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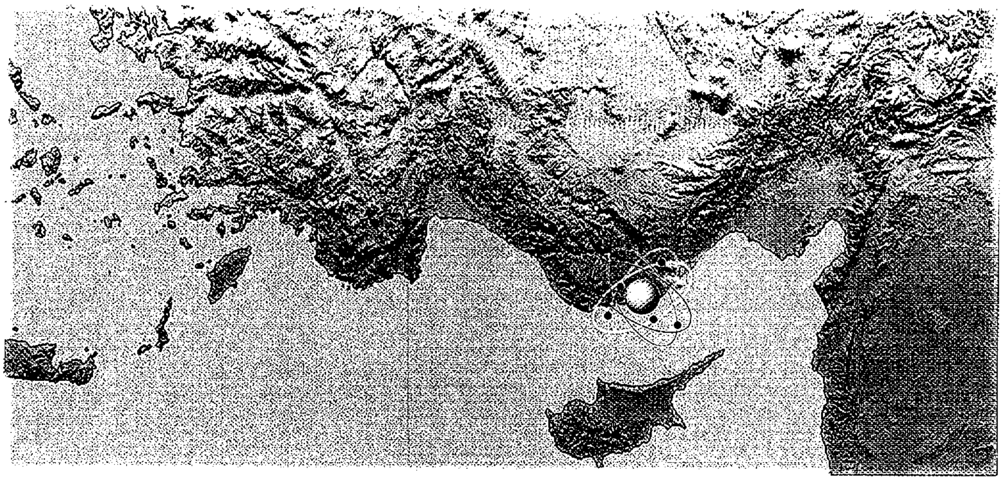
Basic Facts Concerning The Proposed Nuclear Power Plant at Akkuyu in Turkey



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CONTENTS

Foreword

Turkey is a country of more than 65 million people with a land area of 780.000 km^2. It has the leading economy of its region, with a young, dynamic population, whose creative abilities are well accepted. Turkey has made enormous progress during the past twenty years transforming itself into a developed economy, able to produce some of the world's most sophisticated products. There is nevertheless much potential for further development, which needs to be realized if all the Turkish people are to enjoy the standards of living to which they rightly aspire.

One of the stumbling blocks in Turkey's economic development is the lack of reliable, diversified and low-cost energy. Domestic oil and gas resources are inadequate, and coal reserves are predominantly of low-energy high-pollutant soft coals. There is some hydroelectric and renewable energy capacity but is far from satisfying the demand.

Turkey's energy consumption in 1998 is 74.17 million tonnes of oil equivalent (mtoe) and it is expected to reach to 170.318 mtoe by 2010. Turkey's demand for natural gas by 2010 is expected to reach 55.156 billion cubic meters and 83 billion cubic meters in 2020. In order to meet the electrical energy demand, it is estimated that by 2010 Turkey has to launch new power plants with an additional capacity of 42 GW.

Building a nuclear power plant implies utilization of the technology of the 21st century. This technology comprises not only energy technology but also most modern clean methods and system relating to agriculture, that is use of nuclear energy to improve the agricultural output, technology relating to medicine such as utilising nuclear system in cancer and other diseases' therapy and upgrading all areas of industry. Therefore, opting for nuclear technology is opting for modern and contemporary technology in many areas of our lives.

A desire to obtain nuclear technology has nothing to do with developing nuclear arms. Turkey is a party to the Nuclear Non - Proliferation Treaty (NPT), which restricts nuclear power states to five. Turkey has a full scope nuclear safeguards agreement with the IAEA with which it commits itself to prevent all nuclear proliferation activities in Turkey. Turkey is also a party to the Comprehensive Test Ban Treaty (CTBT) and is firmly committed not to conduct nuclear tests. Turkey has concluded bilateral cooperation agreements on peaceful uses of nuclear energy with South Korea, Canada, France and Argentina and similar agreements are in the process of conclusion with Japan. A cooperation agreement on peaceful uses of nuclear energy between

Turkey, Germany and USA has also been initialled. In addition, an agreement relating to early notification of nuclear accidents has been signed with Bulgaria. Thus Turkey is committed by international and bilateral agreements to the peaceful use of nuclear energy.

Turkey has embarked on the construction of a nuclear power plant on its territory due to its advantages in comparison with other sources of energy. As regards environmental pollution effects, nuclear power plants, in comparison to fossil fuel burning plants, have a much better record. With respect to greenhouse gas emissions, nuclear and hydroelectric capacities reduce the CO_2 emissions per unit energy produces than fossil fuel. Thus, except for nuclear and hydro power, which has a slow growth potential due to full utilization, there are few other economically viable options with minimum emissions for long term power generation. In view of the foregoing, Turkey is obliged to adopt nuclear energy as a key part of its national energy strategy.

From the scientific and technical point of view, Turkey is prepared for the utilization of new technology for peaceful purposes. There is a nuclear research and training center in Çekmece, İstanbul, since 1960 which is utilized by the IAEA as a regional training center for radioactive waste management. The above mentioned center has hosted IAEA's inter regional training courses on several subjects, such as radioactive protection and secondary calibration techniques etc. The center has the necessary infrastructure related to environmental assessment activities in the Black Sea.

Turkey has already ratified the Nuclear Safety Convention (NSC). The Turkish Atomic Energy Authority (TAEK) is fully equipped to perform its regulatory function in the operation of the Akkuyu Plant. In addition, TAEK has specialized departments in the area of nuclear safety, radiation health and safety, research-development-coordination and technology.

IAEA Report of the First Review Meeting of the Contracting Parties on the Nuclear Safety Convention held in Vienna on August 12-23, 1999, reaffirms that; "Turkey gave an extensive report including much more information than required by the Convention. This demonstrates how seriously Turkey is committed to the safety of future installations in the country."

Turkey intends to build its first nuclear power plant in the most seismically stable region in Turkey. Detailed studies carried out at the site of the nuclear power plant in cooperation with the IAEA and the United States Nuclear Regulatory Commission (USNRC) confirmed the safety of the site. The plant will be constructed in accordance with IAEA standards and guidelines. It will be constructed by experienced and well known nuclear power plant producers of the world, according to the highest safety standards in design, building and operation. Moreover, TAEK has granted site license for Akkuyu in June 1976. Thus the Akkuyu Nuclear Power Plant will be at least as safe as those in the supplier countries.

This booklet attempts to explain to non-experts the results of the preparatory studies carried out regarding proposed nuclear power plant at Akkuyu. The information presented here has been organized in four parts. Following a short overview of Turkey's energy policies and prospects, IAEA work related to the review of the seismic safety of the site is reviewed and seismic conditions at the Akkuyu Nuclear Power Plant site is discussed in Parts II & III, respectively. Part IV deals with the possible consequences of a highly unlikely accident assumed to occur at the proposed power plant. In Conclusion, it is demonstrated that the nuclear power plant to be built at Akkuyu presents no risk to the people in the immediate vicinity or neighbouring region and that nuclear energy is the most environmentally friendly and economically efficient option.

PART I
INTRODUCTION
A Short Overview of Turkey's Energy Policies and Prospects

Introduction

Energy issues are directly related to the development of a country and the living standards of its people. Turkey is currently in a rapid industrialization process with a young and dynamic population of over 65 million. Due to relatively high growth rate of the population, increasing consumer oriented attitudes and as a result of rising levels of affluence, the primary energy demand is rising rapidly at an average annual rate of 6.7 percent. Turkey is currently projected to remain a net importer of energy, with more than 60 percent of its needs to be imported in 2010.

Turkey's national energy policies are designed to provide the required energy on a timely, reliable, cost-effective, environmentally friendly and high-quality basis so as to serve as the driving force of development and social progress.

