TECHNICAL REVIEW OF DIAGNOSTICS FOR JT-60SA

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EU WG on Diagnostics: Silvana Nowak\textsuperscript{1}, Eric Gauthier\textsuperscript{2}, Jean-Marcel Traverexe\textsuperscript{2}, Philippe Lotte\textsuperscript{2}, Didier Mazon\textsuperscript{2}, Jean-Claude Vallet\textsuperscript{2}, Peter de Vries\textsuperscript{3}, Roberto Pasqualotto\textsuperscript{4}, Carlo Sozzi\textsuperscript{1}, Alex Bruschi\textsuperscript{1}, Marco Tardocchi\textsuperscript{1}, Marc Beurskens\textsuperscript{5}, Gabriella Pautasso\textsuperscript{6}, G Conway\textsuperscript{6}, F P Orsitto\textsuperscript{7}.

\textsuperscript{1} ENEA IFP-CNR Milano (Italy)
\textsuperscript{2} CEA Cadarache (FR)
\textsuperscript{3} EFDA-JET Culham (UK)
\textsuperscript{4} ENEA RFX Padova (Italy)
\textsuperscript{5} CCFE Culham (UK)
\textsuperscript{6} IPP Garching (Ge)
\textsuperscript{7} ENEA Frascati (Italy)

**General observations on the diagnostic needs of JT-60SA and proposals for upgrades or new systems**

The analysis work carried out in 2011 by the EU WG on diagnostics was included in two documents: i) the DRAFT v2.2 DOC on SARP App D Diagnostics and ii) the doc on SARPv2.1 Revision Appendix D and Diagnostics for JT-60SA, reported in Annex I.

The present document (Technical Review of Diagnostics for JT-60SA, TRD) collects the DRAFTv2.2 and the related comments made by JA/TROs (Technical Responsible Officers) of the Research Plan of JT-60SA version 3.0 (SARPv3 December 2011).

Since it is written after the completion of the process of SARPv3, it contains elements of an agreed strategy to be developed on the diagnostics systems of JT-60SA.

The document takes as reference all the information available on the diagnostics for JT-60SA: diagnostics needs and description/specifications of diagnostics systems. References for this document are: i) JT-60SA Research Plan SARPv2.1; ii) PID (Plant Integration Document) v2.7 Chapter 2.16 Diagnostics (September 2011).

The document is divided in the following chapters:

1. General observations related to the diagnostic set of JT-60SA diagnostics compared with the planned set for ITER and comments by EU-WG and JA/TROs.

2. Required measurements and essential diagnostics for scenario evaluation


4. Real Time Control and diagnostics

5. Diagnostics for DEMO

6. Conclusions and future work
1. General observations related to the diagnostic set of JT-60SA diagnostics compared with the planned set for ITER.

As ITER satellite device JT-60SA can have the same or even more refined capability of measurements of scenarios. A general impression about the capability of the JT-60SA diagnostics set can be obtained comparing the planned set of diagnostics on ITER (see ITER Diagnostics T Donne’ et al. NF 47(2007)S337). A consequent analysis can be carried out.

This comparison has been carried out for the following groups of diagnostics:

- neutron and fusion products
- optical systems
- spectroscopy and Neutral Particle Analyzers
- microwave diagnostics
- plasma facing components and operational diagnostics

In the following paragraphs a brief analysis will be done, and comments by the EU/WG and JA/TROs will be added in each section.
1.1. Neutron and fusion products

Table I shows the comparison between ITER and JT-60SA diagnostics related to fusion products.

<table>
<thead>
<tr>
<th>Table I</th>
<th>system</th>
<th>ITER</th>
<th>JT60SA</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>neutron and fusion products</td>
<td>radial neutron camera</td>
<td>Y</td>
<td>Y</td>
<td>SA/7 channels</td>
</tr>
<tr>
<td></td>
<td>vertical neutron camera</td>
<td>Y</td>
<td></td>
<td>SA/under study</td>
</tr>
<tr>
<td></td>
<td>microfission chambers</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>neutron activation monitors</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>gamma ray spectroscopy</td>
<td>Y</td>
<td></td>
<td></td>
<td>ITER interfaces/SA under study</td>
</tr>
<tr>
<td>high res neutron spectroscopy</td>
<td>Y</td>
<td></td>
<td></td>
<td>ITER interfaces/SA under study</td>
</tr>
<tr>
<td>neutron flux monit (ex vessel and divertor)</td>
<td>Y</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>

It appears (inspecting the Tab I) that two systems need to be considered for JT-60SA:

i) the diagnostics related to the fast particles, i.e. gamma ray spectroscopy and high resolution neutron spectroscopy;

ii) a vertical neutron camera.

The seven channels of the radial neutron camera on JT-60SA will be equipped with fast electronics to detect the interaction of fast particles with Alfvén eigenmodes.

Observations on Fast Particles in SARP.

In the Chapter 6 of SARPv2.1 and v3—High Energy Particle Behaviour, a short abstract on the needs of Fast Particle diagnostics is given. The diagnostics cited are: i) Charge exchange neutral particle analyzer (CX-NPA) using natural diamond detectors; ii) FIDA (Fast Ion D-Alpha) on P-NBI (85keV) for the measurement of low energy ions (either produced by P-NBI or slowing down ions from N-NBI); iii) Collective Thomson Scattering using the 110 GHz gyrotron radiation (source for the ECRH) to measure the N-NBI produced ions (E≤500keV); iv) IR camera and Lost Ion (scintillator) probe to measure the lost fast ions.

