3. The Cadarache site

Cadarache satisfies all the ITER site requirements.

From the point of view of the layout and geotechnical characteristics, the site requirements are more than satisfied thanks to a large available surface and to the presence of a good quality limestone substrate.

The design assumptions are satisfied, widely exceeded for most of them. Two exceptions with minor impact are:

- The seismic level is slightly higher in Cadarache than on the generic site.
- Concerning the electrical supply, an additional voltage drop compensator will be necessary.

These two aspects require an adaptation of the ITER generic design. The evaluation of the consequences of such an adaptation is almost completed for the first and is finished for the second. No major technical difficulty is anticipated. The extra cost will be reasonable for aspects related to the seismic issue and small for the electrical issue.

A reference route for the transport of large and heavy loads has been technically and financially evaluated. An alternative solution that could be cheaper is under investigation.

3.1. Overview of CEA Cadarache

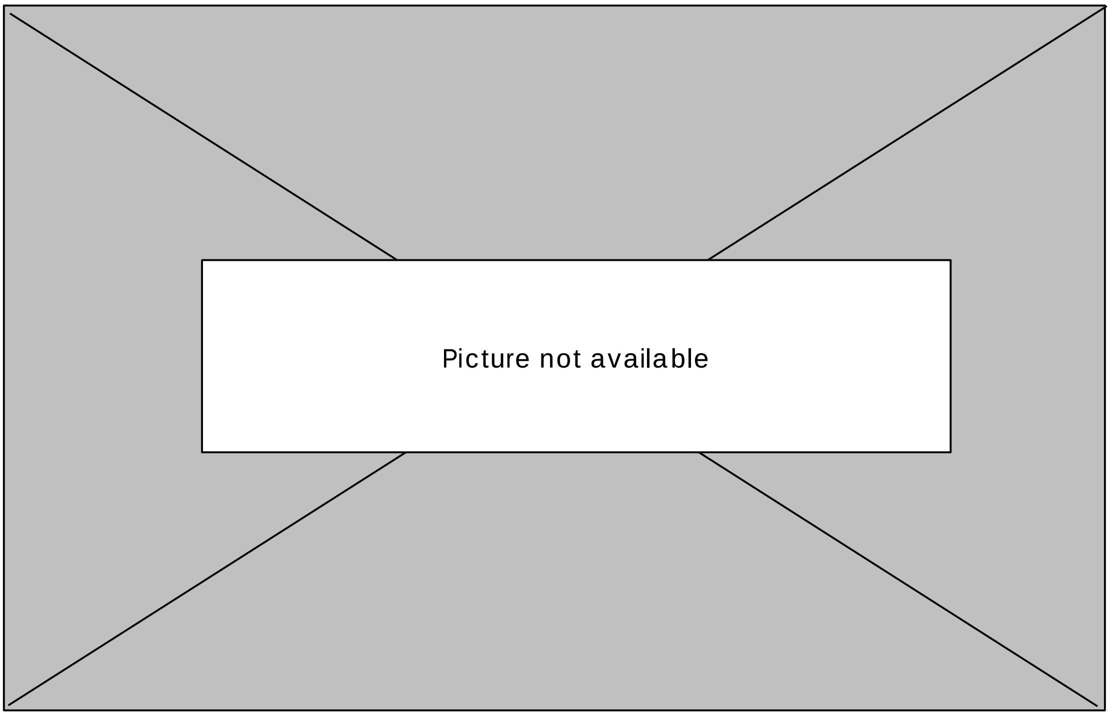

Figure 3.1: Aerial View of Cadarache Centre

Cadarache, established in 1959, is with its 1600 hectares the largest research centre of the French Atomic Energy Commission (CEA). Due to the number of staff (2500) and annual budget (400 M€) the centre has a large impact on the region. It is located at the very heart of historical Provence, halfway between Aix-en-Provence and Manosque.

Cadarache is the main CEA centre for power-oriented research (see Figure 3.1 and Figure 3.2), with experimental reactors, specialised laboratories, workshops and test facilities. Work is also carried out on plant safety and on the protection of the environment. The Euratom-CEA Association coordinates the French activity on magnetic thermonuclear fusion and has operated the superconducting tokamak Tore Supra since 1988. As well as the different specialised laboratories and reactors a number of general services are also available on the Cadarache site.

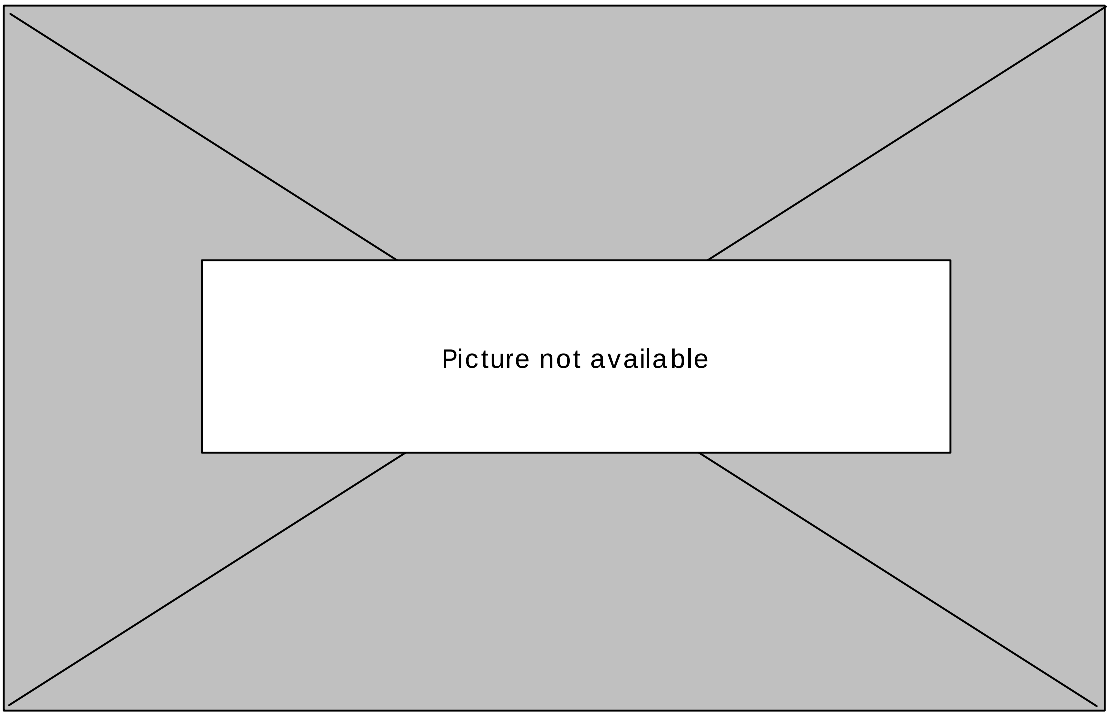

Figure 3.2: Aerial View of some of the Test Reactors on Site

- **Local Security Service**: The FLS (Formation Locale de Sécurité) is responsible for the protection of installations and other property with respect to classical risks, both internal and external. It has the latest and most modern equipment at its disposal to intervene in case of (nuclear) incident or accident. The FLS is responsible for the execution of the site emergency plan. All alarm systems from the different installations are connected through a fibre network to the FLS central command unit.

- **Radiation Protection Service**: The SPR (Service de Protection contre les Rayonnements) has as mission to make sure that the national radiation protection regulations are implemented. All the SPR staff have been trained by the INSTN (Institut National des Sciences et Techniques Nucléaires), who themselves have a representation in Cadarache. In addition to the control task the SPR also has an assistance task.
- **Medical Service**: A medical team is permanently present on site. Just as the security services they have modern equipment available to deal with accidents. The medical service also monitors the general health of the staff in Cadarache, with a special emphasis on radiological matters.
- **Technical Services**: The “Services Techniques” are responsible for the overall infrastructure and communication on site and specifically for the installation of general alarm systems, overall infrastructure and communication on site. They have a large experience with respect to the particular needs of nuclear installations.
- **Waste and Combustibles Service**: The “Service de Gestion des Déchets et des Combustibles” takes care of all the problems with the treatment, containment and elimination of nuclear waste and effluents within the framework of the French regulations. A treatment station is equipped with, amongst others, incinerators, presses and temporary storage facilities for all classical nuclear waste. A large experience on tritiated waste products has been built-up in cooperation with CEA Valduc, another CEA nuclear centre, with particular experience with tritium.