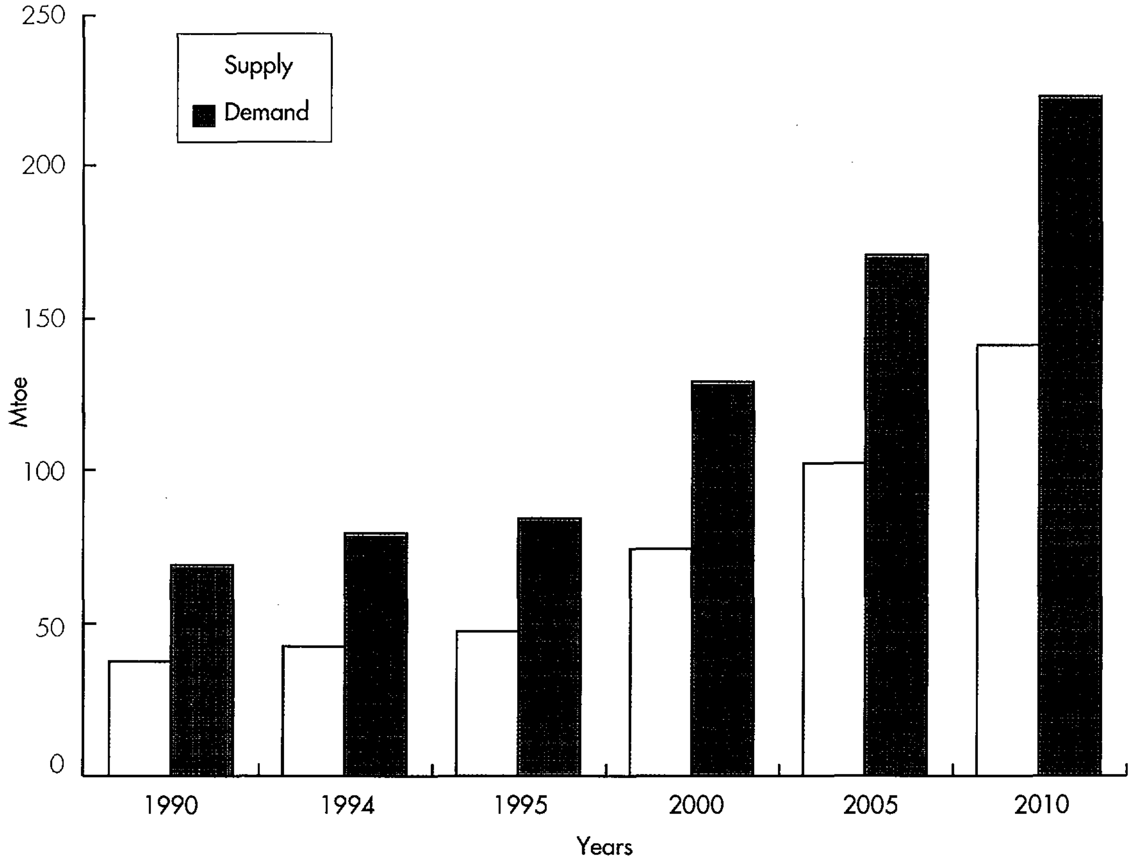
Meeting such a demand requires critical planning, and within this framework, the Ministry of Energy and Natural Resources is currently aiming for the year 2020. Supply and demand projections constitute the basis of these policies and the ongoing work is continuously updated within the context of national and international developments. Moreover, the legal and institutional arrangements needed for reliable and sustainable future supplies of energy are emerging as a matter of government responsibility.

Of Turkey's existing primary energy resources, oil and natural gas reserves are extremely limited. A large portion of Turkey's 8 billion-tonne coal reserves is brown coal of low quality. Lignite is the most common energy source in Turkey but there has been a significant shift in the balance through the conversion from coal to natural gas in electricity generation in industry and in the residential sector in urban areas.

Turkey's potential indigenous fuel sources for power generation comprise 105 billion kWh lignite, 16 billion kWh high quality coal, and 125 billion kWh hydro. The total potential adds up to 246 billion kWh and this situation clearly calls for the government to bring forward innovative policies.

As for electric power, the installed capacity of Turkey reached 23,264 MW and the annual gross per capita consumption of electricity reached 1,784 kWh at the end of 1998. Total electrical energy consumption was 114 billion kWh in 1998. This annual figure is estimated to reach 200 billion kWh in 2005, 290 billion kWh in 2010, and 547 billion kWh in 2020 (Fig.1). To meet this demand, it is necessary to add to the system approximately 42,000 MW capacity by the end of 2010 and 86,000 MW by the end of 2020. This translates into an annual addition of nearly 4,000 MW capacity to the

Figure 1 Total Energy Demand and Supply in Turkey



Source: Energy Policies of IEA Countries, OECD Publication, 1997, Paris

existing system until the year 2010. The annual cost of this investment will increase to approximately $4-4.5 billion with additional investments to be made for the transmission and distribution system.

Nuclear energy is therefore necessary for the diversification of Turkey's electric power resources. It will play a major role in contributing to the production of electricity and combating global warming. Experience has shown that nuclear energy has many advantages: competitive long term power costs, reliability of fuel supply, stable prices, a good safety record, the benefit of advanced technology and, environmental friendliness.

Among other forms of energy, only nuclear power satisfies all these requirements.

According to Turkey's current energy plans, by the year 2010, 1500 MW nuclear energy will be added to the national grid. Between the years 2010-2020, nuclear energy plants with an additional 8,000 MW capacity must be added. This translates into about 12 percent of the installed national energy. Therefore, the suggestion that nuclear energy will account for only a negligible portion of Turkey's future energy needs is not based on facts.

PART II

IAEA WORK IN RELATION TO THE SEISMIC SAFETY OF AKKUYU (TURKEY) NUCLEAR POWER PLANT SITE

Seismic Safety

The International Atomic Energy Agency (IAEA) had a Technical Cooperation Project in order to assist Turkey in nuclear safety issues in relation to the nuclear power plant project at Akkuyu. This project (TUR/9/005) was operational from the middle of the 1970s. The assistance involved mainly expert services and training of personnel from TAEK (Turkish Atomic Energy Authority) and TEK (Turkish Electricity Authority). Recognizing the high seismic activity in many parts of the country, seismic safety of the Akkuyu site was given top priority in this project. Several man-months of expert services per year were rendered to either TAEK or TEK during the period 1981-1985.

TEK submitted a ten volume document to TAEK titled "Detailed Site Investigations Report" (DSIR) comprising all site related information and evaluations. In the report, geological and seismic issues were given the most prominent consideration. TAEK requested assistance from the IAEA to review this document. In October 1983 an IAEA review team (one staff member and four independent experts) visited Ankara and Akkuyu for a duration of two weeks. The report of this mission was issued on 6 January 1984 (IAEA-TA-2174). The report agreed with the information and evaluations of the DSIR but also recommended further investigations to clarify specific issues and to reduce uncertainty in the calculated parameters.

TAEK requested further assistance from the IAEA in monitoring the follow up of the implementation of these recommendations. This assistance was given within the framework of the same project (TUR/9/005) and five IAEA reports were issued until 1986 (IAEA-TA-2188 dated February 1984, IAEA-TA-2206 dated April 1984, IAEA-TA-2282 dated October 1984, IAEA-TA-2305 dated January 1985 and IAEA-TA-2366 dated May 1986). On the basis of the advice received from these missions and reports, TAEK was satisfied that the recommendations of the October 1983 review mission related to seismology and geology were fully implemented.

When Turkey decided to revive its nuclear power program, a workshop was held in Ankara on Quality Assurance (QA) for Nuclear Power Program within the framework of TC Project TUR/4/020. Some lectures in this workshop were related to implementation of QA principles to siting and external hazards.

Recent activities related to the seismic safety of Akkuyu Nuclear Power Plant site involves a request by TAEK for IAEA assistance in reviewing the updated Site Reports prepared by TEAŞ (Turkish Electricity Generation - Transmission Co. - formerly TEK) within the framework of TC Project TUR/9/013.

Seismic Conditions

The scientific approach to designing against earthquake effects is in essence a formal prediction that remotely possible contingencies will occur. However, there are also predictions issued by less responsible groups and individuals. These people seem to be able to attract attention, supporters, publicity, and even funding for their groundless claims. How is this possible? The quick answer is: through persistent and relentless promotion of their claims in the mass media, by managing to attract testimonials from experts in fields other than seismology, and by appeals for funding that bypass the customary peer review. Many unfounded predictions attract publicity in the mass media because the mass media today is driven by sensation. Charles F. Richter, who developed the earthquake magnitude scale in 1937 commented in 1977 [1]:

"Journalists and the general public rush to any suggestion of earthquake prediction like hogs toward a full trough... [Prediction] provides a happy hunting ground for amateurs, cranks and outright publicity-seeking fakers."

There have been many well documented false scares [2], and unsuccessful earthquake prediction research has been going on for over 100 years, as has criticism of that research. The clear consensus of responsible scientists is that individual earthquakes are inherently unpredictable because of the chaotic and highly nonlinear nature of the source process. The Earth appears to be in a state of self-organized criticality, always on the edge of instability. Exactly when and where earthquakes occur, and how large they will be when they start, depend on a myriad of fine and immeasurable details of the physical state of the Earth over a large volume, not just in the vicinity of the fault [1].

It is essential to avoid basing major policy decisions on predictions of a pseudo-scientific nature. Seismology and earthquake engineering are not of course similar to astrology, so unfounded claims of the doomsday type cannot serve as guiding principles in engineering decisions. All human endeavour involves acceptance of some risk in order to achieve some benefit. Just as society at large accepts the risk associated with commercial aviation, and flies to distant destinations to save time, or that involved in being inoculated against contagious diseases, the risks associated with generating power through the peaceful use of nuclear energy are made acceptably small thanks to advances in technology. We are aware that this view is in conflict with some current social and political philosophies that place environmental concerns at the top of their list of priorities. We also realize that the differences are deep enough to defy being resolved within the space of this booklet.

In response to the fundamental unpredictability of earthquake *per se*, engineers express the expected severity of ground motion at a given point on earth on the basis of its seismic past and geological features.