The CX-NPA is briefly treated in the PID and the technical specifications of the system are given in table 2.16-7 of PID.

In Appendix-D(Plasma Diagnostic Systems) a Table summarizing the technical specifications for diagnostics of Fast ions is not included. So most of the detailed information related to the diagnostic systems and requirements on measurements is missing.

In practice the entire package of fast particle diagnostics needs a coherent technical treatment.

Moreover, The possibility of measuring fast ion distribution function (E≤500keV) by Charge Exchange on N-NBI is not mentioned: this measurement on JT-60SA could be a test useful for ITER.
It can be observed that fast particles include not only fast ions but also fast electrons: so ECE (electron cyclotron emission) measurements of electron distribution function can be included in the overall picture, as well as Hard X-ray diagnostics.

The waves interacting with fast ions must be diagnosed: interferometry and reflectometry in fact have given a real step forward in the clarification of important details of the Alfven dynamics.

**Technical specifications of diagnostics for fast particles.**

The requirements on measurements for confined Fast ions, taken from ITER physics basis, are reported in the Table I.1. As starting point they could be taken as reference also for JT-60SA.

<table>
<thead>
<tr>
<th></th>
<th>requirement on measurements for Fast particles</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>particles</td>
<td>requested measurement</td>
<td>group</td>
<td>techniques</td>
<td>spatial resolution</td>
<td>time resolution</td>
</tr>
<tr>
<td>D</td>
<td>spatial and energy distribution</td>
<td>physics understanding meas.</td>
<td></td>
<td>$\gamma$-ray spectr; CTS; CXRS; NPA; FIDA</td>
<td>a/10</td>
<td>100ms</td>
</tr>
<tr>
<td>D</td>
<td>fast particle losses</td>
<td>machine protection</td>
<td>LIP; IRV</td>
<td></td>
<td>a/10</td>
<td>0.1-0.5ms</td>
</tr>
</tbody>
</table>

Following the previous observations the Table I.1 is proposed to be inserted in the Appendix D as defining the technical specifications on Fast particle diagnostics; and the sec 1.1.1.(Comments on neutronics and Fast ion diagnostics) can be inserted in the chap 6 of SARP.
1.1.1. Comments on neutronics and Fast Ion Diagnostics (M Tardocchi, A Bruschi)

1. Comments on Fast ion diagnostics in SARPv2.1.

The diagnostic needs for Fast Ions are commented in Chapter 6-High Energy Particle Behaviour: "The contribution of JT-60SA to the ITER and DEMO will be the physics basis of high energy particle behavior. There are three major areas for the contributions. [1] The third one is the development of reliable diagnostics for energetic particle research including calibration method, and reactor-relevant monitoring methods of bulk plasma using energetic particle phenomena, such as MHD spectroscopy. [1] The most influential point of JT-60SA is the possibility to install the cutting edge diagnostics for detailed study of energetic particles because of the moderate neutron flux, compared with ITER. Thus, the development of these diagnostics is also a key part of the contribution from JT-60SA"

JT60-SA will have fast ions due to the injection of 500 keV D ions. (No ICRH is planned)

The various observables and related plasma parameters measured by the proposed set of fast ion diagnostics should be stated in the chapter.

It is suggested to:
1) separate diagnostics for confined ions from the one for lost ions.
2) specify the measured plasma parameters with associated energy, time and space resolution
3) for each diagnostic, assess if real time information is technically achievable and if the added information is worthwhile the investment

2. Neutron and gamma rays

All the neutron and gamma-ray diagnostics proposed in SARPv2.1 seem feasible, but should require an ad-hoc study (of line-of-sight, shielding, detectors) and an ad-hoc design and realization.

2.1. Gamma ray spectroscopy camera:
The detailed information that can be extracted on the fast D and H ion distribution function depends on the cross section of the underlying reactions. A preliminary study should be done on the reactions of interest involving fast D (or H) ions. This is necessary in order to identify the energies and intensities of the gamma rays (signals) and to compare them with expected background level.

2.2. The 2.5 MeV neutron spectrometer is particularly important for the 500 keV D-beam slowing down particle distribution function.

An optimized 2.5 MeV neutron spectrometer with adequate energy resolution would be useful to separate the DD thermal neutron emission from the non-thermal one. Non-thermal component would offer a measurement of the the 500 keV D beam and of its slowing down particle distribution function.
The possibility of having more than one line of sight should also be studied.
2.3. **Neutron camera**: the diagnostic proposed in SARP should be described in terms of hardware and capabilities (neutron monitor or also spectroscopy?)

3. **Collective Thomson Scattering**

3.1. **Collective Thomson Scattering** system is mentioned in SARPv2.1 with a simple statement that it will use the ECRH sources at 110 GHz frequency. The statement needs a preliminary study to be confirmed, since a different probe requires a big additional cost.

