International Energy Agency Cooperative Agreement on Environmental, Safety, and Economic Aspects of Fusion Power
3rd Specialists Meeting on Component Failure Rate Data
IEA ESE/FP Task 5, Failure Rate Database
Meeting Minutes for 15-16 April 2002

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Dr. Peter Petersen, Assistant Program Director of the DIII-D tokamak facility, opened the meeting and welcomed us to the formerly sunny Southern California and to DIII-D. Peter then greeted each of us and discussed that the morning's presentations would be more of a "free form" discussion format and there would only be a few formal presentations. He also invited us to attend the daily DIII-D tokamak pre-operations meeting on tuesday morning. All meeting participants agreed that this would be worth attending.

Then Lee Cadwallader (task coordinator for IEA ESE Task 5) gave an introductory presentation on the structure of the meeting and on some recent IEA ESE news. Dr. Werner Gulden has announced that as Chair of the Executive Committee for this agreement, he will file for a renewal of the agreement this summer. He does not expect any difficulties in obtaining a new 5-year renewal. Lee's presentation slides are included in the CD of the meeting.

After this, Peter Petersen explained that the DIII-D is in operation during our visit. The operating schedule is constrained this year since the facility is funded to operate for 14 weeks and the plan is to reach the 14 weeks by 7 June 2002. That way, the General Atomics physicists will have enough time to analyze some of the operations data for presentation at the U.S. Tokamak Planning Workshop in June and other physics conferences in July. DIII-D operates 5 days/week, with an 8.5-hour day. They use one-shift operation.

Peter showed the fiscal year 2002 (FY-02) operations schedule. The squares depicting days for each calendar month are shaded to indicate operation or shutdown. There are sometimes lengthy shutdowns. A typical DIII-D schedule is 3 calendar weeks of operation and then 2 weeks of maintenance. There is always a mid-year maintenance outage for transformer inspection and maintenance. Peter explained that some equipment demands attention, thus forcing shutdowns to be certain minimum lengths. For example, the sixty diagnostic instruments on the DIII-D require about 1 week for calibration before pulse operation. A few diagnostics also require a calibration check immediately after machine shutdown. Peter stated that the Motional Stark Effect diagnostic instrument requires the most time of all diagnostics to calibrate. The Motional Stark Effect (MSE) instrument measures the plasma current density profile. Neutral particles can become polarized from the Stark Effect, which occurs when fast moving neutral particles experience an electric field. The angle that polarized particles travel is measured by a set of mirrors, lenses, photoelastic modulators, and a linear polarizer. The light is transmitted to detectors in a diagnostics area by fiber-optic cables. The detector consists of lenses, an interference filter and a photomultiplier tube.

Peter mentioned that another diagnostic, the Thomson scattering device, is also time-consuming to calibrate. In similar complexity to the MSE, the Thomson scattering diagnostic operates by shining a laser beam through the plasma. Some of the photons in the beam will scatter on plasma electrons and undergo a Doppler shift, which is proportional to the velocity of the electron on which it was scattered. Thus, by collecting the scattered light and measuring the frequency shift, the velocity of the electron can be determined. When the velocity distribution is known the temperature of the electrons can be determined. By counting the number of photons being scattered the electron density can be determined. The MSE and Thomson devices are important to understand the nature of the plasma, and are the two most important diagnostics. Lots of time is spent to maintain and calibrate the diagnostics in fusion experiments to ensure that results are as meaningful as possible, because the run time is expensive. Several years ago, when Peter Petersen last calculated it, a DIII-D plasma pulse cost about $5k.

Another time-consuming task is testing of the power supplies, which are used to establish the desired magnetic configuration and to control the plasma in addition to powering the auxiliary plasma heating sources (neutral beams and electron cyclotron heating). The power for plasma heating is needed to drive up the plasma temperature, to generate fusion power out of the plasma. The power supplies usually require two weeks of testing before an operating campaign, simply because there are so many power supplies in the facility.

Peter commented that the well-publicized commercial electrical power issues of the summer of 2001 did impact DIII-D. The power cost rose to $0.32/kW-h in Southern California and DIII-D could not afford power. The plant was shut down, but they could not afford to use the opportunity as a normal maintenance shutdown. The plant was depowered to minimal activity – only building support (lights, ventilation, security systems) and computers were operated. DIII-D cooling pumps were shut down. Liquid nitrogen was not available from the vendor. When a price cap of $0.069/kW-h was put into effect, DIII-D regained operation at that cost level. The DIII-D budget had a provision of $1M to purchase a new gyrotron, but the funds were used to buy electrical power instead. Now, the electricity price has stabilized at $0.11/kW-h.

The largest power draw at DIII-D is motor generator startup. This startup normally requires about 11 MW. The electric utility company's past rate structure required DIII-D to shutdown when the utility had peak load on its grid. DIII-D has now chosen another rate structure which is slightly more costly, but which does not include the unpredictable requirement for shutdowns.

