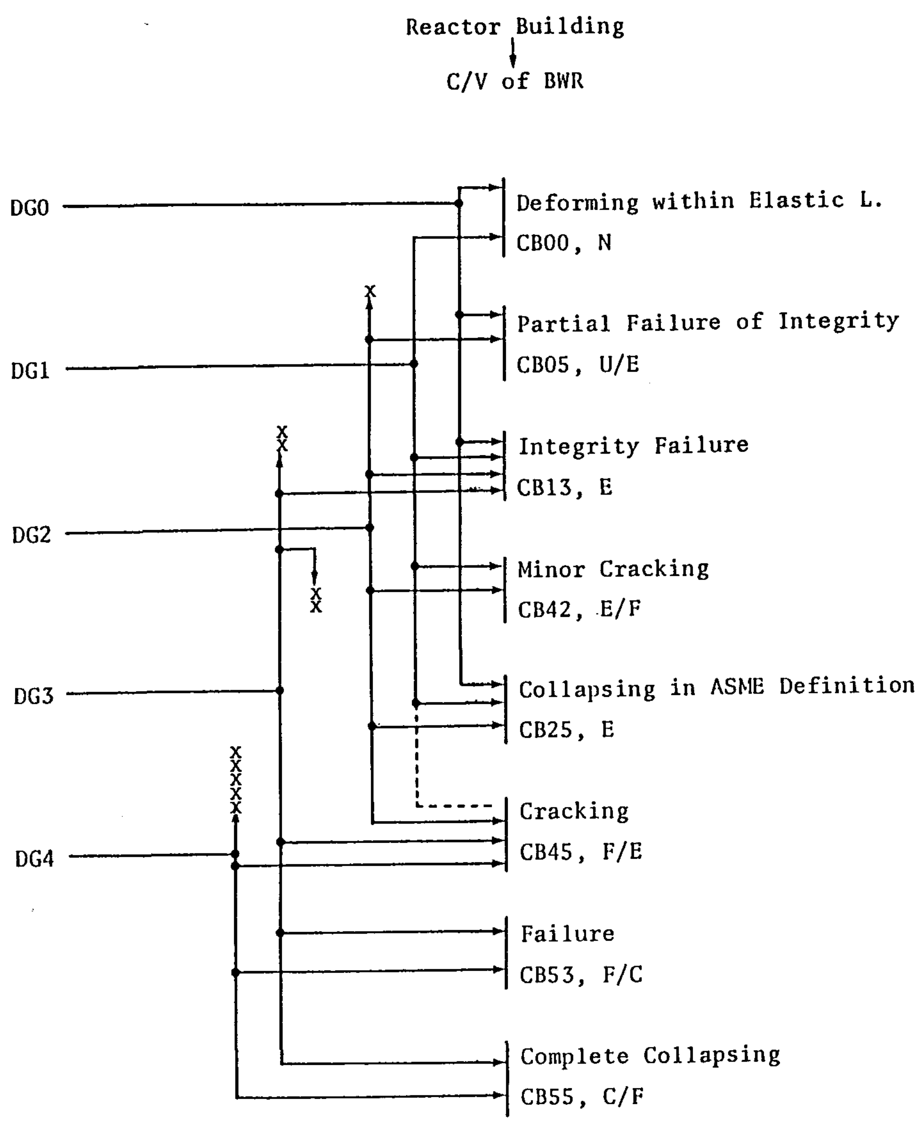
Containment Integrity of Reactor Building



	CI00	CI05	CI55
DG0	1	0	0
DG1	0.1	1	1
DG2	99	0.1	1
DG3	99	99	1
DG4	99	99	1

Fig. 3 State Transition Chart and Conversion Matrix.



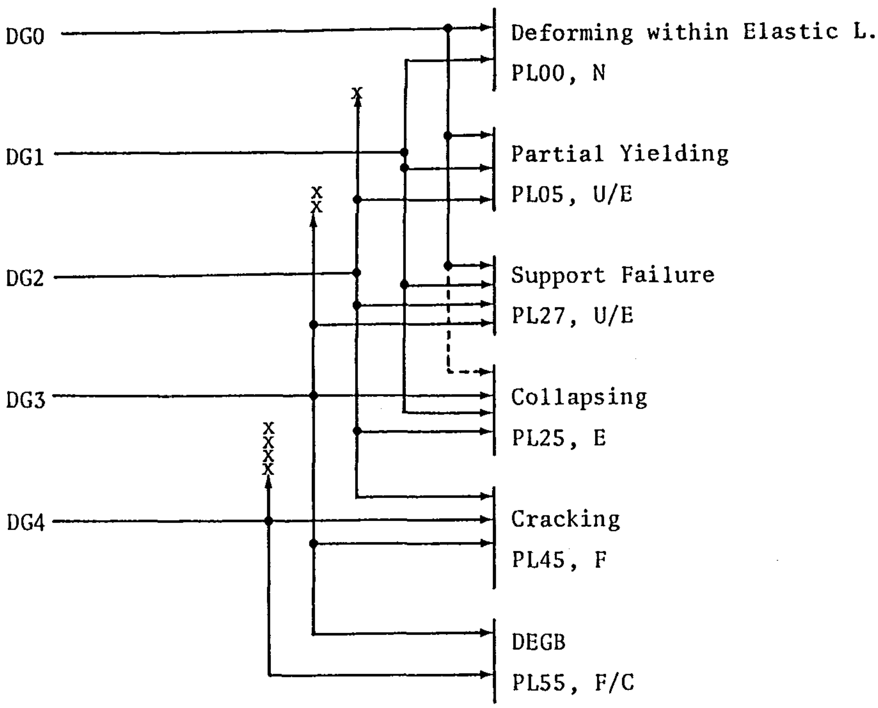
	CB00	CB05	CB13	CB42	CB25	CB45	CB53	CB55
DG0	1	1	1	0	1	0	0	0
DG1	1	1	1	1	1	0.1	0	0
DG2	99	1	1	1	1	1	0	0
DG3	99	99	1	99	99	1	1	1
DG4	99	99	99	99	99	1	1	1

Fig. 4 State Transition Chart and Conversion Matrix.

