【機密性２情報】

外的事象のリスク及びAMの認識、外的事象PSAの技術水準等について

１．　我が国の原子力安全規制行政においてシビアアクシデントを意識した取組が開始されたのは、TMI 事故後の１９８０年代に入ってからである。具体的には、世界の主要国で確率論的リスク評価（PRA）の結果を踏まえた安全性向上策や定量化されたリスクを指標にする安全目標に関する議論が行われていることを受けて、工学的安全施設が共通原因故障で起動しない、あるいは操作を誤るなどの事態がシビアアクシデントを招く可能性が少なからずあるというPRAの結果から得られた知見を踏まえて、そのような標準的ではないプラント状態を誤解なく認識して運転できるためのSPDSあるいは運転支援システムを設置することやそれの提供する情報も踏まえた適切な運転操作に関する手順書（兆候ベース手順書）を整備するべくの検討が開始されたのである。

しかしながら、こうした議論の基本になる国内の原子炉についてのPRAは公的機関においてはプラントの運転管理の在り方に係る情報が入手できず、機器の故障率データが整備されていなかったために、なかなか実施されず、原子力工学試験センター安全解析所でモデルプラントのPRA/PSAが実施されたのは１９８０年代後半になってからであった。実プラントのデータが入手できない日本原子力研究所はもっぱらPRAの方法の開発整備に力を注ぎ、１９８５年までには地震や火災を起因事象とするPSAの方法論の開発にも着手していた。

２．　１９８０年代、原子力発電に運転に係る情報の効果的活用の重要性の認識が高まり、国際的な情報交換などの共同作業が行われるようになったことを受けて、原子力工学試験センターに原子力発電安全情報研究センターが設置された。この運営に関する諮問委員会として設置された原子力発電安全情報高度化委員会（小生が委員長）では、このセンターの使命である原子力発電に関する事故・故障情報から教訓を引き出す作業に関連して、海外のPRAへの取組や規制活動についての情報、特に米国におけるシビアアクシデントに関する研究や安全目標を巡る議論も必然的に調査することになった。その結果、上述の取組みについても我が国としてどう対応するべきか意見交換がなされ、SPDSの設置、兆候ベース手順書の在り方の整備作業に併せて、兄弟組織である安全解析所の活動

としてモデルプラントのPRAの実施などを提起し、実施に向けての世論作りを行っていった。

３．　１９８６年にチェルノビリ事故が発生した。この時期、資源エネルギー庁はエネルギー調査会原子力部会において原子力政策の見直しを行っていたので、この部会報告である「２１世紀の原子力ビジョン」には、こした場で議論されていたヒューマンエラー対策、シビアアクシデント対策、事故拡大予測システムの研究や緊急時手順書の充実を中心とする取組推進の提言が組み込まれた。そして、これらの取組みは、直ちに「セイフティ２１計画」として推進された。モデルプラントのPSAの実施、「ヒューマンファクター」という運転者に任せていた領域についての研究を国が推進するべく上述の安全情報研究センターにヒューマンファクター研究センターが併設されたのもその一部であった。

４．　原子力安全委員会は、チェルノビリ事故後直ちに、事故調査委員会を立ち上げ、翌年５月には報告書をとりまとめた。そのなかでは設計基準事故を超えた事象の理解を深め、運転管理面に適宜反映することなどが勧告された。委員会は、これを受けて海外動向のレビューも踏まえてシビアアクシデントの考え方、シビアアクシデント時の格納容器の機能、ソースタム、複数立地、PSA等について検討する共通問題懇談会（座長は佐藤一男氏）を直ちに設置し、これらの検討を開始した。

この懇談会は１９９２年に報告を取りまとめた。この報告を受けた原子力安全委員会は、１）原子炉設置者において効果的なアクシデントマネージメントを自主的に整備し、万一の場合にこれを的確に実施できるようにすることは強く奨励されるべきであると考える。２）原子炉設置者においては、原子炉施設の安全性の一層の向上を図るため、報告書が示す提案の具体的事項を参考としてアクシデントマネージメントの整備を継続して進めることが必要である。また、行政庁においても、報告書を踏まえ、アクシデントマネージメントの促進、整備等に関する行政庁の役割を明確にするとともに、その具体的な検討を継続して進めることが必要である。等のことを決定した。

５．　この間、米国においては、NRCがシビアアクシデントに関する政策声明を出した後、１９８８年の運転者宛手紙（GL８８−２０）で個別プラントのPRAの実施を慫慂したが、これは内部事象に起因するリスクの評価

を求めたものであった。しかし、NRCは、同時に外部事象推進グループを設置して、運転者に評価を要求するべき外部事象のリスクを評価するための有望な技術の調査を開始した。このグループは、国立研究所LLNLとEPRIが実施した各プラントサイトの地震ハザードの比較検討を行うなど、各運転者がPRA作業を実施するのに使用できる標準的なツールとデータを特定した。そして、その結論を踏まえて、NRCは１９９１年に運転者に対してIPEの結果に地震、洪水、火災、火山、異常気象等の外部事象に起因するリスクの評価を付加する作業であるIPEEEの実施を１９９４年までに完了するよう求めた。

６．　共通問題懇談会の議論において、PRA/PSAでいかなる外部事象を考慮するべきかがテーマに取り上げられた記憶はない。当時は、上にあるように、これらに係るリスクを定量的に評価する方法論はなお内外の学会で議論されている段階で実務に使える段階には至っていないとの認識であったし、外部リスク解析結果を含めた実際の炉のPRAの結果が利用可能ではなかった。したがって、それらに起因するリスクが原子炉のリスクに占める割合についての認識を関係者が共有することはなかった。