DIII-D requires about $25M/year for 14 weeks of operation. The power costs about $2.5m/year, or roughly 10% of the costs, and there are other costs as well. Liquid nitrogen, other consumable items and refurbishments amount to almost 10% of the cost, and about 80% of the costs are for staff salaries. GA receives about $50M/year from the Department of Energy to operate and maintain the DIII-D facility; the other $25M is for planning, acquiring, analyzing, and presenting plasma data. The cost is about $300k to add one more week of plasma operations. For next fiscal year, the DOE is sending another $2 or 3M to increase from 14 to 21 weeks of plasma operations.

GA has roughly 40 scientists and plasma physicists on the DIII-D staff, and usually maintains a count of about 40 to 50 visitors (from LLNL, PPPL, MIT, ORNL, etc.).

The DIII-D staff has a plan to install resistive wall mode coils next year; this installation will require perhaps 6 or 7 months. The DOE funding to increase up to 21 weeks of operation will challenge the staff, given that half of the year will be a plant modification outage.

The DIII-D staff closely monitors radiation exposure, not only direct radiation at the site boundary, but also personnel exposure. Initial entry into the vacuum vessel after a vent generally has on the order of 9 millirem/hour. The staff endeavors to wait for one month before requiring a vessel entry; by then the radiation field has decayed to 4 millirem per hour. The individual worker dose goal for maintenance work inside the DIII-D vessel is typically 500-600 person-millirem/year. In 1996, the annual individual worker dose goal was 500 millirem, but the ALARA committee chose a more ambitious individual worker goal of 300 millirem per year for 1997 based on the expectation that there would not be any major vessel entries for the coming year. The DIII-D collective dose was 950 person-millirem in 1996. The personal dose goal has served much better at DIII-D (GA, 1998).

Some of the radiation-producing activation products from DIII-D operations are bromine isotopes in the epoxy insulation material in the magnet coils, and short-lived cobalt isotopes in the inconel vacuum vessel walls. The State of California sets the site boundary dose at a limit of 100 millirem/year of direct radiation. The DOE/General Atomics agreed limit is 40 millirem/year. The actual dose is only about 10 millirem/year at the site boundary. Initially, DIII was only a hydrogen machine, but there was an impetus to become a deuterium machine (D-D). Neutron shielding was added to be able to meet the site boundary doses and maintain ALARA for the facility. Now the DIII-D experiment has as much radiation shielding as the building floor can tolerate for weight load.

Then Peter Petersen presented some slides from his FY-2002 First Quarter Review, held on January 17, 2002. DIII-D were vented last summer. There are two types of vent. One is when nitrogen is admitted into the machine and no personnel entry is required. This is the cleaner of the two types of vent and is called a “clean vent”. After a clean vent, operation can usually be recovered within a day. The other vent, called a “dirty vent”, also begins with nitrogen, but the vacuum vessel is opened, air is admitted, and workers can enter for hands-on maintenance or inspection tasks. After a dirty vent, operation cannot be recovered within one day. A major ‘dirty’ vent usually requires at least 6 weeks of recovery time. The summer 2001 vent was a dirty vent during which two resistive wall mode coils and two PPPL articulating ECH launchers were installed. The staff also performed magnetic error field measurements and calibrated diagnostics from within the machine. The magnetic field errors diminish to machine performance since they tend to slow down plasma rotation, which allows can stabilize resistive wall mode instabilities. DIII-D can generate a 2.2 Tesla field on axis.

A recent electron cyclotron heating (ECH) accomplishment was reaching 5 seconds of operation at 1 MW for the CPI-P2 gyrotron. CPI is the Communications and Power Industries, Incorporated company (Microwave Power Products Division) of Palo Alto, California. The reason this gyrotron can reach such high power levels is that it has a diamond window, which can tolerate longer runs. Diamond does not absorb as much power as previous window materials, such as sapphire. Gyrotrons with diamond windows should be able to operate at times of up to 10 seconds. DIII-D has installed the CPI-3 gyrotron, and built a control system for the Gycom gyrotron units.

Six magnet correction coils outside of the machine were installed to reduce magnetic field errors. During the error fields measurements last year, the error fields were found to be smaller than was first anticipated.

Next, Peter Petersen discussed the Trouble Report database (Petersen, 1992; Petersen, 2000). The DIII-D uses a web-based trouble report system. Anyone can file an electronic trouble report, however most are filed by control room operators. Some fields of the electronic report are equipped with pull-down menus to allow quick selection of systems at fault, and to choose personnel assigned to the report. The typical time between plasma pulses is 12 to 15 minutes. If the machine cannot fire its next shot within 15 minutes of the last shot, then a trouble report is filed to document the cause of the delay and who is responsible to correct the situation. The computerized inputs began on May 19, 1987. Before that, the DIII-D reports were all printed on paper and stored in a flat database. Peter remarked that he built the database over the Christmas holidays one year, to use the database skills he had acquired.