Building (include C/V)

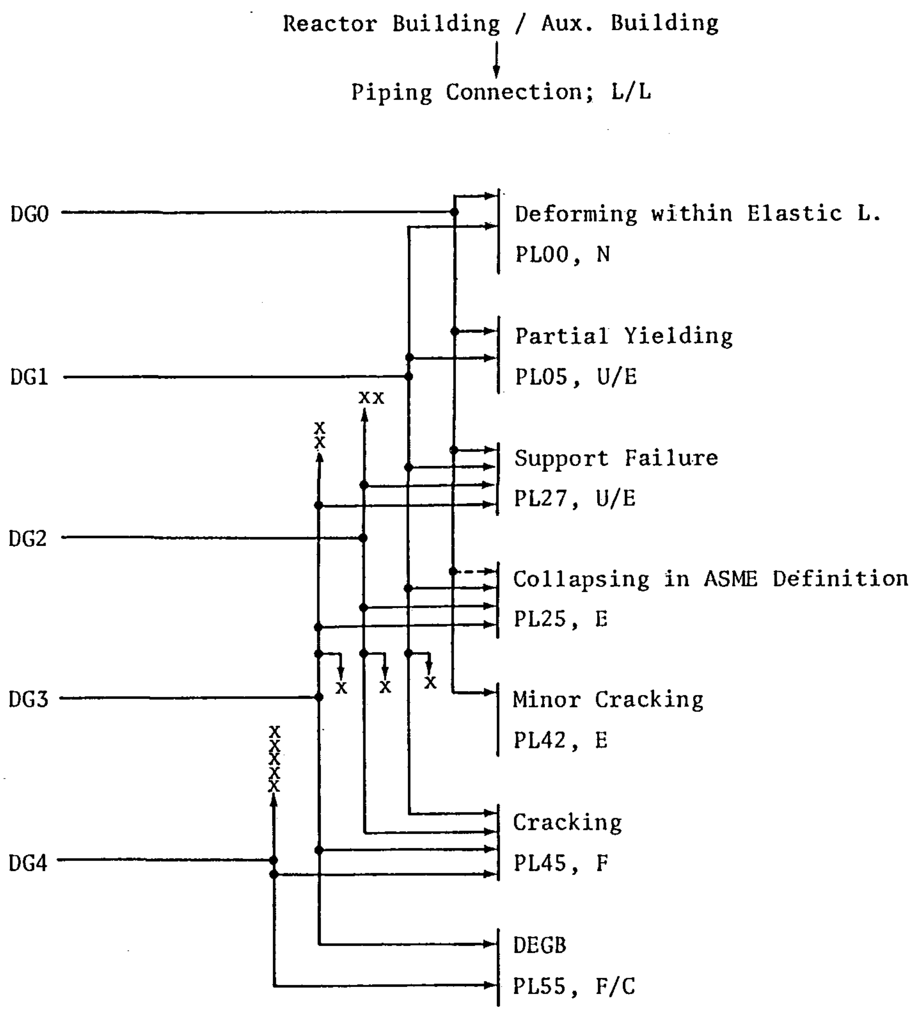
↓

Large Scale Piping



	PL00	PL05	PL27	PL25	PL45	PL55
DG0	1	1	1	0.1	0	0
DG1	1	1	1	1	0	0
DG2	99	1	1	1	1	0
DG3	99	99	1	1	1	1
DG4	99	99	99	1	1	1

Fig. 5 State Transition Chart and Conversion Matrix.



	PL00	PL05	PL27	PL25	PL42	PL45	PL55
DG0	1	1	1	0.1	1	0	0
DG1	1	1	1	1	99	1	0
DG2	99	99	1	1	99	1	0
DG3	99	99	1	1	99	1	1
DG4	99	99	99	99	99	1	1

Fig. 6 State Transition Chart and Conversion Matrix.

Reactor Building / Aux. Building

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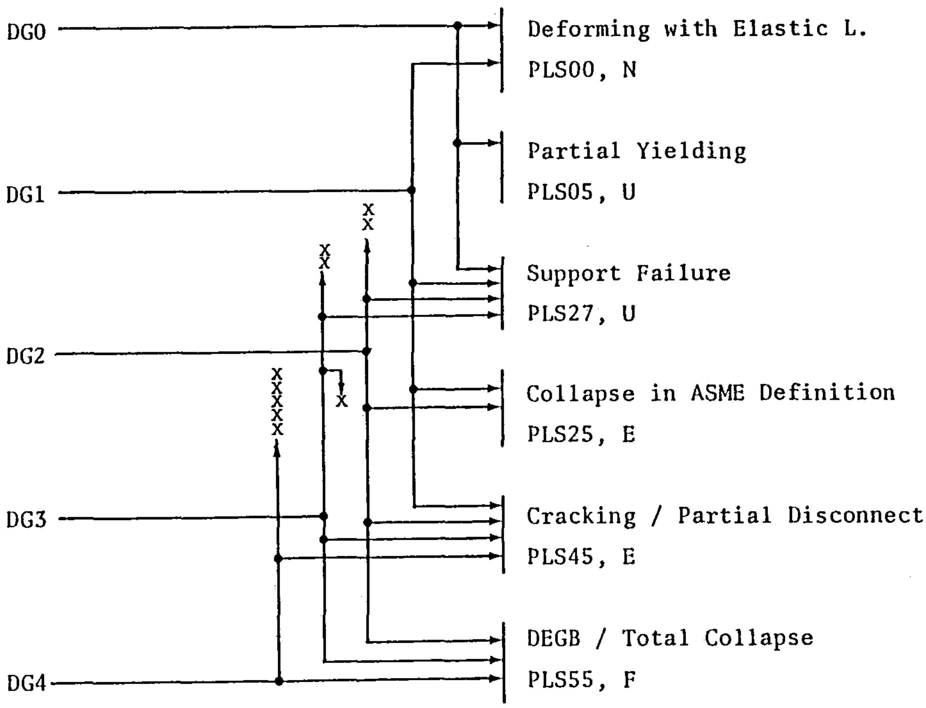
Piping Connection; L/S