Earthquake occurrence is generally confined to recognized seismogenic areas. These are geological structures that display earthquake activity or manifest historic surface rupture. A geographic area that is characterized by similarity of geological structure and seismicity pattern is called a seismotectonic province.

The seismic design parameters (typically expressed through some easily understood index of the ground motion) for nuclear power plants require very low probabilities of occurrence. This means that the governing design quantities have very long return periods. The process of establishing to which severity of earthquake ground motion a given nuclear facility must be designed to withstand is called seismic hazard assessment. Information from a variety of sources is therefore required, corresponding to different time intervals. This is illustrated in Table 1.

By its nature, the process of seismic hazard assessment is limited by incomplete or even erroneous knowledge and information, uncertainty and the random nature of the subject. No earthquake that occurred in the past will ever occur again. The frequency of earthquake occurrence, even on the same fault, is typically measurable in decades or centuries, and yet safety requirements force engineers and scientists to take account of the effects on the built environment of an event that in statistical terms occurs every 5-10,000 years. Records of strong ground motion caused by earthquakes are only about 65 years old, and instrumental seismology is no older than 100 years.

The earthquake engineering community involved in the seismic design of

Table 1. Databases in Seismic Hazard Assessment [3]

Type of Data	Time Frame (Years)	Earthquake Magnitude Threshold	Time Resolution
Local networks	1-10	0	Seconds
Modern instruments	3-40	2	Seconds
Early instruments	100	4	Seconds/Minutes
Historic evidence	100s-1000s	4-5	Minutes/Years
Archeological evidence	100s-1000s	5-6	Years
Paleoseismological evidence	10,000	6	Decades/Centuries
Neotectonical evidence	100,000 +	6-7	Millennia

critical facilities, such as nuclear power plants, has responded to the conflicting and paradoxical situation represented by earthquakes by resorting to what is known as defense in depth, or compounded safety at every stage of the design process. This means that in the face of every uncertain situation, the worst case scenario is adopted as the basis. While there is undoubtedly a price to pay for such conservatism, the strategy has paid well in that no nuclear plant designed according to the standards required for Akkuyu that has experienced earthquakes has shown any signs of distress, and has continued to function normally. The most recent examples have been the plants in Japan that were shaken during the major January 1995 earthquake that caused wide spread damage to other structures in the port city of Kobe.

Much of the work related to establishing the seismic safety of the Akkuyu site was done during the 1980s. Suitably qualified international firms and domestic public agencies including universities were engaged by TEK during this period to carry out the required investigations. All of these parties worked according to international standards and guidelines, such as those contained in IAEA or USNRC documents. A strict program of quality assurance and control was enforced in all phases of the work, and frequent IAEA missions provided continuous monitoring of the quality of the overall undertaking. As required by law, TAEK acted as the independent regulatory agency that considered and approved the reports submitted to it by the utility company, TEAŞ (or TEK as it was then known). In all, more than 100 subprojects were undertaken during this period.

Tectonic Framework of the Akkuyu Site

From the earliest stages of the site-related work, the primary target has been the establishment of the appropriate levels of hypothetical earthquakes to be considered in the design. The size of the region investigated, type of information collected, scope and detail of the investigations were all determined by the nature and complexity of the geological, seismological and geotectonic characteristics of the region.

The seismotectonics of the region was originally studied by ENG, a consortium of Swiss, French and German firms that had been engaged by TEK. This was later modified when the major seismotectonic features of the region, and the seismic sources were refined. A lengthy investigation of the microearthquakes (events with magnitude 3 or less) of the region was carried out in three different phases during 1977-88. Extensive field and remote imagery work was conducted in the second half of the 1980s to review further and reach a stable representation of the neotectonics of the region surrounding the Akkuyu site. This work concentrated in the rectangular area defined by latitudes 35.5-37.5 deg N and longitudes 32-35 deg E. Revised work involved the following items:

- Intensive literature survey on the geotectonics of the region
- Compilation of a neotectonic base map
- Description of active and/or capable faults that govern the seismicity of the region
- Plotting the epicenters on the neotectonic map to produce the seismotectonic map
- Definition of the seismic source regions through integration of historic, instrumental, and microearthquake data with the active tectonic features, and
- Characterizing each source region

The basic map is shown in simplified form in Figure 1:

The neotectonic map shown in Figure 2 was compiled after an extensive literature survey and cross-checking with previous seismic hazard studies conducted for the Eastern Mediterranean area. For the Akkuyu site a detailed neotectonic map was prepared on the basis of visual observations and photo or remote imagery interpretations.

The topical interpretation of these fault structures and their synthesis with the macroseismic activity recorded in the study area have led to the definition of the 11 zones marked in Figure 2 [4]. These zones exhibit consistency of seismicity patterns, and geological structures, representing the consensus of experts. These judgements have been subjected to IAEA peer review.

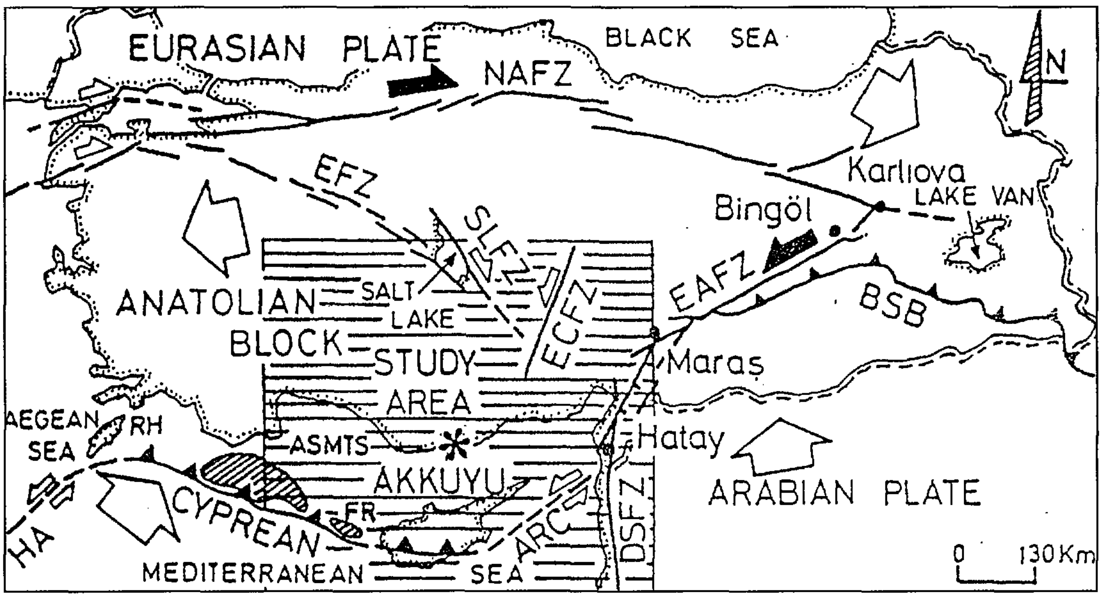


Figure 1. Major Tectonic Structures of Turkey and Adjacent Areas [4]

Zone 5 in Figure 2 deserves some attention because it has been speculated that the Ecemiş Fault Zone included in this region may extend further south, and in fact come closer to the plant site. Ecemiş forms the boundary between western and eastern Taurus. It extends from the north of Mersin (the capital city of Içel province, about 100 km north east of Akkuyu) in the NE direction to a point near Gemerek, a township of Kayseri at a distance of 320 km. Because of its peculiar structural position it has been subjected to many geological investigations. The Ecemiş fault zone was formed after Paleocene-Early Eocene (approximately 40 million years ago) and before Oligocene (38 million years ago) since when it was filled with molasse type sediments.