Peter demonstrated the database by calling it up on the screen and entering an example report. The database uses a visual interface on an SQL server. Computerization has helped them to move to a paperless database. There are roughly 5,000 trouble reports now stored in the database.

Emergency response at DIII-D is very dependent on the telephone system. Peter remarked that they had an incident in the previous week where a backhoe had inadvertently dug into a buried telephone line and severed the line. DIII-D had to shut down operations; it is a safety precaution to have working telephones during plasma operations. Peter recalled one other time some years ago that the phones were out of service; this occurred when the backup batteries for the telephones ran down after a power outage.

Peter explained that DIII-D tracks its availability. The availability is calculated by this formula = (actual hours operated÷scheduled hours of operation). The DIII-D availability is quite good; it rather constantly resides a range of 75 to 80%. The physicists use this availability in their planning for each fiscal year. Peter pointed out that if the machine operated a 'bad' plasma shot; that is, a shot that the physicists thought was a mistake, then that shot time it is counted as downtime rather than successful machine operation time. If an important diagnostic device fails or important data are not collected for a shot, then that shot is also considered to be downtime even though the machinery (vacuum system, pumps, magnets, plasma heating, all power supplies, fuel gas injection, etc.) had functioned correctly. The Chief Operator and the physicists must agree that a shot produced relevant data – the plasma formed, heated, diagnostics all recorded data; all demanded hardware functioned – and then the shot is declared a success and the time is counted toward the run time goal of 14 weeks for the year.

DIII-D requires about 8 to 10 minutes between shots for magnet coils to cool down. If not allowed to cool down, the coils will ratchet up in temperature over the day, which could lead to insulation degradation. The staff bakes out the DIII-D vessel at 350°C, usually for 12 to 16 hours, but the machine operates with the vacuum vessel at room temperature.

Peter related a story about the hurried nature of frequent, short vents. People are rushed to perform tasks when there are frequent vents. Once on the Octopole experiment, a workman's stool was left inside the machine because of the hurried nature of frequent venting. The staff heard the noise from the stool banging around during magnet coil tests. They prudently stopped their preparations for operation to investigate the unrecognizable noise. The technicians said that the noise was coming from inside the machine. They vented the Octopole to nitrogen and opened a port to inspect the machine interior. They saw the stool inside. A frustrated staff member quickly entered the Octopole vessel to retrieve the stool; he had forgotten about the nitrogen gas. The man was promptly overcome by nitrogen and fainted. A second staff member grabbed him by the collar and dragged him out of the Octopole vessel, where he revived in the fresh air.

Then Peter Petersen discussed tokamak maintenance. He showed the building layout and described the major tokamak systems. He remarked that they now collect 500 megabytes of information per plasma shot, and that computers were the only means to reliably collect this level of data every 15 minutes. The DIII-D staff includes 44 engineers, 12 computer programmers, 33 technicians, 21 support personnel, 48 physicists on staff and an average of 48 visiting physicists to collaborate on the plasma operations.

Similar to other successful facilities, DIII-D schedules maintenance tasks, log their maintenance, and forecast their manpower loading. The staff developed a computer program for this work. The program is called PACMAIN, which stands for <u>P</u>reventive <u>A</u>nd <u>C</u>orrective <u>Main</u>tenance. They developed a template to apply to periodic maintenance of new parts. They can redefine the maintenance frequency or maintenance acts needed if a part fails. The staff uses their experience and judgement to set initial frequencies of maintenance. If they do not have experience with a new type of component, they will rely on the vendor or manufacturer's suggestions. Maintenance is prioritized into 5 levels:

1 – high, safety-related
2 – high, impacts operations
3 – might impact operations
4 – probably will not impact operations
5 – low priority, will not impact operations

This system is independent of the spare parts inventory on the site. The spare parts team has a different priority system. The PACMAIN system is web based. Peter demonstrated the system via the internet and paged through a maintenance example.

Then Bill Cary discussed the DIII-D Spare Parts Inventory and Controls. The overview of his talk was "what we 'spare' and what we do not 'spare'."

Mr. Cary stated that each group manager determines his own spare part forecast for the year; how many and what components are to be 'spared'. For the tokamak, 1 hot spare computer of each type is kept available to replace a control computer. Likewise with hard drives and computer power supplies. The staff also performs autobackup of their plasma shot data each night; these data are valuable and are backed up for retention.

