



# The evaluation of the reference earthquake for the siting of high risk industrial plants

Aim of this paper is to recommend a methodology for the proper assessment of the risk associated with the operation of hazardous industrial plants, largely distributed all around the world, with emphasis on the potential earthquake effects. This type of risk, in-fact, in the Author's opinion is still very poorly understood by society. The industrial Augusta-Priolo Gargallo area has been chosen as an example

■ Leonello Serva, Fiorenzo Fumanti

## La valutazione del rischio di incidente rilevante dovuto a terremoti nella scelta dei siti di impianti industriali

In questo lavoro viene proposta una metodologia per la valutazione del rischio associato al funzionamento di impianti a rischio di incidente rilevante, diffusi in tutto il mondo, con particolare enfasi agli effetti di potenziali terremoti. È opinione degli Autori che tale tipo di rischio sia poco conosciuto dalla società. Come caso di studio è stata scelta l'area industriale di Augusta-Priolo Gargallo

The last strong earthquakes that have affected very populated areas (Kocaeli, Turkey, Aug. 17 1999,  $M_w=7.4$ , Figure 1; Guyarat, India, Jan. 26 2001,  $M_w=7.7$ ; Tohoku, Japan, Mar. 11 2011,  $M_w=9.0$ , Figure 2) have clearly highlighted that high risk plants, such as chemical plants and refineries, can be deeply affected and therefore, as the Nuclear Power Plants (NPPs), can create significant additional risk to human beings, property and the environment.

In this paper we want stress the concept that, because

of what stated above, it is time to apply the siting approach also to these facilities. As for the NPPs, it can be applied also *a posteriori* and, because of that, a priority should be given to the existing very industrialized areas of the world in order to be aware with the level of risk there present and start appropriate actions, if necessary. The case of the Italian Augusta-Priolo Gargallo (Syracuse, Sicily) area is here examined.

### Methodology (summarised and customised from the IAEA Technical Guide Series No. SSG-9)

Siting is the process of selecting a suitable location for any type of facilities, based on the appropriate assessment and definition of the design parameters in order to protect the facility from environmental hazards and to

■ Leonello Serva  
Past Coordinator of the Working Group ISPRA for the technical support to IPPC/AIA Commission of MATTM. Member of Scientific Committee of ISSC of IAEA

■ Fiorenzo Fumanti  
ISPRA - Geological Survey of Italy

minimize the impact of the plant to the environment.

Safety is in fact the achievement of:

- proper operating conditions,
- prevention of accidents or
- mitigation of accident consequences,

resulting in protection of workers, the public and the environment from undue toxic hazards.

As said above, siting is the demonstration of the accep-



**FIGURE 1** Tupras Refinery, Korfez, Izmit Bay (Turkey). August 17, 1999, M=7.4 earthquake  
Source: Gayle Johnson, 2002



**FIGURE 2** Fire boats fighting against a blaze at the Cosmo Oil facility in Ichihara City, Chiba Prefecture near Tokyo March 12, 2011  
Source: REUTERS/Kyodo, In Focus by Alan Taylor, The Atlantic

tability of the site on the basis of established criteria and derivation of the site-related design bases for the facility. The proper team to perform the job is composed by experts in power engineering, chemical engineering, ecology, demography, emergency planning civil engineering, soil mechanics, geology, seismology, hydrology, meteorology.

Therefore siting results in the analysis of:

- effects of the region on the plant – i.e., external events occurring in the region, which could be of natural or man-induced origin,
- effects of the plant on the region – i.e., characteristics of the site and its environment which could influence the transfer of released contaminants to persons and to the environment,
- population characteristics of the region (i.e., density, distribution and others) in relation to the possibility of implementing emergency measures.

Possible natural phenomena and human induced situations and activities in the region shall be identified and evaluated according to their significance for the safe operation of the facility. Pre-historical, historical and instrumentally recorded information and records of the occurrences of such events shall be collected and evaluated. Appropriate methods shall be used for establishing the hazards associated with major external phenomena.

The size of the region shall be large enough to include all features and areas that could be of significance in the determination of the following hazards: Seismicity and surface faulting, Subsurface material, Vulcanism, Flooding, Extreme meteorological phenomena, Human induced events, Dispersion in air and water, Population distribution, Emergency planning, Land use, Availability of cooling water, Others.