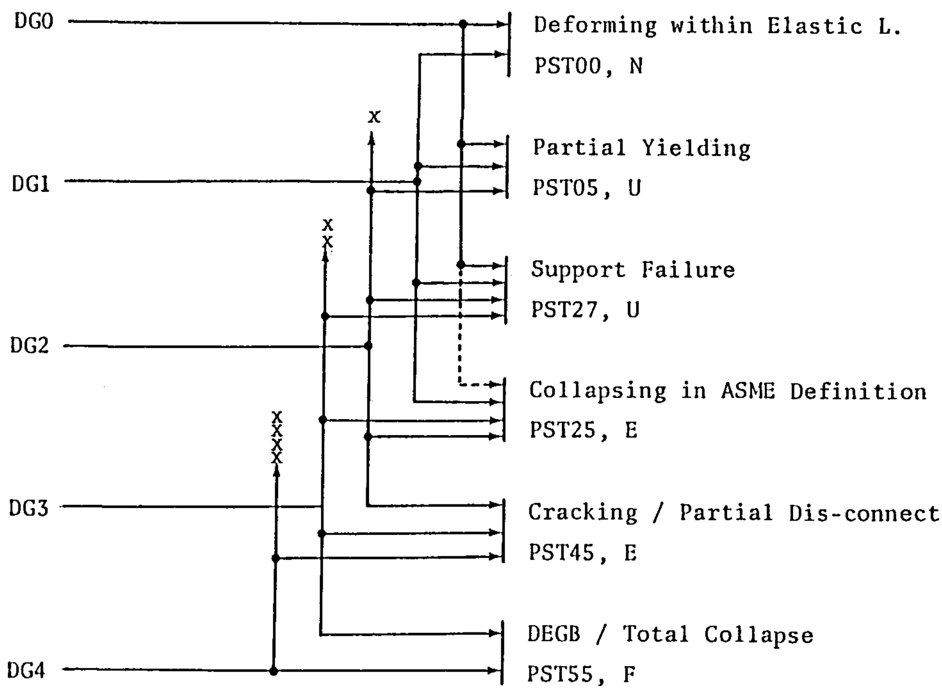
	PLS00	PLS05	PLS27	PLS25	PLS45	PLS55
DG0	1	1	1	0	0	0
DG1	1	1	1	1	0	0
DG2	99	99	1	1	1	1
DG3	99	99	1	99	1	1
DG4	99	99	99	99	1	1

Fig. 7 State Transition Chart and Conversion Matrix.

Reactor Building / Aux. Building

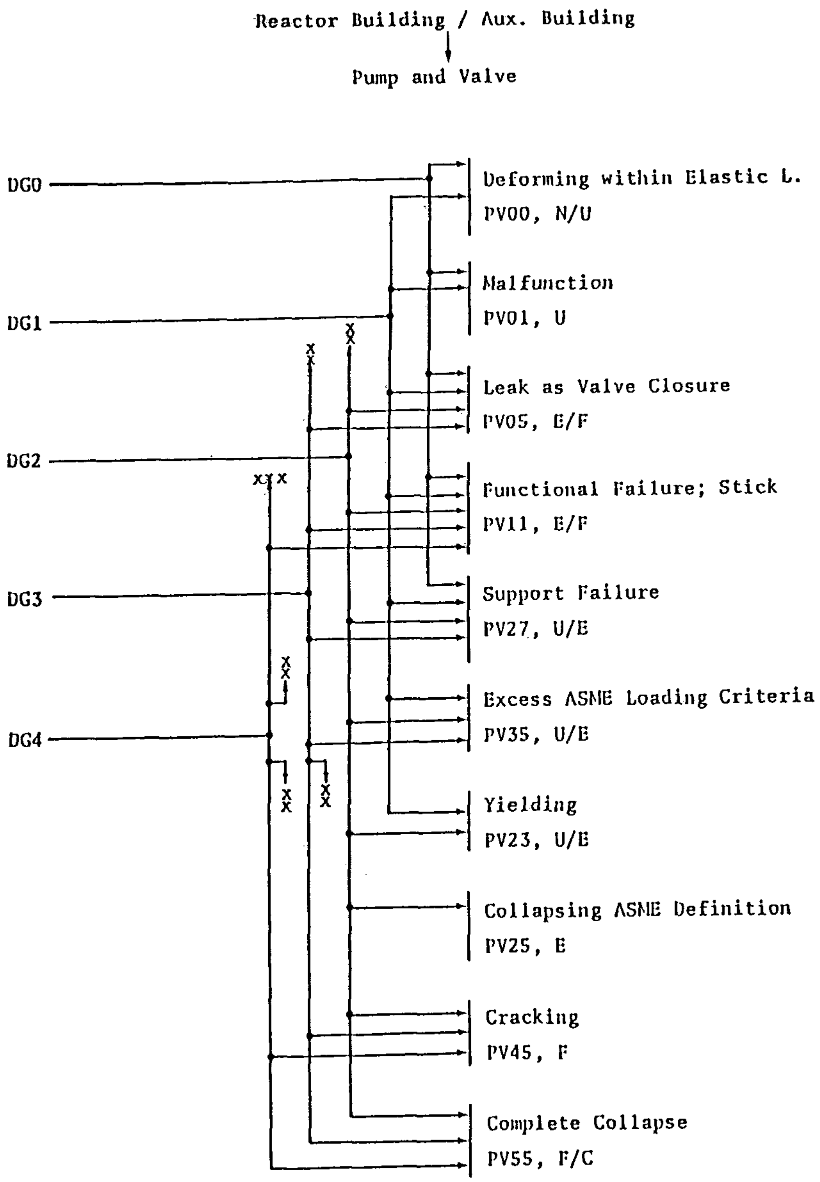
↓

Piping; Small Scale including Cable Tray



	PST00	PST05	PST27	PST25	PST45	PST55
DG0	1	1	1	0.1	0	0
DG1	1	1	1	1	0	0
DG2	99	1	1	1	1	0
DG3	99	99	1	1	1	1
DG4	99	99	99	99	1	1

Fig. 8 State Transition Chart and Conversion Matrix.