For vacuum and cryogenic system mechanical parts, the staff keeps rebuild parts on hand for all large components, such as pumps. Mr. Cary stated that they keep one hot spare pump on hand to replace any of the small pumps used in these systems. Overnight replacement is possible. They replace the system bellows units at 10,000 cycles; one spare is kept on site. The bellows manufacturer states that the bellows are good for 15,000 cycles, but DIII-D has experienced bellows failures at near 12,000 cycles. Thus they use a 10,000 cycle limit to get the most life out of a bellows without risking a breached bellows unit. They refurbish 5 small vacuum pumps each year for reuse on the machine.

Mr. Cary also explained that for tokamak water systems, coolant pump motors on the outdoor pumps can experience up to 8 failures per year. The staff also replaces about 10% of the flow and pressure switches on cooling systems each year.

For plasma heating, they do not keep any spare ECH gyrotrons, these units are too costly at about $800k/unit. The staff does keep a few gyrotron magnets and some gyrotron magnet power supplies as spares, and they refurbish failed units on site.

For ICRH, they keep one set of tetrode tubes on site for each of the 3 manufacturer units they operate at DIII-D. That is because these tubes are a special order article, priced at $125k/tube, with a 6 to 9 month estimated delivery schedule after ordering. This downtime would be too excessive for DIII-D, so a spare is on hand.

Some of the spare parts concerns for DIII-D are the neutral beam ion sources. TFTR has some important spare parts, ion source units. But, these ion sources are tritium contaminated from operation in the TFTR D-T operations phase. Contamination makes those ion source parts difficult to use. The initial manufacturer has gone out of business, so the staff uses rebuild parts on the ion sources. An important issue is that the ion source accelerator grids are losing their cooling tube wall thickness because of corrosion and erosion, and pinhole leaks have occurred. These leaks allow water intrusion into the NBI vacuum, which is directly connected with the vacuum vessel. It is a serious problem for DIII-D. Peter Petersen explained that during an ECH upgrade, the coolant lines were opened for coolant tie-ins. These lines are shared with the NBI, so some air (oxygen) made its way into the coolant system and there was consequently more corrosion of the tube walls.

For high voltage systems, the staff keeps four 12.47 kV circuit breakers on hand; pulsed operation wears these units out. They also use 3 to 4 tetrode high voltage regulators each year. For the heating and current drive power systems, they keep 144 chopper capacitor drawers on hand, 32 silicon controlled rectifiers on hand, and 4 spare batteries (24 and 48 Volt batteries). One spare circuit breaker for each type of breaker in use is also kept on hand.

The Computer Automated Measurement and Control (CAMAC) system has 62 types of modules. Most are aging; the manufacturer companies have folded. When the Tokamak de Varennes in Quebec, Canada shut down several years ago, DIII-D purchased many spare modules from the Canadians. For a few of the CAMAC systems, new compact PCI™ units are being used.

Oscilloscope reliability is an issue. The older phosphor tubes for the oscilloscope screens are failing. These cannot be replaced or refurbished. Mr. Cary said that the staff is slowly replacing the oscilloscopes with newer, digital units.

Mr. Cary stated that they are aware that the spare parts program requires institutional memory, and some of the staff are nearing retirement age. They are striving to put as many historical records in the database as possible so that eventually they can use the computerized system for most of the forecasting and other needs.

Then Lee Cadwallader presented information about recent US work on failure rate data and a plan to analyze DIII-D operations data. Much of the US work is now driven by a new US research direction to test the viability of liquid walls. A plan to collect remote handling reliability data will serve to support comparative analyses of solid wall downtime for replacement of tiles and liquid wall maintenance needs. The DIII-D reliability effort is to examine the vacuum vessel and vacuum system component reliability. This tokamak has operated for about 15 years, and has collected operations data. If liquid lithium walls are to be used in the US National Spherical Torus Experiment, then the primary confinement boundary reliability should be known.

After lunch, the meeting participants had a detailed tour of the DIII-D, led by Peter Petersen. Peter showed many of the details of the facility, and after the end of the operating day our tour was able to enter the tokamak area to see the machine itself.

The tour began with the DIII-D cross-sectional model on the wall outside the control room. We then proceeded to the control room during plasma operations, followed by the heating system rooms. After that, we saw the support systems, including the cooling systems, gas supply systems, in incoming electrical power systems. Then we re-visited the control room for the final shot of the day, and after appropriate safety sweeps were performed, we entered the machine floor to see the features of the DIII-D tokamak itself.

Peter described that early in DIII-D life, they had used a copper foam support behind the carbon tiles that protect the vacuum vessel walls. The copper foam helped to transfer heat from the tiles to the actively-cooled vessel walls. Unfortunately, the copper foam deteriorated and tiny copper particles were entering the vacuum vessel, poisoning the plasma. The staff changed the copper foam for foils made from carbon to conduct the heat out from the tiles.