もちろん、共通問題懇談会は、NRCが５つの代表的プラントのリスク評価結果を１９９１年に公表した報告書NUREG１１５０（ここでは外部事象のリスクは二炉についてのみ分析された）をドラフト段階からレビューしている。ただ、この結果は、外部事象を含めた解析結果における地震リスクの寄与度合が二つのプラントで大きく異なっており、これの主因は地震ハザードの推定の仕方が確定していないことによると理解された。また、米国の耐震設計の考え方は敷地直下にＭ６．５の震源を想定する我が国より甘いとの認識もあって、この結果を直ちに云々するのではなく、日本原子力研究所で開発に着手されていたこの地震ハザードの策定方法を実用化する取組の成果を待つべきとの思いをもった。

なお、共通問題懇談会の報告には、こうした議論の形跡はない。それは委員会メンバーの関心は、ほとんどがシビアアクシデントを従来の立地指針や原子炉設計審査指針、防災指針の体系とどう関係づけるか、シビアアクシデントマネジメントの手段として海外で採用が進められていた格納容器ベント機能を取り入れる場合、格納容器を安全確保の最後の砦としてきたこれまでの安全論理とそれをどう整合させるかなどにあり、その概念整理に多くの時間が使われたからである。

7．　この原子力安全委員会提言がシビアアクシデントマネジメントに関して自主的取組を強く奨励することを選択したのは、当時は国内プラントのPSAもそれから導かれるSAMの取組の内容も発展途上にあったから、直ちには処方箋的な強制規定を策定することは不可能であり、事業者に対して取組の方向性を示し、継続的にその取組を誘導していくことが合理的と判断したからである。ただし、原子力安全委員会として、方法論の整備に併せてPSAのスコープを拡大していく等の要請を行わなかったこと、当時の我が国には米国のLLNLのようなこれを作成する能力を備えた組織がなかったのだから、原子力関係者が地震学界と交流しながら地震PSAのための地震ハザードの作成に投資することを求めることもしなかったこと、さらに、こうしたことはおろか、そこに述べた取組についても期待されるスケジュールを示さなかったこと、さらには、委員会として、安全目標を定めること、内外動向を調査し、その結果に基づいてこれらに係る事業者の取組を適宜に誘導する取組も行わなかったことは、今から考えると不適切。

米国の場合、シビアアクシデント対応は我が国と同様、運転者の自主的対応とされているものの、規制当局が安全目標を定め、PRAの方法論を整備し、IPEEEを通じて、運転者に対してそれらを考慮したプラントリスクの把握を求めたことから、運転者は、その後においては、それらを含む全ての取組においてリスク感度を念頭にその質について絶えず気配りしながら、行動していた。

8．　小生は、通産省原子力発電技術顧問として、予防保全部会等の部会長に任じられていたから、１）定期安全レビュー制度を創設して、これにPSAの実施を含めることにより、これの成果を公開で評価する際に１０年後の改良改善を求めることができるようにすること、２）故障率データベースや外部事象を起因事象とするPRAの実施手順書を整備していくことにより、これを民間が実施できる環境を整備すること、３）外部事象も考慮に入れたリスクを指標とする安全目標を制定して、広範な安全の質の保証が追求される環境を整備すること、等を目指した。

その結果、１）は行政の採用するところとなり、２）はNUPECにそうした取組を推奨した結果、NUPECは１９９４年度から原研の成果の移転を図り、地震PSAや火災PSA手法の研究開発に着手した。また、２０００年頃からは、原子力学会等においてPSA手順書の整備が開始され

た。３）は２００１年から原子力安全委員会において専門部会が立ち上がった。この部会の議論においては、指標となるリスクはIPEEEに基づくものであるとの了解が当初よりあったと理解している。

９．　津波については、１９８０年代に、三陸沿岸に原子力発電所を立地できないかとの相談を受けたこともあり、一時関心を持ったが、手に入ったのは力武先生の研究論文だったとの記憶がある。ただ、それによれば１００年のうちに浜岡や三陸では１０ｍ 級の大津波が来襲する可能性があるとされていたが、福島沖には断層モデルがないため、過去の経験から判断するしかないが、今後１００年のうちに来襲することがあるとしても１ｍ 程度のものであるとされていたので、それ以来、関心を持つことはなかった。

１０．テロもまた重大な関心を持つべき外部事象のひとつである。これについては、９．１１以後、原子炉等規制法が改定され、設計基礎脅威（DBT）が公安当局の協力を得て策定され、事業者においてこれを踏まえた対策を講じることが義務化されるなど、急速に規制体制の整備が進んだ。

ただし、安全確保と核セキュリティ確保の要求には相反的なものと相補的なものがあるから、二つの規制当局間では絶えず協議が必要であり、なかでも、核セキュリティ上の要求で安全強化につながるものについては、この協議を通じて、安全確保の面からの考察も加えて措置内容を決めていくのが合理的である。しかしながら、原子力安全委員会は、その定めた安全設計審査指針において人為事象に対する安全設計上の考慮を要求しているにも拘らず、こうした取組の基本方針を示すことはなかった。したがって、我が国の規制当局における二つの担当課において積極的にそうした協議が行われることはなかったようである。米国からの核セキュリティの取組強化に関する情報が安全規制分野と共有されなかった遠因もここにあると思量する。

なお、２００５年になって、原子力委員会は原子力政策大綱において核セキュリティを所掌事項であると宣言し、２０１１年に至って最新の国際規範であるIAEAの基本原則の公表と同時に、我が国における核セキュリティに係る取組の基本方針を制定し、そこでこのような考え方を示したところである。

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TSUNAMI HAZARD PROBABILITY IN JAPAN

By T. Rikitake and I. Aida

Abstract

An analysis of future tsunami hazard on the coast of the Japanese Islands is made in terms of probability for a coastal site being hit by a tsunami, of which the wave height exceeds a certain level during a period from 2000 to 2010. Tsunami wave height at a site on the Pacific coast is estimated mostly based on numerical experiment, in which a typical fault model of the tsunami-generating earthquake is assumed. Meanwhile, probability of the tsunami-generating earthquake occurring during 2000 to 2010 is evaluated either from historical data of earthquake occurrence or from near-shore crustal strain accumulation.