Others have suggested that the existence of Lutetian age sediments on both sides of the fault justifies the speculation of a Pre-Lutetian, post early Eocene time interval for the development of the Ecemiş Fault. Quaternary (approximately 2.5 million years ago) activity of the Ecemiş Fault Zone has been observed particularly in the northern part of the zone. There is no clear evidence of Quaternary faulting related to the eastern branch of Ecemiş Fault Zone. Geologic interpretations of the past displacement of the fault and

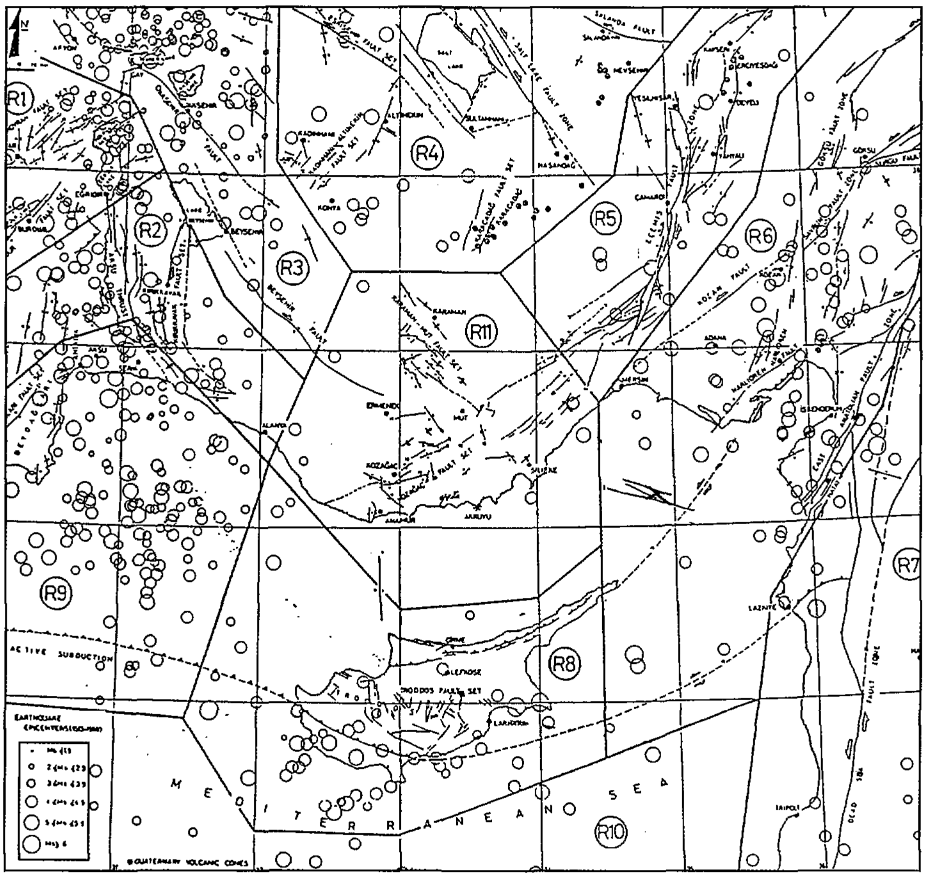


Figure 2. Seismicity, Tectonics and Regionalization Map of the Akkuyu Region

the lineaments have led to the conclusion that the possibility of the Ecemiş Fault Zone continuing south-westward to the Akkuyu site area is very remote. Detailed geological investigations carried out in the near vicinity of the southern end of the zone have proven that it terminates north of a village called Belenköy, 30 km north of Mersin.

Seismic Hazard Assessment of the Akkuyu Site

Akkuyu is located in the least seismically hazardous area in the current earthquake zones map of Turkey, which has been revised recently in accordance with probabilistic procedures. (A non-specific overview of the seismic hazard in Turkey available in numerical format).(*)

Seismic hazard analysis may be based on deterministic or probabilistic concepts. The former procedures are applicable for sites with well-defined local and regional seismogenic fault structures. It may be possible to estimate the motions that would result from a maximum event assumed to occur on a specific fault. Probabilistic approaches are suitable when the seismic hazard is not attributed to specific fault structures. Both approaches were taken for Akkuyu over a long period of time starting in 1976.

It should be recognized that seismic hazard analysis is subjected to greater uncertainties than those associated with other environmental phenomena such as predicting the speed of an extreme wind, or the amount of precipitation over a given duration. The types of uncertainty are:

- Random uncertainty due to physical variability of the earthquake process,
- Model uncertainty due to incomplete knowledge concerning the processes that govern earthquake occurrence and ground motion generation.

The second type of uncertainty is a spread of possible views about what would be considered the best estimate. It is not uncommon for this type of uncertainty to cause differences in results differing by factors of two among the competing hypotheses. Highly effective techniques have been developed to handle these sources of incomplete perfection in our ability to look at the relatively short history of recorded strong motion seismology and to extrapolate it to the future. The use of events with estimated probabilities of annual occurrence as

(*)http://www.metu.edu.tr/home/wwwdmc

small as 1/5000 is a way of defending against the unknown circumstances that the future may bring.

The most recent estimates of seismic hazard at Akkuyu have covered the time interval from 53 AD to 1988. This was done in order to assess whether inclusion of recent data would alter the former conclusion concerning the design level. There are relatively few entries for the period before 1900, but it is useful that the historical record extends far into the past. It provides information on the larger events over a long time period.

The regional seismicity is presented in Figure 3. This shows all significant historical earthquakes in the mapped region taken from NOAA's* catalogue plus all events with magnitude larger than 4 since 1963. The figure also shows the plate tectonic boundaries that surround the Turkish plate. The depth distribution of events is useful in interpreting the plate margins and the nature of their activity, and in mapping the extent of active subduction (the dipping of a tectonic plate underneath another). Figures 4 and 5 show cross sections across the site region traversing it in the N-S and E-W directions, respectively for events since 1900. This data includes events with M (magnitude) less than 3 since 1990. The apparent concentration of activity at 10 km is an artifice because all events with no reported depth have been plotted at 10 km, which is an average figure for all crustal events. These figures confirm that subduction is dipping predominantly toward the north and the east, with perhaps some subduction from east to west. They also confirm that no subduction occurs beneath the Akkuyu site, but it does occur at a distance of 100 km or more. This suggests that one of the hypothetical design earthquakes might be a large subduction event approximately 100 km from the site. The largest event in our catalogue is the 1926 subduction event (M = 8.3) at a depth of 100 km several hundred km to the west of the site area.

Plan views of the information contained in Figures 4 and 5 are given in Figures 6 and 7, for the region and site area, respectively. These figures also confirm the general statements about the seismotectonic features of the area. The implication of this information interpreted in the light of the regions defined in Figure 2 is that the source zone R11 within which the site is located is a relatively quiet block, in contrast with the active plate boundaries that lie to the south and the east. This model is fully consistent with the historical seismicity record. The levels of seismic hazard for the Akkuyu site are therefore modest.

*National Oceanic and Atmospheric Administration of the USA

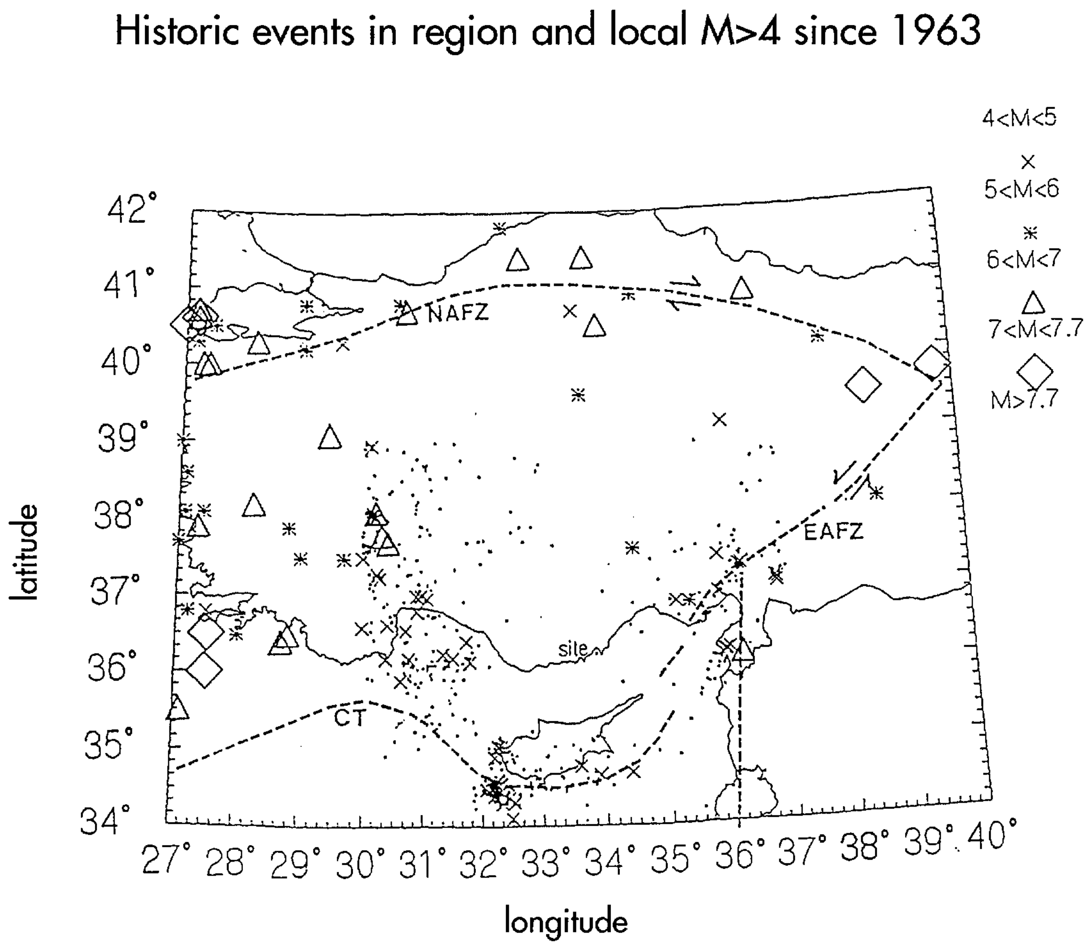


Figure 3. Significant Earthquakes in the Mapped Region, Plus All Events of M>4 since 1963. Approximate locations of plate boundaries are shown.