The rolling shield roof experienced a problem during its life. The weight of the roof is large, and the wheels that support the roof would lose mass and create dust when in operation. When dust built up on the wheel tracks, the roof could not move very well when the wheels were driving through the dust. The staff solved this problem by installing small vacuum cleaners near each wheel, so the wheel track is vacuumed clean before the wheel contacts the track.

Peter described an event with the central solenoid coil. DIII-D has two central solenoid coils for versatility. One of the coil cooling lines developed a water leak. The leak was in a region directly under the tokamak and was not easily accessed. The staff opened a port from inside the vacuum vessel and worked on the leak area outside the tokamak by accessing it from inside the tokamak through the port. They were able to sleeve the leak and seal it so that they could use both central solenoid coils again.

Peter showed us the helium liquefier in the DIII-D building. They produce about 150 liters/hour from gaseous helium, using a Sulzer liquefier. There is a 4,000 liter helium cryogenic storage dewar in the building.

Peter pointed out the many power supplies that are placed throughout the facility. There are sets of magnet power supplies, microwave heating power supplies, neutral beam power supplies, and electrical distribution for operating pumps, fans, compressors, and other support equipment. In one basement area, Peter described that many years ago one of the chopper power supplies (a 1.5-m by 1.5-m by 1.5-m unit) that convert direct current into alternating current suffered a fault and caught fire. The staff tried to extinguish the fire with small, hand-held extinguishers, but the fire was burning too well for the small extinguishers to be effective. The local Fire Department was called. They quickly arrived, and used CO_2 and dry powder extinguishers to put the fire out. After the trek to get to the basement area, the Fire Department Lieutenant asked if there were any other power supplies like that one, in difficult-to-access areas. He was assured that there were many such power supplies throughout the facility. After that the Fire Department performed walkthroughs to become more familiar with the DIII-D facility so that they could be better prepared in case of any future fires.

Next we visited the supply area where deionized water, gases, and liquid nitrogen are stored. Peter explained that DIII-D receives 2 truck deliveries of liquid nitrogen per week from Los Angeles, and one delivery truck of helium gas per month from Texas. We saw the mechanical draft heat exchangers where the heat from coolant water is rejected to the air, and the outdoor pumps that circulate the cooling water. There is a great deal of support equipment for a tokamak experiment.

Peter showed us the outdoor power supplies. He explained a fault with one of the 15 kW supplies and the capacitor bank. The capacitor bank had active cooling. The cooling lines were copper. The power supply insulators had gotten coated with outdoor dust over a couple of months, then a rainstorm occurred. The insulator dust and dirt coating was wetted and an arc occurred. The arc touched the copper cooling line on the capacitor bank and about 1 foot (~0.3 m) of the copper tube was vaporized by the intense electrical arc. They repaired the cooling line and now have a preventive maintenance check of the cleanliness of the insulators at the site, and a building has been erected around the capacitor bank.

After this, we returned to the control room to see the final shot of the day. There was no plasma formed, it was a cleaning shot to leave the machine in good condition overnight, so that it could be started quickly and easily the next day. After the pulse was completed, the operators safed electrical equipment, informed personnel outside of the control room that operation was terminated for the day, and then they took radiation measurements in the tokamak area. After verifying radiation safety and that the equipment was depowered, we were allowed to enter. Peter showed us the neutral beam units, the cooling hoses for magnets, the main cooling water piping, the machine grounding straps, the microwave heating transmission lines in to the vacuum vessel, the pellet injectors, and other equipment. This completed our tour of the machine.

Peter Petersen and his wife, Gerda, invited us to their home for dinner. The participants enjoyed themselves very much. Neill Taylor summed it up well, “Peter, your choice of a meal was skillfully done, and was even more skillfully carried out by Gerda.’

April 16, 2002

IEA participants attended the DIII-D morning operations meeting this morning. The meeting was brief, but covered the important operations aspects of the planned pulse activities for the day. One of the physicists gave some highlights of the previous days' operation, and a brief statement of what today's operations were to do. The engineers in charge of systems interacted to verify that systems were configured correctly and that small repair activities had been completed so that the machine was ready to begin operations. This was a very professional and succinct meeting; it was much like the so-called NASA "stand up, tag up" meetings, except the staff went into some orientation detail about what the physics objectives were for the day. Important information was transmitted among all of the staff, and face-to-face information transfer between cognizant system engineers was accomplished.

After the operations meeting, Tonio Pinna began our day's presentations with a discussion of the Component Failure Rate Data Base. The database has an International Thermonuclear Experimental Reactor (ITER) emphasis, but can be used for designs besides ITER. There is internet on-line access to the database via Internet Explorer or Netscape web browsers. The access is currently only allowed for researchers working in fusion safety, screened by Tonio. Such researchers are typically the IEA task participants. Access is currently limited to "read-only". Tonio has used Lotus Domino software, and the database resides on the AFX server at Frascati. In the future, users will have access that allows them to write, so that they can perform data entry into the database.