Combining the wave height estimate with the probability evaluation of tsunami occurrence, probabilities of a site being hit by a tsunami, of which the wave height exceeds certain levels, are evaluated on the Pacific coast. It seems that the probability for a violent tsunami, of which the wave height exceeds 5 m, is highest along the Pacific coast in central Japan, reaching a value of 41 per cent. On the other hand, a probability value as high as 69 per cent is found for a moderately large tsunami having a wave height of 1 m or so along the Shikoku and Kyushu coasts.

A crude probability evaluation is also made for tsunamis on the Japan Sea coast, where tsunami activity is substantially lower than that of the Pacific coast. The probability for a violent tsunami seems to amount to only 1 per cent or so for a 10-yr period. Similar probabilities for tsunamis excited by a distant source off Peru, Chile, Kamchatka, and Aleutian-Alaska are also evaluated. In this case, probabilities of tsunami wave height exceeding 1 and 3 m are, respectively, evaluated as 19 and 15 per cent on the Pacific coast, such probabilities being not quite negligible.

Introduction

In contrast to seismic zoning or earthquake hazard analysis, very few analyses of future tsunami hazard have been conducted in Japan. Probably, the work by Takahashi (1951) is the only quantitative estimate of future tsunami damage on the Pacific coast of the Japanese Islands. The degree of future hazard is defined by the sum of squares of tsunami wave amplitude expected at a site on the coast during a 100-yr period. Assuming that the period of tsunami wave is approximately constant, the aforementioned quantity is proportional to tsunami wave energy that reaches the site concerned. Since the estimate relies on the historical record, it can be applied to the future only on the condition that the tsunami activity in the past can be extended to the coming 100-yr period.

Aida (1969) conducted a numerical experiment on tsunami wave generation and propagation based on the sea-bottom deformation caused by an earthquake. By now, such computer simulation of tsunami waves has developed so markedly that highly plausible wave height and form on a 200 m depth contour can be obtained based on an earthquake fault model determined seismometrically.

Meanwhile, it has in recent years become possible to evaluate probability of a major offshore earthquake occurring in seismic areas adjacent to the Japanese Islands on the basis of recurrence time of earthquakes and/or accumulation of near-shore crustal strain (Wesnousky *et al.*, 1984). Although the accuracy of such evaluation is not always high, it is important that something can be said about future occurrence of major offshore earthquakes in terms of probability.

Combining numerical tsunami experiment and probability evaluation of off-shore earthquake occurrence, it is possible to evaluate the probability of having a tsunami, of which the maximum water elevation exceeds a certain value, at a site on the coast provided various parameters of the earthquake fault model are given. As there are a number of potential tsunami sources, probabilities for all the sources are to be synthesized. The overall probability of tsunami hazard at any site on the coast will thus be evaluated.

The previously mentioned probability evaluation will here be applied to tsunami arising from sources off the Pacific coast of the Japanese Islands. Attention should be drawn to the fact, however, that a major tsunami sometimes occurs in the Japan Sea, although less frequently. Even a tsunami from very distant sources, such as from South America, Aleutian Islands, Kamchatka, and so on, sometimes hits Japan. A crude evaluation of hazard probability for tsunamis of these kinds will also be made in this paper.

Tsunami Waves Arising from a Typical Fault Model

Imminence of a great earthquake of magnitude 8 or so occurring in the Tokai (literally east sea) area off the Pacific coast of central Japan has become widely accepted not only by seismologists but also by the public at large in recent years. One of the most likely fault models of the anticipated earthquake, which is certainly associated with the subduction of the Philippine Sea plate, would be the one shown in Figure 1. The fault plane having a length of 130 km and a width of 60 km dips down to the west with an angle of 34° from the horizontal plane. The upward slip of the western side of the fault at the time of earthquake occurrence would amount to 3.8 m along the dipping plane, while a 1.3 m left-lateral slip would take place in the strike direction of the fault. The seismic

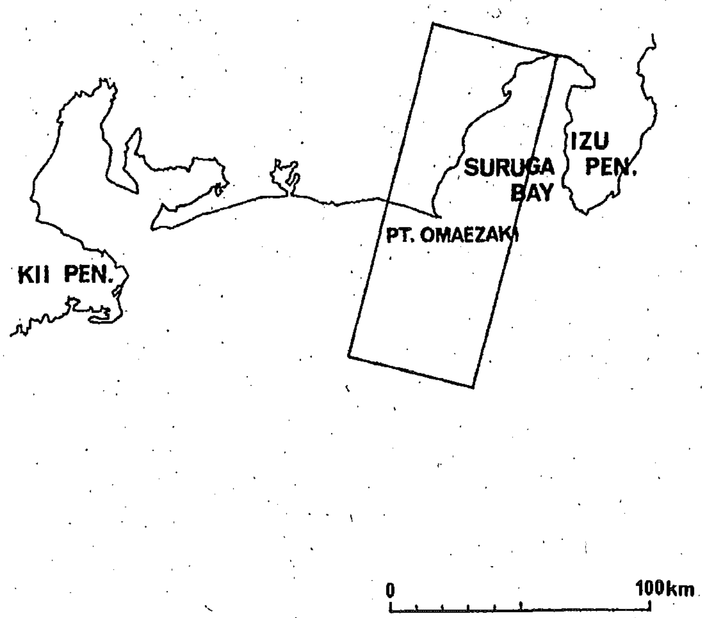

FIG. 1. Horizontal projection of the fault model for the hypothetical Tokai earthquake.