The assessment of the CTS should be done searching for:
- a sufficient range of JT60SA plasma regimes where studies on fast particles are made, in which EC resonance for 110 GHz or its harmonics are out of the hot plasma bulk, to reduce ECE noise. *This seems to be ruled out from preliminary evaluations.*

- a probe frequency more suitable for CTS, among those where a powerful source is available, even if the effort for setting up a different CTS probe source is highly increased, due to the need for an additional source. *This seems also ruled out from preliminary evaluations.*

3.2. **Preliminary evaluations.**

*In none of the presented JT60SA plasma regimes the EC resonance for 110 GHz or its harmonics are out of the plasma boundary, thus it is most likely that the ECE noise would prevent the CTS signal to be detected with sufficient S/N ratio.*

Different probe frequencies (140 and 170 GHz, where powerful sources are available) were studied preliminarily, with the outcome that at these frequencies the resonances are always present within the plasma boundary.

Preliminary evaluations at lower frequencies, where the EC resonance is out of the plasma boundary, show that the central regions of the plasma are not accessible due to the high density cutoff of the extraordinary wave. Further studies have to be done in order to find a suitable (presumably much higher) frequency. The outcome could be a frequency in a range where sources with the required probe power are presumably not available (or only prototypes are being developed), and is beyond the scope of the present work.
1.1.2. Comments by JA/TROs

The research plan is a base to determine the diagnostics needs. The current version is the start point of the discussion, especially from the viewpoint of the diagnostics specification. This situation was explained to EU colleagues, including Phillip Lauber (EU TRO for Chapter 6 High Energy Particle Behaviour), in an informal meeting in the IAEA TM on EP, held in Austin in this September. The presentation by Duarte Borba in the RCM reflected our agreement in the informal meeting about the fast ion diagnostics for JT-60SA.

It is not straightforward to estimate requirements for the fast ion and neutron diagnostics, since the signal to noise levels of these diagnostics are low, compared with those in ITER, and are dependent strongly on considering the operation region for the JT-60SA experiments. Actually, at present, we are not sure that the operation region for AE experiments could be same with the main target operation region of our interest. Therefore, the detailed assessment of our research area, covered in the chapter 6, should be done at first. In this context, Koji Shinohara is proposing surveys of the experimental conditions by using the stability code in EU and Japan.

In the mean time, ad-hoc study could be carried out for most of the diagnostics, e.g. CTS. It could be a good item of the collaboration. Results from ad-hoc studies of the diagnostics would be described in SARPversion 3.1.
1.2. Optical systems

Table II shows the comparison between ITER and JT-60SA related to the optical systems.

<table>
<thead>
<tr>
<th>Table II</th>
<th>system</th>
<th>ITER</th>
<th>JT-60SA</th>
<th>comments</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>optical systems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thomson scattering (core)</td>
<td>Y</td>
<td>Y</td>
<td>ITER LIDAR/SA conventional TS</td>
</tr>
<tr>
<td></td>
<td>Thomson scattering (edge)</td>
<td>Y</td>
<td>Y</td>
<td>ITER Conventional TS</td>
</tr>
<tr>
<td></td>
<td>Thomson scattering (div)</td>
<td>Y</td>
<td></td>
<td>ITER interf/SA under study</td>
</tr>
<tr>
<td></td>
<td>toroidal polarim/interf</td>
<td>Y</td>
<td>Y</td>
<td>SA 1beam tangential / 1 beam vertical</td>
</tr>
<tr>
<td></td>
<td>polarimeter system</td>
<td>Y</td>
<td></td>
<td>ITER:vertical and equatorial fan</td>
</tr>
<tr>
<td></td>
<td>collective thomson scattering</td>
<td>Y</td>
<td></td>
<td>ITER low field side front end/SA CTS under study</td>
</tr>
</tbody>
</table>

Inspecting Table II the following systems can be considered for JT-60SA:

i) Divertor Thomson scattering
ii) Polarimeter system
iii) Collective Thomson Scattering

A Collective Thomson Scattering for the measurements of fast particles is available on ITER: only the low field side front end has been decided. Preliminary comments on feasibility of a CTS on JT-60SA are given in sec.1.1.1.

In Appendix D, a Divertor Thomson Scattering system (DTS) is mentioned with attractive requirement on measurements (10mm space resolution along the leg, 10 ms time resolution), but the lay-out is not described neither in SARPv2.1 nor in the PID2.7.

The ITER divertor Thomson Scattering system is projected to measure the outer leg of the divertor. It is planned for measurements of the electron temperatures between 0.3 and 200eV, at electron densities above $10^{19} \text{m}^{-3}$, every 1 ms, with a space resolution of 50mm along the leg and 3mm across the leg, and accuracy of 20% on electron density and temperature.

ITER has a poloidal polarimeter with vertical as well as poloidal line of sights: this system is devoted to the measurements of Faraday rotation and Cotton-Mouton, thus providing measurements to be used as constraints to equilibrium codes (Faraday rotation) and line integral of plasma density (Cotton-Mouton).

The core measurements of plasma density in JT-60SA are done by Thomson Scattering (TS), complemented by two CO2 interferometers, of which: one has one line of sight and it is collinear to the TS line of sight with the purpose of providing a calibration for TS, and another has 1 line of sight and it is vertical.
The content of Table II gives some indication for JT-60SA: in general the capability for the measurement of plasma density can be reinforced through the installation of new line of sights of interferometer and/or providing a polarimeter system which can be useful also for the measurement of the q-profile. The polarimeter in principle measures the Faraday rotation (in first approximation proportional to the line integral of density times the poloidal magnetic field) and the Cotton-Mouton ellipticity (proportional to the line integral of plasma density).