Tonio gave the meeting participants an on-screen tour of the database. The database is structured to be a nested database. A user can view the component type, the failure modes, and all other pertinent information about the database entries. A user can download or 'export' an Excel file of the data; but this feature is only available via Lotus Notes software at the present time. Excel spreadsheets have been selected for their ease of data input to the database rather than for the linking to a fault tree quantification program.

Tonio explained the database outline. Narrative descriptions of the component and data value fields should be entered by the analyst. The narrative document is either accepted or not accepted. The not accepted classification means that the data value is "user's data" only and it requires validation of the data source acceptability for inference to fusion and that the value has been calculated correctly. The data validation step has two classifications, either Validated or Not Validated. Validation means that the data value has been entered into the database correctly. Tonio also has included a provision in the database for IEA consensus. A field tells analysts that data is "approved" or "not approved", meaning that the value has been compared/assessed against independent data and that the data users (who are principally IEA task participants) have certified or approved the data value as being an accurate number for that component.

Currently, there are about 830 data values in the common data part of the database, and there are about 330 data values in the user data part of the database.

Tonio then gave an internet-based presentation of the database. He led an on-line tour of the database features, and showed some examples of stored data. He also described the database downloading capability.

Tonio discussed the future work with the database. Planned tasks include improving routines for data entry via Lotus Notes e-mail software, improving the user interface, and reorganizing the data in the database. Tonio also wants to begin validation of the data values before the end of this calendar year. Tonio would like task participants to review the user data and validate that these data numbers have been entered correctly. Then those 330 data values can be moved in to the common data portion of the database. Tonio also hopes that the task participants can reach consensus on the common data values within the database.

Tonio has a task to analyze the Joint European Torus (JET) Active Gas Handling System (the tritium fueling system for JET D-T operations). He plans to put those data results into the database. Tonio has also published a first edition of the database user's manual (Pinna, 2002), but he wishes to update this initial edition over the next few months [note – Tonio has completed this update and a pdf of the user's manual is included in the CD proceedings]. He would like to have our comments on the updated edition of the report.

Then Tonio began another presentation about recent failure rate data work in Italy. His work with JET data began in November 2001 and will end in November 2002. The task spans the entire operating lifetime of JET, 1983 – present. Tonio has been working with Gilio Cambi (University of Bologna) to reduce these data to component failure rates. Their JET work focuses on two systems, the Active Gas Handling System mentioned above, and the JET vacuum system. If the task is renewed by the European Fusion Development Association (EFDA) for another year, then Tonio will look at other systems, e.g. power supplies. The next system will be decided at a later time.

Tonio and Francesco also mentioned that data from the Tritium Laboratory Karlsruhe (TLK) facility in Germany will be collected. TLK began operation in 1994 (Penzhorn, 2000). It may be possible to analyze their trouble report data, their off-normal or 'out of normal' operating experiences, to find component failure rates for tritium-bearing components. There might be some limited support by the TLK staff to assist with needed data values (numbers of components in systems, descriptions of methods of operation, system run times, etc.).

Tonio also mentioned the Frascati Tokamak Upgrade (FTU) experimental campaign on operating experience. Over 2000-2001, the FTU closely monitored their operational availability and reasons why the availability would deviate from the expected values. Tonio showed some plots of unavailability data.

Tonio briefly described a European task on remote handling reliability. The task began in December 2001 and will end in December 2002.

Lee Cadwallader presented an overview of recent data work in France, Japan, Germany, and the Russian Federation that was assembled from e-mail exchanges with task participants that could not attend the meeting. Dr. Mohamed Eid from CEA-Saclay (meid@cea.fr) sent his regards to the meeting, but he could not attend. He continues to work on piping reliability and crack propagation issues. Our new Japan contact for task 5 is Dr. Satoshi Konishi from JAERI (konishi@tpl.tokai.jaeri.go.jp). A new task participant from Germany is Dr. Mihaela Ionescu-Bujor from Forshungszentrum Karlsruhe (Ionescu-Bujr@irs.fzk.de). Our Russian colleagues, Dr. Boris Kolbasov, Dr. Kurbatov (both use kolbasov@nfi.kiae.ru), and Dr. Mikhail Subbotin of Kurchatov Institute (msub@fc.iterru.ru), are busy with a proposal for ITER reliability data gathering and analysis.

Next, Francesco Scaffidi-Argentina presented information about JET. He explained that there have been recent changes with the management of the JET facility in moving from Euratom to participation under EFDA. JET is now designated as a User Facility, meaning that interested parties, customers, can make arrangements with JET staff to perform the customer's experiments or plasma shots. There are 21 countries participating in EFDA now (Latvia joined just this year).