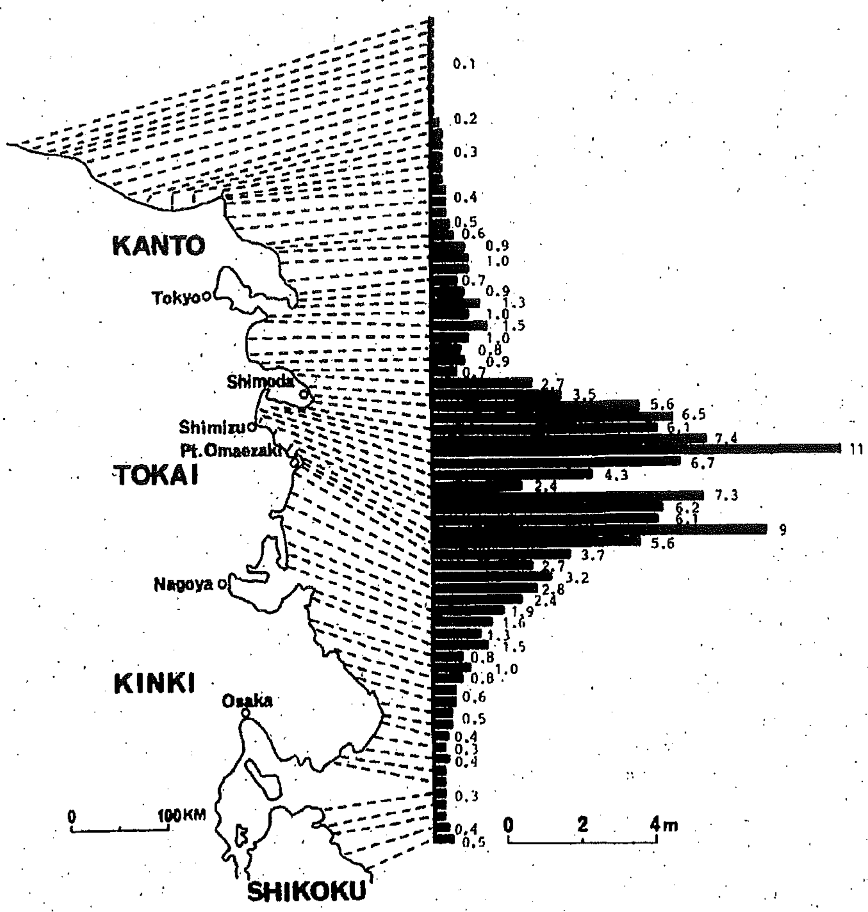

FIG. 2. Wave height distribution of the tsunami excited by the hypothetical Tokai earthquake of which the fault model is shown in Figure 1.

moment would amount to 1.56×10^{28} dyne-cm, which corresponds to a moment magnitude of 8.1. The model is a slightly modified version of the one proposed by Ishibashi (1981).

Aida (1984) estimated the behavior of tsunami wave on the 200 m depth contour based on the previously mentioned fault model. The wave height, which is defined by the total amplitude of the first wave, is then converted into the wave height at the nearest shore, taking into account the amplification factor during wave propagation over the continental shelf (Aida, 1977). In such a way, tsunami wave heights, that are likely to hit the Pacific coast in association with the hypothetical Tokai earthquake, can be estimated. In Figure 2 are shown the wave heights thus estimated at various seashore sites. Very large wave heights exceeding 5 m are to be observed at sites close to the fault assumed.

TSUNAMI-GENERATING EARTHQUAKES

Figure 3 shows the seismic zones from which major tsunamis on the Pacific coast are originated. The tsunami associated with the hypothetical Tokai earthquake is generated at the easternmost portion of zone VII. According to the existing studies on earthquake origin (Iida, 1983), typical fault models can be assigned to zones I, III, VI, VII, and VIII, although the details of those models are put aside here for the sake of brevity (Aida, 1984). Probable tsunami wave heights from these sources can then be estimated on the Pacific coast in a fashion similar to the last section. For other zones, no representative models of tsunami source are known. However, wave height on the coast can be approximately inferred from the actual data of typical tsunamis in the past. It is therefore possible to estimate tsunami wave height at various sites on the Pacific coast on the condition that a tsunami is generated from one of the zones shown in Figure 3.

We are in a position to see how often a tsunami-generating earthquake occurs from the cited zones. Probability of a major earthquake of $M = 7$ or over occurring in respective zones is evaluated primarily on the basis of historical records. When the number of historical earthquakes is sufficiently large, we make use of a Weibull distribution analysis for estimating mean recurrence period and thus occurrence probability. Meanwhile, we have to rely on a Poisson distribution in the cases of scarce data on the assumption that earthquake occurrence is stationary and random. Weibull distribution analysis is widely used in quality control engineering and was first introduced into the earthquake prediction study by Hagiwara (1974). The analysis is different from the Poisson distribution analysis because the probability increase after a particular earthquake can be evaluated.

Zone I, or the seismic area off Hokkaido-Kurile, can be divided into six subareas, each of which having been a seat of major earthquakes in the past. A Weibull distribution analysis of recurrence period is made for the data set as a whole, while a fault model that represents that of the 1952 Tokachi-Oki earthquake ($M = 8.1$) is chosen as the typical tsunami source. As major earthquakes have already occurred in the 1950's, 1960's, and 1970's in all of these subareas, the probabilities of having a major earthquake off Hokkaido-Kurile during a period from 2000 to 2010 are not high as can be seen in Table 1.

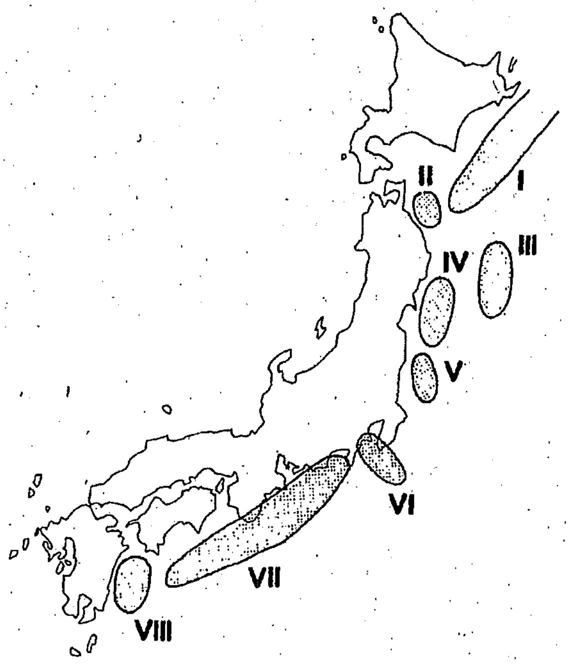

FIG. 3. Seismic zones for major tsunami-generating earthquakes off the Pacific coast of the Japanese Islands.