The use of a Li-beam for the measurement of edge density has proven (based on JET experience) strongly linked to the plasma configuration and availability of the beam itself, so a redundancy on edge density measurement could be necessary: the possibility of a reflectometer to measure the edge density through the pedestal with reasonable space resolution can be considered.
1.2.1. Comments on measurements of temperature and density by TS.  
(M Beurskens, M Kampenaars, R Pasqualotto, R Scannell)

1. Signal levels seem appropriate and expected error bars are around 5%-8% for the temperature
2. Separate profile simulations using a Monte Carlo simulation code were carried out. These give very promising results and show that data quality on the High Field Side (P5-system) can be as good as the JET Low Field Side data (which has F/20 and a 5J laser)
3. An investigation started on how much the blur due to collection optics aberrations is an issue. Here two different issues are recognised:
   a. Across the laser beam, the blur may cause signal loss, depending on the relative widths of laser beam and scattering volume, but this seems acceptable
   b. The same blur along the laser line of sight would affect the spatial resolution of course. The image size of a single fibre varies from 6-11mm for the P2 system. The resolution is reduced by ~25% (if this system is chosen).
4. A general concern is that collection lenses and fibres are very close to the plasma. The transmission of the optics may be affected in high performance plasmas with high NBI power due to DD neutrons.
5. A possibly attractive alternative is the collection optic layout used for the High Resolution TS at JET; a single collection lens close to the plasma and an array of parabolic mirrors at a larger distance to couple the light into the fibres. However, for a detailed optical design the space constraints need to be known;
6. Finally, a question (and concern) that arose it is on the obtainable accuracy of the HFS equilibrium.

1.2.2. Comments by JA/TROs.

Design status of the divertor Thomson scattering system is preliminary. Feasibility study about the signal amplitude and layout of the laser beam line and collection optics have done. In FY2012, conceptual design of the collection optics and assessment of optical component are planned.

Japan-EU collaboration on the alternative design of collection optics for the Thomson scattering is welcomed. We are ready to provide the design data around the port of JT-60SA tokamak.

Comments on the need to consider a polarimetry system for JT-60SA are given in sec.1.3.2.
### 1.3. Spectroscopy and Neutral Particle Analyzers

Table III shows the comparison between ITER and JT-60SA related to spectroscopy and Neutral Particle Analyzers.

<table>
<thead>
<tr>
<th>Table III system</th>
<th>ITER</th>
<th>JT-60SA</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>spectroscopy and NPA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CXRS</td>
<td>Y</td>
<td>Y</td>
<td>ITER based on DNB/SA based on Heating beams</td>
</tr>
<tr>
<td>Halpa spectroscopy</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>VUV impurity monitor (main Ch and div)</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vis and UV impurity mon(Div)</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>X-ray crystal spectrometer</td>
<td>Y</td>
<td></td>
<td>SA planned</td>
</tr>
<tr>
<td>Radial X-ray camera</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Beam emission spectroscopy</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPA</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>MSE based on heating beams</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Hard X-ray monitors</td>
<td>Y</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In general the comparison between ITER and JT-60SA gives the indication that:

i) CXRS system has the limitation linked to the penetration at centre of the 80keV heating beams at high density in particular for scenario #3 (Full Ip inductive, ne0=1.23×10^{20} \text{m}^{-3}) and #4(ITER like inductive, ne0=1.1×10^{20} \text{m}^{-3}).

ii) MSE could have the same limitation in scenarios #5-1 and #5-2 where the density is lower ne0=0.7-0.8×10^{20} \text{m}^{-3}.

The CXRS diagnostic is similar to the MSE diagnostic concerning its capabilities and difficulties. But even if the NBI penetration is poor during high density plasmas, CXRS is more sensitive than MSE and will probably be able to give Ti and Vi measurements but with the price of a worse time resolution and higher error bars.

The presence of CXRS measurements requires that two or three NBI are firing in addition to the two MSE NBI. It would mean that these NBI are also not part of the NBI actuators in the feedback control if the measurement is necessary.

The capability to measure at the same time the toroidal and poloidal plasma velocity, combined with the E(r) measurement by MSE and plasma pressure gradient will give some redundancy in the measurements for instance the E(r) value.

**CXRS has the capability to measure fast ions in the plasma up to the NBI particle speed. This possibility needs to be considered, in particular for the NNBI at 500 keV, even if the N-NBI does not aim to the plasma centre by its orientation.**

The description of the whole q profile diagnostics, including its specificity are missing in the SARP Appendix D, while the MSE system is described briefly in the PID document.
1.3.1. Comments on q profile measurement (D. Mazon (CEA Cadarache) P. Lotte (CEA Cadarache) F. Orsitto (ENEA Frascati))

The q-profile measurements can be considered central to the mission of JT-60SA device.

Real Time Control (RTC) appears as a related key element of the JT-60 SA Research Plan in order to perform RTC of the advanced steady state scenarios.

1. In particular, it is crucial to control the current density profile during the high \( \beta \) phase (also in presence of ITBs).

   But before controlling it is mandatory to get a very accurate reconstruction of the q profile in real-time, with a clear assessment of the error bars (indeed knowing the error bars a ‘better’ controller could be designed).

2. The internal constraints of the equilibrium code (mainly MSE and polarimetry) play a major role in the determination of the q profile and particular care should be made to make those two measurement systems compatible and consistent in order to avoid divergence of the code.