The Cadarache research centre has the necessary infrastructure. Taking into account the presence on site of French and European experts on magnetic fusion and the wide expertise on nuclear installations, the site is well capable to host an installation like ITER.

It is nevertheless foreseen to implement specific services on ITER site, as:

- a welcome building, with conference room, exhibition hall for public and scientists…
- a restaurant, more dedicated to ITER employees and visitors;
- local safety antennas (firemen, medical service for immediate intervention).

3.2. Land and implantation

The location at the Northeast of the current boundary of the Cadarache site is confirmed (see Figure 3.3). This zone is one of three zones, which had been considered in previous studies for ITER localisation. It was preferred to the two others after comparison on the basis of various criteria (quality of the substrate, hydrogeology, access, impact on the environment, topography, etc.). The selected zone is close to Tore Supra, allowing ITER to benefit from the existing equipments and laboratories, notably during the construction phase. The available surface on the selected site is well over 180 ha, easily fulfilling the site requirements and design assumption (SR.A1 & SA.A1, chapter 2.5).

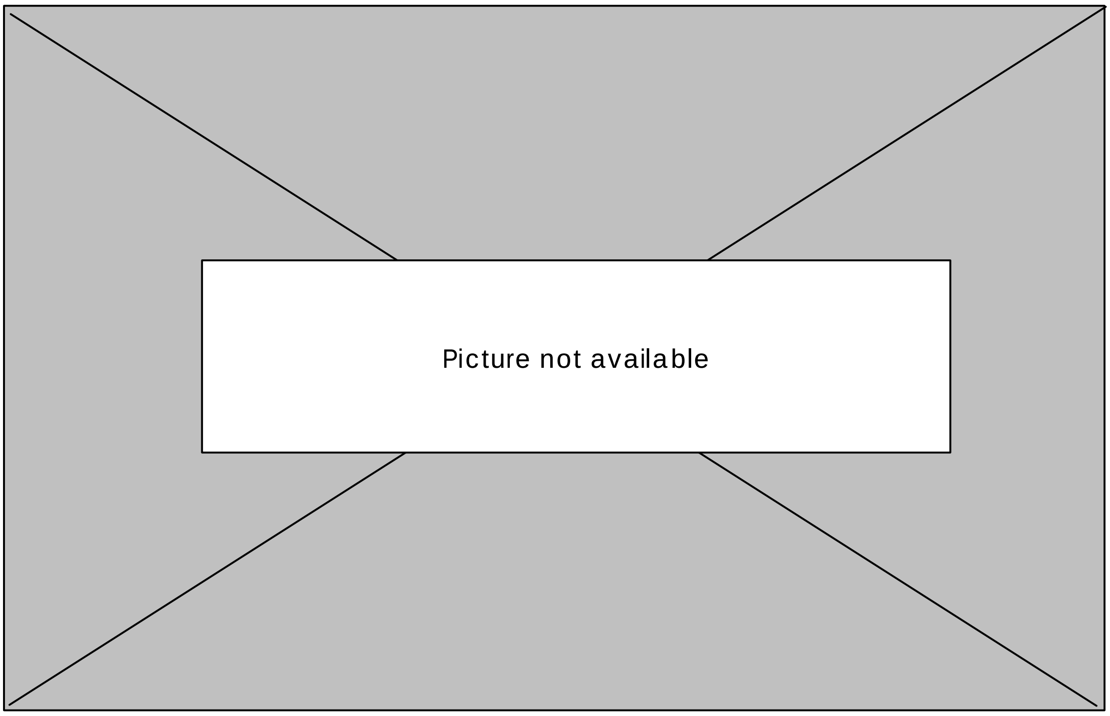

Figure 3.3: ITER Location on the Cadarache Site

3.2.1. Meteorology

Site design assumptions on meteorology have been detailed (SA.A6, see chapter 2.5), because these figures may have a significant impact on the design. The data for Cadarache is well documented due to the presence of nuclear facilities for more than 40 years. Two meteorological stations are in operation at the centre and the following data are permanently recorded:

- Maximum air temperature
- Minimum air temperature
- Average air temperature over 24 hours
- Rainfall over 24 hours
- Rainfall over 1 hour
- Wind speed at 110m elevation
- Relative humidity

All data are within the design assumptions except:

- The maximum air temperature, which has been 40.1 °C once over a period of 40 years (35 °C in the ITER design assumptions). This figure could have an impact on the cooling system (see chapter 3.4).
- The maximum relative humidity, which is 100 % (95 % in ITER design). This figure has no significant impact because it occurs only during limited periods when the temperature is low.

The climate at Cadarache is a mix between continental and Mediterranean, relatively dry and warm. One of the major characteristics is the large daily variation of the air temperature as shown in Figure 3.4.

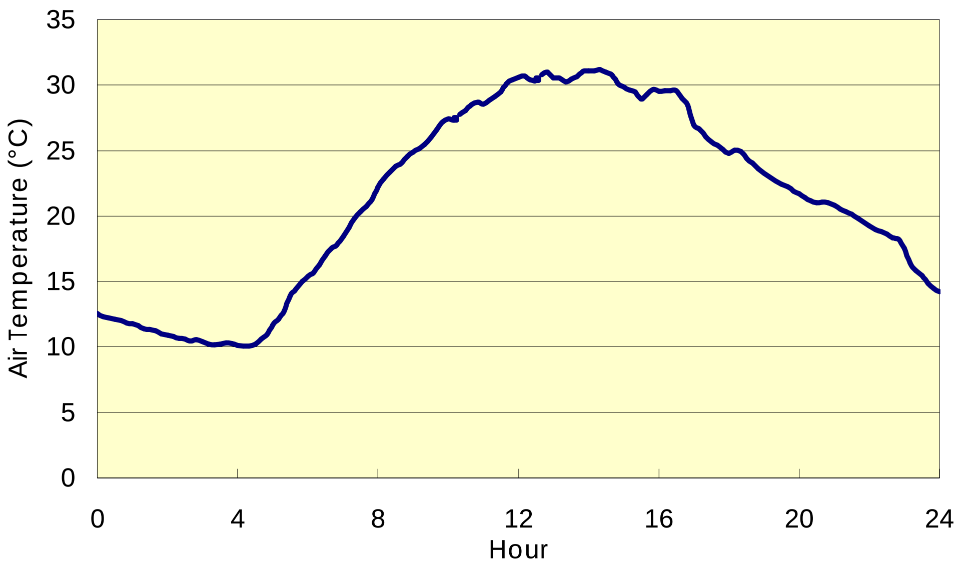

Figure 3.4: Temperature Variation on 18 June 1999

3.2.2. Geotechnical and hydrological aspects

While the topsoil is partially alluvia (see Figure 3.5), a first campaign of drillings, conducted during autumn 2000, has localised a limestone substrate of good quality at around ten metres depth at most. These results have been used to establish the final levels of the different platforms, taking into account soil support strength requirements (SR.A2) and hydrological assumptions (SA.A4).