For zone III, from where the great 1896 Meiji Sanriku and 1933 Showa Sanriku tsunamis were originated, a fault model equivalent to that of the 1896 one is assumed, although the source location is somewhat shifted to the south because a conspicuous seismic gap exists there.

No historical data for evaluating occurrence probability of a major earthquake are available for zone VI. However, the crustal strain monitoring over the Sagami Bay area to the southwest of Tokyo is useful for probability evaluation. As for the fault model, the one for the 1923 Kanto earthquake ($M = 7.9$) is adopted.

For the easternmost portion of zone VII, both historical data and crustal strain are available. The fault model assumed is already shown in Figure 1. The probability of having a great earthquake there exceeds 40 per cent for the 10-yr period in question. As for the middle and southern parts of zone VII, the probabilities are small because the 1944 Tonankai ($M = 7.9$) and 1946 Nankai ($M = 8.1$) earthquakes have already occurred there, respectively. In view of the small probabilities, the height of the tsunami wave from these parts of the zone is estimated by means of interpolation of the 1944 and 1946 tsunami data.

Zone VIII is known for frequent occurrences of earthquakes having a magnitude around 7, so that a fairly high probability is obtained (Table 1). As for the fault model, the one for the 1968 Hyuganada earthquake ($M = 7.5$) is adopted.

No fault models are specified for zones II, IV, and V, but tsunami wave heights from these sources are estimated based on tsunami data in the past. Only a tsunami of 1 m or so in wave height is expected from these source areas.

Overall Tsunami Hazard Probability

The information presented in the previous two sections makes it possible to evaluate the probability of tsunami wave height exceeding a certain level at a seashore site during a period from 2000 to 2010, as will be shown in the following.

As an example, let us evaluate the tsunami probability at Shimoda near the extremity of Izu Peninsula (see Figure 2). According to Figure 2, the wave height due to the coming Tokai earthquake at Shimoda amounts to 5.6 m. On the other hand, the probability of the said earthquake occurring during the period in question is evaluated as 0.41 (Table 1). The probabilities for Shimoda being hit by a tsunami wave caused by the hypothetical Tokai earthquake are then evaluated for wave heights equal to or larger than 0.5, 1, 2, 5, 7, and 10 m as 0.41, 0.41, 0.41, 0.41, 0, and 0, respectively.

The respective probabilities at the same site due to the Kanto earthquake or the earthquake arising from zone VI are obtained as 0.22, 0.22, 0, 0, 0, and 0. Similarly, the respective probabilities for the middle portion earthquake of zone VII are evaluated as 0.05, 0.05, 0.05, 0, 0, and 0. Meanwhile, those for the southernmost portion earthquake of zone VII amount to 0.04, 0.04, 0.04, 0, 0, and 0. No tsunami wave height exceeding 0.5 m is expected at Shimoda from other tsunami-generating areas shown in Figure 3.

Denoting the probability of tsunami wave height exceeding a certain level due to a tsunami from the ith area by p_i, the synthetic probability p is estimated by

$$p = 1 - \prod_{i=1}^{n} (1 - p_i) \tag{1}$$

where n is the total number of tsunami-generating areas. Applying equation (1)

TABLE 1

PROBABILITIES OF A LARGE EARTHQUAKE OCCURRING FROM OFFSHORE EARTHQUAKE AREAS DURING 2000 TO 2010*

No.	Earthquake Area	Mean Latitude (°N)	Mean Longitude (°E)	Mean Magnitude	Year of Last Earthquake	Mean Return Period (yr)	Probability for 2000–2010	Remark
Ia		44.5	151.2		1963		0.037	
Ib		44.0	149.0		1958		0.050	
Ic	Off Hokkaido -Kurile	43.3	147.6	7.9	1969	85.3	0.021	W
Id		42.6	146.2		1973		0.017	
Ie		42.2	144.6		1952		0.070	
If		40.7	143.6		1968		0.026	
II	Off Aomori Prefecture	40.7	142.4	7.3	1945	69	0.14	P
III	Off Sanriku	39.4	144.4	7.9	1933	107	0.089	P
IV	Off Miyagi Prefecture	38.2	142.0	7.4	1978	34.9	0.28	W
V	Off Fukushima Prefecture	37.2	141.6	7.5	1938	146	0.066	P
VI	Sagami trough	34.7	139.8	8.0	1923	159	0.22	W
VIIa		34.7	138.3		1854		0.41	
VIIb	Nankai trough	33.9	136.8	8.0	1944	117	0.045	W
VIIc		32.9	134.4		1946		0.042	
VIII	Hyuganada Sea	32.1	132.1	7.0	1984	7.2	0.68	W

* P and W in the last column indicate that Poisson and Weibull distributions are used, respectively.

TABLE 2

SYNTHETIC PROBABILITIES OF TSUNAMI WAVE EXCEEDING THE KEY HEIGHTS AT SHIMODA

Tsunami Wave Height (m)	Probability
≧0.5	0.58
≧1	0.58
≦2	0.46
≧5	0.41
≧7	0
≧10	0

to the probabilities for Shimoda, the synthetic probabilities of tsunami wave exceeding respective heights are evaluated (Table 2).

Similar probability evaluations are made for key sites along the Pacific coast of the Japanese Islands as shown in Figures 4, 5, 6, and 7 for Hokkaido, Tohoku, Kanto-Chubu-Kinki-Shikoku, and Shikoku-Kyushu coasts, respectively.