3. On top of this relying only on MSE is not sufficient, because
   - MSE measurement is dependant on NBI beam which is not penetrating enough in the plasma during high density to diagnose properly the central part of the q profile
   - MSE can be perturbed by reflected light from the metallic wall
   - MSE is not available all the time during long pulse operation and cannot be used to perform RT control

Current profiles mainly rely on 2 MSE diagnostics which seems able to cover a large part of the different plasma scenarios. But:
   - The two NBI need to be reliable with very few breakdowns during all the long pulse length
   - Central measurement of q profile will be difficult for high density plasmas due to poor NBI penetration, even using a higher integration time for measurements.
   - If used for MSE, these two beams will not be part of plasma actuators in real time control.

It is thus necessary to have a passive diagnostic (polarimetry) as complement of MSE measurements.

The use of two MSE diagnostics can in principle give a measurement of \( B_{pol}(r) \) and \( E(r) \) at the same time. But this is a difficult measurement and the geometry configuration of the 2 couples MSE/beam needs to be very different so as to have enough sensitivity to determine \( E(r) \).

In principle the best sensitivity is obtained when using a blue shift combined with a red shift observation of NBI. This capability needs to be verified here in the proposed geometry.

The fact that MSE is able to measure the plasma radial electric field makes MSE measurement independent of the CXRS measurement that generally gives the value of \( E(r) \). This is a very good point in favor of using MSE for active control of plasma current.

In the Carbon phase of JT60SA, no strong perturbation of MSE measurement due to reflected light on the walls are expected. Nevertheless we need to check that no reflecting metallic object (as water pipe) will be seen by MSE viewing lines.
MSE perturbations have been observed at JET during the very high power phases or during strong ELMS, probably due to light reflection on Beryllium walls.

During the metallic wall phase of the machine, MSE diagnostics will be strongly affected by light reflected from the walls that will probably make the MSE measurement difficult or impossible. ITER will have to face the same type of problem, and we can imagine that within that time alternative solutions will be found to cope with the wall reflections, but this is not certain. This is another strong reason to examine the feasibility of a polarimeter diagnostic during the machine construction.

It needs to be mentioned that there is nevertheless a possibility to perform accurate measurements with MSE (even close to plasma core) if this measurement is very important, even during the high density phase. For this, one of the NNBI that has a very good plasma penetration can be used (solution chosen for ITER). But this solution requires the installation of an additional MSE optics, and this measurement will only be possible when the observed NNBI is firing, and this beam cannot therefore be an actuator at the same time. This possibility could nevertheless be discussed with plasma scenarios physicists. Furthermore the positions where the N-NBI could provide the MSE measurement must be checked.

Interfero-polarimetry diagnostic has now demonstrated its capability to provide accurate measurements of current profiles when used for providing central information to equilibrium codes. This diagnostic is available all the time during long shots, does not depend on Neutral Beam and has thus strong capabilities to be used for real time profile control. But to be really performing this diagnostic needs to have enough chords so as to cover all the plasma regions. Vertical chords are necessary to take the plasma Shafranov shift into account. The possibility to install such a diagnostic with 8 or 10 chords even if difficult due to the presence of the plasma divertor needs to be accessed.

The integration of the MHD markers in the q-profile evaluation, i.e. the values of the radial positions of the rational q where the magnetic islands form, is one of the recent achievements in the analysis of current profiles. In particular these MHD markers are useful to calibrate the MSE system measurements. The MHD spectroscopy is becoming an integrated part of the q-profile evaluation.

4. possible improvements/new proposals

4.1. The insertion in the SARPv3 of a new paragraph is proposed where a dedicated q profile diagnostic will be described in detail, with in particular the specification required in terms of time and space resolution, inputs, outputs, link with the Real time infrastructure. The European code EQUINOX which is a RT Grad Shafranov solver is now implemented in JET and can use both polarimetry and MSE as constraints (simultaneously).

• This code has been fully validated and has been from the beginning designed for RT applications.
• It is proposed to install EQUINOX in JT60SA with the help of the European specialists. A close synergy between EQUINOX and the diagnostics providing the contraints (MSE and polarimetry diagnostic) has to be organized since the beginning.
4.2. At present a polarimetry system is not planned for JT-60SA a preliminary study is proposed to be inserted into the SARPv3.

*Preliminary evaluations lead to the conclusion that a polarimetry system is technically feasible on JT-60SA.*

4.3. A preliminary study of the use of N-NBI for MSE measurements is proposed to be inserted into the SARPv3. This measurement would be useful as a test for ITER where heating beams are planned for MSE measurements.

1.3.2. Comments by JA/TROs

On comment 1.3.1, we understand the importance of q profile measurement (items 1-3) for both real-time control and detailed analysis after the shot.

For the purpose, investigating polarimeter system as well as N-NB MSE and MHD markers can be beneficial.

Regarding items 4.1-4.3 in the item 4 (possible improvements/new proposals), they are too much specific to the current profile evaluation so that they should be discussed and investigated other than the research plan Chapter 3 describing “Operation Regime Development”. For the operation regime development, it would be needless to mention that making full use of all the diagnostics is essential. It is not appropriate in the Chapter 3 to describe how to measure q profile (4.1), how to solve equilibrium with constraint of MSE data (4.1), a statement that we should study polarimetry systems for JT-60SA (4.2), and another statement that we should study N-NB MSE (4.3). These items are too specific to be discussed in Chapter 3 for v3.