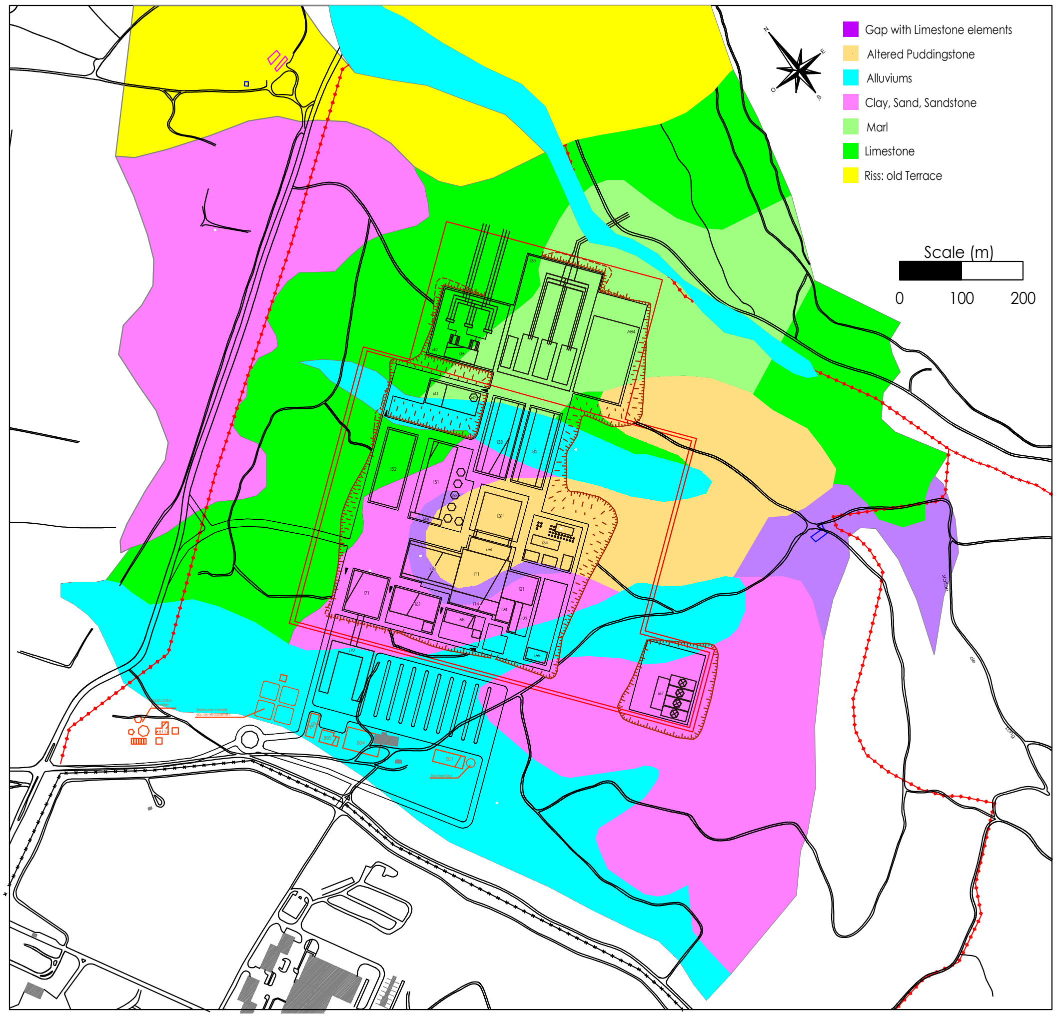

Figure 3.5: Soil at Natural Ground Level

During a ground surface review, no major singularity, which could have shown underground problems, was found.

Nevertheless, a very detailed geological investigation has been launched. This investigation includes (see Figure 3.6):

- **Geological measurements using seismic refraction**: the objective is to identify faults. This programme will cover most of the ITER area.
- **Drillings, destructive drillings and core samples**: the objective is to determine the soil composition and characteristics, necessary for the design of the building foundations. Some of these drillings will be equipped with water level probes and recorded. The depth of these drillings will be 60 m and will concentrate mainly on the area where the nuclear buildings are foreseen.
- **Geotechnical tests, dilatometry and cross-hole tests**: the objective is to measure the dynamic characteristics of the soil, which will be used for the foundation design and the seismic modelling.

The site could be moved by some tens of metres to optimise the location in view of the results of this campaign. The soil characteristics will be known and used for further design of the building foundations.

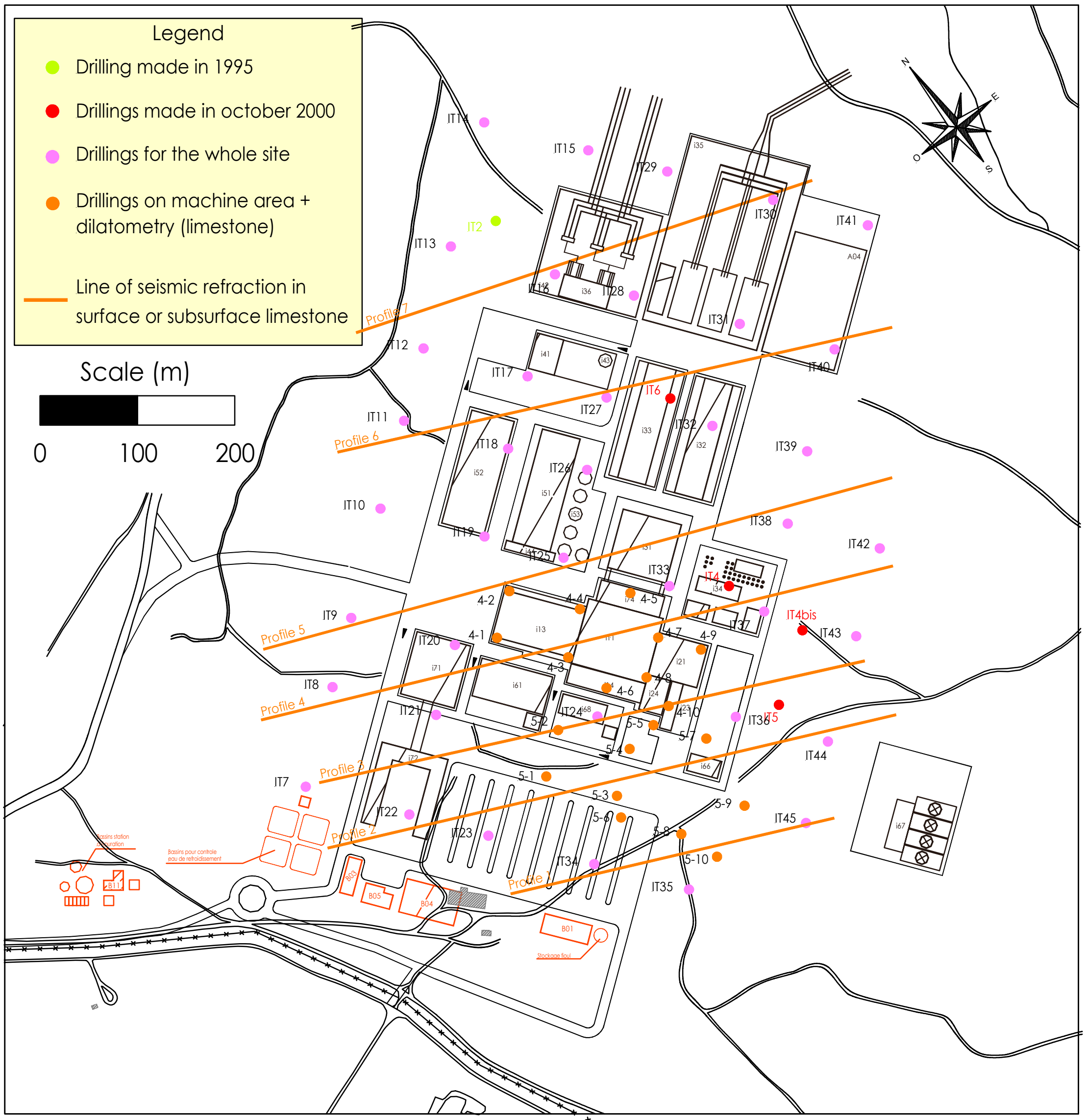

Figure 3.6: Detailed Geological Programme

3.2.3. Site layout

The arrangement of the buildings is in accordance with the generic site layout except for the cooling towers, which are positioned according to the dominant winds about 300 m away. The office building is rotated to improve its access (see Figure 3.7). Additional buildings and services (restaurant, medical service, access control, fire station, sanitary sewage station, pluvial water basins, etc.) have also been sketched. A special area for temporary workshops and storage during the construction phase has also been selected.