It is observed from these figures that the highest probability of tsunami wave having a height of 5 m or larger is expected for the Pacific coast of central Japan. Most seashore sites in Shizuoka Prefecture are characterized by a probability higher than 40 per cent during the 10-yr period in question. Such a high probability is certainly brought about by the anticipated Tokai earthquake that is feared to occur in the near future. There are also a few sites, where a wave height exceeding 5 m is expected on the southernmost coast of Hokkaido and the Sanriku area in Tohoku of North Japan, although the probabilities are smaller than 10 per cent.

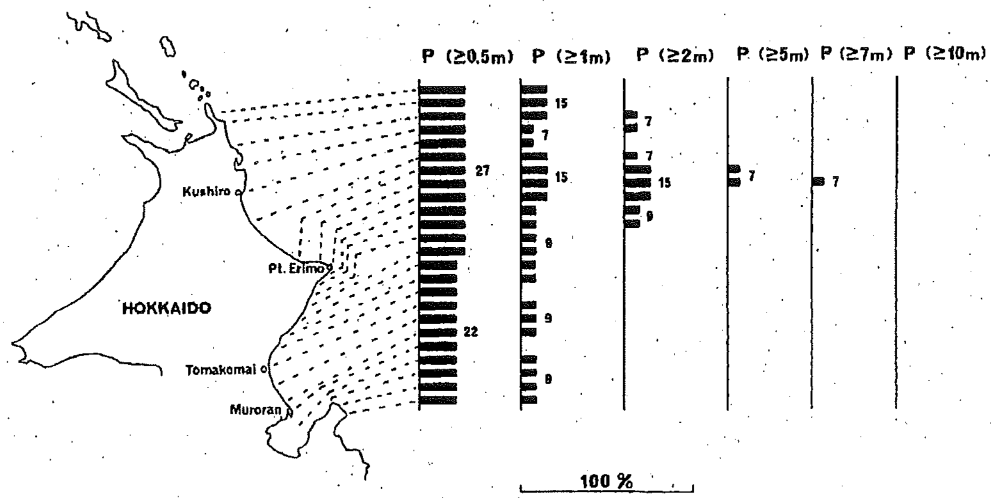

FIG. 4. Probabilities for the Pacific coast of Hokkaido being hit by a tsunami of which the wave height exceeds respectively 0.5, 1, 2, 5, 7, and 10 m during a period from 2000 to 2010.

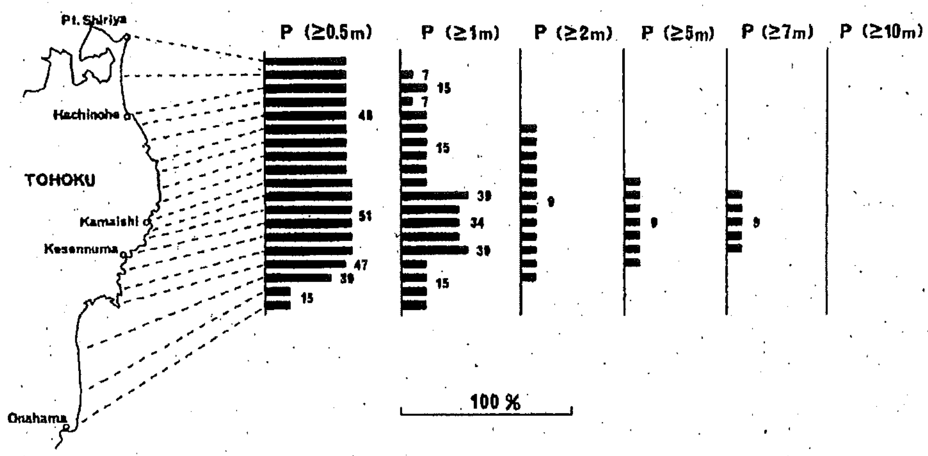

FIG. 5. Tsunami probabilities for the Pacific coast of Tohoku. Other legends are the same as those for Figure 4.

As for tsunami waves having a height of 1 m or thereabout, a high probability amounting to 69 per cent is assigned to the Pacific coast of Shikoku and Kyushu because of frequent Hyuganada earthquakes in zone VIII. It is therefore said that the worst sites for a highly dangerous tsunami are located on the Pacific coast of central Japan and that such sites for a moderately dangerous tsunami are found on the Shikoku and Kyushu coasts.

We also see that probabilities of being hit by a tsunami having a wave height of 0.5 to 1 m exceed 50 per cent at most seashore sites except Hokkaido. This means that the possibility of moderate tsunami hazard cannot be ignored along the whole Pacific coast of the Japanese Islands.

TSUNAMI HAZARD ON THE JAPAN SEA COAST

The tsunami associated with the 1983 Nihonkai Chubu earthquake (M = 7.7) that occurred underneath the Japan Sea off Akita Prefecture killed 100 people.