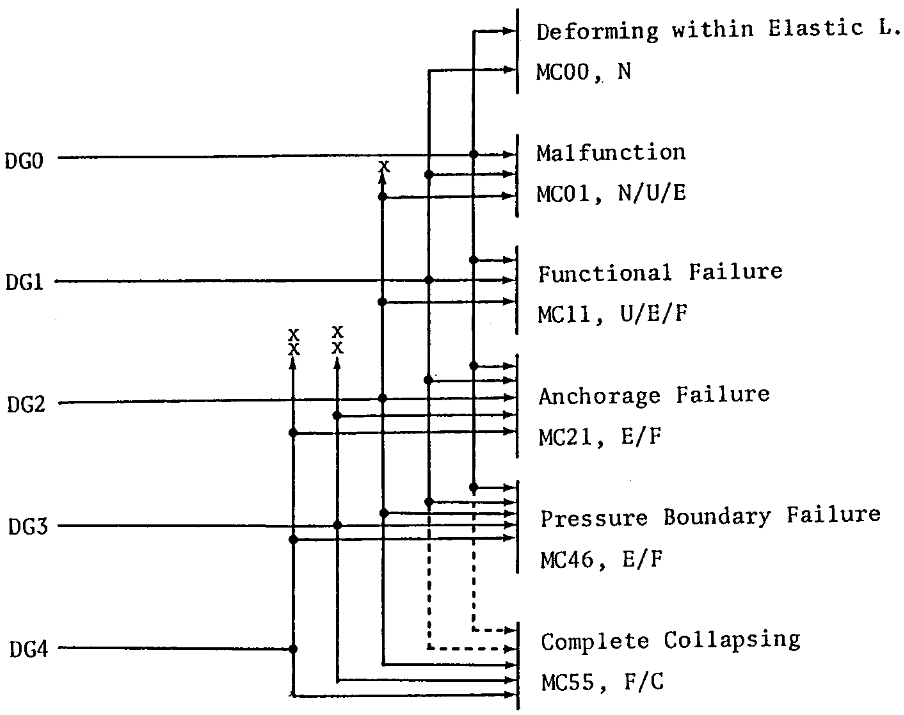
	PV00	PV01	PV05	PV11	PV27	PV35	PV23	PV25	PV45	PV55
DG0	1	1	1	1	0	0	0	0	0	0
DG1	1	1	1	1	1	1	1	0	0	0
DG2	99	99	1	1	1	1	1	1	1	1
DG3	99	99	1	1	1	1	99	99	1	1
DG4	99	99	99	1	99	99	99	99	1	1

Fig. 9 State Transition Chart and Conversion Matrix.

Reactor Building / Aux. Building

↓

Mechanical Component



	MC00	MC01	MC11	MC21	MC46	MC55
DG0	1	1	1	1	0.1	0.1
DG1	1	1	1	1	1	0.1
DG2	99	1	1	1	1	1
DG3	99	99	99	1	1	1
DG4	99	99	99	1	1	1

Fig. 10 State Transition Chart and Conversion Matrix.

Reactor Building / Aux. Building

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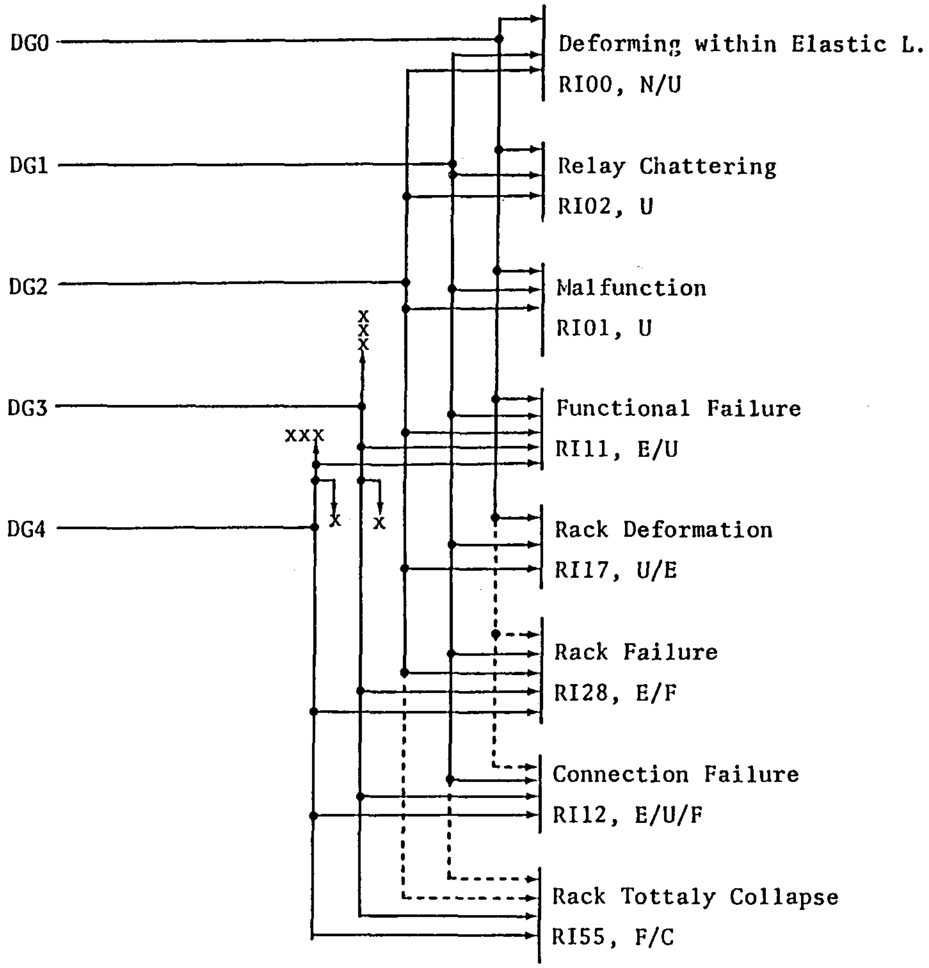
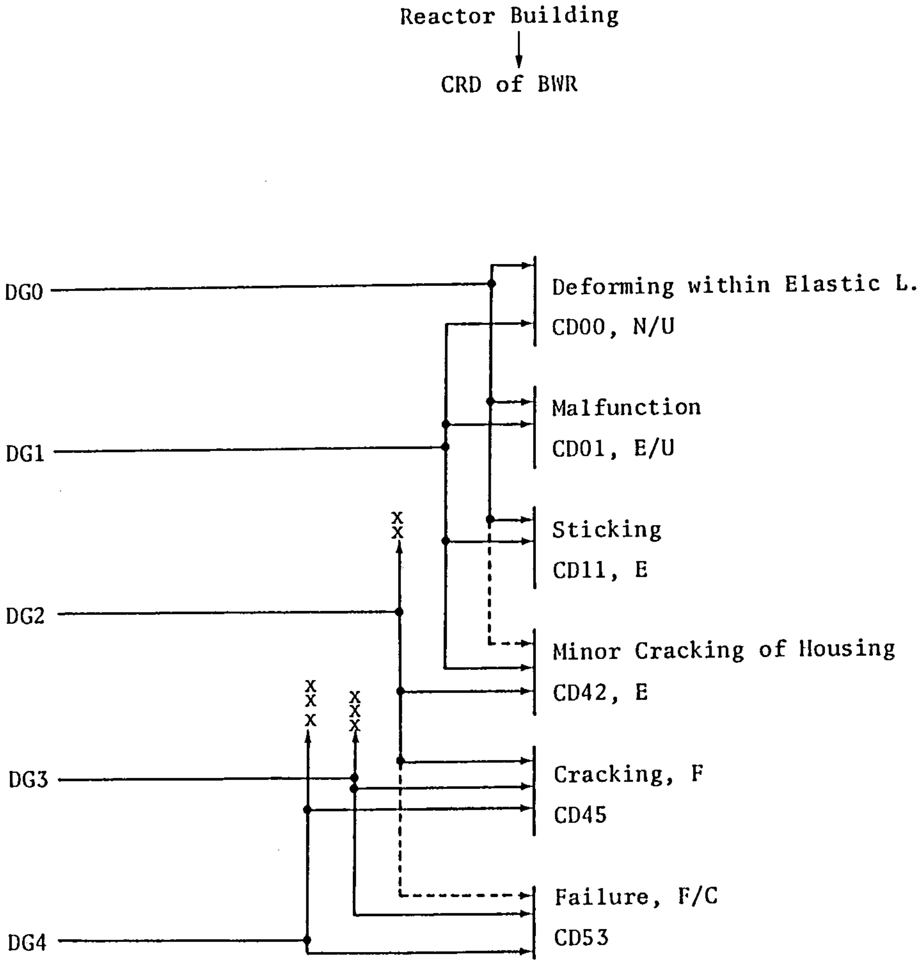
Instrumentation and Control System