Since the natural ground is hilly, buildings are implemented on three different platforms to reduce the overall excavation. Nevertheless, all the nuclear buildings have their foundations on limestone:

- **Platform 1, 306 m above sea level**: control room, pumping station, site service buildings and emergency power supply;
- **Platform 2, 320 m**: cooling towers;
- **Platform 3, 310 m**: all other buildings.

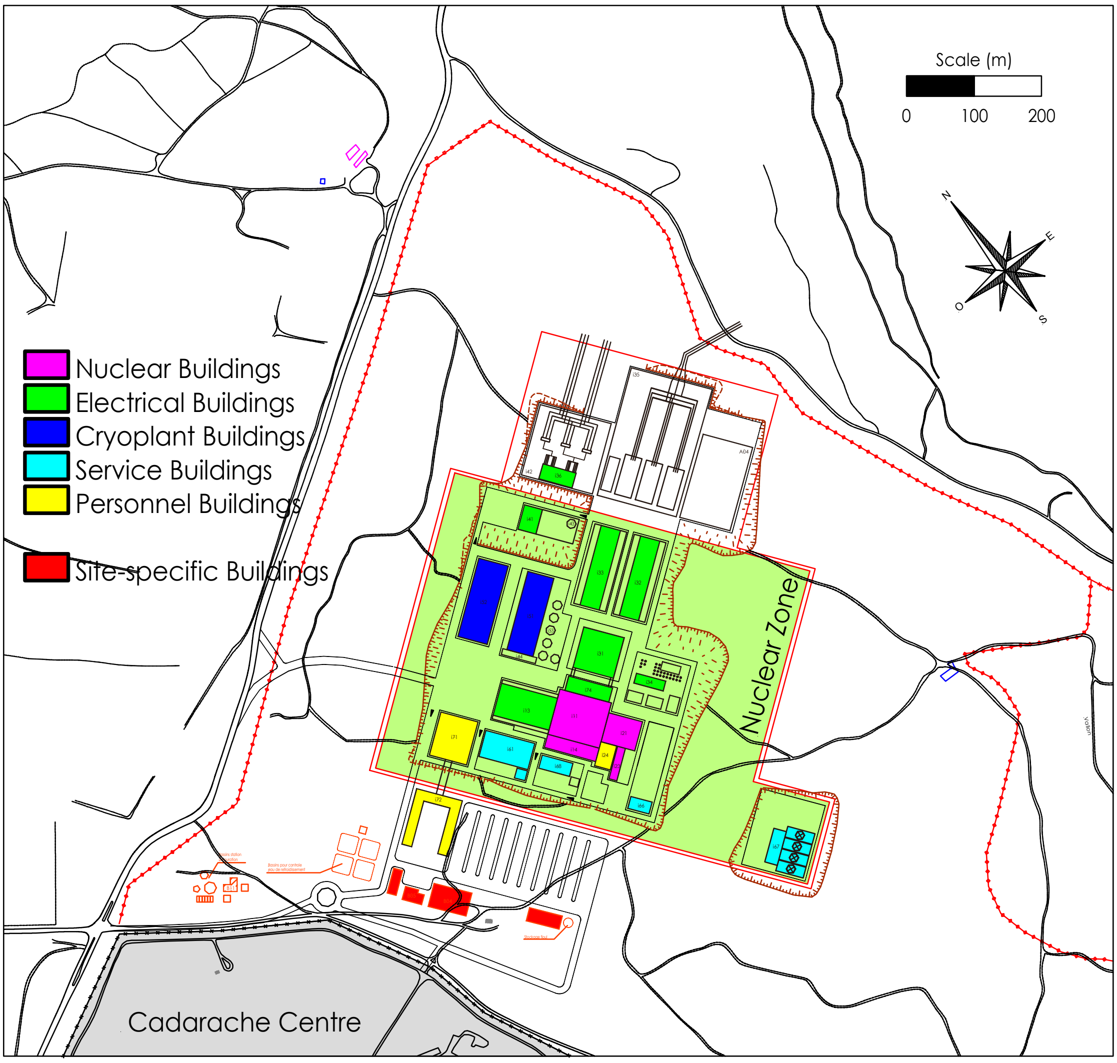

Figure 3.7: Detailed Layout of the Buildings

Excavated materials will be stored in a nearby small valley in order to reduce the overall environmental impact and transportation costs. The establishment of the platforms meets the design assumptions on topology (SA.A2) and geotechnical characteristics (SA.A3).

Architectural studies intended to estimate the visual impact were made. Figure 3.8 gives a preliminary outline.

Figure 3.8: Insertion of ITER in the Landscape, seen from the Castle of Cadarache

Figure 3.9: Artist Views of ITER Plant

3.2.4. Sanitary and industrial sewage

A new sanitary sewage treatment station will be built on the ITER site with a total capacity of 1500 people (SR.A4). This facility will also be used during the construction phase, but since the total number of people on site is estimated to be about 3000 at this time (assumption SA.H), a temporary connection with the existing Cadarache station will be made (see green lines on Figure 3.10).

For industrial sewage, ITER will be connected to the existing network, which already has the corresponding additional capability (SR.A4) (see red lines on Figure 3.10).

Potable water will be supplied by the existing pumping station, which feeds basins (SR.A3). This water is used for both drinking and fire security purposes. A new basin will be built to improve the storage capacity, especially in case of fire (see blue lines on Figure 3.10). Water from these basins is supplied by gravity.

Supply and sewage scheme for the cooling water system (doted red lines on Figure 3.10) is detailed in chapter 3.4.

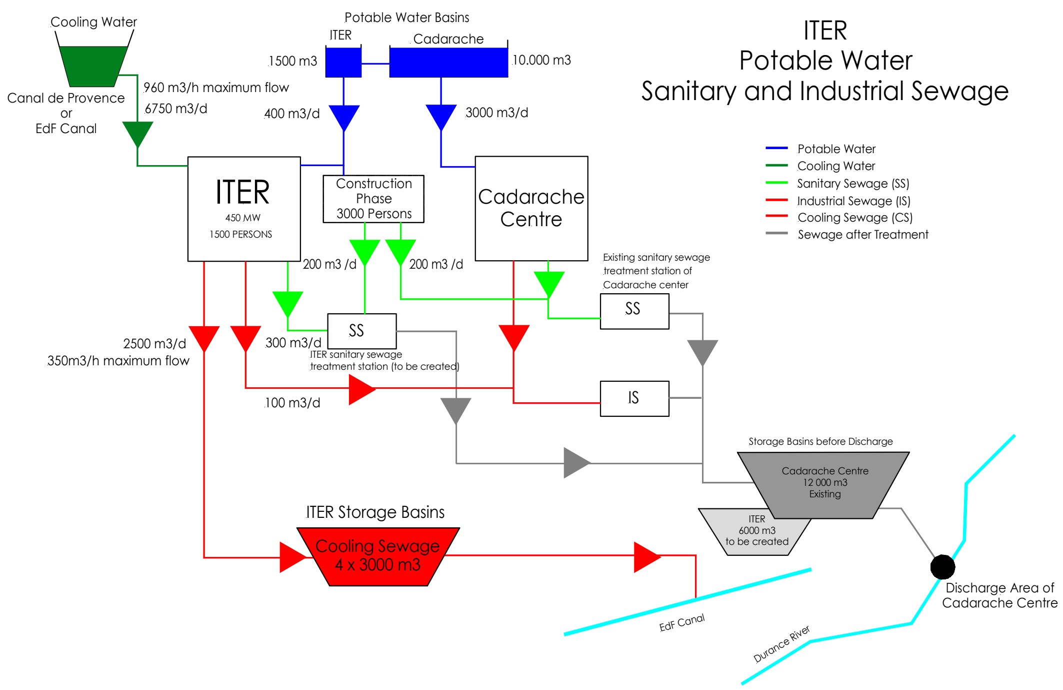

Figure 3.10: Overall Scheme for Water Supply and Sewage

3.3. Seismic aspects

The design of the safety classified buildings has been made by the ITER team on the generic site in accordance with the guidelines of ASME[9] and the U.S. NRC[10], with the objective to be applicable to a wide range of sites, with the exclusion of those with unusually soft soils. The primary scaling parameter used in the construction of the acceleration versus frequency spectrum is the design maximum ground acceleration, which has been assumed to be 0.2 g for the generic ITER site (SA.A5). At Cadarache, the "Règles Fondamentales de Sûreté" (RFS) require the use of two excitation spectra:

- the so-called "Séisme Majoré de Sécurité" (SMS): magnitude 5.8, distance to the epicentre 7.1 km, design maximum ground acceleration 0.315 g;
- the "Paléoséism": magnitude 7, distance 18 km, design maximum ground acceleration 0.281 g.