Francesco described that JET had three campaigns in 2000, C1, C2, and C3, for a total of 94 operating days. The C4 campaign was performed from January to March of 2001, with a total of 58 operating days. Then the machine shut down for installation of 11 new diagnostics (there are about 200 diagnostics on JET now), installation of some error field correction coils, divertor modifications to add a septum, and changeout of magnet cooling fluids. In the past, freon had been used as the cooling fluid, now for environmental reasons, a non-ozone depleting fluid, perfluoropolyether, will be used.

In 2002, JET will run the C5 commissioning campaign after the long outage, then operate in campaigns C6 and C7 for a total of 108 planned operating days. Then there will be another outage to remove the septum.

Francesco remarked that metal flakes are known to fall under the divertor tiles while the machine operates. These flakes are difficult to reach. The outage work included vacuuming up these flakes. Francesco stated that about one-third of the flakes were recovered and these were analyzed. About 2 grams of tritium were in the flakes under the divertor, or about 1E+12 Bq of tritium per gram of flake material.

JET's new capabilities will include the closed Mark II GB divertor with the septum removed. Without the septum, they can explore plasma operations with higher triangularity; that is, the X-point of the plasma can move lower without the septum present. Another capability is the increased power of the neutral beams, up to 7.5 MW.

Then Francesco gave some facts about JET. The tokamak is operated in two shifts, 5 days per week. The shifts run from 0630 to 2200 hours. The shifts overlap for shift change data transfer. Each shift also has a lunch break. The machine presently requires perhaps 25 to 30 minutes between shots. The initial EFDA goal was 20 successful shots/operating day. The new target for 2002 is to add one or two more shots per day.

Jet has an EIC, or engineer in charge, who serves as the safety and operations person, and there is a session leader (SL) for the operating day. The EIC and SL are supported by the science coordinator (SC) and the diagnostics coordinator (DC).

Francesco commented on increasing JET availability. JET is quite comparable to DIII-D in its typical yearly availability of 75 – 80% (actual run time ÷ scheduled run time). The power supplies are the components that give the highest unavailability for JET, just like DIII-D. JET improved its power supply monitoring, and the staff performed a fault analysis of the power supplies. They replaced some ohmic heating electrical power switches and increased their voltage and current protection devices on the power supplies. These changes began to improve power supply availability. Then the JET staff added on personnel training on the power supplies. These steps had the most impact on power supply reliability.

Francesco explained that JET staff members are assigned to working groups, such as Control & Data acquisition System (CODAS), Diagnostics, Experiments, operations, etc. There will be working groups busy on systems through the end of the year. Two systems are receiving special attention, the power supplies (as mentioned above) and the CODAS. The CODAS collects a couple of gigabytes of data per shot; there are many diagnostics generating data and the JET pulses are long time durations by fusion standards. These factors combine to yield large amounts of data per pulse. CODAS reliability is important to JET.

Francesco announced that the UKAEA and EFDA would host the next meeting of IEA Task 5 at the Joint European Torus, in either late 2003 or early 2004. The details will be set at a later time.

Task Participant Discussion Session on 16 April

After presentations were completed, a round table discussion commenced. Topics included the state of fusion programs, upcoming data needs, and any other subjects pertinent to this task.

The long term blanket program in Europe performed a study of fusion blanket safety. Mohamed Eid, a task participant, was involved in that study.

Luciano Burgazzi (University of Bologna) is working on the International Fusion Materials Irradiation Facility (IFMIF) safety study. He needs data for a variety of equipment related to particle accelerators.

The ITER Generic Site Safety Report (GSSR) is complete now. The GSSR does not stress probabilistic assessment, the report does not dwell on frequencies of event occurrence. The reasoning is that the safety team cannot easily defend these frequencies, and the initial feedback from regulatory bodies they have contacted is that the regulators wish to see the severity of accidents for this new technology rather than the argument for low probability of occurrence. Therefore, the ITER safety team is leaning toward the traditional 'deterministic' safety analysis that analyzes high consequence-low probability events rather than probabilistic safety assessment that analyzes the spectrum of low to high consequences with high to low probabilities.

There is a study under way in Europe, the European ITER Siting Study (EISS), and the safety work for this study will be traditional safety analysis.

JET is planning to perform an Occupational Radiation Exposure (ORE) assessment for their ex-vessel maintenance activities. Therefore, they may seek some generic repair times for components, if they do not have good data from their past repair activities. Peter Petersen said that DIII-D does not perform ORE for ex-vessel maintenance, there is no radiation exposure ex-vessel. The DIII-D exposures are from in-vessel from tasks requiring vessel entry. Mr. Jerry Levine, the ES&H manager at PPPL, may be able to provide some data on ex-vessel maintenance task doses at TFTR after the beginning of D-T operations.

Participants suggested contacting Dr. Pascal Garin of the CEA, who is the ITER safety analysis task leader, to determine what ITER data needs exist. Lee Cadwallader sent him e-mail in early May but has not received a response as of this writing.