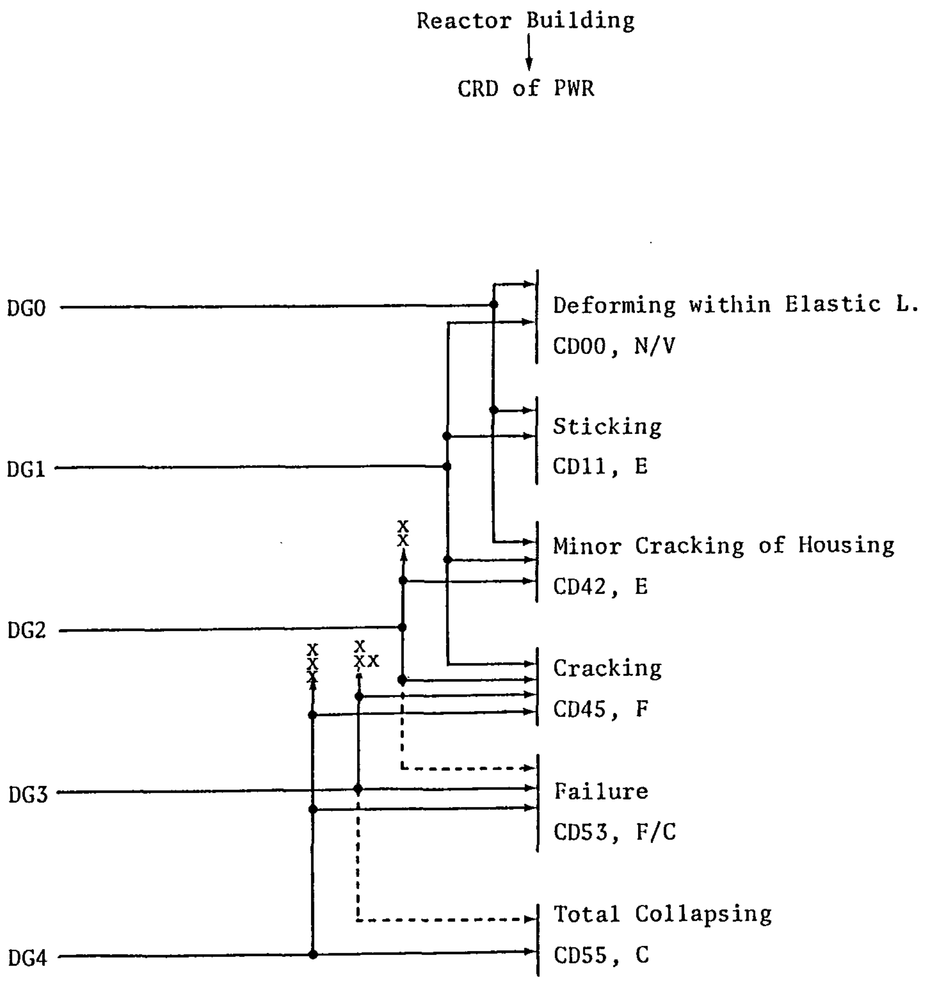
	RI00	RI02	RI01	RI11	RI17	RI28	RI12	RI55
DG0	1	1	1	1	1	0.1	0.1	0
DG1	1	1	1	1	1	1	1	0.1
DG2	1	1	1	1	1	1	1	0.1
DG3	99	99	99	1	99	1	1	1
DG4	99	99	99	1	99	1	1	1

Fig. 11 State Transition Chart and Conversion Matrix.



	CD00	CD01	CD11	CD42	CD45	CD53
DG0	1	1	1	0.1	0	0
DG1	1	1	1	1	0	0
DG2	99	99	1	1	1	0.1
DG3	99	99	99	1	1	1
DG4	99	99	99	1	1	1

Fig. 12A) State Trasition Chart and Conversion Matrix.



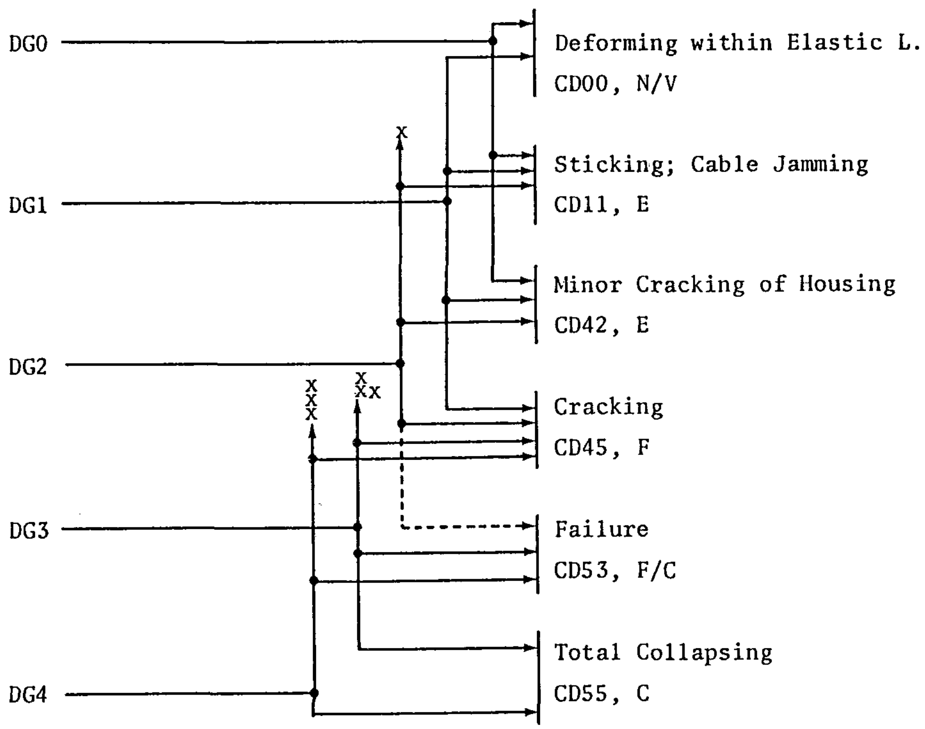
	CD00	CD11	CD42	CD45	CD53	CD55
DG0	1	1	1	0	0	0
DG1	1	1	1	1	0	0
DG2	99	99	1	1	0.1	0
DG3	99	99	99	1	1	0.1
DG4	99	99	99	1	1	1