The comparison between the generic site (ASME 0.2 g) and Cadarache site specific Design Response Spectra is shown in Figure 3.11.

[9] ASME III Appendix N- Dynamic Analysis Methods
[10] NRC: U.S. Nuclear Regulatory Commission

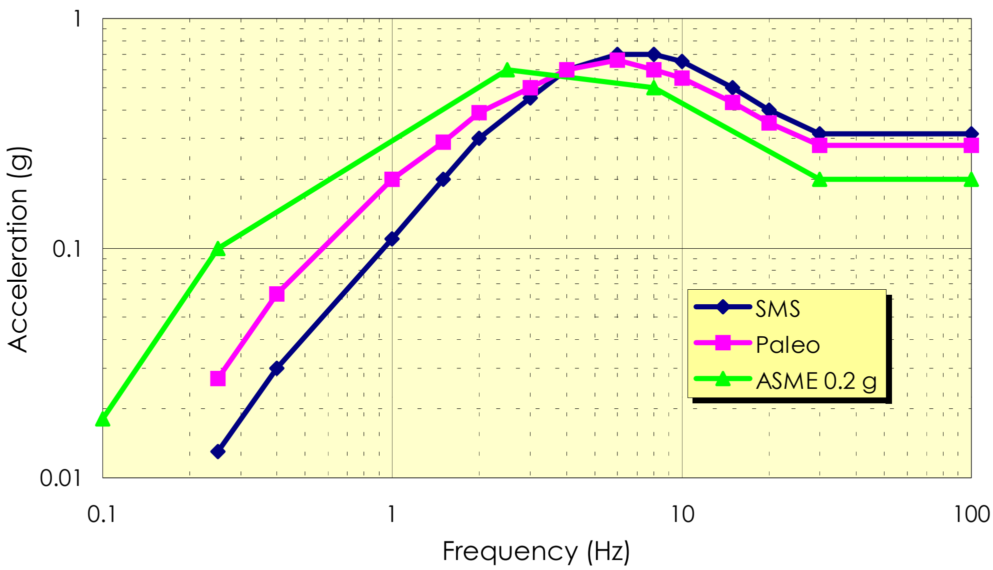

Figure 3.11: Comparison between the generic site "ASME" and Cadarache site specific Design Response Spectra (SMS and Paleo, both being applied)

Studies were launched to estimate the capacity of the Tokamak Building, as designed by the ITER team, to cope with Cadarache seismic conditions and to determine the necessary adaptations and reinforcement if any. Two studies were made in parallel and the first results are:

- **Response of the ITER generic tokamak building to the Cadarache spectrum**: a 3D mesh of the building was made (see Figure 3.12) and then a spectral analysis. About 150 eigenmodes have been identified in each of the three directions, covering a frequency range between 0 and about 20 Hz. Main modes, for which the effective mass is the largest, are shown in Table 3.1. Main modes in the horizontal directions, x and y, are in the range 3.6 – 3.7 Hz. Within this frequency range, the Cadarache spectrum and the ITER generic spectrum are rather similar (see Figure 3.11). **Stress computations show that the building, as it is now designed is able to withstand the Cadarache seismic conditions without any major reinforcement.** However, a few weak points have been identified at the level where the superstructure is connected to the upper slab (see Figure 3.12). This problem is **not site-specific** and the attachment would have to be redesigned in any case. The studies have been made in close collaboration with the ITER Joint Central Team and have shown a possible interaction between the tokamak and the building: further studies will be performed to complete the sensitivity analysis of the Tokamak Building and tokamak versus uncertainties such as stiffness (soil, mechanical supports, concrete, etc.) and distribution of masses (in building levels, in vacuum vessel ports, etc.). For the Cadarache site, considering that the soil is extremely stiff, the cross coupling of the Tokamak and Building modes is foreseen to be insignificant. The work has already been initiated in the ITER team yielding a preliminary report. Floor spectra are also computed; they will be used to assess the design of the safety related equipment inside the tokamak building. It has to be noted that this assessment has not yet been done for the generic site.

Direction	Frequency (Hz)	Effective mass	Comments
Horizontal X	1.74	7.1 %	Superstructure mode
	3.63-3.66	38.3 %	Building + tokamak translation and bending
	3.91 & 4.34	12.4 %	Building + tokamak / superstructure in opposition
Horizontal Y	2.22	0.1 %	Bending mode of the north front wall
	3.63-3.95	52.6 %	Building + tokamak translation and bending
	4.70 & 5.22	9.3 %	Building + tokamak / superstructure in opposition
Vertical Z	2.54	0.7 %	Bending mode of the roof support
	6.73-6.97	85.1 %	Overall vertical motion of the building

Table 3.1: Main Eigenmodes of the Building

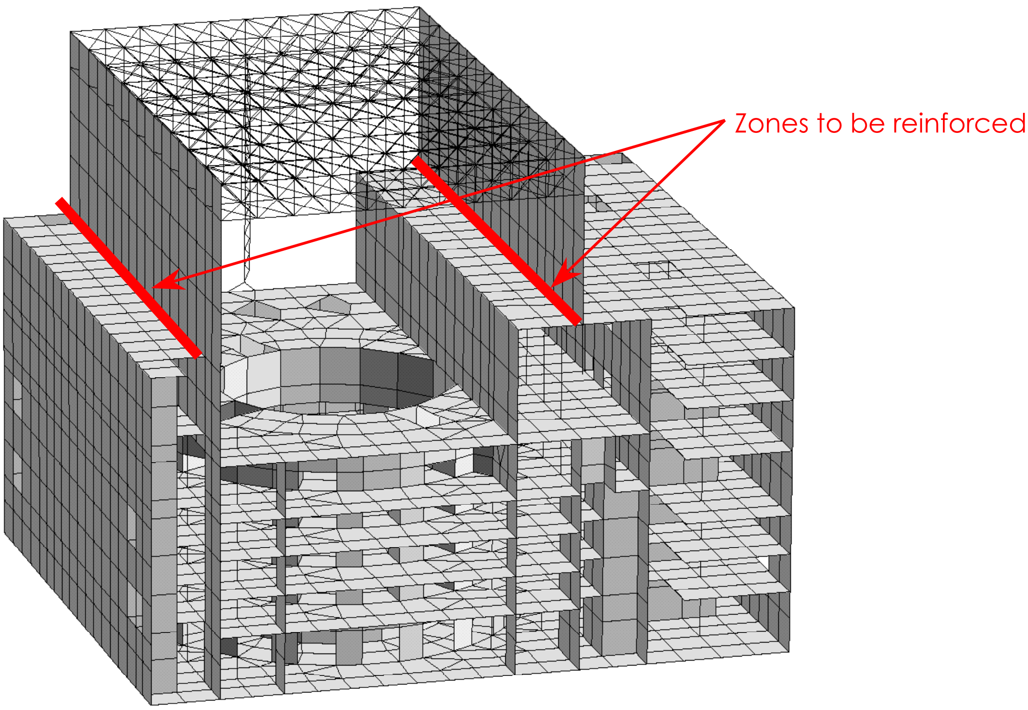

Figure 3.12: 3D Tokamak Building Mesh and necessary Reinforcements (see arrows)

- **Study of the use of paraseismic bearings for the ITER tokamak building**: These bearings are made with elastomer foils interleaved with stainless steel plates, implanted on specific concrete supports (see Figure 3.13). They are commonly used as supports for bridges and more specifically for nuclear buildings. Due to the excellent quality and homogeneity of the limestone in Cadarache, it would be possible to use such bearings for ITER. A preliminary design and layout (see Figure 3.14) have been proposed, leading to a decrease in the overall acceleration on the building and then on the equipments to 0.1 g, i.e. two times less than for the generic design. Significant savings are expected in the design of the building and all inner equipment thanks to the reduced acceleration. On the other hand, an overall motion of the building of roughly 75 mm is foreseen, with a frequency around 0.56 Hz. The interfaces with nearby buildings will need to be checked carefully because of this motion (see Figure 3.15).

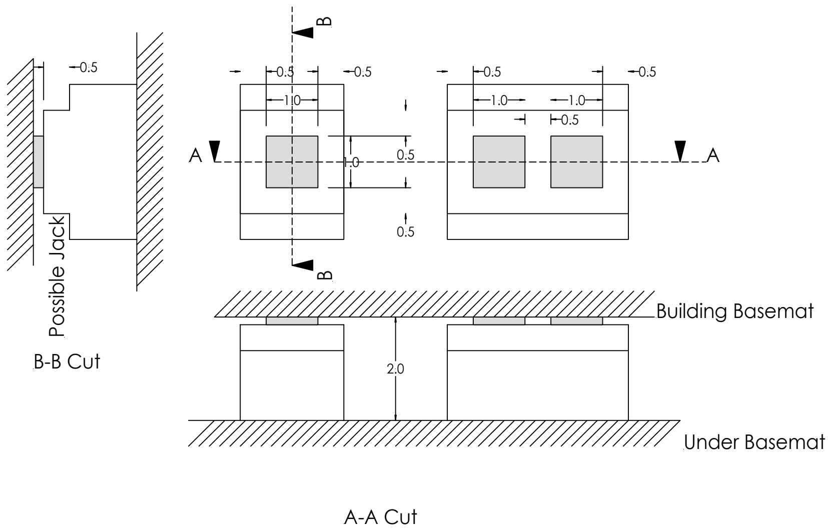

Figure 3.13: Schematic of 1 m² Paraseismic Bearings

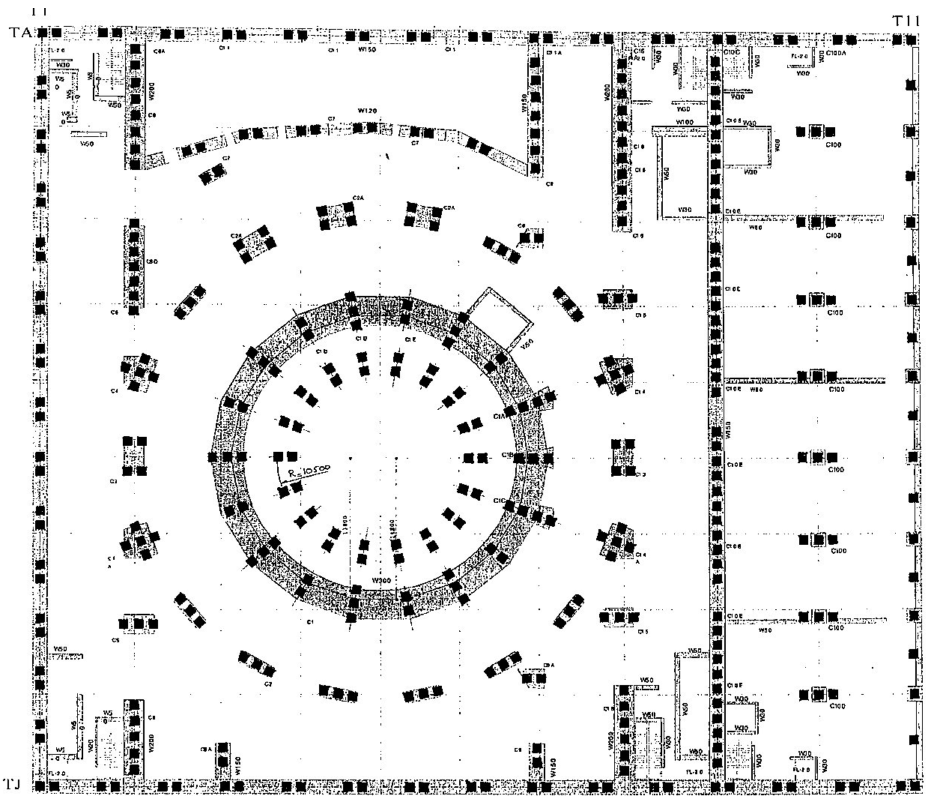

Figure 3.14: Position of the 400 Paraseismic Bearings under ITER Tokamak Building

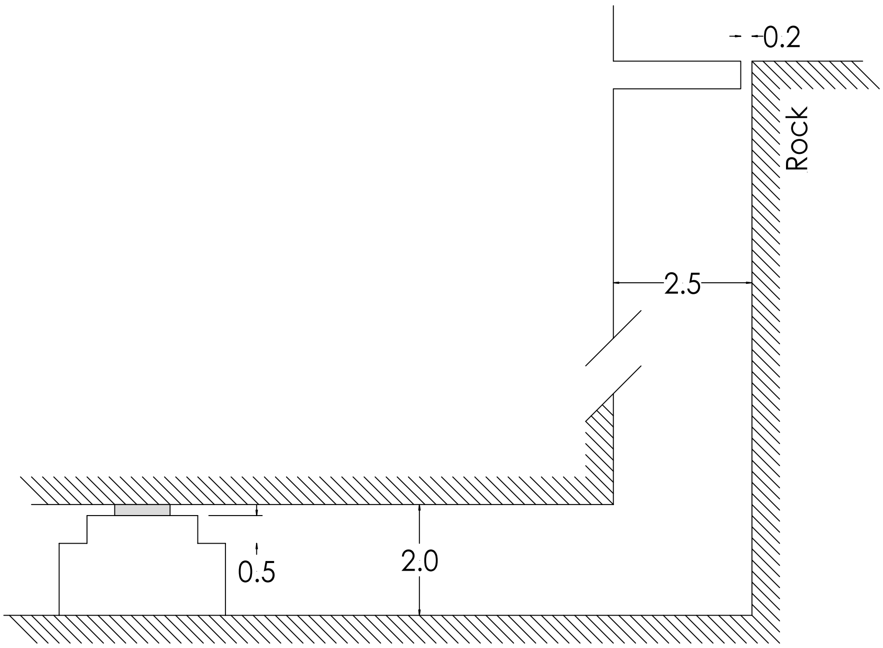

Figure 3.15: Principle for External Walls

Both options (local reinforcement of tokamak building and the use of paraseismic bearings) are feasible and show that the location of ITER is possible in Cadarache, with respect to the seismic level, without major modifications as compared with the generic design.

In the hypothesis of paraseismic bearings, the interface between the building and outer equipment must be carefully looked at.

3.4. Heat sink and water supply

A consumption of 1.5 million m^3 per year has been estimated for the cooling water circuits (SR.B and SA.B). This is roughly equivalent to the actual total consumption of the Cadarache research centre. It will, therefore, be necessary to install a new supply system. Amongst several solutions, one possibility is preferred: supply by means of gravity from the EDF canal of Vinon-sur-Verdon. The investment cost for this solution are slightly higher than for the other possibilities, but this is offset by the reduced cost during exploitation since no pumping station will be necessary (see Figure 3.16) The climate in Cadarache, warm but very dry in the summer, allows the overall dimensions of the cooling towers to be reduced, the wet bulb temperature in Cadarache being 24 °C (against 29 °C in the hypothesis taken by ITER). However, the displacement of the cooling towers leads to an increase in the length of pipe work necessary by 300 m (2 x dia 2 m) with respect to the calculated length.

About two thirds of the water evaporates in the cooling towers. The rest will most likely be discharged into the Durance, after the necessary controls, making use of the current discharge outlet of Cadarache.

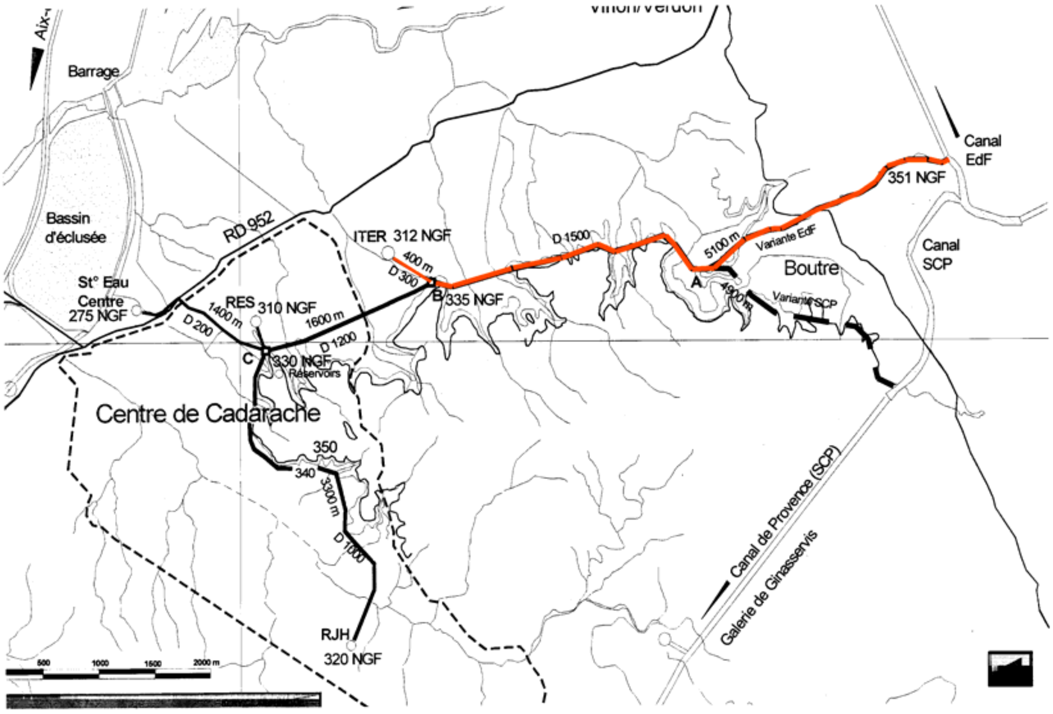

Figure 3.16: Possible Water Supply Route

3.5. Electrical power

The Network capability to supply the ITER Electrical Power at Cadarache has been tested with reference to the ITER site requirements and assumptions reported in chapter 2.5. The ITER electrical loads are divided in Steady State Electrical Power Network (SSEPN) and Pulsed Power Systems (PPS). The first one is mainly related to the power required by the ITER auxiliaries, while the Pulsed Power is to supply ITER poloidal and toroidal coils and additional heating systems. The active power required for SSEPN is P = 120 MW and the reactive power is Q = 60 Mvar. The active and reactive power assumed for PPS are, respectively P = 500 MW, Q = 400 Mvar during 1000 s every 1800 s.

The electrical network around Cadarache is well equipped with many lines and two powerful nodes:

- **Boutre**: 5 km east of the ITER site, with an interconnection at the 400 kV / 225 kV level and one autotransformer;
- **Sainte-Tulle**: 8 km north of the ITER site, with an interconnection at the 225 kV / 63 kV level.

Moreover, Tore Supra is already supplied by a 400 kV dedicated line and the Cadarache centre by two 63 kV lines, one being supplied independently by a nearby hydroplant as backup in case of emergency. The current high voltage supply situation is shown in Figure 3.17.

The public company RTE[11] has been asked to provide a supply scheme for ITER. Many options have been studied and compared with respect to technical, financial and environmental aspects. This last aspect has been decisive since the visual impact of 225 kV and 400 kV pylons is significant. The presently foreseen upgrades due in 2010 to the current high voltage supply scheme are shown in Figure 3.18.

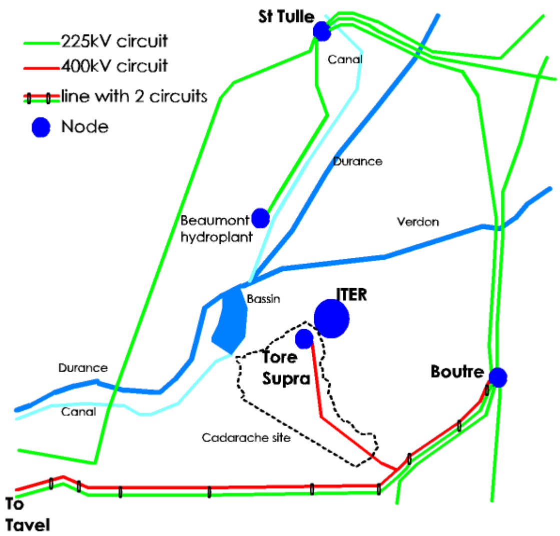

Figure 3.17: Current High Voltage Supply Situation

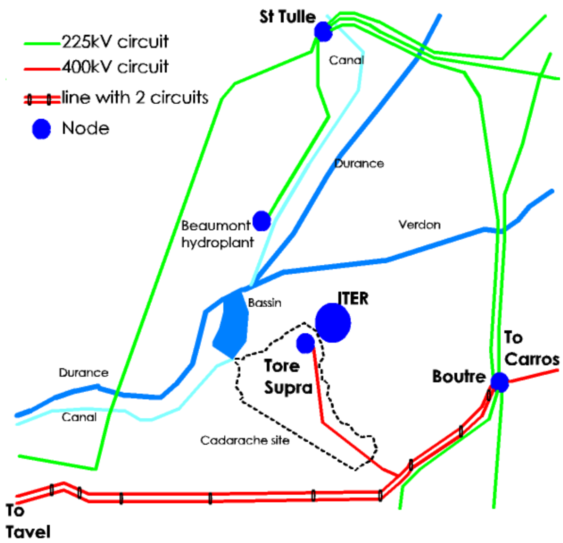

Figure 3.18: Foreseen High Voltage Supply Scheme (2010)

All the modifications are on CEA property:

- Creation of a new 400 kV / 225 kV node on the east boundary of Cadarache centre;
- Modification of the 400 kV existing T connection with the addition of 3 breakers to improve the reliability;
- Extension of the 400 kV line from Tore Supra to ITER;
- Construction of a double 225 kV line from the new node to ITER in parallel with the 400 kV line.

The proposed ITER high voltage supply scheme is presented in Figure 3.19.

The scheme fulfils all ITER site requirements (SR.C).

The design assumptions with respect to the reactive power are not satisfied because the assumed 400 Mvar would cause too high a voltage drop on the network ($\Delta V > 6\ \%$). For this reason, the power of the fast ($\Delta t \sim 10$ ms) ITER static VAR compensator will have to be increased from 540 Mvar to 750 Mvar and driven as voltage regulator (SA.C1 and SA.C2). In this way the maximum voltage drop can be maintained within an

[11] Réseau de Transport de l'Électricité, part of Électricité de France

acceptable value (< 4 %). This design modification will have a modest impact because there are margins in the present design with respect to the thyristor design.