Participants also suggested contacting ITER Canada to inquire about their data needs. Lee Cadwallader contacted Charles Gordon to determine if ITER Canada would have any ITER data needs in the near future. Dr. Gordon consulted with two colleagues, Dr. Katherine Moshonas of ITER Canada and Mr. Al Wight of Candesco Research Corporation. Mr. Wight's [annotated] response is given below:

C-98 [note: C-98 is a Canadian Regulatory Guide, titled "Guidance for Meeting Reliability Requirements for Safety Related Systems of Nuclear Reactor Facilities" and it was issued by the Atomic Energy Control Board] requires reliability analyses for all "systems important to safety" for Class I Nuclear Systems. This can be done by Fault Tree Analysis or other comparable method, but however it is done, will require basic component failure rate data. Ontario Power Generation (OPG) has a huge database of failure data which I presume they would make available to us. This database would cover things like valves, pipes, relays, etc. which will cover most of the stuff we might use. Really exotic stuff, like cryogenics, superconducting magnets, vacuum pumps, etc., we would need to get from elsewhere - other industries, manufacturers' testing, other tokamaks. (Note - it doesn't require a lot of data to deduce a failure rate - using chi-squared distribution, failure rate of order 0.1 can be deduced from 0 failures in a few decades of operating history.) Systems important to safety need to have defined reliability targets. For example a process system needs to demonstrate 0.3 failures per year and a special safety system needs to demonstrate 0.001 failures per demand. The design of "Systems important to safety" needs to demonstrate capability to meet the target, which usually requires some sort of reliability analysis (such as fault tree analysis), and must be monitored and tested during operation to demonstrate that they continue to meet the target.

Mr. Wight continued with:
Specifically, to answer your questions: The [Canadian] regulator expects quantitative assessment of "systems important to safety" using "site specific failure data" if available, or generic failure data if not. A large amount of reliable failure rate data is available. When it isn't, we shall have to find it. The Canadian Nuclear Safety Commission (CNSC) will expect us to evaluate "risk", which will require a certain amount of probabilistic type of assessment. Not necessarily a full-blown Level I Probabilistic Safety Assessment (note: level 1 refers to complete system fault tree models, system interaction analysis, initiating event identification and quantification, plant event trees, etc.) but some elementary Event Tree or Fault Tree analyses for important events or systems. MAPLE [note: MAPLE stands for Multipurpose Applied Physics Lattice Experiment; these are two 10 MW-thermal pool-type reactors built at Chalk River to produce Technetium-99m for medical uses] licensing was based on this approach. We'll need reliability analyses for all "systems important to safety", not just the tritium building.

Therefore, we can conclude from Mr. Wight's reply that failure rate data would be important for ITER regulation in Canada, and that if detailed data is not obtainable, then generic data would be used to satisfy quantification of a limited set of fault trees and event trees for safety-related systems.

The results of this discussion were:

New projects requiring failure rate data are IFMIF, the US Fusion Ignition Research Experiment (FIRE) tokamak design, and possibly ITER, depending on the host country site.

IEA Task 5 can support ITER via

- Personnel safety studies, and occupational radiation exposure studies for maintenance, inspection and operations
- Fire hazards to the plant and to workers/public

The consensus by task 5 participants for values in the data base:

There are three levels that Tonio has defined in the database

Acceptable – the data come from known sources, applications and calculation methods

Validated	the data are entered into the database correctly
Consensus	the data value in question has satisfied two requirements. The first requirement is the data value falls near an independent comparison data value. The second requirement is that the data value is reviewed and approved by two or more independent analysts. After those two requirements are met, then other task participants have the opportunity to comment on the web-based data within a time frame of one month.

The discussion session ended and the meeting was adjourned at about 4 pm.

References

GA, 1998. Project Staff, DIII-D Research Operations Annual Report to the Department of Energy, October 1, 1996 through September 30, 1997, GA-A22827, General Atomics, October 1998.

Penzhorn, 2000. R.-D. Penzhorn et al., "Status and research progress at the Tritium Laboratory Karlsruhe," Fusion Engineering and Design **49-50** (2000) 753-767.

Petersen, 1992. P. I. Petersen and S. M. Miller, "The DIII-D Trouble Report Database," Proceedings of the 14th Symposium on Fusion Engineering, San Diego, California, 30 September -3 October 1991, IEEE, 1992, pages 776-778.

Petersen, 2000. P. I. Petersen, "Systematic characterization of component failures for the DIII-D tokamak," Fusion Engineering and Design **51-52** (2000) 571-577.

Pinna, 2002. T. Pinna, Fusion Component Failure Rate Database (FCFR-DB), Vers. Dec. 2001: User's Manual and Collected Data, FUS-TN-SA-SE-R-43, ENEA, March 2002.

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