However, we agree with your comments that “specification required in terms of time and space resolution” should be described (in Chapter 3).

This will be handled for future version of the research plan after clarifying the requirements for each scenario. It was too short to discuss the detail of the requirements until version 3.
### 1.4. Microwave diagnostics

Table IV shows the comparison between ITER and JT-60SA related to microwave diagnostics.

<table>
<thead>
<tr>
<th>Table IV</th>
<th>system</th>
<th>ITER</th>
<th>JT-60SA</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>microwave diag</td>
<td>ECE main plasma</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflectometer main plasma</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reflectometer for plasma position</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Divertor interferometer</td>
<td></td>
<td>Y</td>
<td></td>
</tr>
</tbody>
</table>

#### 1.4.1. Comments on Electron Cyclotron Emission (S Nowak, C Sozzi)

JT60SA has two Horizontal Radial lines of sight foreseen for ECE (one high time resolution instrument and one FTS, ms-range time resolution)

**1. Requirements on ECE capabilities for stabilisation of NTM / Sawtooth (ST) / Locked mode / Disruptions**

**Evaluations based on JET**

- Range of NTM mode frequency: \( \sim 0.01 \) to \( 30 \) kHz/\( \sim 30\mu s \) (up to \( n=3 \))
- Sawtooth period \( \tau_{ST} \leq 500\)ms can trigger NTM in Standard Scenario
- NTM \((2,1)\) growths to saturated island \( w_{sat} \) (up to \( 8-12\)cm) in \( t \leq 0.5s-0.8s \)
- NTM mode can lock in \( t \leq 1.5s \) (often \( t \leq 0.5s \)) and cause disruptions

**Proposed strategy for NTM control** (aiming to couple with the real time control \( \leq 5 \) ms)

- NTM identified after \( \sim 10\)ms-20ms from the onset for typically island width \( w \sim 3-5\)cm
  
  \( \Rightarrow \) action: before the growing to \( w_{sat} \) control with external sources (preemptive ECRH/ECCD)
  
  (sample acquisition at least every \( 1\)ms-2\)ms)

- NTM triggered by long ST periods (\( \leq 500\)ms)
  
  \( \Rightarrow \) action: shortening of ST period (\(<250\)ms) by preemptive ECRH/ECCD predicted by real
  
  time measurements & calculations (\( t \sim 5\)ms)

**Requirements/Proposals**

- **2.1.** HR ECE should have at least \( 48 \) channels, about \( 2 \) cm spatial resolution (\(~\)half of the
  
  expected island size at its the onset) depending on the magnetic field, polarization, harmonic
  
  number (better resolution for \( 2^{nd} \) harmonic), size of emitting volume, finite antenna pattern, spectral
  
  width of detection; **spectral resolution \sim 0.5GHz-1 GHz** (i.e. \( 1 \) GHz, \( 48 \) channels, \( \delta R \sim 2\)cm as
  
  minimum requirement, \( 0.5 \) GHz as a possible future upgrade if better resolution is required) and
  
  time resolution in the range of \( \sim 100\mu s - 1\)ms).

- **2.2.** A dedicated ECE/NTM RTC diagnostics with enhanced spatial resolution can be considered or
  
  a line-of-sight system if reliable technology will be proved in the near future.
2.3. ECE for fundamental plasma measurements: time resolution for Fourier TS (Michelson, Martin-Puplett) can be significantly increased (about 5 ms per plasma profile) using rotating mirror technology. For this system a slightly oblique line of sight (tor angle about 10°, performances nearly equivalent to perp view) could be considered for electron distribution studies: 2 HR lines of sight (1 FTS + Radiometer) + 1 oblique (FTS). The two lines of sight needs of course two separate waveguides and antennas towards the plasma but can partially share the FTS detection system.

1.4.2. Comments on diagnostics for fluctuation (and transport) measurements (M Romanelli, G Conway and F P Orsitto)

The nature of the machine requires the presence of diagnostics to investigate the core turbulence (for advanced scenarios studies) as well as the edge turbulence (fuelling studies for DEMO).

The list of predicted turbulence scales (Tab.5-2) and the required turbulence diagnostics (Tab.5-3) define an exhaustive set of systems to characterize plasma turbulence. A study is needed to assess the feasibility of some diagnostic cited in Tab.5-3 (and not reported in Table D-4): for example the microwave scattering to measure the ETG (Electron Temperature Gradient) turbulence characterized by small wavelengths.

It is suggested that microwave reflectometer and correlation ECE are of the highest priority (accounting also for the applicability and feasibility of the diagnostics) offering the possibility of studying density and temperature fluctuations at wavelengths characteristic of the ion and trapped electron driven modes. These systems are cited in Table D-4.

In this context it could be of some interest siting the reflectometer or BES (beam emission spectroscopy) together with the ECE viewing optics with the aim of measuring density/temperature cross-phase angles.

It is also suggested to plan for a heavy ion beam probe (HIBP) diagnostic to measure fluctuations of the ion distribution function along with density and temperature fluctuations in order to characterize turbulent transport including relative phases of fluctuating fields.

Furthermore ECE imaging is an emerging diagnostic of great potential for large scale events such as MHD and edge blobs/filaments.