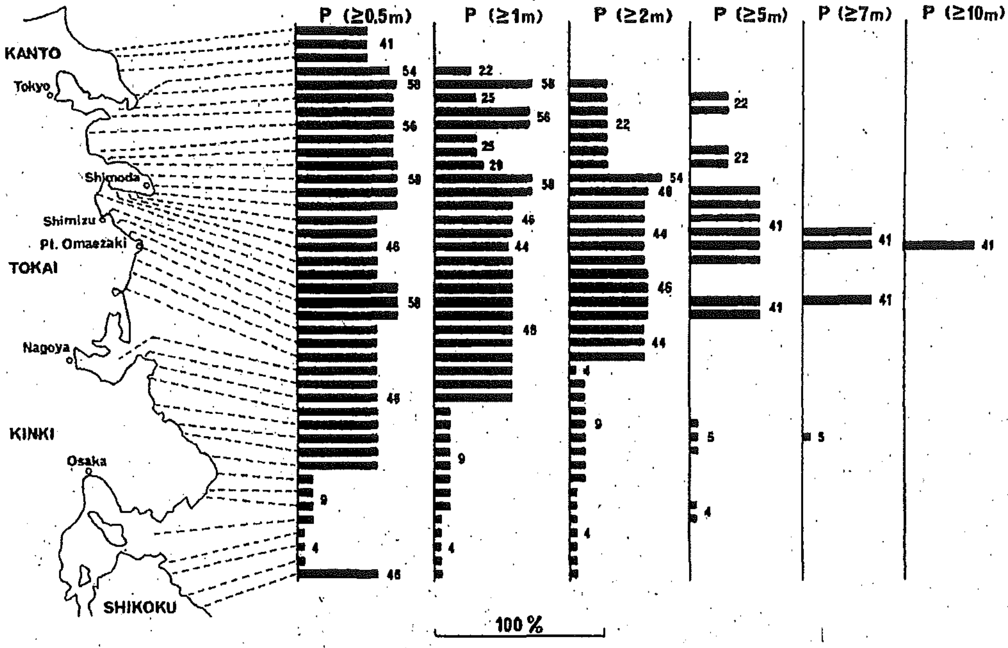

FIG. 6. Tsunami probabilities for the Pacific coast of Kanto-Tokai-Shikoku. Other legends are the same as those for Figure 4.

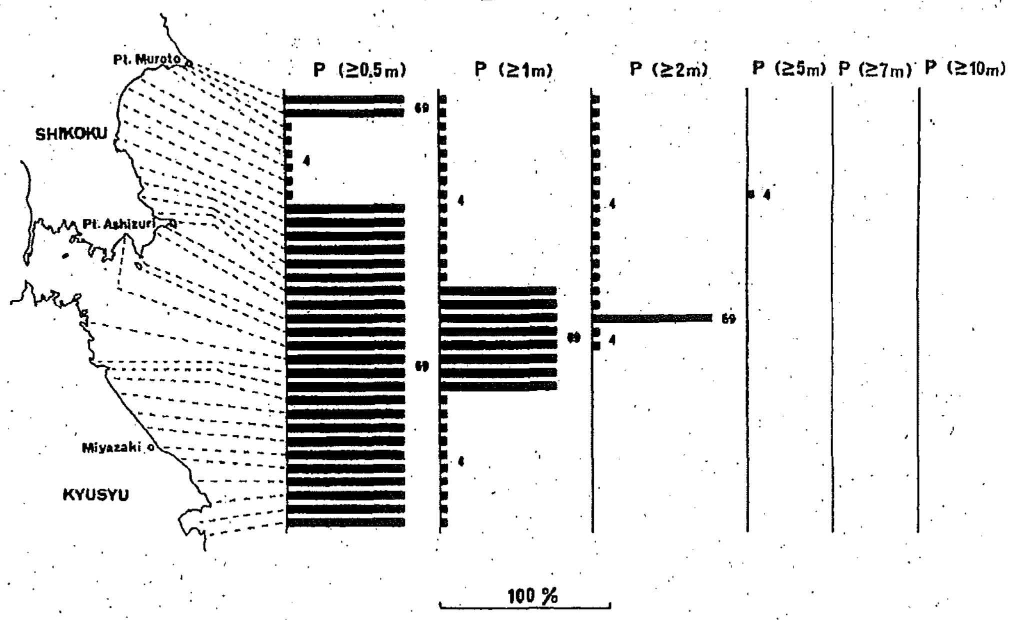

FIG. 7. Tsunami probabilities for the Pacific coast of Shikoku-Kyushu. Other legends are the same as those for Figure 4.

Maximum water height locally exceeded 10 m at some beaches. In view of this and a few violent tsunamis found in Japan's history, hazard analysis is also important for tsunamis occurring in the Japan Sea.

In contrast to offshore earthquakes on the Pacific side of the Japanese Islands, it is no easy matter to evaluate occurrence probability of tsunami-generating earthquakes located in the Japan Sea because occurrence frequency is extremely small. The available history is too short for discussing the recurrence period. Nevertheless, Shimazaki (1984) attempted to estimate recurrence periods based on the size of epicentral areas and historical records for the past 400 yr and concluded that an earthquake equivalent to the 1983 event probably recurs every 600 to 1200 yr.

Kanamori and Astiz (1985), who relied on the relation between age of subducting plate and aseismic slip, estimated a recurrence period of the 1983 earthquake as 600 to 1370 yr.

Let us assume that the mean recurrence period is 1000 yr. When a Poisson distribution is assumed, the probability of this class of earthquake occurring in the Japan Sea amounts to about 1 per cent for a 10-yr period. As the area occupied by the northern half of the Japan Sea may accommodate approximately four earthquakes of this class, the probability amounts to 4 per cent for the northern half of the Japan Sea. No great earthquakes occur in the southern half of the sea.

Wave height of the tsunami excited by an earthquake of the previously mentioned class exceeding several meters, the probability of a 100 to 200 km segment of Japan Sea coast being hit by a tsunami having a wave height of several meters, is evaluated as 1 per cent or so for a 10-yr period.

Tsunamis of somewhat smaller scale, which are characterized by a wave height of about 1 m or thereabout, occur approximately every 10 yr or so in the Japan Sea as inferred from the historical record. Assuming a Poisson distribution, the probability of having at least one tsunami of this class occurring in the Japan Sea amounts to 50 per cent for a 10-yr period, so that the probability of such a tsunami hitting a coastal segment of 100 km in length is about 3 per cent.

Tsunamis from Distant Sources

A tsunami caused by a great earthquake (M = 8.5, 1960) that occurred off Chile gave rise to much damage to Japan. The maximum tsunami height along the coast of Japan was reported as large as 4 m. The numbers of dead and missing people were 119 and 20, respectively. It is therefore important to estimate possible tsunami hazard due to an earthquake that occurs at an extremely distant locality.