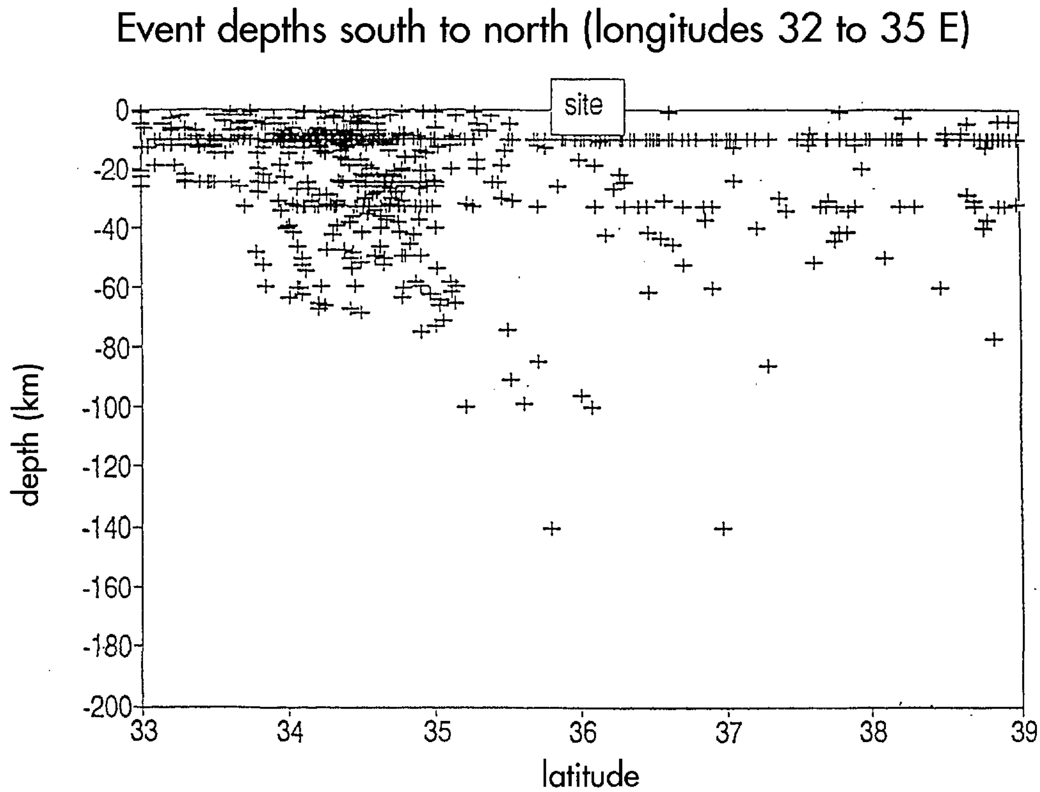


Figure 4. Depths of Earthquakes from 1900-1988. Section N-S.