1.4.3. Comments by JA/TROs

Description about the diagnostics for each MHD issue will be added in the next revision of SARP.

We are pleased to hear your evaluation that the list of predicted turbulence scales (Tab.5-2) and the required turbulence diagnostics (Tab.5-3) cover the turbulence studies in JT-60SA.

We agree to your important comment “The nature of the machine requires the presence of diagnostics to investigate the core turbulence (for advanced scenarios studies) as well as the edge turbulence.”
Relating this comment, the sentences "In the development of the scenarios envisaged in JT-60SA, critical aspects involving turbulence and transport at both the edge and the core have to be investigated. To this end, a set of fluctuation diagnostics has to be operational in the device. In particular, there are needs to have good diagnostics covering fluctuations over a large spectral range for both edge and internal transport barrier locations." are inserted in the section of 5.2 Fluctuation measurement.
1.5. Plasma facing components and operational and divertor diagnostics

Table IV shows the comparison between ITER and JT-60SA related to plasma facing components and operational diagnostics.

<table>
<thead>
<tr>
<th>Table V</th>
<th>system</th>
<th>ITER</th>
<th>JT-60SA</th>
<th>comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>plasma facing components and operational diag</td>
<td>IR cameras, visible IR TV</td>
<td>Y</td>
<td>Y</td>
<td>SA IR TV first wall &amp; diveror</td>
</tr>
<tr>
<td></td>
<td>IR thermography divertor</td>
<td>Y</td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pressure gauges</td>
<td>Y</td>
<td></td>
<td>SA planned</td>
</tr>
<tr>
<td></td>
<td>residual gas analyzer</td>
<td>Y</td>
<td></td>
<td>SA planned</td>
</tr>
<tr>
<td></td>
<td>langmuir probes</td>
<td>Y</td>
<td></td>
<td>SA planned</td>
</tr>
<tr>
<td></td>
<td>dust and erosion monitors</td>
<td>tbd</td>
<td></td>
<td>SA feasibility study</td>
</tr>
</tbody>
</table>

A detailed presentation of Plasma Wall Interaction and divertor diagnostics is not given in the Chapter 8 Divertor, SOL and PWI, while requirements on measurements are given in Table D-3 (Edge, SOL and Divertor measurements, Appendix D).

The Divertor operational parameters are not specifically mentioned.

In Appendix D, A Divertor Thomson Scattering system (DTS) is mentioned with attractive requirement on measurements (10mm space resolution along the leg, 10 ms time resolution), but the lay-out is not described neither in SARPv2.1 nor in the PID2.7.

The dust and erosion monitors can be object of a focused research on JT-60SA also in preparing solutions for ITER.

Divertor erosion monitors can measure the changes in thickness of the inner and outer divertor target plates during plasma operations.

There are two techniques under consideration for ITER: i) speckle interferometer and ii) laser radar.

The use of the Thomson Scattering system to detect dust generated in disrupting discharges has been recently mentioned in a review paper on JT-60U by A Isayama.

Dust microbalances are considered for ITER, measuring the local dust concentration under divertor targets. There is some experience on quartz microbalances on JET.
1.5.1.Comments on Plasma Wall Interaction (PWI) Diagnostics on JT60SA (E. Gauthier, JM Travère and IRFM team)

1. PWI Diagnostics
The diagnostic systems for PWI can be used for the energy balance and Infrared thermography.

1.1. Energy balance
Thermocouples can be installed in divertor and first wall. Calorimetry is done on the water cooling.

1.2. IR thermography (first wall, SN, DN)

The systems needed (necessary) are:

a) For Wide angle observation: 2 systems, co and counter Ip (coverage & disruption)

b) For Divertor physics: high space resolution (<3mm) high time resolution (<100µs)
   - Routine Power flux and RT control
   ⇒ 5 IR systems are needed for JT-60SA.

c) An additional Visible fast Camera (wide view) for detecting Disruption, ELMs, UFO, filaments, turbulence
In Tore Supra the IR systems are Routinely used in Real Time for machine protection since 2005. Purposes: i) avoid overheating, ii) detect and mitigate electric arcs in front of LH launchers
1.5.2. **Diagnostics for Disruptions (P de Vries, G Pautasso)**

Disruptions and the resulting heat loads and forces are a key issue for ITER and DEMO and disruption studies should be high on the list of JT-60SA experiments. It is therefore important that the device is equipped with a good set of diagnostics that monitor these events in all aspects. Most present day devices have developed these diagnostics over the years, according to the progress in the understanding of disruptions.

*JT-60SA has the chance to prepare an optimum set of disruption diagnostics.*

Disruption diagnostics can be divided into 3 main groups: 1) Those that will enable to predict and avoid/mitigate disruptions, 2) Those that study the detailed physics and 3) Diagnostics that monitor the consequences of the disruptive events (i.e. heat loads and forces). Regarding the 3 groups, the following points should be considered.

1. **Prediction and avoidance of disruptions**
   A good set of basic, robust, real-time signals that monitor the basic stability limits of the Tokamak should be available from the start of operations. These are (at least) the monitoring: locked mode, rotating MHD activity, radiative fraction, stability of vertical position, *should be ready from the start of operations*. This will for example put a constrained on the development of bolometry (i.e. radiation measurements). More complex algorithms to predict disruptive events can be developed independently (see also Chapter 4).