### Seismic hazard and the case of Augusta-Priolo Gargallo

Usually the plants with high risk of accident are aggregated in industrial complexes where several activities are carried out. Particularly representative of the problems related to the high concentration of industrial activities and their interaction with natural phenomena is the Augusta-Priolo Gargallo territory, historical-

ly affected by violent earthquakes and high-intensity tsunami events (Table 2). At present, the area presents more plants with high accident risk (three refineries, two petrochemical plants, one gas storage plant, one explosive deposit, one thermoelectric plant with heavy refinery residues combustion, three mineral oil deposits, one gas production plant and a consortium plant for wastewater treatment) and other industrial or energy settlements.

The hazards related to earthquake are:

- the ones linked to the Vibratory Ground Motion (VGM) in term of acceleration, velocity and displacement of the earth surface (Class (1) features that can substantially influence the severity of the design basis earthquakes;
- the ones linked to the associate phenomena of the quake, like the potential: surface faulting (the permanent offsetting or tearing of the ground surface by differential movement across a fault during an earthquake); tsunami (if the area is on the coastline), areal uplifting/subsidence; ground collapse; liquefaction and landsliding (Class (2) features that can have direct influence also on the acceptability of the site.

**Class (1) features**

Class (1) features define the parameters of the ground motion of the design-basis earthquakes. To reach this goal, it is necessary to compile a speci-



**FIGURE 3** Seismogenic tectonic structures of interest for the definition of the VGM at Augusta-Priolo Gargallo  
Source: APAT, 2004

fic and complete database for the construction of a seismotectonic model from which the potential earthquakes affecting the site can be derived. These earthquakes are then used to define the nature of earthquakes used as a basis for design of the facility. Thus, it is essential to obtain an integrated geological and seismological database. The elements of this database should be studied in greatest detail in the

Seismogenic source	Minimum distance between site and seismogenic source	Estimated hypocentral depth	Maximum Magnitude	Geometry of the source	Tectonic Style
Malta Escarpment-W Catania Gulf	21 km	10-15 km 20-25 km	7.2 7.4	340° (strike) 60° (dip)	Extensional
Malta Escarpment-E Catania Gulf	37 km	10-15 km 20-25 km	7.2 7.4	340° (strike) 60° (dip)	Extensional
Lentini Graben	18 km	10-15 km 20-25 km	6.2 6.4	250° (strike) 60° (dip)	Extensional
Climiti Mount	8 km	10-15 km 20-25 km	5.7 5.9	320° (strike) 60° (dip)	Extensional
Avola - Noto	30 km	10-15 km 20-25 km	6.0 6.2	30° (strike) 60° (dip)	Extensional

**TABLE 1** Characteristics of the seismogenic sources of Figure 3

region close to the site where it will be more complete. In this connection, four scales of investigation are appropriate: regional, near regional, the vicinity of the site, and the immediate area of the site. The main purpose of the regional studies is to provide knowledge of the tectonic framework of the region and its general geodynamic setting and to identify those seismogenic features that may influence the seismic hazard at the site. The main purpose of the near regional investigations is to characterize the more important seismogenic structures for the assessment of seismic hazards. Investigation of the site vicinity, as already mentioned, is designed to define in greater detail the neotectonic history of faults with the special purpose of resolving the possibility of surface faulting at the site (fault capability) and identifying sources of potential instability (Class 2 features). Investigations at the site area should emphasize the definition of the physical properties of the foundation materials and the determination of their stability and response under dynamic earthquake loading.

Figure 3 and Table 1 represent, as an example, the seismogenic sources, derived by the studies cited above, significant for the assessment of the seismic hazard in the Augusta-Priolo Gargallo area.

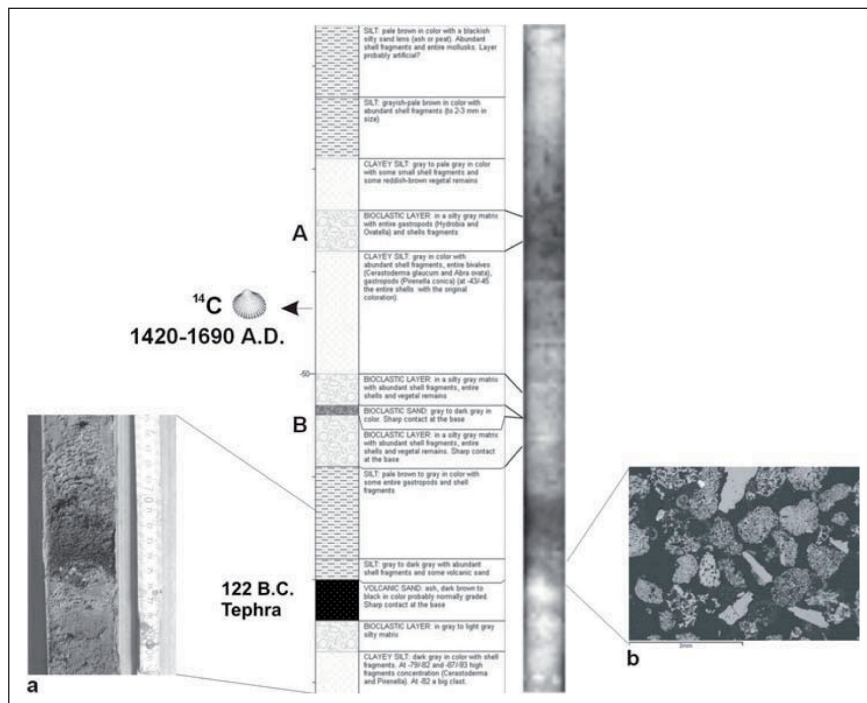
### Class (2) features

For the Class (2) features cited above; if engineering solutions are not available or, if available, the cost of applying them is such that the project becomes economically unfeasible, another site should be recommended.

The potential effects of tsunamis and the potential presence of capable faults are particularly important for the Augusta-Priolo Gargallo area.

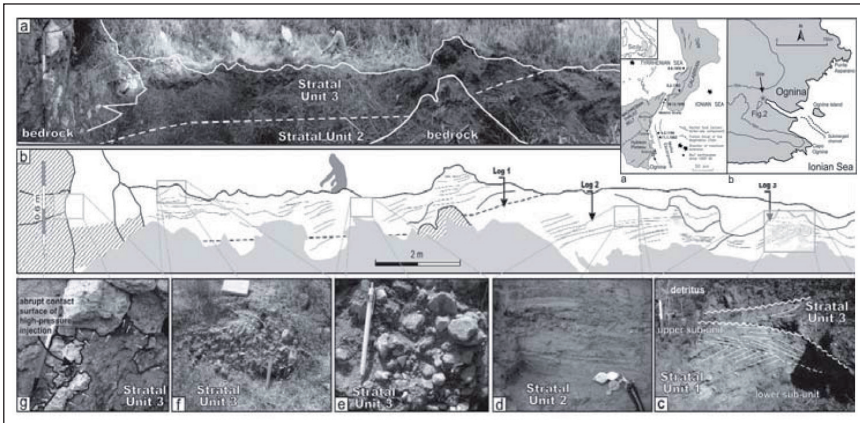
Regarding the tsunami, in Figure 4, 5, 6, the geological data (the so called tsunamites) for the assessment of the tsunami hazard in the area (see figures for the details) are reported. Of course, other very important data are the modeling of the tsunami according to the Magnitude of the source zone and the historical data (Table 2).

Regarding the potential for the surface faulting ha-



**FIGURE 4** Stratigraphic log of Priolo (SR) coastal plain (about 500 m from the coastline) with evidence of paleotsunami (1693 (A); 1169 (B); 570-122 B.C.).

Source: Smedile et al., 2007



**FIGURE 5** Geological evidence of paleotsunami in the Augusta-Priolo Gargallo area (Ognina section, events)  
 Source: Scicchitano et al., 2008

zard in the Augusta-Priolo Gargallo, it is first important the definition of this feature, that is: a fault is considered capable if it shows evidence of past movement (significant deformation and/or dislocation) of a recurring nature within such a period that it is reasonable to infer that further movement can occur at, or near the surface. In highly active areas, where both earthquakes and geological observations consistently reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years

may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods may be required. When faulting is known or suspected, investigations should include detailed geological-geomorphological mapping, topographical analyses, geophysical (including geodesy, if necessary) surveys, trenching, boreholes, determining ages of faulted sediments or rocks, local seismological investigations and any other appropriate techniques, to ascertain when the last movement occurred.



**FIGURE 6** Scattered boulders deposited on the Priolo coastal area after the 1169 and 1693 Tsunami events  
 Source: Scicchitano et al., 2007

Id_Code	Year	Month	Day	Subregion	Reliability	Cause	Earthquake Intensity	Earthquake Magnitude	Tsunami Intensity
3	1169	2	4	Sicilia Orientale	4	ER	10	6.6	4
4	1329	6	28	Sicilia Orientale	2	VA			3
14	1693	1	9	Sicilia Orientale	2	ER	8.5	6	2
15	1693	1	11	Sicilia Orientale	4	ER	11	7.4	5
26	1783	2	5	Calabria tirrenica	4	EA	11	6.9	4
27	1783	2	6	Stretto Messina	4	EL	8.5	5.9	6
38	1818	2	20	Sicilia Orientale	4	EA	9	6	2
54	1908	12	28	Stretto Messina	4	ER	11	7.2	6
66	1990	12	13	Sicilia Orientale	4	ER	7	5.7	2

Reliability: 0 very improbable; 1 improbable; 2 questionable; 3 probable; 4 definite.

Cause: EA earthquake associated; VA volcano associated; ER submarine earthquake.

Intensity of tsunamis: 1 very light; 2 light; 3 rather strong; 4 strong; 5 very strong; 6 disastrous (Sieberg-Ambraseys Tsunami Intensity Scale)

**TABLE 2** Tsunami occurred in the Ionian coast of south-eastern Sicily during the last millennium according to the catalogue of Tinti et al. (2004)

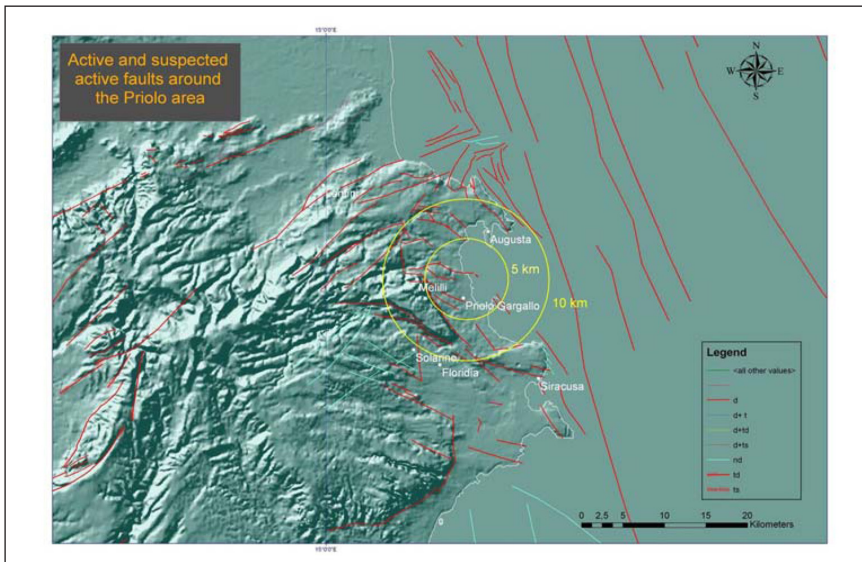
In Figure 7 the potential capable faults located in the near vicinity of the Priolo Gargallo site are reported. Two technical solutions to face this problem are represented in Figure 8 and 9 (see the details in the figures).

**A final hypothesis**

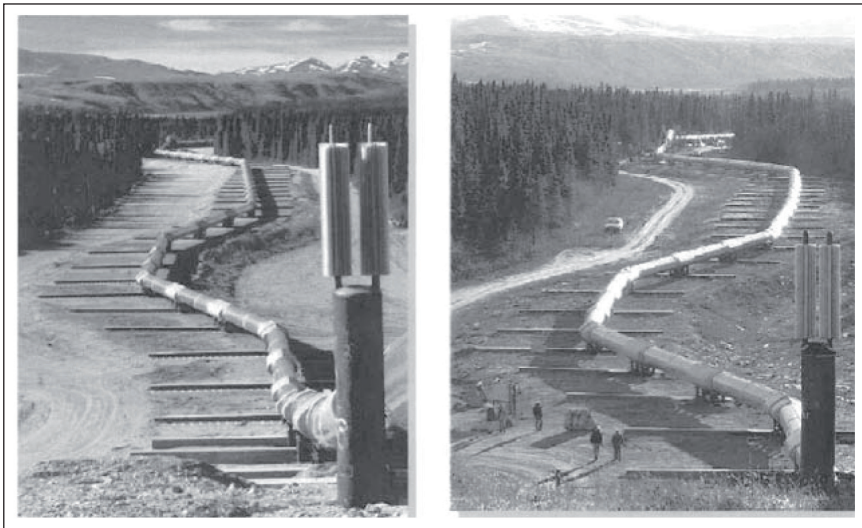
The details required on the database (quality, quantity and type of geological, geophysical, seismologi-

cal and engineering data) should be strictly linked to the level of risk/environmental impact of the high risk plant under analysis. In Figure 10 a comparison between these facilities, the civil constructions and the NPPs is reported.

It is evident that there are no high risk plants having the same level of risk of an NPP, however an industrial area containing different types of plants,



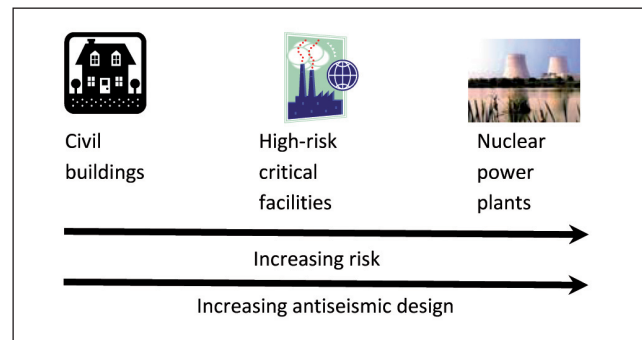
**FIGURE 7** Capable and suspected capable fault around the Priolo Gargallo area  
Source: ISPRA, ITHACA Project



**FIGURE 8** Trans-Alaska Pipeline - Before and after the 2002 earthquake. At the Denali Fault crossing, the pipeline is supported on 33 steel box beams and concrete beams. These beams were sized and arranged to accommodate a fault slip. Note movement and bowed segment after fault displacement, which acts to compress the pipeline crossing segment  
 Source: modified after <http://gallery.usgs.gov>



**FIGURE 9** Megara to Korinthos High Pressure Natural Gas Pipeline. Encasing of pipeline at active faults crossings  
 Source: <http://users.ntua.gr/gbouck/proj-photos/megara.html>



**FIGURE 10** Level of risk of High Risk Plants

including some dealing with very toxic substances (Tables 3 and 4), in the Author opinion, should be treated only a little less than an NPP; the Augusta-Priolo Gargallo area and others in the Italian territory should be treated very similar to an NPP. For some aspects, also a single plant dealing with very toxic material located in an intensively populated area (e.g., downtown) and a large dam should be treated in a similar way.

More in general we can say that the methodology should be similar to the NPPs when we are dealing with a system of plants for which an accident

can cause relevant risks on man and/or the natural environment in terms of areal extension and level of contamination. A similar concept is also expressed by Gurpinar, 1997. In such a case, as for the nuclear, we should define, as design earthquake SL2 the maximum potential earthquake, i.e., the ten thousand years return period earthquake. The engineering treatment of this earthquake can be significantly different from the one defined in the nuclear, and this theme is not treated here. Class 2 features should be analyzed with the same details of the nuclear.



It is evident that it is a highly cost approach. However, the benefit is also high in case such event occurs during the plant lifetime. In any case, I believe that the owners of these plants could work in a weighted synergy (in terms of cost/risk reduction benefit) for the solution of the problem, and public institutions, at national and local scales, should help the owners of such plants, by providing not only guidance but also data and expertise; in this regard the Italian System of the Environmental Agencies (ISPRA-ARPA-APPA) can play a significant role.

In the meantime the detail is minor if we are dealing with hazardous plants (Table 3 or the ones treating material reported in Table 4 that are taken from the “Seveso2” Law) not located in a large industrial area and, more in general, for plants having minor risk but requiring an emergency plan. In this case, the 500-1000 years return period earthquake, as SL2, could be adequate. An approach of this type is reported in Barone et al., 1998. Still minor should be the geological and seismological database for an oil pipeline, a strategic communication center, a sludge plant. It is important, however, to point out that also in this case the data coming from the rich Italian historical seismic catalogues could not be sufficient for the solution to the problems. In particular, the geological stability of the site under static and dynamic loads should always be proved and the existing catalogues are still incomplete for several areas of the Italian territory, as proved by

For Man	Large VLPG storage plants
	Large Chlorine storages
	Phosgene storages and process users
For Environment	Large diesel oil or fuel oil tank farms

**TABLE 3** Most hazardous industrial plants



Dangerous substances	Qualifying quantity (tonnes) for the application of the Law	
Ammonium nitrate	350	2500
Ammonium nitrate	1250	5000
Arsenic pentoxide, arsenic (V) acid and/or salts	1	2
Arsenic trioxide, arsenious (III) acid and/or salts	-	0,1
Bromine	20	100
Chlorine	10	25
Nickel compounds in inhalable powder form (nickel monoxide, nickel dioxide, nickel sulphide, trinickel disulphide, dinickel trioxide)	-	1
Ethyleneimine	10	20
Fluorine	10	20
Formaldehyde (concentration ( 90 %)	5	50
Hydrogen	5	50
Hydrogen chloride (liquefied gas)	25	250
Lead alkyls	5	50
Liquefied extremely flammable gases (including LPG) and natural gas	50	200
Acetylene	5	50
Ethylene oxide	5	50
Propylene oxide	5	50
Methanol	500	5000
4, 4-Methylenebis (2-chloraniline) and/or salts, in powder form	-	0.01
Methylisocyanate	-	0.15
Oxygen	200	2000
Toluene diisocyanate	10	100
Carbonyl dichloride (phosgene)	0,3	0.75
Arsenic trihydride (arsine)	0,2	1
Phosphorus trihydride (phosphine)	0,2	1
Sulphur dichloride	1	1
Sulphur trioxide	15	75
Polychlorodibenzofurans and polychlorodibenzodioxins (including TCDD), calculated in TCDD equivalent	-	0.001
The following CARCINOGENS: 4-Aminobiphenyl and/or its salts, Benzidine and/or salts, Bis(chloromethyl) ether, Chloromethyl methyl ether, Dimethylcarbamoyl chloride, Dimethylnitrosamine, Hexamethylphosphoric triamide, 2-Naphtylamine and/or salts, and 1,3 Propanesultone 4-nitrodiphenyl	0.001	0.001
Automotive petrol and other petroleum spirits	5000	50000

**TABLE 4** Dangerous substances according to the “Seveso2” Law

the ongoing paleoseismological techniques (Michetti et al., 2000).

It is important to point out here that also other non industrial structures, like bridges, communication facilities, galleries, can play a significant role in the risk reduction, especially in emergency phases. It is well known, in fact, that these structures in a young geological framework, such as Italy, can be crossed by active (capable) fault (Azzaro et al., 1998) and because of that, I believe that also these structures should be considered as the third categories of industrial plants. Regarding these long structures, the limit of the acritical application of the Gutenberg-Richter relationship as described by Mochan et al., 1997 should be emphasized and so should the great importance of the realistic definition of the differential motion of bridges and lifelines, since it enables

to take into account wave passage, loss of coherency and site effects, making the deterministic seismosynthesis (e.g. Panza et al., 2001) particularly suitable for our purposes.

On the other hand, the quantity and quality of data could be much higher than required for NPPs, this is the case of sites for high level radioactive waste. In such case, in particular, the stability of the site should be demonstrated for periods of tens or hundreds thousands of years.

At this point it is important to point it out that siting can be done also if the plant is already existing. In such a case, it permits to define engineering solutions to increase its safety. This work, in the nuclear, has been and is presently done successfully and without a significant economical cost, for many Eastern European plants. ●

## references

- R. Azzaro, L. Ferrel, A.M. Michetti, L. Serva, E. Vittori, *Environmental hazard of capable faulting: the case of the Pernicana fault* (Mt. Etna, Sicily). *Natural Hazards*. U. K., vol. 17, pp.147-162, 1998.
- APAT, *La messa in sicurezza dell'area industriale di Priolo-Augusta rispetto ai rischi da terremoto e maremoto*. Rapporti APAT, vol. 41, 28 pp, 2004
- D. Barone, G. Macchi, G. Petrangeli (Coord.), A. Pugliese, A. Ricchiuti, T. Sanò, *Comitato Termotecnico Italiano, Sottocomitato 7: Gruppo "Tecnologie di Sicurezza". Proposte di Linee guida per la verifica sismica di impianti a rischio di incidente rilevante esistenti*. Unpublished, 1998.
- P.E. Gayle Johnson, *Refinery Damage and Emergency Response in the 1999 Izmit, Turkey Earthquake*. *California state land commission, Prevention First symposium proceedings 2002*. [http://www.slc.ca.gov/Division\\_Pages/MFD/Prevention\\_First/Documents/2002/Paper%20by%20Gayle%20Johnson.pdf](http://www.slc.ca.gov/Division_Pages/MFD/Prevention_First/Documents/2002/Paper%20by%20Gayle%20Johnson.pdf)
- A. Gurpinar, *A review of seismic safety considerations in the life cycle of critical facilities*. *Journal of Earthquake Engineering*, Vol.1, pp. 57-76, 1997
- IAEA, *Seismic Hazards in Site Evaluation for Nuclear Installations Specific Safety Guide*. Series No. SSG-9, 2010.
- IAEA, *Site survey and Site Selection for Nuclear Installations*. DS433, Safety Series 50-SG-S9, 1984.
- A.M. Michetti, Blumetti A.M., Esposito E., Ferrel L., Guerrieri L., Porfido S., Serva L. e Vittori E., *Earthquake Ground Effects and Seismic Hazard Assessment in Italy: Examples from the Matese and Iripnia areas, Southern Apennines*. In: "Active Fault Research for the New Millennium", Proceedings of the Hokudan Symposium and School on Active Faulting, pp. 279-284, 2000.
- G. Molchan, T. Kronrod, G.F. Panza, *Multi scale seismicity for seismic risk*. BSSA, Vol. 87, no 5, pp. 1220-1229, 1997.
- G.F. Panza, F. Romanelli, F. Vaccari, *Seismic wave propagation in laterally heterogeneous anelastic media: theory and application to the seismic zonation*. *Advances in Geophysics*, vol. 43, pp. 1-95, 2001.
- L. Serva, *An analysis of the major regulatory guides for NPP seismic design (a guideline for high risk facilities)*. *Energia Nucleare*, Anno 10, n. 2, maggio-agosto 1993, pp. 77-96, 1993.
- L. Serva, A.M. Blumetti, L. Guerrieri, A.M. Michetti, *The Apenninic intramountain basin: the results of repeated strong earthquakes over a geological time interval*. *Atti del Convegno: Evoluzione geologica e geodinamica dell'Appennino - In memoria del Prof. Giampaolo Pialli*. Foligno, 16-18 febbraio 2000.
- G. Scicchitano, C. Monaco, L. Tortrici, *Large boulder deposits by tsunami waves along the Ionian coast of south-eastern Sicily (Italy)*, *Marine Geology*, vol. 238, pp. 75-91, 2007.
- G. Scicchitano, Costa B., Di Stefano A., Longhitano S.G., Monaco C., *Tsunami deposits in the Siracusa coastal area (south-eastern Sicily)*. *Rendiconti della Società Geologica Italiana*, 6, pp. 37-41, 2008.
- A. Smedile, De Martini P.M., Barbano M.S., Gerardi F., Pantosti D., Pirrotta C., Cosentino M., Del Carlo P. & Guarnieri P., *Identification of paleotsunami deposits in the Augusta Bay area (eastern Sicily, Italy): paleoseismological implication*. XXVI Convegno GNGTS. Extended Abstract Vol., pp. 207-211, 2007.
- S. Tinti, Maramai, A., Graziani, L., *The new catalogue of Italian tsunamis*. *Nat. Hazards* 33, pp. 439-465, 2004.