



The Abdus Salam
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Educational, Scientific
and Cultural Organization


International Atomic
Energy Agency



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**"2nd Workshop on Earthquake Engineering for Nuclear
Facilities: Uncertainties in Seismic Hazard"**

14 - 25 February 2005

Tsunami of 26th December 2004

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Atomic Energy Regulatory Board
India**

2nd Workshop on Earthquake Engineering for Nuclear Facilities
Uncertainties in Seismic Hazard Assessment
Trieste - Italy, 14 - 25 February 2005

Tsunami of 26th December 2004

Trieste, Italy, 14-25 February 2005

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Acknowledgement/Sources

- Ms. Alpa Seth, Advisor, GSDMA, Govt. of Gujarat, India,
- Ms Prathibha Gandhi Ph.D. scholar, IIT Madras
- Roshan A.D., C&SED, AERB
- Atomic Energy Regulatory Board, Mumbai, India
- Nuclear Power Corporation of India Ltd., India
- <http://www.drgeorgepc.com/>
- <http://training.fema.gov/EMIWeb/downloads/9-Tsunamis-Rev2.ppt>
- <http://www.publicaffairs.noaa.gov/grounders/tsunamis.html>
- <http://wcatwc.arh.noaa.gov/>
- http://www.owlnet.rice.edu/~esci108/108_EQ_Lec_4.ppt
- <http://www.usgs.gov/>
- http://www.geophys.washington.edu/SEIS/PNSN/INFO_GENERAL/NQT/glossary.html
- <http://www.geotech.org/survey/geotech/dictiona.html#sectS>
- <http://www.nicee.org>, IIT Kanpur, India
- <http://www.asc-india.org>

Terminology

- **Run-up:** Vertical height a wave reaches above a reference sea level as it washes ashore.
- **Wave height:** Vertical measurement of the wave before it reaches shore.
- **Inundation distance:** Horizontal distance a tsunami reaches landward

Tsunami of 26th December 2004

Outline of presentation

- Introduction: Tsunami
- The event of 26th December 2004.
- Major effected areas
- Effects on Indian Nuclear installations.
- Past events of tsunami in Indian ocean.
- Present AERB safety provisions against tsunami.
- Summary of observations.

Introduction: Tsunami

Introduction: Tsunami

- A tsunami is a series of ocean waves of extremely long wave length and long period generated in a body of water by an impulsive disturbance at sea or ocean bed that displaces the water.**

Introduction...

- A tsunami can be generated by ANY disturbance that displaces a large water mass from its equilibrium position:
 - Earthquake
 - submarine landslide
 - Marine volcanic eruption
 - Falling debris like meteors.
- Unlike ocean-wide tsunamis caused by earthquakes, tsunamis generated by non-seismic mechanisms usually dissipate quickly and rarely affect coastlines far from the source area.

Introduction...

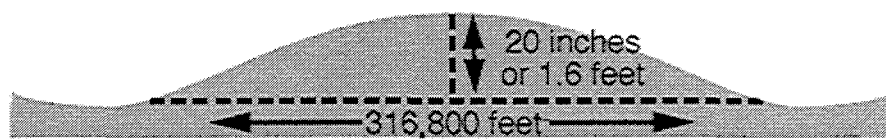
- Principal difference between the wind generated wave and tsunami is that the former is generated due to surface disturbance and later one is due to deep water disturbance.
- Wind-generated waves usually have period of five to twenty seconds and a wavelength of about 100 to 200 meters (300 to 600 ft).
- A tsunami can have a period in the range of ten minutes to two hours and a wavelength in excess of 500 km (300 miles).

Introduction...

- The rate at which a tsunami wave loses its energy is inversely related to its wavelength. Since a tsunami has a very large wavelength, it will lose little energy as it propagates.
- Hence in very deep water, a tsunami will travel at high speeds and travel great transoceanic distances with limited energy loss.
- The speed of a tsunami = $(D.g)^{1/2}$
where
'g' is acceleration due to gravity
'D' is depth of the water.

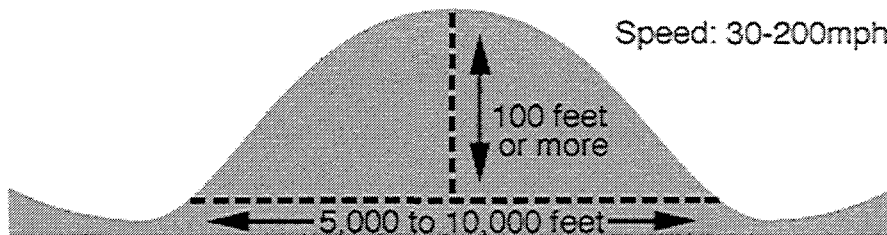
Introduction...

Speed: 450-650mph



Tsunami in deep ocean

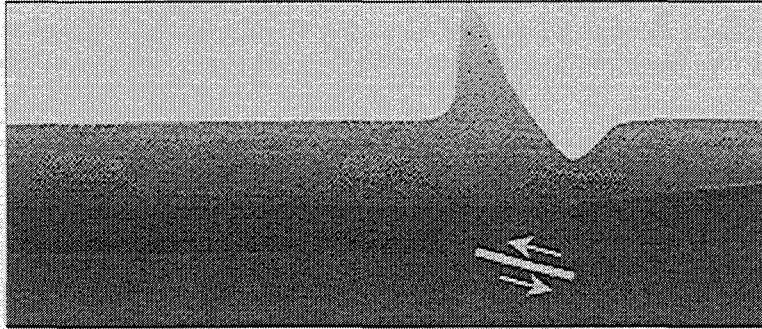
Speed: 30-200mph



Tsunami in shallow waters, near coast

Introduction: Seismically generated tsunami

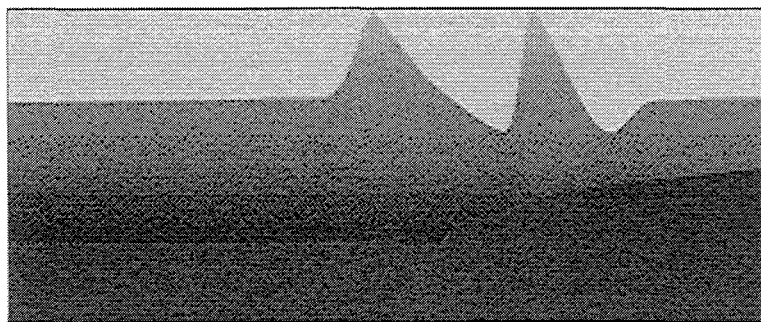
1. Initiation



The near the source of submarine earthquakes, the seafloor is "permanently" uplifted and down-dropped, pushing the entire water column up and down. The potential energy that results from pushing water above mean sea level is then transferred to horizontal propagation of the tsunami wave (kinetic energy).

Introduction: Seismically generated tsunami...

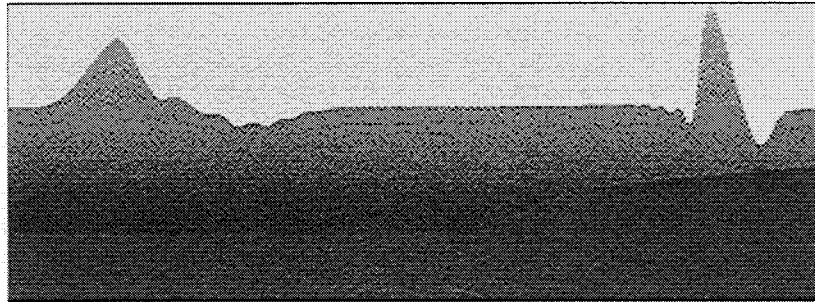
2. Split



Within a few moments of the earthquake, the tsunami is split into two with one traveling out to the deep ocean (distant tsunami) and another one traveling towards the nearby coast (local tsunami). The height of this two oppositely traveling tsunamis is approximately half that of the original tsunami.

Introduction: Seismically generated tsunami...

3. Amplification



As the tsunami travels over the continental slope the amplitude increases and wavelength decreases resulting in steepening of the leading wave. This is an important parameter of wave run-up at the coast.

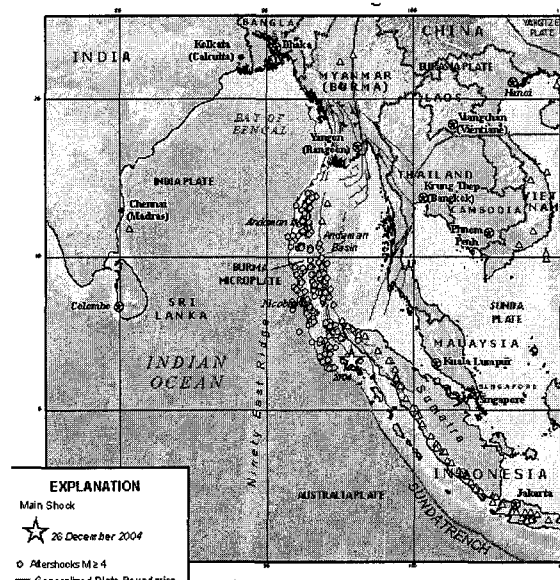
Introduction: Seismically generated tsunami...

4. Run up



The event of 26th December 2004

The event of 26th December 2004.



Ref.: www.usgs.gov

The event of 26th December 2004.....

❖ Sumatra-Andaman islands earthquake

- Date : *26th December 2004*
- Magnitude: *9.0*
- Epicenter : *3.307° N 95.947° E*
- Epicentral Depth : *30 km*
- Epicentral Distances:
 - *250 km (155 miles) SSE of Banda Aceh, Sumatra, Indonesia*
 - *310 km (195 miles) W of Medan, Sumatra, Indonesia*
 - *1260 km (780 miles) SSW of BANGKOK, Thailand*
 - *1605 km (990 miles) NW of JAKARTA, Java, Indonesia*

The event of 26th December 2004.....

❖ Sumatra-Andaman earthquake is the fourth largest earthquake in the world since 1900 and is the largest since the 1964 Prince William Sound, Alaska earthquake.

❖ The tsunami generated by this earthquake caused more casualties than any other in recorded history.

The event of 26th December 2004.....

❖ Fatalities

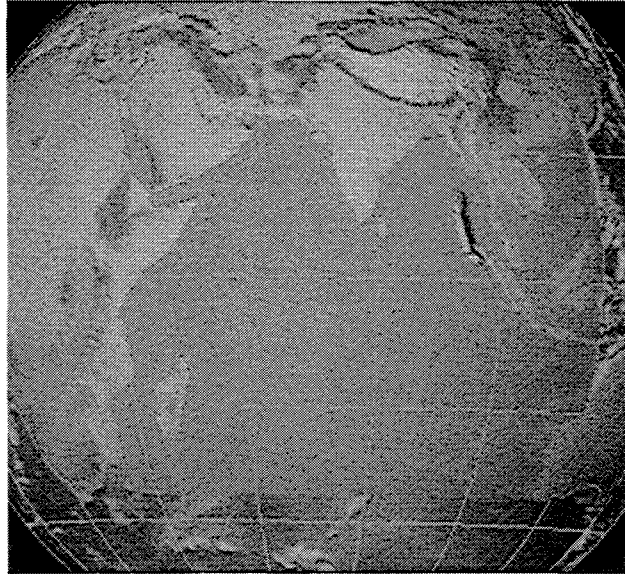
<i>Country</i>	<i>Fatalities</i>	<i>Missing</i>	<i>Displaced</i>
Indonesia	1,06,500	Total = 27,000	1,236,000
Sri Lanka	30,800		
India	10,300		
Thailand	5,300		
Somalia	150		
Tanzania	10		
Seychelles	3		
Bangladesh	2		
Kenya	1		
Total = 1,53,066 ?			

The event of 26th December 2004.....

- After shocks above 6.5

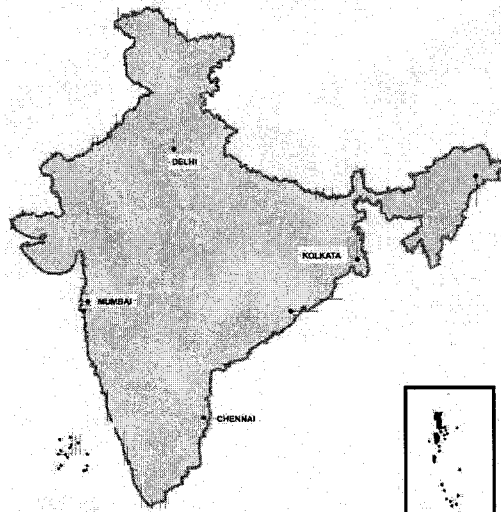
<i>Date</i>	<i>Lat.</i>	<i>Long.</i>	<i>Magnitude</i>
2004-12-26	3.30°N	95.97°E	9.00 Mw
2004-12-26	6.91°N	92.95°E	7.40 Ms
2004-12-26	8.87°N	92.37°E	6.60 Ms
2005-01-01	5.10°N	92.30°E	6.70 Ms

Propagation of tsunami around the continents



Major effected areas in India

Tsunami- other major effected areas...



Tsunami- other major effected areas...

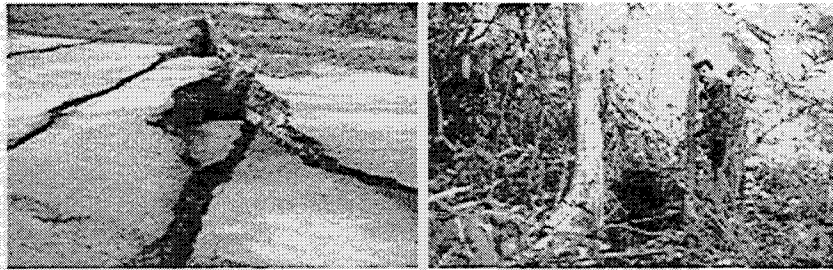
Andaman & Nicobar Islands



Up-throw of coral beds and rock strata due to uplift on the western coast of middle Andaman Island near Flat Island. (Source: IIT Kanpur, India)

Tsunami- other major effected areas...

Andaman & Nicobar Islands



Damage to road connecting Baratang and Baludera Beach, (Source: IIT Kanpur, India)

Splitting of a tree trunk due to ground rupture (≈ 1.2 m wide).

Tsunami- other major effected areas...

Andaman & Nicobar Islands



Severe damage to Passenger airport terminal building at Port Blair. (Source: IIT Kanpur, India)

Tsunami- other major effected areas...

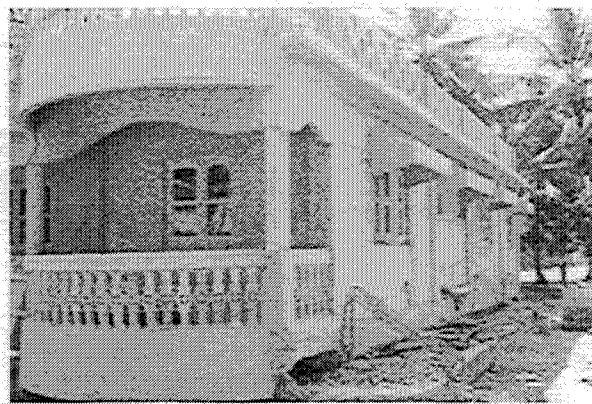
Andaman & Nicobar Islands



Chengappa Bridge over Austen Strait connecting Middle Andaman and North Andaman Islands, 230 km north of Port Blair. (Source: IIT Kanpur, India)

Tsunami- other major effected areas...

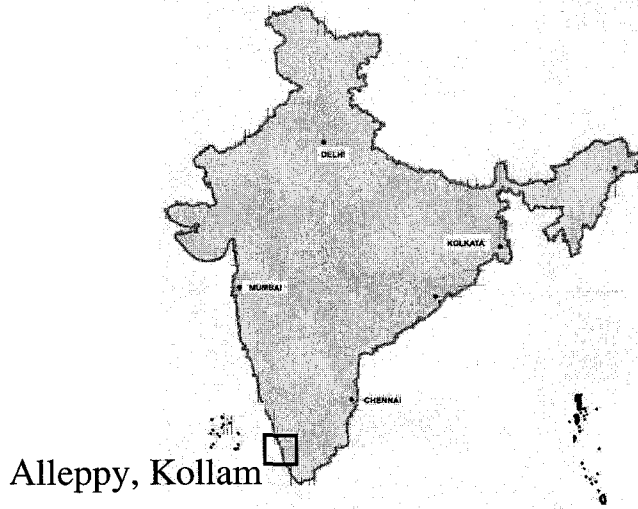
Andaman & Nicobar Islands



Collapse of a open storey reinforced concrete house at Rampur, near Mayabunder. (Source: IIT Kanpur, India)

Tsunami- other major effected areas...,

Area: Alleppy, Kollam, Kerala state



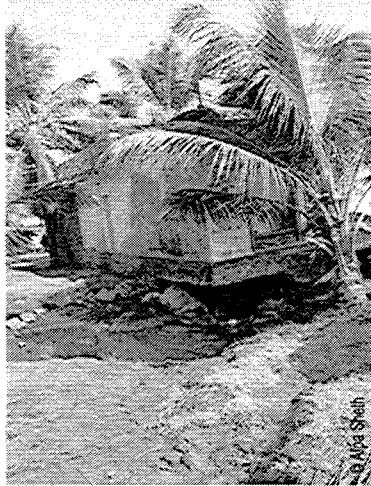
Tsunami- other major effected areas...

Area: Alleppy, Kollam, Kerala state

Parameter	Edavanac ad, Cochin	Waliazhik kal, Alleppy	Karunagapp allym, Kollam
Number of Waves	2	3	3
Duration	10 mins	15 mins	15 mins
Wave height (m)	6	3	4
Inundation Height	1.6	-	-
Inundation distance	<200 m	~100 m	-

Tsunami- other major effected areas...

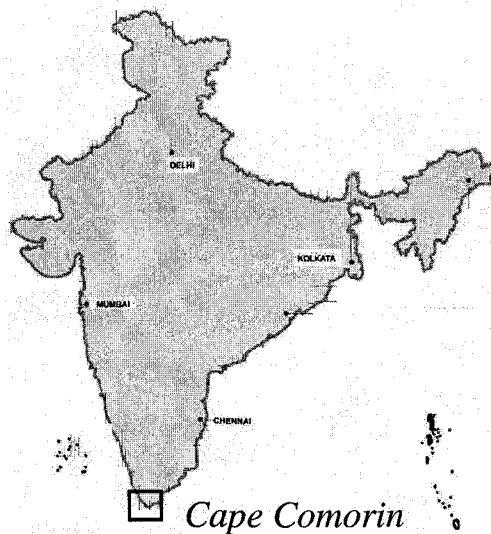
Area: Alleppy, Kollam, Kerala state



Scouring effect due to tsunami

Tsunami- other major effected areas...

Area: Cape Comorin, Tamilnadu state



Tsunami- other major effected areas...

Area: Cape Comorin, Tamilnadu state

Parameter	Kolachel	Manakudi	Sottavelai beach	Cape Comorin
Number of Waves	3	3	3	3
Duration	15 mins	15 mins	15 mins	15 mins
Wave height (m)	4	9-11	9-11	9-11
Inundation Height	2.1	2	-	-
Inundation distance (Max)	~100 m	~100 m	~200m	~100m

Tsunami- other major effected areas...

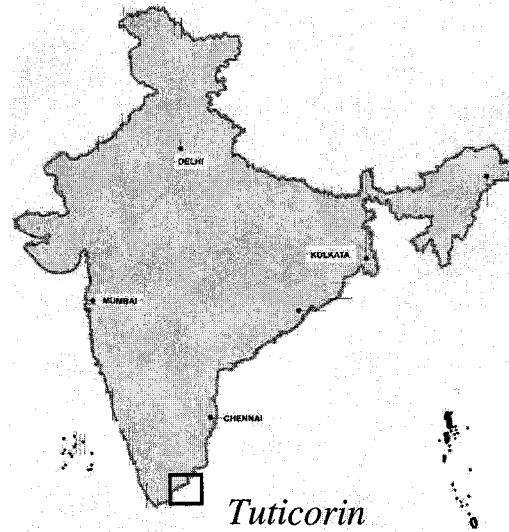
Area: Cape Comorin, Tamilnadu state



Scouring effect due to tsunami

Tsunami- other major effected areas...

Area: Tuticorin, Tamilnadu State



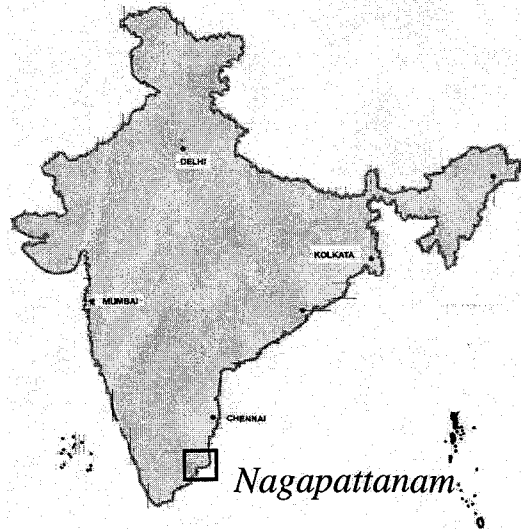
Tsunami- other major effected areas...

Area: Tuticorin, Tamilnadu State

Parameter	Tuticorin
Number of Waves	3
Duration	15 mins
Wave height (m)	4
Inundation Height	2.1
Inundation distance (Max)	~100 m

Tsunami- other major effected areas...

Area: Nagapattanam, Tamilnadu State



Severe most
effected area

Tsunami- other major effected areas...

Area: Nagapattanam, Tamilnadu State

Parameter	Velankanni	Seruthur	Akkaraipettai
Number of Waves	5 (3 main)	5	5
Duration	Within 10-15 of each other	Within 10-15 mins	-
Wave height (m)	~12-15	6	15
Inundation Height	2	1.5	-
Inundation distance (Max)	100-500 m	~200 m	~1000m

Tsunami- other major effected areas...

Area: Nagapattanam, Tamilnadu State

Parameter	Ariyanattu Vadaku	Naliyanthottam	Nagore
Number of Waves	-	-	3
Duration	-	-	15 mins
Wave height (m)	-	-	>6
Inundation Height	-	-	
Inundation distance (Max)	~250 m	~800 m	~1200m

Tsunami- other major effected areas...

Area: Nagapattanam, Tamilnadu State



Partially damaged house

Tsunami- other major effected areas...

Area: Nagapattanam, Tamilnadu State



Scouring below the foundation of the house

Tsunami- other major effected areas...

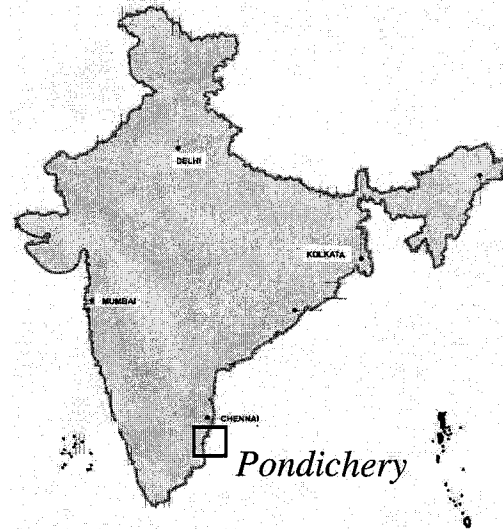
Area: Nagapattanam, Tamilnadu State



Overturning due to scouring around the foundation, pump house

Tsunami- other major effected areas...

Area: Pondichery



Tsunami- other major effected areas...

Area: Pondichery

Parameter	Karaikal, Pondichery
Number of Waves	3
Duration	First two within 45mins, last after 1.45 hrs
Wave height (m)	10
Inundation Height	2.1
Inundation distance (Max)	~500 m

Tsunami- other major effected areas...

Area: Pondichery

Parameter	Silver Beach	Halanguda	Singarathoppu
Number of Waves	4	3	-
Duration	First three in 15 mins, last after 3 hrs	Within 15 mins of each other	-
Wave height (m)	6.5	-	10
Inundation Height	-	1.2	>2
Inundation distance (Max)	~250 m	~800 m	~1200m

Tsunami- other major effected areas...

Area: Pondichery

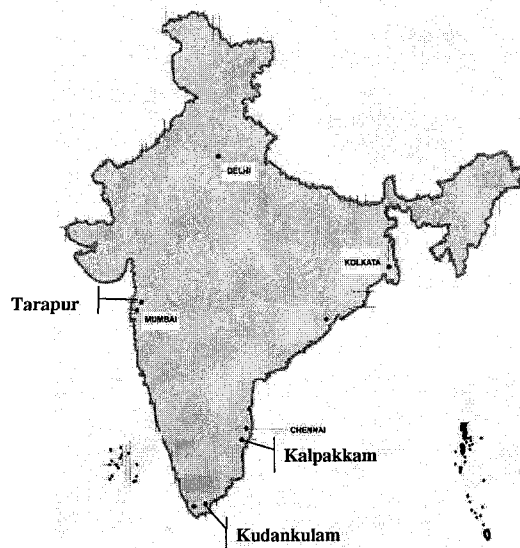


Collapse of load bearing walls

Effects on Indian nuclear installations

Affects on Indian nuclear installations.....

Kalpakkam

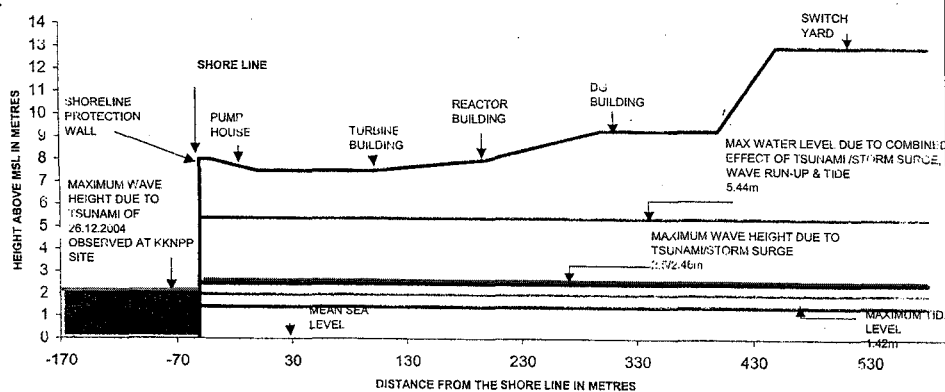


Effects on Indian Nuclear Plants...

Location	
Tarapur	No effect
Kudankulam	No effect
Kalpakkam	<ul style="list-style-type: none"> • Insignificant effects on NPP • In the township, life loss and damage to property

Effects on Indian nuclear installations...

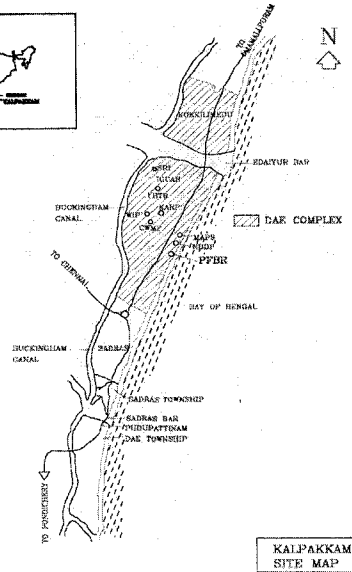
Kudankulam Nuclear Power Project (KK-NPP)



Comparison of Tsunami height with respect to plant grade elevation for Kudankulam site

Effects on Indian nuclear installations...

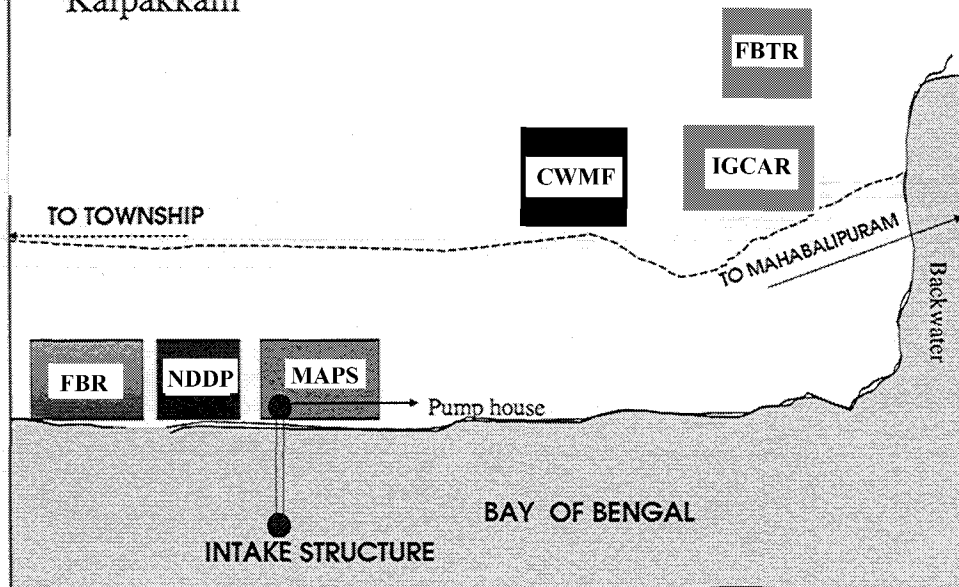
Kalpakkam, Chennai



KALPAKKAM SITE MAP

Effects on Indian nuclear installations.....

Layout of Department of Atomic Energy units- Kalpakkam



Effects on Indian nuclear installations.....

Madras Atomic Power Station 1&2, Kalpakkam

• **EVENT**

- First wave arrived at 0910 hr.
- Duration : 10 minute
- Subsequent smaller waves did not reach plant
- Maximum water level at plant site 10.56m, 4.464m above (Kalpakkam) MSL

Effects on Indian nuclear installations.....

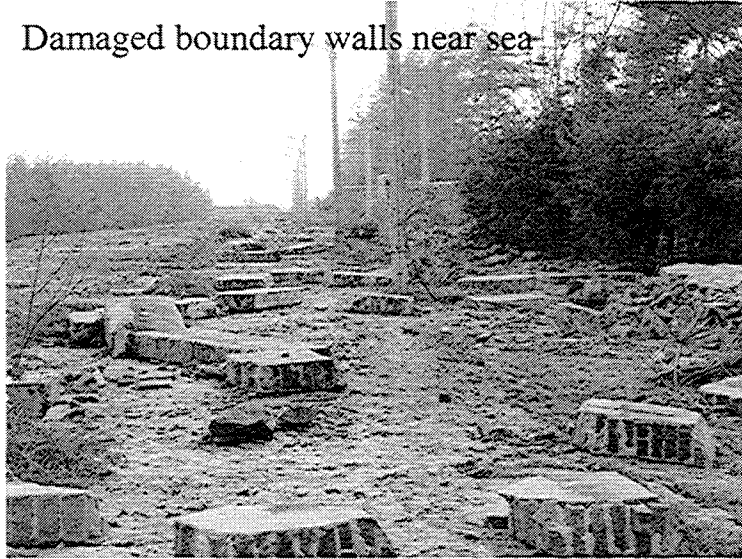
Madras Atomic Power Station 1&2, Kalpakkam



Effects on Indian nuclear installations.....

Madras Atomic Power Station 1&2, Kalpakkam

Damaged boundary walls near sea



Effects on Indian nuclear installations.....

Madras Atomic Power Station 1&2, Kalpakkam

❖ **Status of Plant**

MAPS-1 - Was under Shutdown for en-mass coolant channel replacement

MAPS-2 - Plant was operating at 215 MWe

Effects on Indian nuclear installations.....

Madras Atomic Power Station 1&2, Kalpakkam

❖ **Sequence of activities following Tsunami on Dec. 26**

• **26.12.2004**

- 0910: Due to high waves, seawater level in the forebay increased upto about 1.9 m above the operating floor in pump house
- 0914: All Condensor Cooling Water Pumps and all but one Process Sea Water Pump tripped. Vacuum started falling. Turbine was tripped manually
- 0915: Reactor tripped on PHT high pressure. Reactor cooling started
- 1020: Reactor was brought to cold shutdown state with one PSWP operating.

MAPS-2 emergency alert declared.

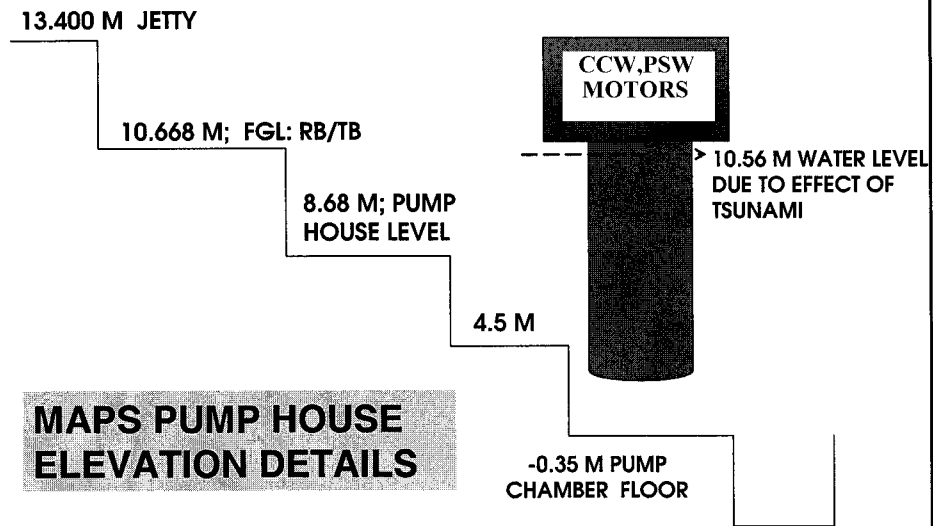
Effects on Indian nuclear installations.....

Madras Atomic Power Station 1&2, Kalpakkam

- Plant was promptly brought under safe shut down condition.
- Damage to Plant – Nil, except minor damage to the double fencing near pump house.
- Observations on the effect of Tsunami on MAPS
 - No water entered turbine building, reactor building or service building.
 - Water entered Sea water pump house floor area and drained back.
 - Emergency Process Sea Water Pumps at the pump house floor level got submerged in water.

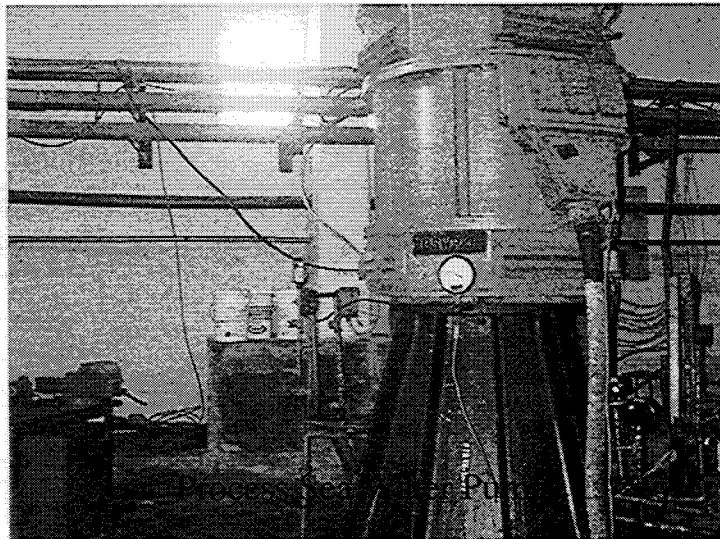
Effects on Indian nuclear installations.....

Madras Atomic Power Station 1&2, Kalpakkam



Effects on Indian nuclear installations.....

Madras Atomic Power Station 1&2, Kalpakkam



Effects on Indian nuclear installations.....

Madras Atomic Power Station 1&2, Kalpakkam

Sequence of activities following Tsunami on Dec. 26...

• **27.12.2004**

2130: Emergency alert lifted

• **29.12.2004**

AERB Team Inspected

• **31.12.2004**

AERB reviewed the safety status of plant

• **02.01.2005**

MAPS-2 was started.

Effects on Indian nuclear installations.....

Fast Breeder Reactor (FBR) Project, Kalpakkam

- Construction activity of FBR project was going on at the time of event. Excavation for the foundation pit of the NICB was completed. 2nd layer of concrete was being poured.
- Small length of the sea side boundary wall gave way due to water surge leading to some sea water entry to foundation pit.
- Approximately 200 people working inside the foundation pit escaped to higher grounds before the sea water entry to foundation pit. One fatality.
- Neither Administrative building nor any structure under construction was damaged.

Effects on Indian nuclear installations.....
Fast Breeder Reactor Project, Kalpakkam



Excavated pit of FBR after mud mat

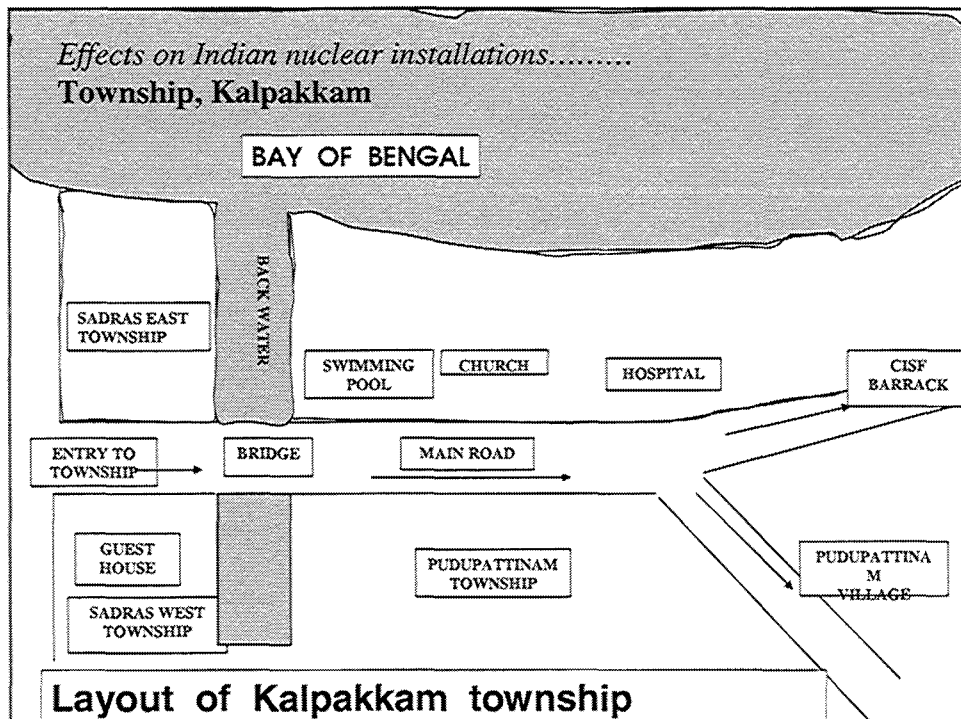
Effects on Indian nuclear installations.....
Fast Breeder Reactor Project, Kalpakkam



Pit after tsunami

Effects on Indian nuclear installations.....
Indira Gandhi Center of Atomic Research, Kalpakkam

No effect of tsunami



Effects on Indian nuclear installations.....

Township, Kalpakkam

- Total Casualties : 61
- Houses close to the coast (approx. upto 100 metres from coast) suffered damage like entry of slush, breakage of compound walls, doors and windows. Approach road to the bridge inside the township eroded for about 2 meter width.
- Power supply, water supply and internal communication were restored on 27th evening.

Effects on Indian nuclear installations.....

Township, Kalpakkam



Entry of flood waters through the streets of residential area

Effects on Indian nuclear installations.....

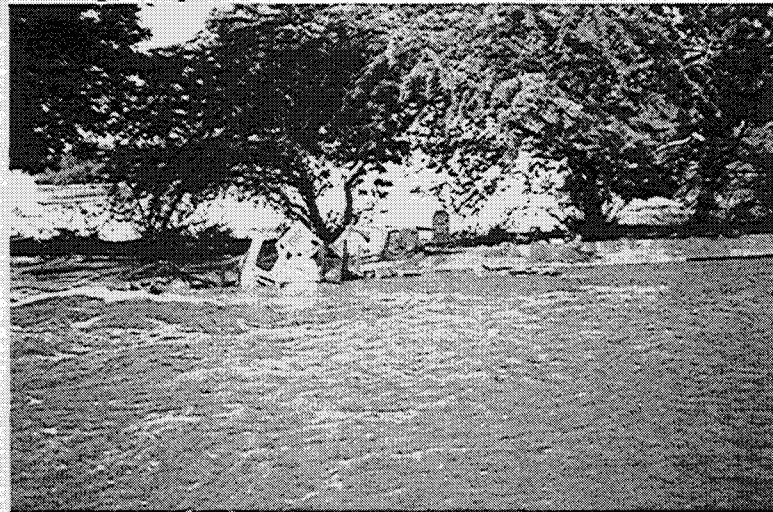
Township, Kalpakkam



Entry of flood waters through the streets of residential area

Effects on Indian nuclear installations.....

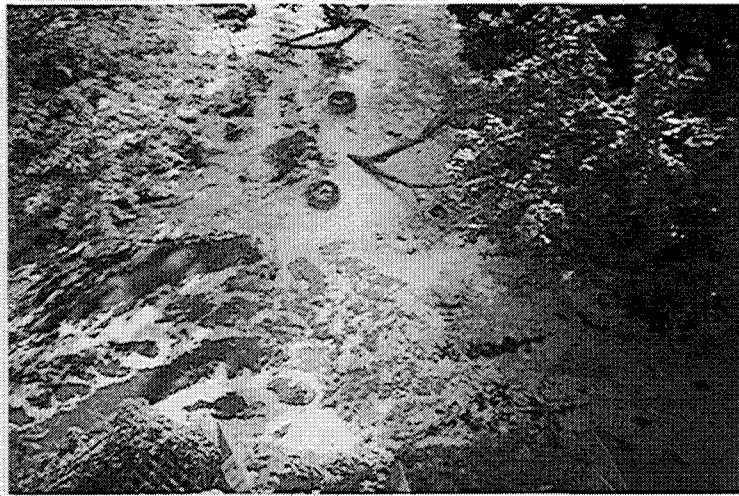
Township, Kalpakkam



Entry of flood waters through the streets of residential area

Effects on Indian nuclear installations.....

Township, Kalpakkam



Entry of flood waters through the streets of residential area

Effects on Indian nuclear installations.....

Township, Kalpakkam



Receding flood waters after tsunami, residential area

Past events of tsunami in Indian ocean

Past events of tsunami in Indian ocean.

Year	Description
1797	A magnitude 8.4 earthquake near the central part of the western Sumatra generated a tsunami that flooded Padang, more than 300 fatalities.
1833	A magnitude 8.7 earthquake near the south coast of the western Sumatra triggered a huge tsunami that flooded the southern part of western Sumatra, numerous victims.
1843	A tsunami that came from the southeast and flooded the coast of the Nias Island, many fatalities.
1861	A magnitude 8.5 earthquake affected all the western coast of Sumatra, several thousand fatalities.
1881	A magnitude 7.9 earthquake in the Andaman Island region generated 1 m high tsunami on India's eastern coast.
1883	Krakatau explosion. 36,000 fatalities, primarily on the islands of Java and Sumatra.
1941	A magnitude ~7.7 Adaman Islands earthquake. Anecdotal accounts exist of a tsunami, however, no official records exist.
1945	A magnitude 8.0 Marcan coast earthquake caused tsunami wave that flooded West coast of India including Mumbai

Past events of tsunami that flooded Indian coast.....

1881 - Car Nicobar Island, India, Mw 7.9

Date :31 st December, 1881
Epicenter : Bay of Bengal, West of Car Nicobar Island, India
Magnitude : Mw 7.9 ± 0.1
A tsunami was generated by this earthquake in the Bay of Bengal. Though the run-ups and waves heights were not large, its effects were observed in the Andaman & Nicobar Islands and also were recorded on the east coast of India. At Nagapatinam, 4-feet high waves were observed. This was the only place on the Indian coast that is known to have observed the largest wave heights.

Past events of tsunami that flooded Indian coast.....

1883 - Eruption of Krakatoa Volcano

Date :27th August 1883
Location : (Sunda Strait), Indonesia
Magnitude : -
The huge tsunami was well documented in terms of visual observations of heights reached along the coasts of Java and Sumatra as well from a recording at a tide gauge at Batavia (Jakarta). The waves were so powerful that coral blocks weighing as much as 600 tons were thrown ashore. The tsunami is reported to have been about 1.5 meters at Chennai (formerly Madras). In Sri Lanka (then known as Ceylon), the waves were big enough to leave small boats in harbors stranded and then re-floated them.

Past events of tsunami that flooded Indian coast.....

1941 - Andaman Islands, India, Mw 7.7

Date :26th June 1941
Epicenter : 23.6 kilometres WNW of Yadita (Middle Andaman Isl.), India
Magnitude : Mw 7.71
A tsunami was triggered by this earthquake in the Bay of Bengal. It is believed that nearly 5,000 people were killed by the tsunami on the east coast of India. As per journalistic sources, the height of the tsunami was of the order of 0.75 to 1.25 meters. At the time no tidal gauge was in operation.

Past events of tsunami that flooded Indian coast.....

1945 - Mekran Coast Earthquake, M8.0

Date :27 November 1945
Epicenter : 87.1 kms SSW of Churi (Balochistan), Pakistan
Magnitude : Mw 8.0
A major Indian Ocean-wide tsunami was generated by this earthquake which struck the coast of India and was recorded as far as the Seychelles. The tsunami reached a height of 40 feet in some Mekran ports and were 6.5 feet high in Karachi. The tsunami had a height of 11.0-11.5 meters in Kuchh, Gujarat. The height of the tsunami in Mumbai was 2 meters.

Present AERB safety provisions against tsunami

Present AERB safety provision against tsunami...

- *AERB safety code, Code of Practice on Safety in Nuclear Power Plant Siting, AERB /SC/S* specifies the safety requirements against tsunami related flood.
- Design Basis Flood Level (DBFL)
 - $DBFL = h_1 + h_2 + h_3$
 - h_1 : Wave run-up
 - h_2 : High tide level
 - h_3 : Storm surge or tsunami or long period water waves

Present AERB safety provision against tsunami...

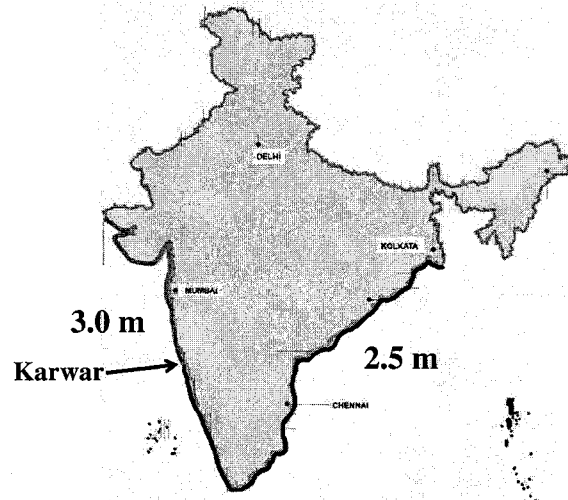
- AERB Safety Guide, “Seismic Studies, and Design Basis Ground Motion for Nuclear Power Plant Sites”, AERB/SG/S-11 specifies the design/safety criteria with respect to tsunami.

Present AERB safety provision against tsunami...

The provisions were developed on the basis of the following data

Year	Description
1881	A magnitude 7.9 earthquake in the Andaman Island region generated 1 m high tsunami on India's eastern coast.
1883	Krakatau explosion. 36,000 fatalities, primarily on the islands of Java and Sumatra. Caused damage in Chennai and parts along east coast of India, with a reported tsunami height of 1.5 m.
1941	A magnitude ~7.7 Adaman Islands earthquake. Anecdotal accounts exist of a tsunami along east coast, however, no official records exist. As per journalistic sources, the height of the tsunami was of the order of 0.75 to 1.25 meters
1945	A magnitude 8.0 Marcan fault earthquake caused tsunami wave that flooded West coast of India including Mumbai, with tsunami heights upto 2.0m

Present AERB safety provision against tsunami...



The suggested design values of tsunami heights for Indian Coast,
AERB/SG/S-11

Present AERB safety provision against tsunami...

- Calculated water level due to storm surge at Kudankulam Nuclear Power Plant (KK-NPP) was less than specified height (2.5m) of tsunami.
- Design of grade level of Kudankulam nuclear power plant (KK-NPP) was governed by tsunami.
- The DBFL was derived from:
(wave run-up) + (high tide) + (2.5m: tsunami)

Present AERB safety provision against tsunami...

- The water level due to storm surge was higher than specified tsunami height for fast breeder reactor (FBR) project, Kalpakkam
- Design of grade level of fast breeder reactor (FBR) project at Kalpakkam was governed by tropical cyclone.
- The DBFL was derived from:
(wave run-up) + (high tide) + (storm surge)

Summary of observations

- Events of tsunami had been reported since 1881.
- Five tsunamis struck Indian coast during last 123 years.
- Tsunamis were generated by earthquakes having magnitude $> 7.5Mw$

Summary of observations.....

- In the past, four events of tsunami generated wave heights ranging from 1.5 to 11m. The values of inundation level was reported between 1.5 to 2.0m.
- The tsunami of December 26, 2004 was more devastating. But, it did not have any significant effect on the Nuclear Installations.

Summary of observations.....

- The tsunami of 26th December 2004 was more severe in many other affected areas in India:
 - Number of Waves : 3-4
 - Wave heights ranged from 4 to 15 m, with majority of the reported values around 5.0 m
 - Inundation distance varied from 100m to 1000m with majority of reported values around 200m.
 - Inundation depth, above ground level, varied from 1.5 to 2.1m.