2. **Diagnosis of the disruption itself**
   Most standard diagnostics to study disruptions will be available at JT-60SA. A few points could be raised. Firstly to ensure good equilibrium reconstruction (before/ during the disruption) which could be important input for modelling. This should be available in at least four sectors of the device. Secondly, the diagnosis of the development of runaways should be emphasised. Besides the standard Hard X-ray, neutron diagnostics, detailed measurements of the temperature and especially density into the thermal and current quench phase would be extremely valuable input to the modelling of the runaway generation. Moreover, a counter-current IR camera, (next to a co-current camera, see 1.5.1) would be of use as the synchrotron radiation from the fast electrons could give an indication on the position of the runaway beam and its strength.

3. **Diagnosis of the disruption consequences**
   The device should be equipped with as many force and displacement sensors (both vertical and side-ways) as possible. It should have good measurements of current in the vessel and other passive structures (important to interpret experimental observations).

   The halo currents can be measured either by shunts or Rogowski coils, mounted between tiles and support, in order to have a measurements of the current profile in the divertor and wall. Again this data should be available for at least 4 sectors. The measured currents through the tiles can also be used to control detachment.

   Fast thermography (IR camera’s) looking at the divertor and wall, preferably at again different sectors to see asymmetries, is essential to assess the heat loads. This can be combined with a fast visible or filtered camera.

   Bolometer and diode arrays should be installed at different toroidal locations, to carry out studies on disruption mitigation and look for example into the asymmetries when applying Massive Gas Injection.
1.5.3. Comments by JA/TROs

Details of magnetic diagnostics for the disruption study will be determined in few years. We will discuss a basic concept for the diagnostics for the disruption research in the next revision of SARP.

As pointed out, Mie scattering technique can be used to detect dusts flying across the laser beam. When the design study of the divertor Thomson scattering system is progressed, possible use of Mie scattering technique will be discussed in chapter 8. Implementation of QMB diagnostics in the divertor cassette is under consideration.

Design studies of IR and visible cameras have progressed sufficiently to be mentioned in the SARP document. So in SARPv3.1, we will describe more detailed requirements in the context of the PSI research. Thermo-couples will be also described in v3.1.
2. Required measurements and essential diagnostics for scenario evaluation.

<table>
<thead>
<tr>
<th>operating scenario</th>
<th>control</th>
<th>evaluation</th>
<th>essential diagnostics</th>
</tr>
</thead>
<tbody>
<tr>
<td>L mode</td>
<td>plasma shape and position, Btor, IP, Vloop, equilibrium, MHD, line average density, runaway electrons, surface temperature of divertor tiles</td>
<td>Zeff, ne(r), Te(r), Ti(r), Prad(r), gas composition, Dalph</td>
<td>Interferometry/polarimetry, CXRS, Thomson, ECE, Vis Spectr, MHD, neutron monitors, divertor thermocouples and probes</td>
</tr>
<tr>
<td>inductive ELMY H mode</td>
<td>equilibrium and position, MHD mode n and m, line average density, runaway electrons, surface temperature of first wall and divertor plates, Te(r), Ti(r), Vtor(r), Vpol(r), position of q=1.5 and q=2 surfaces, detection and measurements of NTMs</td>
<td>q(r), Zeff, ne(r), gas pressure and composition, pedestal measurements of ne and Te, Prad(r), Dalph, deposition of heat in divertor, neutron profile, Ti(r), neutral density (near wall), plasma parameters in the divertor (ne, Te), neutron flux, erosion of divertor tiles</td>
<td>Interferometry/polarimetry, CXRS, Thomson, ECE, Vis Spectr, MHD, neutron monitors, divertor thermocouples and probes</td>
</tr>
<tr>
<td>hybrid mode</td>
<td>equilibrium and position, MHD mode n and m, line average density, runaway electrons, surface temperature of first wall and divertor plates, Te(r), Ti(r), Vtor(r), Vpol(r), position of q=1.5 and q=2 surfaces, detection and measurements of NTMs</td>
<td>q(r), Zeff, ne(r), gas pressure and composition, pedestal measurements of ne and Te, Prad(r), Dalph, deposition of heat in divertor, neutron profile, Ti(r), neutral density (near wall), plasma parameters in the divertor (ne, Te), neutron flux, erosion of divertor tiles</td>
<td>Interferometry/polarimetry, CXRS, Thomson, ECE, Vis Spectr, MHD, neutron monitors, MSE, divertor thermocouples and probes</td>
</tr>
<tr>
<td>steady state high beta</td>
<td>equilibrium and position, MHD mode n and m, line average density, runaway electrons, surface temperature of first wall and divertor plates, Te(r), Ti(r), Vtor(r), Vpol(r), position of q=1.5 and q=2 surfaces, detection and measurements of NTMs</td>
<td>q(r), Zeff, ne(r), gas pressure and composition, pedestal measurements of ne and Te, Prad(r), Dalph, deposition of heat in divertor, neutron profile, Ti(r), neutral density (near wall), plasma parameters in the divertor (ne, Te), neutron flux, erosion of divertor tiles</td>
<td>Interferometry/polarimetry, CXRS, Thomson, ECE, Vis Spectr, MHD, neutron monitors, MSE, divertor thermocouples and probes</td>
</tr>
</tbody>
</table>
3. Comments on technical specifications of diagnostics.

3.1. