INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR (ITER) PLANT LAYOUT AND SITE SERVICES

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Abstract

The ITER site has not been determined at this time. Nevertheless, to develop a construction plan and a cost estimate, it is necessary to have a detailed layout of the buildings, structures, and outdoor equipment integrated with the balance of plant service systems prototypical of large fusion power plants. These services include electric power for magnet feeds and plasma heating systems, cryogenic and conventional cooling systems, compressed air, gas supplies, de-mineralized water, steam, and drainage. Nuclear grade facilities are provided to handle tritium fuel and activated waste, as well as to prevent radioactive exposure of either the workers or the public. To avoid interference between services of different types and for efficient arrangement of buildings, structures, and equipment within the site area, a plan was developed which segregated different classes of services to four quadrants surrounding the tokamak building, placed at the approximate geographic center of the site. Location of the twenty-seven buildings (Table I) on the generic site was selected to meet all design requirements at minimum total project cost. A similar approach has been used to determine the location of services above, at, and below grade. The generic site plan can be adapted to the site selected for ITER without significant changes to the buildings or equipment. Some rearrangements may be required by site topography resulting primarily in changes to the length of services that link the buildings and equipment.

1. INTRODUCTION

The ITER EDA activities included the development of a site layout and an engineering design of site services, which are prototypical of large fusion power plants [1,2]. It was clear from the beginning that the design does not present any feasibility issues, however, the cost of the balance of the plant (including all buildings) represents 40% of the direct construction cost and the design for the balance of the plant requires careful definition of the requirements and their early optimization.

2. SITE

The ITER design, in the absence of a specific site, had to be developed to be acceptable at any site proposed by the four ITER Parties. As a substitute for site data, a set of compulsory site requirements and non-compulsory site design assumptions was developed and issued in 1996 [3]. These requirements and assumptions provided the basis for a generic site layout and design requirements for all site-sensitive buildings, structures, and outdoor equipment. They have been used for integration of buildings and services in a site plan, for the development of reliable project cost estimates, and construction schedules. Two requirements that significantly influenced the design include an assumed site seismicity [an acceleration of 0.1g for an earthquake which can happen during the lifetime of the machine (probability $10^{-3}/y$) and 0.2 for an improbable ($10^{-4}/y$) event], and an assumed limitation to size and weight of received shipments. Shipments were limited to maximum dimensions of 14 m width, 19 m length, and 6 m height; with one of these shipments being approximately 1300 tonnes and a hundred or more shipments in a range between 100 and 800 tonnes. The assumption of a limited seismicity simplified the design but required its compatibility with a seismic isolation building option for sites with higher seismicity. The capability to receive large shipments has reduced the number and size of buildings for on-site fabrication and assembly of large components.

To avoid excessive interference between different services and for efficient arrangement of buildings, structures, and equipment within the site, the following plan was accepted:

a) The tokamak building is placed at the approximate geographic center of the site:

b) Buildings, structures, and services are arranged relative to the tokamak building with the following considerations:

- The area to the east (compass directions are arbitrary) is allocated to water cooling and non-electrical site services;
- The area to the west is allocated to electrical power supplies and the cryoplant;
- The area to the north is allocated to construction activities; processing and handling of radioactive material after startup;
- The area to the south is allocated to worker access, receiving materials and operating supplies.

Figure 1 represents the ITER generic site as it would appear in an aerial view from southeast to northwest. The north-south direction is along the entrance road to the site. The electrical switchyards are at the extreme western part of the site and the heat sink (mechanical draft cooling towers) is located to the east. The tall, rectangular building near the site center with an exhaust stack to the right side is the crane hall portion of the tokamak building complex.

All of the buildings and outdoor equipment are connected by a network of roads. The north and south entrance roads to the tokamak building are 50 m wide to allow the horizontal entry of large coils and other prefabricated components. A wide loop road around the east side of the site provides access to the north entrance from the coil fabrication building.

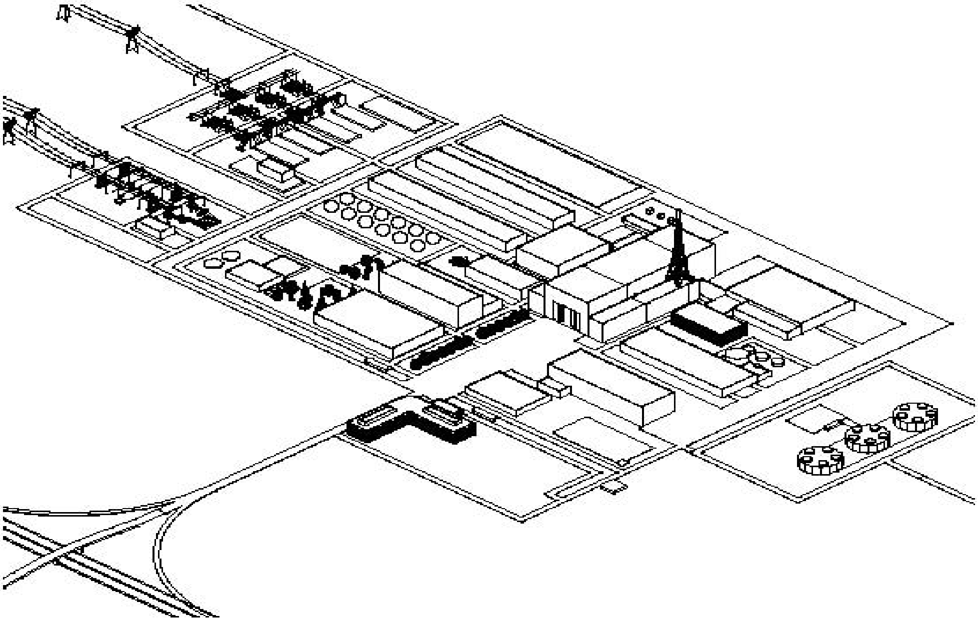

FIG. 1. Aerial view of generic ITER site.

3. TOKAMAK BUILDING

The size of the tokamak building was determined by the tokamak assembly and service methods. The assembly may be performed using a "vertical method" with an overhead crane having a capacity up to 1500 tonnes, or by a “horizontal method" using horizontal transporters instead of a crane. We can not prove that the "horizontal method" is impossible; however, for the *first of a kind* machine, it imposes so many limitations that the "horizontal method" for ITER has been rejected. Application of a "vertical assembly method" to a monolithic central solenoid (CS), which has to be lifted over the toroidal field (TF) coils, requires that the height of the building must be greater than the length of the CS, plus the height of TF coils and their gravity supports. All together, this leads to a height of ~ 96 m from the roof to the bottom floor.

An optimum embedment of the building was determined by site geotechnical characteristics and shielding requirements during tokamak operation and servicing. With the total weight of the tokamak, ~ 60,000 t, we must expect soil loading to be about ~ 70 t/m^2. To make the machine siteable at any reasonable location, we must install pilings in the ground or embed the machine below the level - 30 m where such bearing capacity is a normal value for a typical ground condition. Operation of a fusion reactor with a fusion power ~ 1500 MW and servicing such a reactor require an additional (~ 2 m thick) biological shielding around the machine, and around paths for transportation of irradiated internal components. With the selected approach of servicing through horizontal ports, an embedment of transportation paths permits significant savings on shielding. These considerations led to the design with an embedment of ~-50 m. This puts the entire tokamak machine below grade. This choice may be reconsidered when geotechnical and meteorological site data are available.

Heavy congestion of equipment, pipes, electrical buses, and transportation paths around tokamak requires an extremely careful consideration of equipment layouts and proper balance between the costs associated with a larger pit diameter, versus difficulties of assembly and maintenance in a smaller pit. The problem was amplified by a requirement to have a design compatible with seismic isolation and by a safety requirement to have a double confinement around the plasma volume as well as all its extensions. As a result, all primary cooling systems were placed inside the pit, within special vaults, with the capability to withstand the steam pressure during external LOCA accidents. The primary piping and vault structure form extensions of the double confinement and are within the seismic isolation boundary. Only secondary cooling pipes, electrical cables and HVAC ducts cross the seismic isolation gap between tokamak pit and external structures. To limit the pressure within 240 kPa (abs), a value acceptable from a construction point of view, the water volume in any primary cooling loop had to be limited to ~ 65 m^3. As a result, the cooling system had to be subdivided into 18 loops. The large number of relatively small loops has increased the cost of the cooling system and complicated its servicing. This arrangement is a consequence of an approach to plasma facing components as experimental equipment, without any safety credit, and of very strict limits on tritium emission. This may not be necessary for a power reactor with an established plasma facing component design and it may be reconsidered for ITER when site specific safety requirements are better established.

ITER is an experimental machine. An elaborate system of remote extraction, transportation, and maintenance in a hot cell has been developed to allow for the replacement of components which have become radioactive and contaminated. Many component parts will be reinstalled in the tokamak machine in order to minimize cost and the generation of radioactive waste. Transportation of the objects from the tokamak machine to the hot cell building will be accomplished using air-cushion vehicles and a high capacity lift. Unshielded transport containers travel between the tokamak building and the hot cell building below grade, where heavy building members provide shielding to protect workers and the public. All horizontal ports are accessible by remote handling vehicles using transportation galleries which surround the pit. The air-cushion transportation system for irradiated internal parts has been selected because of its better flexibility and compatibility with smooth, easily cleaned surfaces.

All systems and functions which involve the storage or handling of radioactive material are located in the tokamak, tritium, hot cell, and radwaste buildings. These buildings are connected by dedicated structures designed to provide shielded pathways and to facilitate access control. These buildings are arranged so a contiguous boundary can be established, and the passage of workers and material can be strictly controlled. Rooms and spaces within this region of the ITER plant have been designated according to the expected level of radioactive material or direct radiation expected to be present during various plant operating modes. Drainage from these areas will be collected in tanks within the low level liquid radwaste system. Solid radwaste will also be collected and packaged for eventual disposal by the host country. Airborne contamination and tritium, which might be in the radiologically controlled areas, are collected and processed by ventilation systems. The tokamak, tritium, hot cell and radwaste buildings are served by several ventilation systems, each of which is subdivided into zones according to the function of the building and particular activity of the designated location. Pressure gradients are controlled to assure that leakage is from the outdoors to areas of low contamination potential, and then to areas of higher contamination potential. These zones are all maintained at negative pressure, and exhausted to a tall stack. In addition, areas where a tritium release is possible are equipped with atmospheric detritiation systems. Here, tritium is collected as water and sent to the water detritiation system for tritium recovery and recycling. Where high levels of dust are possible, the ventilation systems will include HEPA filters.

Space around the tokamak machine is at a premium. Design and integration of power and cooling routes, transportation and information channels, ventilation ducts, personnel access and escape routes would be very difficult (if not impossible) without use of CATIA - 3D Computer Aided Design (CAD). Also, 3-D CAD has been used in special studies, which have confirmed the ability to assemble and service equipment within the pit.

4. ITER SITE SERVICES

Proper functioning of the ITER tokamak machine is completely dependent on the provision of a number of services: ICRH and ECRH, high and ultra high frequency power, electrical power (both steady state and pulsed), cooling water, cryogenic fluids, compressed air, gases and other services that must be available. Above grade services have been limited to switchyards and a few other critical locations because of the need to bring heavy equipment and large components onto the site for construction, tokamak assembly and maintenance. Most of the electrical and cooling services have been placed in tunnels, pipe chases or have been buried underground to avoid interference.

The steady state electric power network (SSEPN) (see FIG 2) supplies a maximum ~ 235 MVA of power to ITER systems (excluding coil and auxiliary heating power). The main power system ("Class IV power") has redundant 220 kV connections to the regional utility high voltage grid (assumed 220 kV). The voltage is stepped-down to 11 kV via two main transformers and made available for site distribution through eight main distribution buses. For high reliability, the system design allows for redundant load paths to all equipment at the 220 and 11 kV levels.

The SSEPN design is relatively straightforward; the main difficulty has been to determine electrical loads for the operational states of ITER (Table 2). About 50% of the SSEPN power is routed to the tokamak building complex, where over 14,000 equipment items are connected at voltages ranging from 120 V to 11 kV. Efficient routing of power and cooling requires a trade-off between the proximity of pumps, transformers, etc., to the numbers of pipes and cables that must be routed to the tokamak area. The delivery network has been optimized within the constraints of the buildings and equipment. The SSEPN has fourteen service zones; four of which service the four quadrants the tokamak building. Each zone has a dedicated load center (LC) with a cable tunnel connection to the switchyard. At the LCs, a portion of the incoming 11 kV power is stepped down to 3.3 and 0.48 kV, to service many smaller loads.

The SSEPN is also designed to provide emergency (“Class III”) power to sensitive consumers. This emergency power is supplied through separate distribution cables and equipment, which are physically separated and protected from Class IV cables and equipment. Under normal conditions, the Class III main distribution buses are energized through Class IV power connections. In the event of loss of Class IV power, Class IV power connecting switches are opened and the Class III buses are supplied by four on-site diesel generators located in the Emergency Power Building. The Class III power system is single active failure tolerant. Class III power equipment is divided into two channels, which are also physically separated and protected. Within each channel, loads are divided into Priority 1 and Priority 2. Priority 1 loads include all safety related loads and are resupplied within 30 seconds after loss of Class IV power. Priority 2 loads are supplied after all Priority 1 loads are satisfied and after any faults have been cleared.

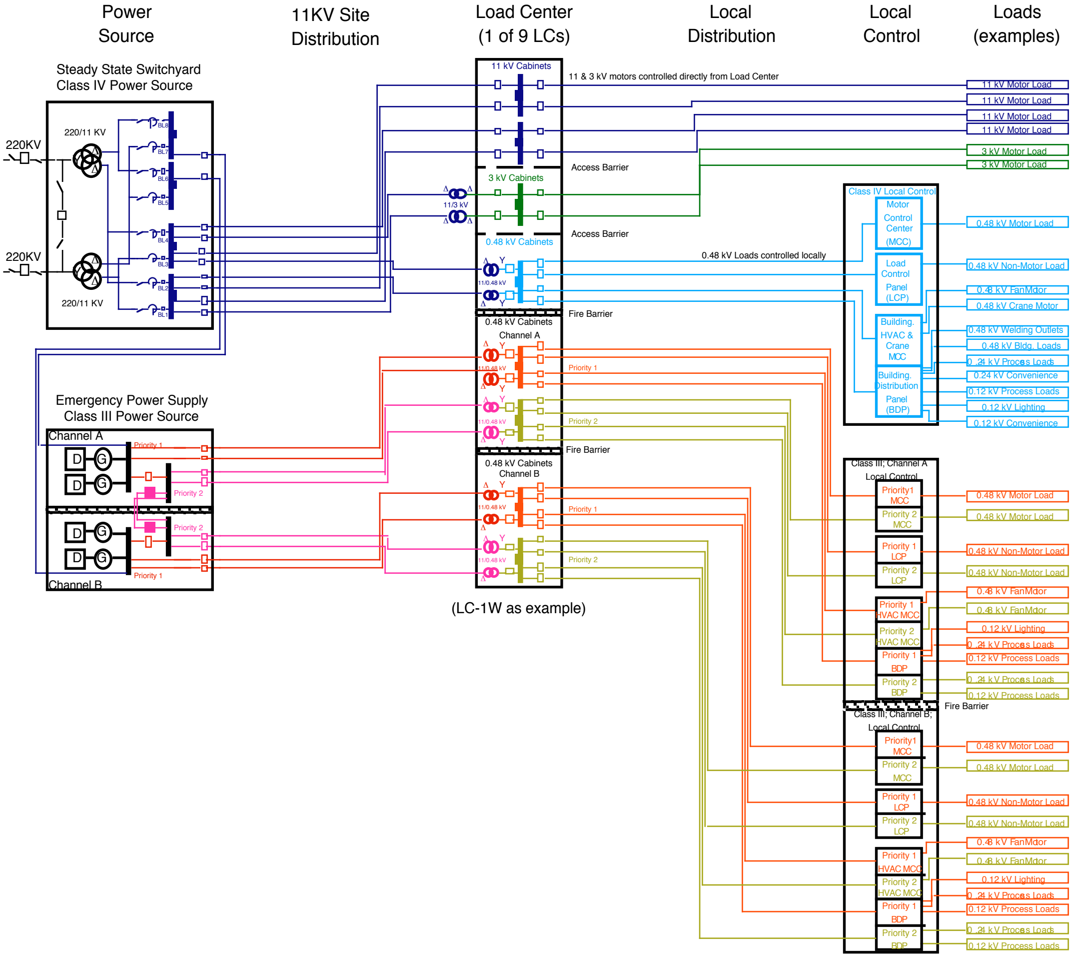

FIG. 2. The steady state electric power network

The cooling system is designed to reject 2,600 MWt from several hundred individual heat source connections throughout the site. It follows the same routing principle as the SSEPN. Water cooled by the cooling towers will be delivered by gravity flow through large penstocks to pumping stations located at - 6 m in the east and west tokamak services buildings for distribution to client systems. To minimize cost, the cooling tower system utilizes a hot mixing basin to average the heat load over the pulse/dwell operation, thereby reducing the maximum duty to the cooling towers. The system is designed for a mean value of power generation taking into account a 1000/2200 pulse/dwell ratio. Additionally, the overall cooling system includes sub-systems to provide component cooling water for systems requiring high quality water and chilled water for low temperature equipment (e.g., HVAC). These systems also use a site zone distribution approach to minimize the overall system cost.

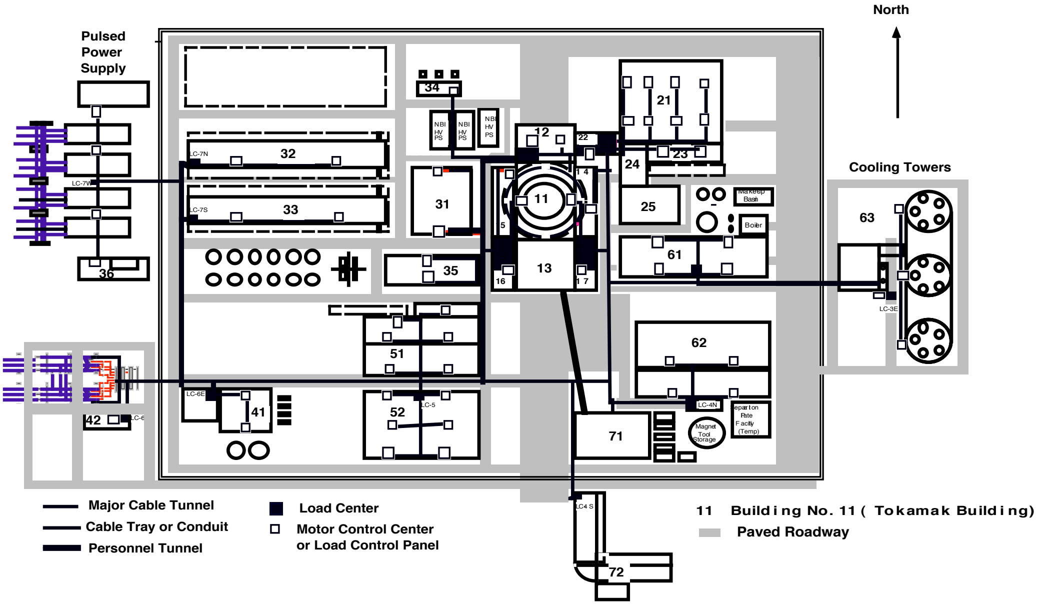

FIG. 3. Site electrical services (numbers on buildings correspond to Table I and II).

Figure 3 shows a site plan with the tunnels, cable trays, and other services indicated. Small black or white boxes indicate the location of load centers and motor or load control panels respectively. Pipes are placed in pipe chases or are buried below the tunnels and other services.

5. CONCLUSIONS

The ITER Generic Site plan has validated the ITER site requirements and design assumptions by demonstrating that buildings and services can be integrated within the cost and schedule goals of the project. They are not overly restrictive and an acceptable construction plan has been developed based on the generic site layout. The sequence of construction activities is a direct result of the integration process. For instance, cable tunnels and pipes chases are constructed early in the schedule so they do not interfere with delivery and assembly of tokamak components. However, placement of cables and pipes in these underground structures can be deferred until later in the schedule, closer to the time they are needed for commissioning.

The integration of site services, such as electrical and cooling water distribution, into the site plan has provided the basis for more reliable cost estimates and construction schedules.

The ITER generic site layout is a cost-effective integration of all the buildings, structures and services that must function together for the ITER mission. There is a high probability that the generic site plan can be adapted to the site selected for ITER without significant changes to the buildings or equipment unless changes are dictated by regulatory requirements. Some rearrangements may be required by site topography, but this will result primarily in changes to the length of services that link the buildings and equipment.

References

[1] “Technical Basis for the ITER Final Design Report, Cost Review and Safety Analysis (FDR)”, to be published by the IAEA (1998).
[2] SHIMOMURA, Y., “ITER Overview (including Safety)”, this Conference.
[3] ITER EDA Documentation Series No. 9, IAEA Vienna (1996) 41-55.

TABLE I. ITER BUILDINGS, OUTDOOR STRUCTURES, AND AREAS

Key	Buildings, Structures, Areas	Foot Print m^2	Floor Area m^2	Volume m^3
11	Tokamak Hall	5,630	29,900	536,000
12	Laydown Hall	2,690	5,380	174,000
13	Assembly Hall	3,580	7,170	232,000
14	Tritium Building	1,670	8,360	71,400
15	Electrical Termination Building	1,670	6,690	71,400
16	Tokamak Services Building - West	1,220	4,880	47,600
17	Tokamak Services Building - East	1,220	4,880	47,600
21	Hot Cell Building	8,430	36,350	43,950
22	Tokamak Access Control Structure	1,300	2,600	24,000
23	Radwaste Building	1,404	2,808	23,026
24	Personnel Access Control Structure	1,260	1,260	5,670
25	Personnel Building	2,592	9,504	38,892
31	Magnet Power Network/Switchgear Building	4,440	8,880	88,800
32	Magnet Power Conversion Building - North	6,000	12,000	105,000
33	Magnet Power Conversion Building - South	6,000	12,000	105,000
34	NBI Power Conversion Building	720	720	7,200
35	RF Heating Power Supply Building	2,500	5,000	57,400
36	Pulsed Power Supply Auxiliary Building	380	690	5,160
41	Emergency Power Supply Building	3,620	6,050	43,610
42	Steady State Power Supply Auxiliary Building	270	270	1,620
51	Cryoplant Cold Box/Dewar Building	8,030	8,030	186,400
52	Cryoplant Compressor Building	10,350	10,350	170,800
61	Site Services Building	8,300	8,300	103,000
62	PF Coil Fabrication Building	9,330	9,330	286,650
71	Control Building	2,880	5,760	40,320
72	Laboratory Office Building	5,500	17,550	67,400
73	Cryoplant Perimeter Guard House	240	240	960
74	Control Room Perimeter Guard House	240	240	960
75	Vehicle Entry Perimeter Guard House	240	240	960
	Building Totals	**101,706**	**225,432**	**2,786,778**
37	Pulsed Power Switchyard	70,000		
43	Diesel Fuel Storage Tanks	2,500		
44	Steady State Switchyard	22,000		
53	Gas Storage Yard	9,000		
63	Cooling Towers and Basin	20,000		
64	Plant Service Water Storage Basin and Tanks	2,600		
	Structure Totals	**126,100**		
	Outdoor Storage/Expansion Areas	30,000		
	Parking Areas	50,000		
	Roadways	130,000		
	Area Total	**210,000**		
	Grand Totals	**437,806**	**225,432**	**2,786,778**

TABLE II. ITER PLANT STEADY STATE LOAD SUMMARY

System		**Class III Power** **No. of**		**Class IV Power** **Plant State**	
	Powered Eqpmt.	**Operation (kW)**	**Maintenance (kW)**	**Operation (kW)**	**Maintenance (kW)**
Fueling	59	10	10	395	260
Remote Handling	469	0	743	0	3,747
Primary Heat Transfer Systems	1,072	140	686	46,530	4,653
Vacuum Pumping	3,301	376	376	1,210	1,039
Tritium Plant	575	2,758	2760	3,811	3,813
Cryoplant	414	62	62	47,786	18,610
Heat Rejection	211	410	50	18,339	5,750
Coil Power Supply	131	1,250	940	2,850	900
Additional Heating	268	446	394	6746	454
SSEPN	387	405	405	555	555
Supervisory Control System	650	151	151	151	151
Diagnostic	500	400	100	2,000	500
Waste Treatment	440	0	9	1282	1476
Buildings	17,137	501	2,923	14,185	20,083
Liquid Distribution	354	43	1,054	14,381	13,042
Radiological Protectior	355	131	131	202	202
Gas Distribution	118	43	26	2160	2160
Others	429	190	178	232	247
Totals	26,870	7,273	12323	162,818	77,644