Fig. 12B) State Transition Chart and Conversion Matrix.

Reactor Building

↓

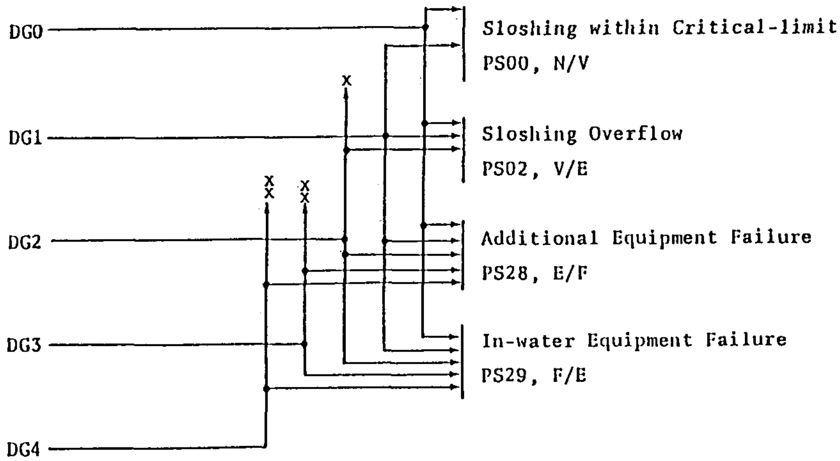
CRD of PTR

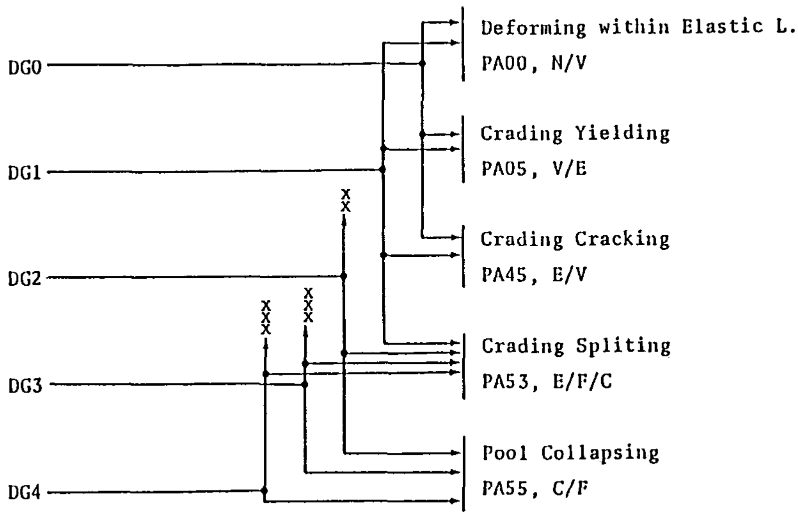


	CD00	CD11	CD42	CD45	CD53	CD55
DG0	1	1	1	0	0	0
DG1	1	1	1	1	0	0
DG2	99	1	1	1	0.1	0
DG3	99	99	99	1	1	1
DG4	99	99	99	1	1	1

Fig. 12C) State Transition Chart and Conversion Matrix.