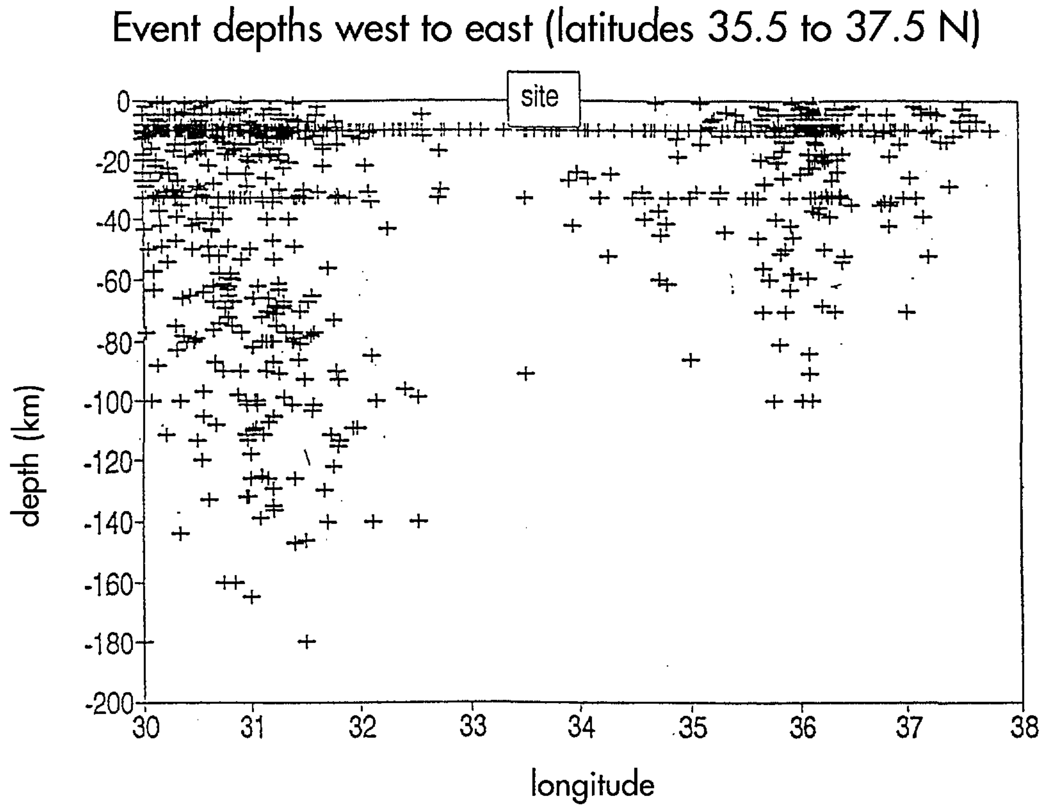


Figure 5. Depths of Earthquakes from 1900-1988 Section E-W

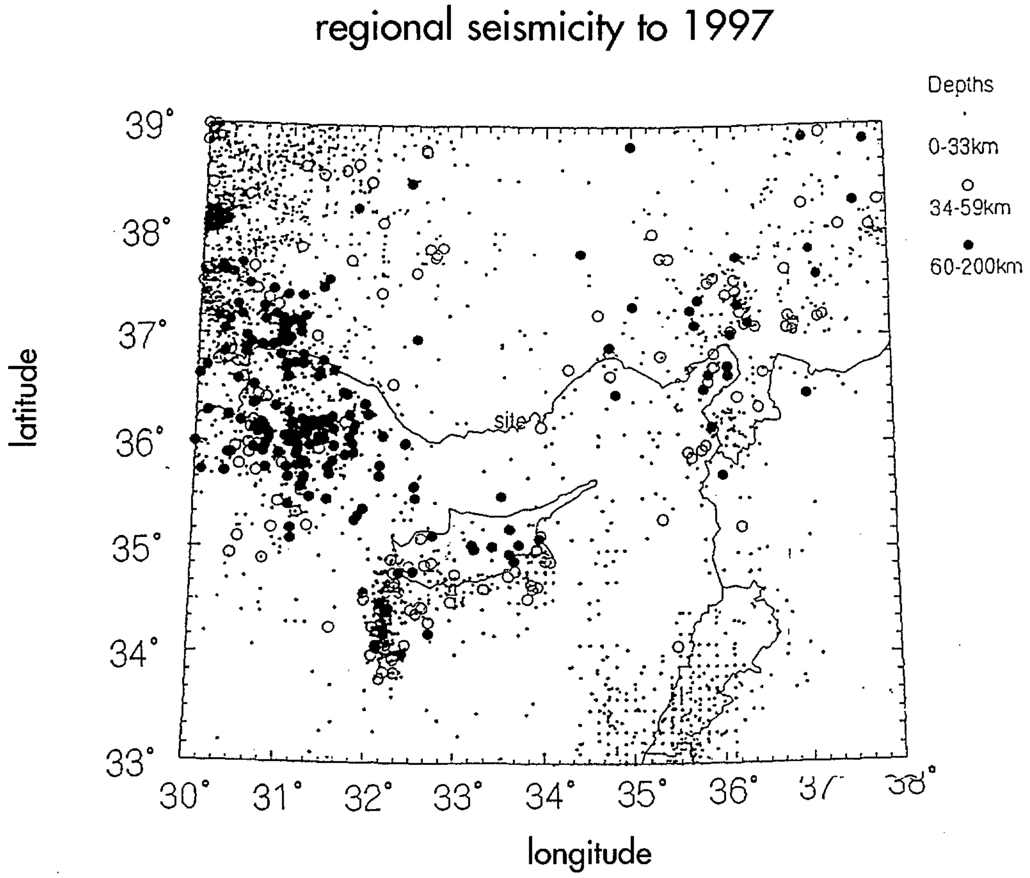


Figure 6. Regional Seismicity to 1997

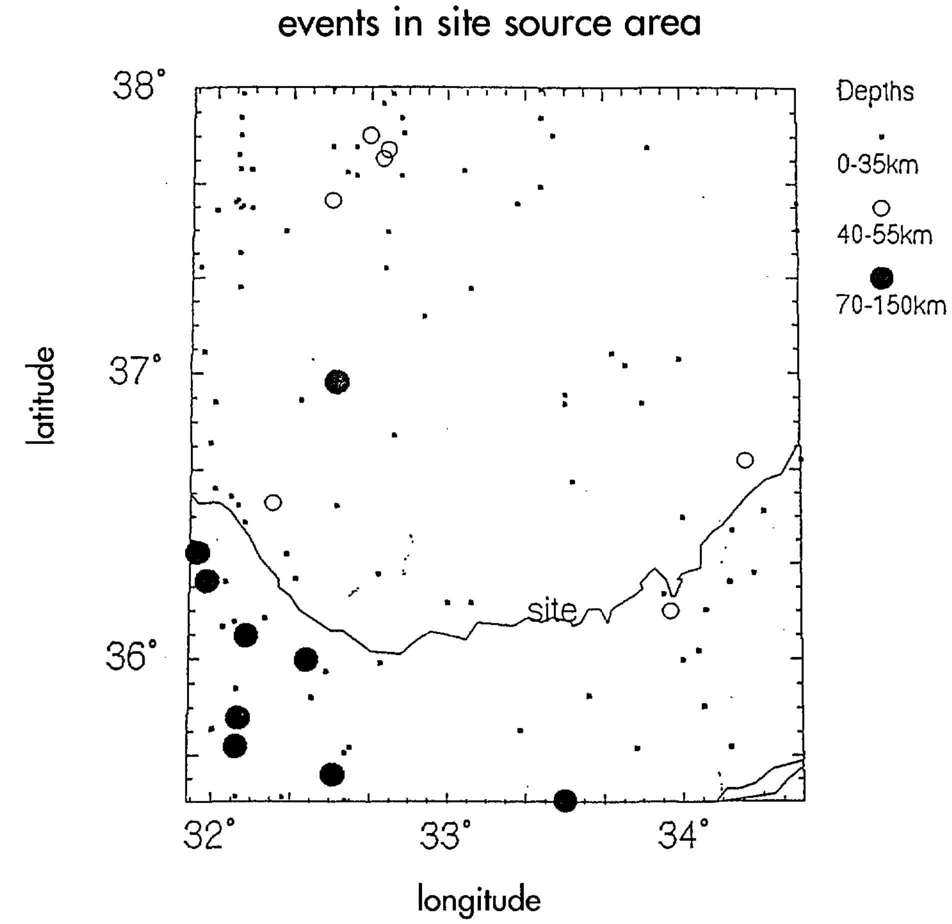


Figure 7. Events in the Site Source Area

Establishing records of past seismicity, or drawing boundaries among regions where similarity of such patterns exists, are not in themselves sufficient for basing rational engineering design requirements. This information needs to be converted to more readily understood forms used in answering the question how a given structure should be constructed so that it fulfills prescribed safety requirements. Safety is explicitly linked to the severity of the ground motion designated to govern the design. It is controlled by many finely interrelated factors. Among these factors are the magnitude of the earthquake that causes the ground vibrations, the distance of the site to the epicenter of that earthquake, and the ground conditions that prevail at the site. The judgement about how ground motion is reduced over distance was based on records of strong ground motion recorded in Turkey, and on how well these correlate with published predictive relations from other parts of the world. Alternative ground motion relations for rock (the foundations of the plant in Akkuyu will rest on rock) were considered for computation of the uniform hazard spectra at Akkuyu. For each ground motion, the uniform hazard spectra were calculated for probabilities of 1/1000 and 1/10,000 per year. Part of this work is summarized in Table 2 in which the peak acceleration of the ground motion is listed as a function of the probability level. The calculations of this table were further correlated with deterministic scenarios.

Comparison of the hazard spectra based on the attenuation relations listed in Table 2 has led the group of experts to the conclusion that the ground motion levels prescribed by a standard spectrum, scaled to 0.25 g have a probability of 1/10,000 or less per year of being exceeded. This conclusion has been verified by other independent calculations.

Table 2. Seismic Hazard Curves for Akkuyu Calculated for Several Different Ground Motion Relationships

Annual Probability (Return Period, yr)	Peak Ground Acceleration in g for Rock, according to the Ground Motion Relation Proposed by:					
	Campbell (1981) [5]	Campbell (1997) [6]	Abrahamson and Silva (1997) [7]	Boore, Joyner, Fumal (1997) [8]	Atkinson, Boore (1997) [9]	Sadigh et al., (1997) [10]
0.01 (100)	0.02	0.02	0.02	0.04	0.03	0.02
0.002 (500)	0.07	0.07	0.07	0.08	0.08	0.07
0.001 (1000)	0.09	0.10	0.10	0.10	0.12	0.11
0.0003 (3333)	0.16	0.20	0.20	0.15	0.20	0.18
0.0001 (10,000)	0.26	0.37	0.36	0.22	0.34	0.26

Note: The shaded cells in this table correlate well with the calculations posted at the Internet site cited in the text, although those calculations had been made for an entirely different purpose, following a different approach.

PART IV
POSSIBLE CONSEQUENCES OF A HYPOTHETICAL SEVERE ACCIDENT AT AKKUYU

Introduction

Nuclear power plants maintain a very high standard of safety since the radioactive fuel they contain in their cores is extremely dangerous. Nuclear technology ensures that even in case of a catastrophic accident the public can be protected from harmful radioactive substances that may leak out of the disabled nuclear power plant. Since all western nuclear power plants are designed to withstand the most severe accident that might happen during the lifetime of the reactor, no harmful effects have ever been observed during normal operations in any nuclear power plant in the western world. Accordingly since not much is known about actual catastrophic accidents in a nuclear power plant, nuclear engineers postulate severe but improbable hypothetical accidents. Nuclear technology imposes standards on the design of nuclear power plants such that, in the event that an improbable and hypothetical catastrophic accident happens, many safety systems come into operation to protect the public from harmful radiation. With the help of these systems it is guaranteed that, the amount of radioactivity that would be released from the disabled reactor does not exceed permissible limits.

Each type of nuclear power plant design has its own design basis accident. (The hypothetical accident that has the most severe consequences). The design basis accident, for a Pressurized Water Reactor (PWR) nuclear power plant is a large loss of coolant accident (LOCA) and a small LOCA for the Pressurized Heavy Water Reactor (CANDU). In these design basis accidents it is assumed that a break in the piping causes coolant loss and the temperature of the uncooled core increases. Safety systems are designed such that in the event of such an accident the radioactive release from the core is limited and contained within the containment, a thick concrete dome covering the entire reactor system. The models that calculate and predict the amount of radioactivity that might be released from such an accident are called the deterministic accident analysis. In this kind of analysis no attention is paid to the minute probability of such a catastrophic accident. The consequence of a catastrophic accident is simulated.

A nuclear power plant is a very complex machine with many parts. These parts are connected to each other and work in unison. If there is a fault in one of these parts, the consequences of such an accident on the whole system can be calculated using what is called the probabilistic risk assessment. In this analysis, it is possible to calculate whether a certain mishap could lead to an accident and the probability of occurrence of such an accident can be calculated.

The radiological impact of the proposed Akkuyu Nuclear Power Plant, at the southernmost point in Turkey, can be estimated by using models ranging from simple and highly conservative to detailed and relatively realistic ones. Every nuclear facility, and especially a nuclear reactor, has to have a construction license so that it can be constructed and an operations license so that it can be operated. Such licenses are obtained from a national authority after a thorough scrutiny of the system and its components. Such a scrutiny is performed by assuming that the system suffers the most severe accidents that can reasonably be postulated. Thus, in general, simple and conservative models are used during licensing phases to estimate an upper limit on the radiological effects of a proposed power plant. On the other hand, detailed calculational models are used in simulation and probabilistic risk assessment studies.

Since any nuclear power plant to be built in Turkey has to be licensed by The Turkish Atomic Energy Authority, a licensing type calculation based on a simple and highly conservative model is likely to be used for the Akkuyu Nuclear Power Plant. The safety philosophy of the Turkish Atomic Energy Authority as stated in OECD documents and in the bid specification for the Akkuyu Nuclear Power Plant is as follows:

"Supplier shall provide the Nuclear Power Plant (NPP) with all necessary safety systems according to his own experience as well as to the regulations, codes and standards applicable."

"It is essential that the plant shall be licensable according to national regulations of the Supplier's country and regulatory positions to be imposed by TAEK on a case by case basis. If some aspects of the proposed plant do not meet the regulatory requirements of the home country of the reactor supplier, these shall be clearly specified and, together with the necessary supporting safety analyses, shall be submitted to the approval of Turkish Atomic Energy Authority."