According to an evaluation based on a Poisson distribution, great earthquakes that generate tsunamis that affect Japan occur off Peru and Chile, with a probability of 27 per cent for a 10-yr period. On the basis of such probability value, it is evaluated that the probabilities of a tsunami with a wave height that exceeds 0.5, 1, and 3 m, hitting the Pacific coast of Japan, amount to 26, 14, and 4 per cent, respectively.

Similar probabilities for a tsunami from Kamchatka and Aleutian-Alaska are evaluated as 15, 6, and 3 per cent, respectively. Combining the effects of the two sources, probabilities of tsunami wave height exceeding 0.5, 1, and 3 m are, respectively, evaluated as 37, 19, and 15 per cent on the Pacific coast of Japan for a 10-yr period. It should be stressed that the tsunami probabilities from distant earthquakes thus evaluated are not quite smaller than those from near offshore earthquakes as shown in Figures 4 to 7.

Conclusions

Combining occurrence probability of offshore earthquakes with tsunami wave height estimated at seashore sites, the probability of tsunami wave height exceeding a certain level is evaluated on the Pacific coast of the Japanese Islands. It seems that probability of a violent tsunami, of which the wave height exceeds 5 m, hitting the coast of the Tokai area in central Japan, amounts to about 40 per cent for a 10-yr period from 2000 to 2010. Such a high hazard probability is due to the earthquake that is expected to occur off the Tokai area sooner or later. The probability of the earthquake occurring within the 10-yr period from 1988 is evaluated as 30 to 35 per cent. As for the probability of a moderately large tsunami having a wave height of 1 m or so, the highest value around 70 per cent is found at some sites on the Shikoku and Kyushu coasts because of fairly frequent occurrence of moderately large earthquakes in the Hyuganada Sea.

It also should be borne in mind that a tsunami originated by a great earthquake that occurs in the north Pacific and off South America sometimes affects the Japanese Islands. According to a crude evaluation, probabilities of a tsunami from such a source hitting the Pacific coast of the Japanese Islands amount to 19 and 15 per cent for a 10-yr period, respectively, for wave heights exceeding 1 and 3 m. Such probabilities are not quite negligible in comparison with those for tsunamis from offshore earthquakes in the vicinity of Japan. It is therefore necessary to modify the graphs in Figures 4 to 7 in such a manner as to make all of the probability columns a little taller.

Tsunami probabilities on the Japan Sea coast are considerably lower than those on the Pacific coast because of low seismicity in the Japan Sea area. A tsunami having a wave height of several meters hits a seashore site on the northern half of Japan Sea coast with a probability of 1 per cent or so for a 10-yr period. For a moderately large tsunami, of which the wave height amounts to about 1 m, the probability is evaluated as 3 per cent. Tsunami probability is almost zero for the southern half of the Japan Sea coast.

The tsunami hazard probability evaluated in this paper may be used for planning public evacuation from a tsunami area, selecting coastal sites for construction purposes or estimating rates for tsunami insurance.

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INSAG-3 Basic Safety Principles for Nuclear Power Plants (1988)

2.3. TECHNICAL SAFETY OBJECTIVE

19. *Objective: To prevent with high confidence accidents in nuclear plants; to ensure that, for all accidents taken into account in the design of the plant, even those of very low probability, radiological consequences, if any, would be minor; and to ensure that the likelihood of severe accidents with serious radiological consequences is extremely small.*

27. The target for existing nuclear power plants consistent with the technical safety objective is a frequency of occurrence of severe core damage that is below about 10–4 events per plant operating year. Severe accident management and mitigation measures could reduce by a factor of at least ten the probability of large off-site releases requiring short-term off-site response. Application of all safety principles and the objectives of paragraph 25 to future plants could lead to the achievement of an improved goal of not more than 10–5 severe core damage events per plant operating year. Another objective for these future plants is the practical elimination of accident sequences that could lead to large early radioactive releases, whereas severe accidents that could imply late containment failure would be considered in the design process with realistic assumptions and best estimate analyses so that their consequences would necessitate only protective measures limited in area and in time.

4.1.1. External factors affecting the plant

136. *Principle: The choice of site takes into account the results of investigations of local factors that could adversely affect the safety of the plant.*

137. Local factors include natural factors and human made hazards. Natural factors to be considered include geological and seismological characteristics and the poten- tial for hydrological and meteorological disturbances. Human made hazards include those arising from chemical installations, the release of toxic and flammable gases, and aircraft impact. The investigations required give information on the likelihood of significant external events and their possible effects on nuclear power plant safety. This is developed in the form of quantified probabilities when possible.

UK HSE Safety Assessment Principles for Nuclear Facilities

<2006 Edition, Revision 1>

- Engineering principles EHA.4 external and internal hazards: frequency of exceedance

  The design basis event for an intern al and external hazard should conservatively have a predicted frequency of exceedance in accordance with the fault analysis requirements (FA.5).

- Engineering principles EHA.7: external and internal hazards 'Cliff-edge' effects

  A small change in DBA parameters should not lead to a disproportionate increase in radiological consequences.

- Fault analysis FA.5: design basis analysis: Initiating faults

  The safety case should list all initiating faults that are included within the design basis analysis of the facility.

  Initiating faults identified in Principle FA.2 should be considered for inclusion in this list, but the following need not be included:

  a) Faults in the facility that have an initiating frequency lower than about 1×10^{-5} pa;
  b) Failures of structures, systems or components for which appropriate specific arguments have been made;
  c) Natural hazards that conservatively have a predicted frequency of being exceeded of less than 1 in 10 000 years;
  d) Those faults leading to unmitigated consequences which do not exceed the BSL for the respective initiating fault frequency in Target 4. *(paragraph 599 f.)*

<1992 VERSION>

- P120: For natural hazards, the uncertainty of data may prevent reasonable prediction of events for frequencies less than once in 10 000 years.□In these cases, plants should meet the requirements of P25 for a design basis event that conservatively has a predicted frequency of being exceeded no more than once in 10 000 years.

- P121: It should be shown that there will not be a disproportionate increase in risk from an appropriate range of events which are more severe than the design basis event.