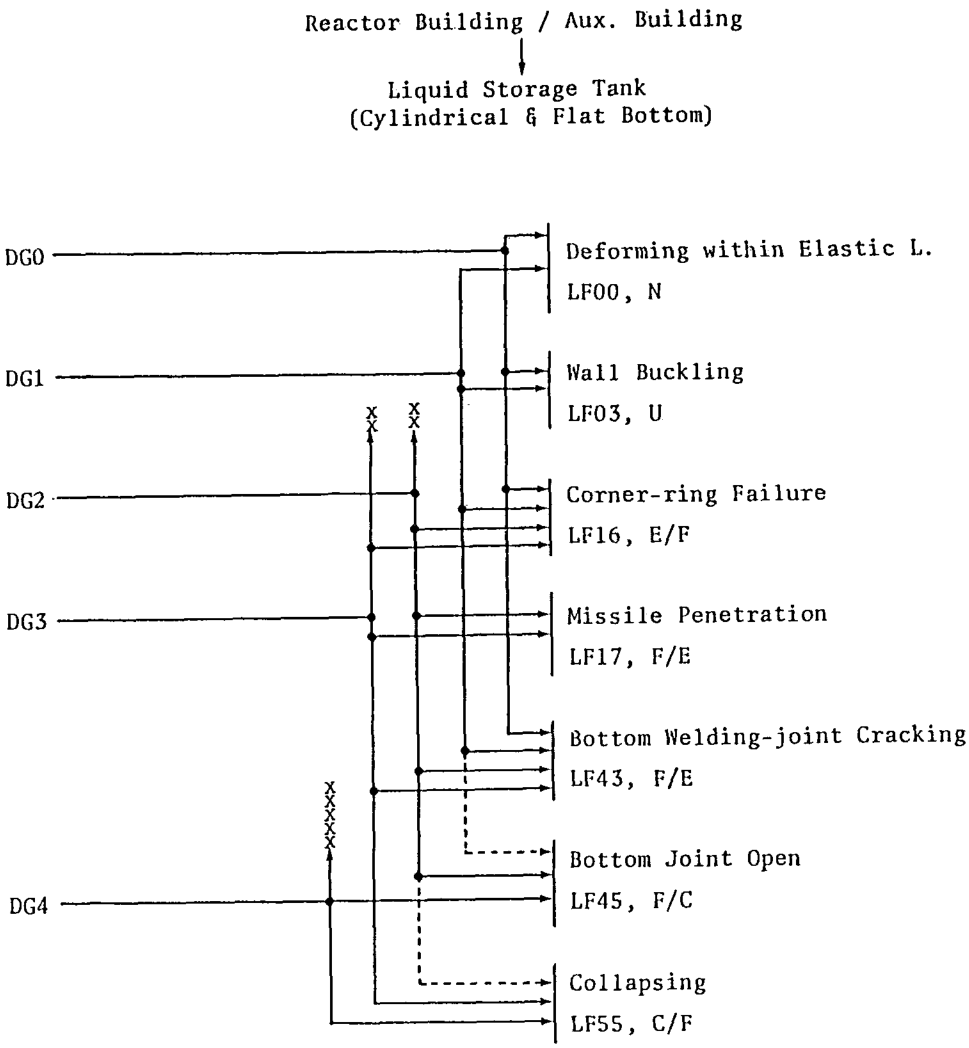
Building
↓
Pool





	PS00	PS02	PS28	PS29	PA00	PA05	PA45	PA53	PA55
DG0	1	1	1	1	1	1	1	0	0
DG1	1	1	1	1	1	1	1	1	0
DG2	99	1	1	1	99	99	1	1	1
DG3	99	99	1	1	99	99	99	1	1
DG4	99	99	1	1	99	99	99	1	1

Fig. 13 State Transition Chart and Conversion Matrix.



	LF00	LF03	LF16	LF17	LF43	LF45	LF55
DG0	1	1	1	0	1	0	0
DG1	1	1	1	0	1	0.1	0
DG2	99	99	1	1	1	1	0.1
DG3	99	99	1	1	1	1	1
DG4	99	99	99	99	99	1	1

Fig. 14A) State Transition Chart and Conversion Matrix.

Reactor Building / Aux. Building
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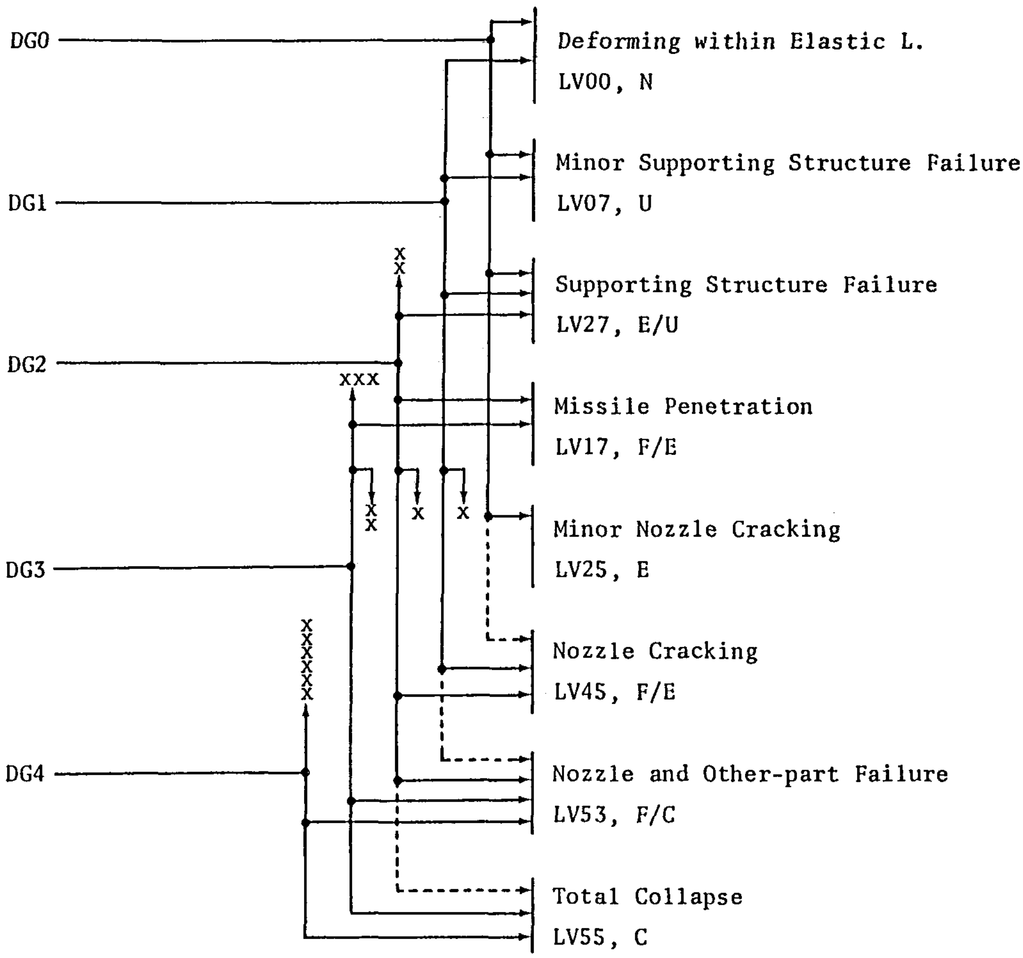
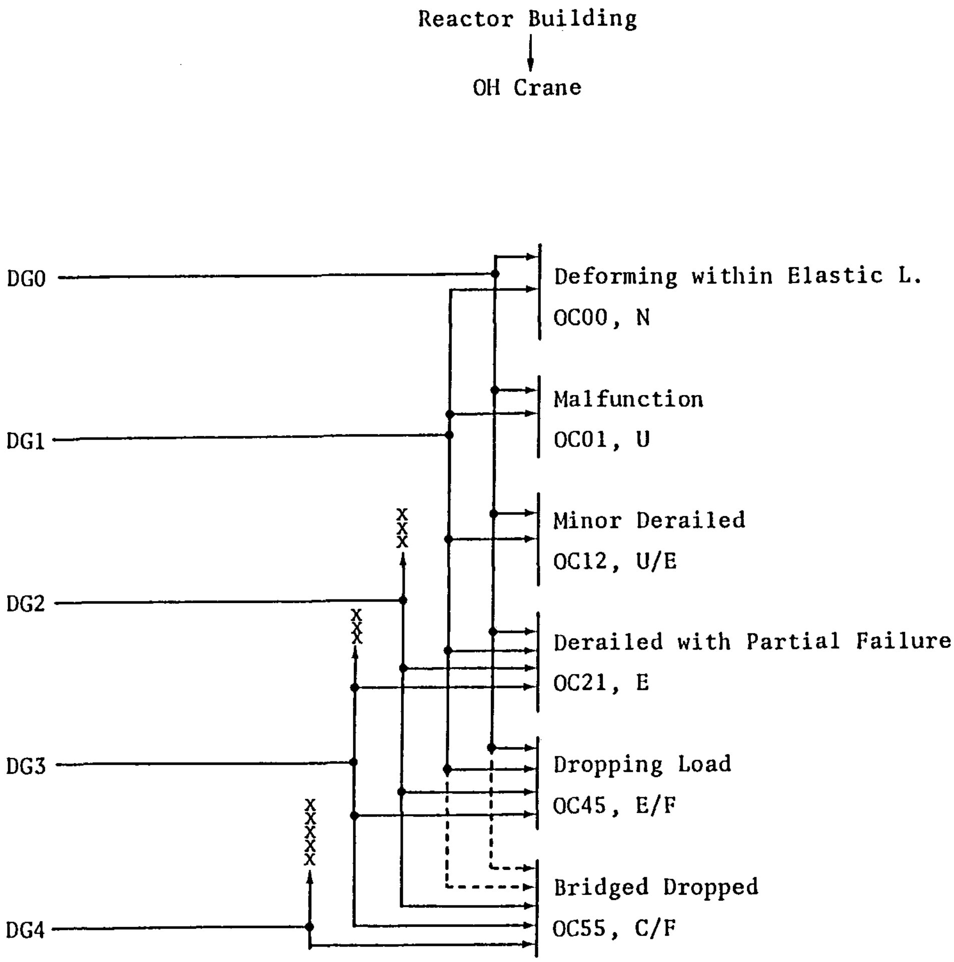
Liquid Storage Tank
(Leg or Skirt supported Vessel)