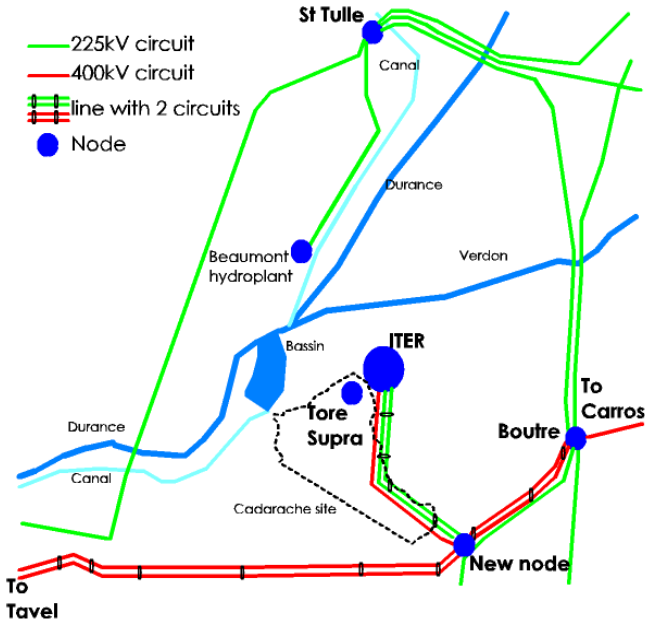

Figure 3.19: Proposed ITER High Voltage Supply Scheme

On the other hand, the design assumptions with respect to the active power (500 MW) can be met with a well acceptable voltage frequency variation (< 50 mHz). In addition, an active power up to ± 1000 MW seems to be deliverable from the grid for a short time (Δt ~ 5 s) instead of the assumed ± 60 MW. On this basis, a scheme with only a double 400 kV line should be studied in detail, leading to significant cost savings on both site adaptation and generic design. Such a large active power step that can be supplied and/or received by the grid and the high value of reactive power locally compensated can also lead to other possible system simplifications and cost savings (poloidal coils switching network, main step down transformers rating, reactive power requirements by poloidal and toroidal converters…). A detailed study will optimise the whole system.

3.6. Transport of heavy and large components

The transport of large and heavy components to Cadarache, which is located at some tens of kilometres from the sea, requires specific studies.

A review of all dimensions and weights of these components has been made in close collaboration with the ITER Joint Central Team. The results, a basis for all further studies, are shown in Table 3.2 (SR.D1 and SR.D2). Since no transport and handling study has yet been undertaken in the frame of the ITER reference design, an estimation of the weight and the size of the handling and packaging devices has been done. In order to remain within the width dimension of the vacuum chamber (8.50 m) the possibility to transport the toroidal field coils (TF coils) in an angled position has been envisaged.

Component	Number	Width (m)		Length (m)		Height (m)		Weight (t)	
Equipment		Bare	Packed	Bare	Packed	Bare	Packed	Bare	Packed
Vacuum vessel 40° sector	9	8.23	**8.50**	12.02	12.50	6.42	**6.90**	600	**700**
TF coils flat	18	9.13	9.30	16.80	17.00	2.80	3.00	280	320
TF coils at 33°2		8.30	**8.50**	16.80	**17.00**	5.96	6.27	280	**350**

Table 3.2: Dimensions and Weight of ITER Components

A preliminary study has indicated that a specific articulated convoy would be necessary for the transport of the packages.

The height constraint hinders passage under most viaducts and bridges along a classic itinerary. The width constraint imposes problems, often insurmountable, with respect to the passage of towns and other built-up areas. The weight constraints give problems for each bridge or viaduct to be crossed and also in a more general way on the distribution of weight along the axles of the transporting unit.

Two study contracts for the transport by road have been given to the public agency "Centre d'Études Techniques de l'Équipement" (CETE):

- in a first instance, the use of an already existing itinerary for "convoi exceptionnnel[12]" between Fos-sur-Mer (Marseille) and Cadarache. Certain sections would require technical adaptations, in particular roundabouts and bridges, but no administrative difficulty is anticipated. This first scheme requires the use of a section of EDF canal (see below);
- in a second instance, a second route, only by road has been evaluated, both technically and administratively. It has the advantage to be faster (no load transfers to and from the barges), but would require more technical adaptations.

Complementarily, the "Centre d'Ingénierie Hydraulique d'EDF" analysed the transportation on the Durance EDF canal by means of ad-hoc barges. One hydroelectric power station would be by-passed via a specifically constructed track. The use of about 40 km of the canal requires, besides the manufacture of the barges, the modification of a few bridges and the construction of specific handling equipment for loading and unloading the components on the barges.

The combination of these three studies on large and heavy components has allowed the definition of two itineraries:

- **The first route follows a mixed itinerary**, road and fluvial, starting from the Marseille-Fos harbour (see Figure 3.20):
  - The Caronte canal and the Étang de Berre on fluvial barge, until Berre l'Étang town;
  - Part of the "abnormal load route" until Mallemort;

[12] Road already qualified for "exceptional" transport

- The EDF-Durance canal up to Peyrolles, including by-pass of the hydroelectric station at Saint-Estève;
- Road and motorway A51 up to Cadarache, implying an enlargement of the D952 road near Mirabeau bridge.

This itinerary is technically feasible and realistic from the point of view of administrative authorisation since the impact on the general public is low.

- **The second route, totally by road between Berre l'Étang and Cadarache**, has the advantage to avoid the load transfers, necessary on the reference itinerary. It will reduce the time necessary for the transports (3 days, compared to 10 days), as well as the risks and cost. However this itinerary requires more technical adaptation of existing roads.

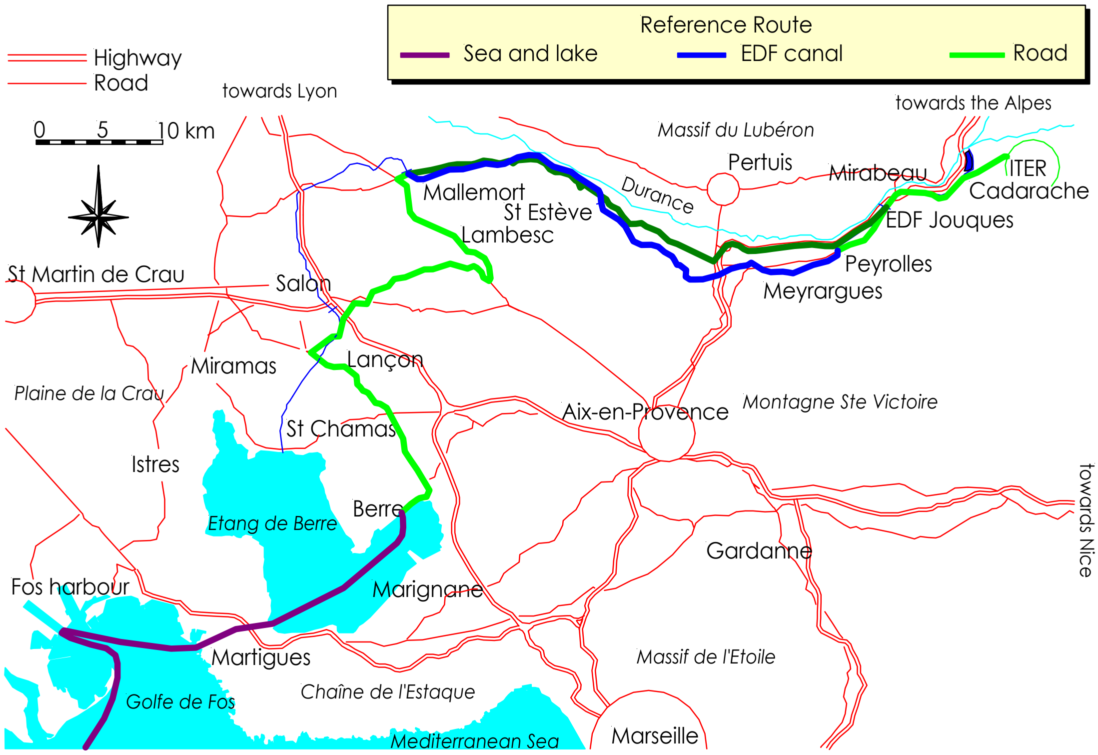

Figure 3.20: Reference routes (by road only, or combination of road and canal), from Fos harbour to Cadarache