Supplier should show a reference plant or reference design for the proposed plant. All regulations, codes and standards applied to the reference plant or reference standard design in effect as 90 days before the date of Bid Submittal shall be listed and safety analyses reports and essential regulatory supporting documents of these references shall be given to the Turkish Atomic Energy Authority.

In the light of above safety philosophy, an example of atmospheric dispersion and dose calculations was carried out for a proposed nuclear power plant at the Akkuyu site by using a simple and conservative model. The employed model is based on the calculational model used by the United States

Nuclear Regulatory Commission (USNRC) during the licensing procedure.

Every nation newly entering into nuclear technology lacks the necessary infrastructure for nuclear licensing rules and regulations. USNRC regulations are therefore the starting point of many national nuclear licensing regulations throughout the western world. It is customary to accept USNRC regulations if the national regulations are not complete. Since almost all national licensing regulations are derived from USNRC regulation safety calculations based on USNRC rules suffice for most of the nuclear power plant safety analyses.

Description of the model

The atmospheric dispersion and dose calculations were carried out according to the United States Code of Federal Regulations Title 10, Part 50 [11] and Part 100 [12], USNRC Regulations, and TID-14844[13]

10 CFR 100 requires the licensee, for a construction license to determine the following:

1. An exclusion area of such size that an individual located at any point on its boundary for two hours immediately following onset of the postulated fission product release would not receive a total dose to the whole body in excess of 250 mSV or a total radiation dose in excess of 300 mSV to the thyroid from iodine exposure,

2. A low population zone of such size that an individual located at any point on its outer boundary who is exposed to the radioactive cloud resulting from the postulated fission product release during the entire period of its passage would not receive a total radiation dose to the whole body in excess of 250 mSV or a total radiation dose in excess of 300 mSV to the thyroid from the iodine exposure.

For a large LOCA for a PWR, the regulatory guides[14], [15] state the assumptions related to the release of radioactive material from the fuel and containment, atmospheric dispersion and dose conversions.

Assumption

The following assumptions are made based on the relevant literature:

1. 25% of the equilibrium radioactive iodine inventory developed from maximum full power operation of the core is assumed to be immediately available for leakage from the containment,

2. 100% of the equilibrium noble gas inventory developed from maximum full power operation of the core is assumed to be immediately available for leakage from the containment,

3. 1% of the other fission product inventory of the core is assumed to be immediately available for leakage from the containment.

4. The reactor containment is assumed to leak at a rate of 0.1% per day,

5. The effects of radioactive decay during hold up in the containment are taken into account,

6. The reduction in the amount of radioactive material available for leakage to the environment by containment sprays, recirculating filter systems, or other engineered safety features are not taken into account,

7. No correction is made for the depletion of the radioactive plume due to deposition on the ground, or for the radiological decay in transit,

8. For exclusion zone boundary calculations, a breathing rate of $3.47x10^{-4}m^3/s$ and for low population zone boundary calculations a breathing rate of $2.32x10^{-4}m^3/s$ are assumed.

These assumptions are very conservative, indeed, but one has to look for the possibility of such an accident and such a release. It has been calculated[16] and scrutinized[17] that the maximum probability of such an accident would be less than 5.6 in a million years for reactors built and operated in the early eighties. Considering the valuable data and experience accumulated since 1970s, the maximum probability of such a catastrophic accident is less than 1 in a million years. The results presented in the following sections are the analyses of such a hypothetical and improbable accident at the Akkuyu Nuclear Power Plant.

In references [14] and [15] it is stated that if adequate site meteorological data is available instead of models proposed in the references, actual data will be used. Therefore, the data of the Akkuyu Nuclear Power Plant On-Site Meteorological Program are used in the analyses.[18]

For atmospheric dispersion calculations, the rules of the Regulatory Guide 1.145[19] have been strictly followed. For this purpose computer code PAVAN[20] was used. PAVAN is used by the USNRC to estimate down-wind ground-level air concentration for accidental release of radioactive material from nuclear reactors. This computer program implements the guidance provided in Regulatory Guide 1.145.

For dose calculations, Iodine isotopes dose conversion factors, average gamma energies of released radioactive material, and the source term calculational methodologies are taken from TID-14844. The inventory of a specific isotope within the reactor core is calculated for the specified power level. Then the amount of the same isotope that may be released from the reactor building is calculated with the assumptions described above. Based on the amount of the leaked isotope, the gamma and thyroid doses are calculated.

Results and Discussion

Even though the thermal power for the Akkuyu Nuclear Power Plant will be less than 4500 MWt in our analysis this power output is considered. Two cases, with different release heights, 45 m (elevated release) and 10 m (ground level release), are analyzed.

The whole-body gamma doses for two hours for the two cases are presented in Figure [8], whereas, the thyroid doses for two hours for two cases are presented in Figure [9]. Since 200 mSV for whole-body dose and 1500 mSV for thyroid dose are acceptable for a construction license 1.5 kilometer distance for the exclusion zone is sufficient since the whole body gamma dose is less than 200 mSV and the thyroid dose is less than 1500 mSV at that distance (USAEC Regulatory Guide 1.3).

Whole-body gamma dose and thyroid dose for 30 days for two cases are presented in Figure [10] and Figure [11], respectively. Based on these results the boundary of the low population zone for a 4500 MWt nuclear power plant is around 6 – 7 kilometers.

Source : Hacettepe University Geological Engineering Department, Remote Sensing Laboratory.