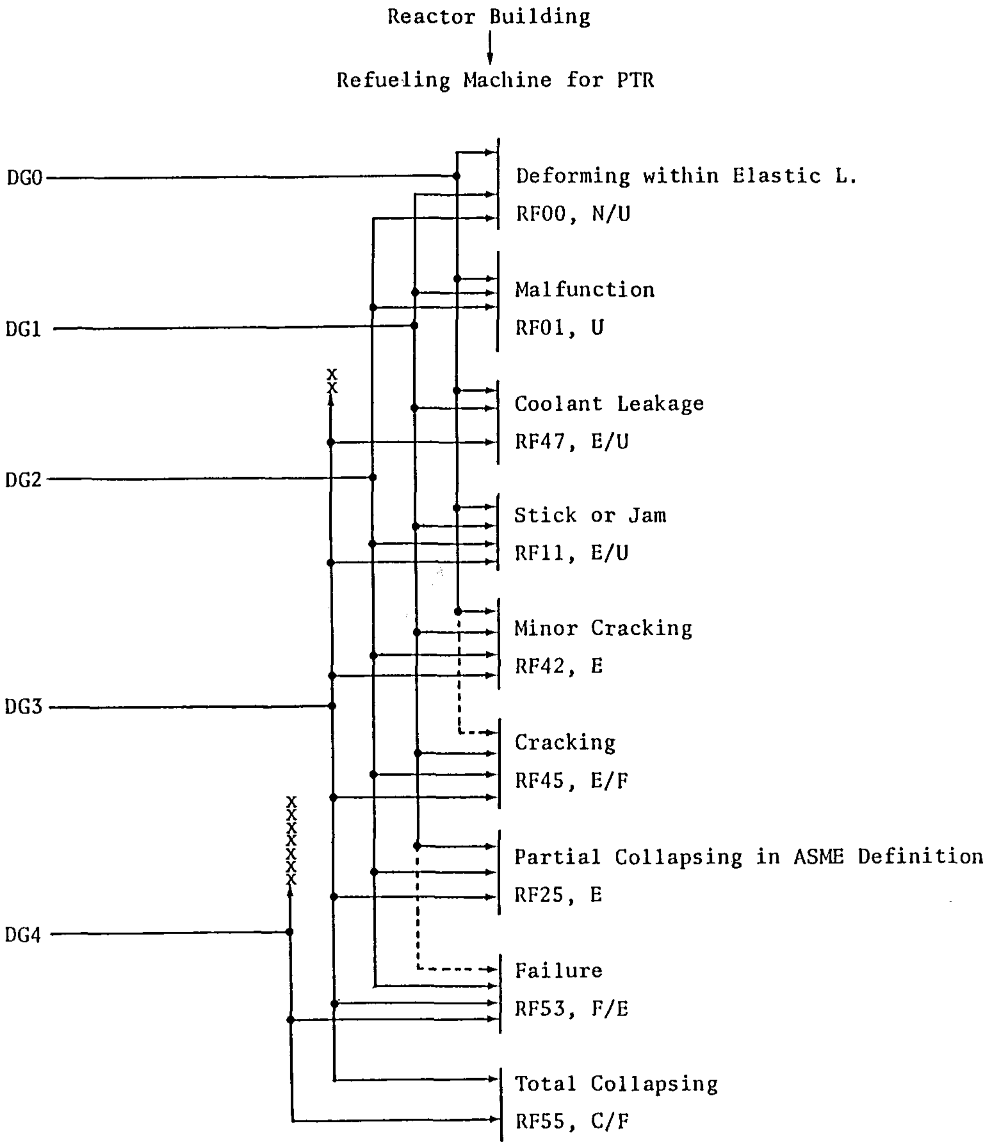
	LV00	LV07	LV27	LV17	LV25	LV45	LV53	LV55
DG0	1	1	1	0	1	0.1	0	0
DG1	1	1	1	0	99	1	0.1	0
DG2	99	99	1	1	99	1	1	0.1
DG3	99	99	99	1	99	99	1	1
DG4	99	99	99	99	99	99	1	1

Fig. 14B) State Transition Chart and Conversion Matrix.



	OC00	OC01	OC12	OC21	OC45	OC55
DG0	1	1	1	1	1	0.1
DG1	1	1	1	1	1	0.1
DG2	99	99	99	1	1	1
DG3	99	99	99	1	1	1
DG4	99	99	99	99	99	1

Fig. 15 State Transition Chart and Conversion Matrix.



	RF00	RF01	RF47	RF11	RF42	RF45	RF25	RF53	RF55
DG0	1	1	1	1	1	0.1	0	0	0
DG1	1	1	1	1	1	1	1	0.1	0
DG2	1	1	1	1	1	1	1	1	0
DG3	99	99	1	1	1	1	1	1	1
DG4	99	99	99	99	99	99	99	1	1

Fig. 16 State Transition Chart and Conversion Matrix.