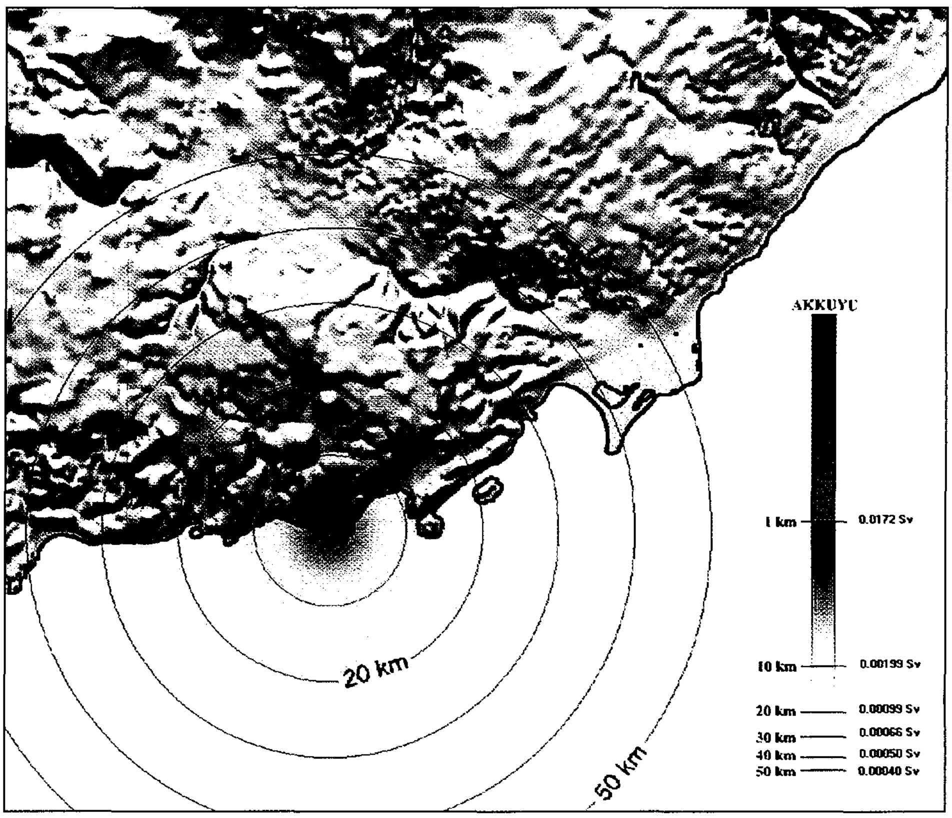
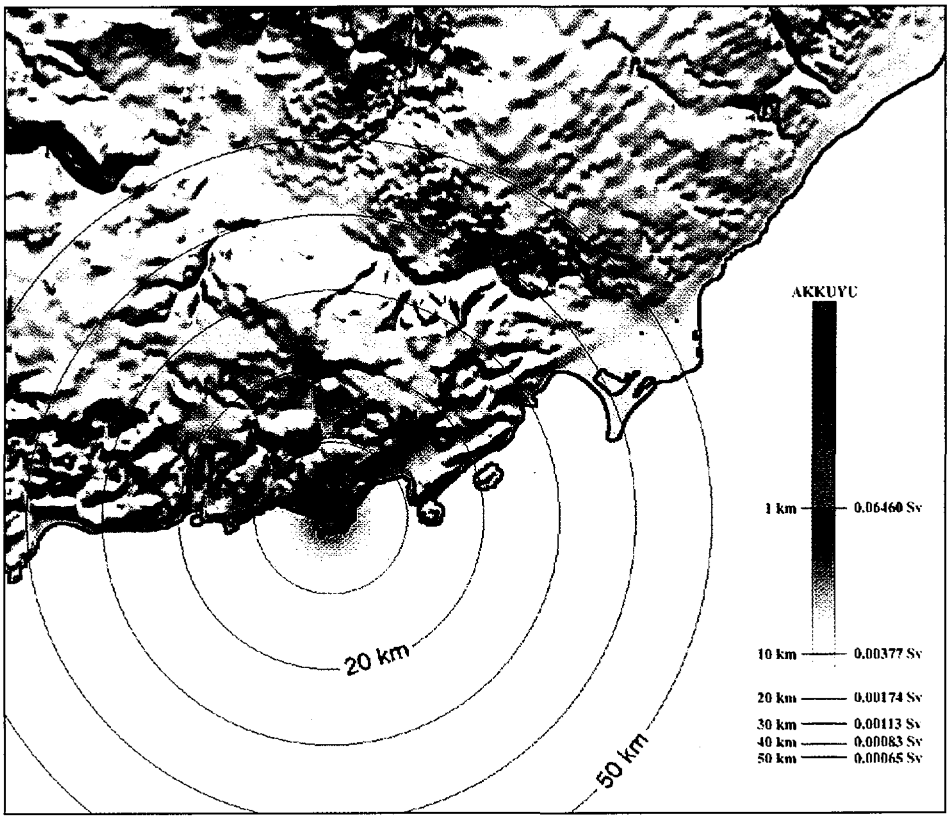
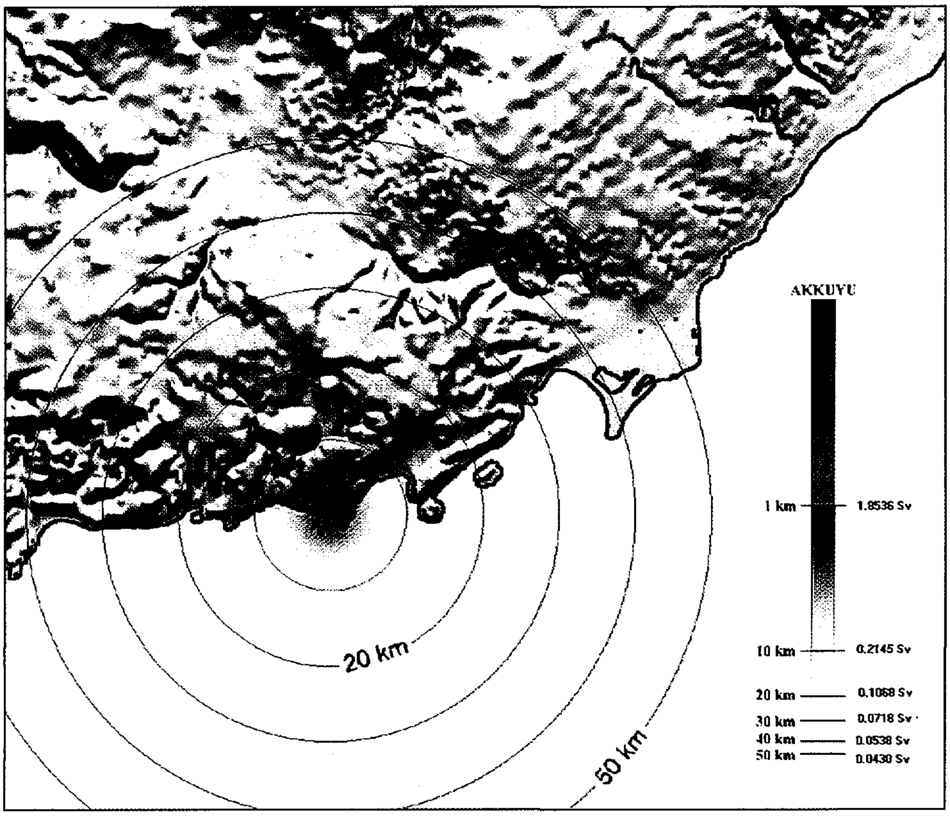


Figure 8 : Whole Body Doses for the Exclusion Zone



Source : Hacettepe University Geologicol Engineering Department, Remote Sensing Laboratory.

Figure 9 : Thyroid Doses for the Exclusion Zone



Source : Hacettepe University Geological Engineering Department, Remote Sensing Laboratory.

Figure 10 : Whole Body Doses for the Population

Source : Hacettepe University Geological Engineering Department, Remote Sensing Laborotory.

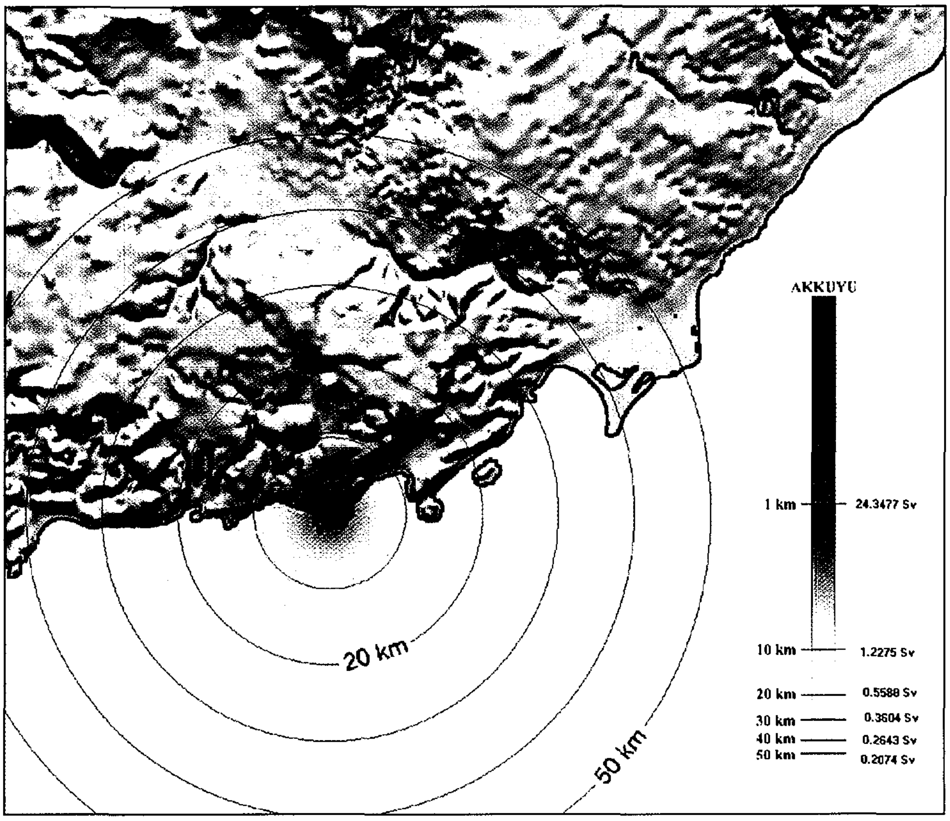


Figure 11 : Thyroid Doses for the Population

While calculating the Iodine source term that is available for release to the atmosphere, no credit has been given for the effects of washdown or filtering from engineered safety systems. It is stated in TID-14844 that such systems could provide reduction factors of 10 – 1000 for iodine isotopes. If the effects of engineered safety systems are taken into account, the calculated thyroid doses will be reduced in significant amounts and consequently the exclusion zone and low population zone areas would be much smaller.

As the above results prove, the effect of a hypothetical and almost improbable accident will be confined within the exclusion zone or low population zone, which is a 10 kilometer radius around the Akkuyu Nuclear Power Plant. Therefore, additional analyses using large-scale atmospheric dispersion models, like Regional Atmospheric Modeling System or similar models, will not reveal plausible results. Dilution of the plume with ever increasing distance, effects of rain and the topography, would reduce the dose rate to extremely small values that are difficult to measure, still less harmful to the public. Detailed results of such studies along with the above mentioned calculations performed at the Nuclear Engineering Department of Hacettepe University in Turkey are available. (*)

(*)http://www.nuke.hun.edu.tr/akkuyu

Conclusions

There is no such thing as a totally aseismic site anywhere on earth where no earthquake will ever occur. But state-of-the-art techniques in strong motion seismology in deciding how severe the design earthquake at the Akkuyu site should be, so that operational safety of the plant will not be compromised, has led to the indicative values in Table 2, page 21. These calculations have been subjected to many critical reviews and accepted as the outcomes of the best estimates.

The worst case scenarios may still postulate the occurrence of a severe accident at Akkuyu, but it has been shown that within the exclusion zone [1 km] and low population zone. [7km] from the plant, radiation dose limits would not exceed licensing limits.

This shows that the lives of the people in the surrounding area and in more remote locations will not be threatened by the nuclear power plant even in the unlikely event that a severe earthquake occurs. These are the basic scientific facts on which The Government of Turkey has decided to join the community of nations operating nuclear power plants.

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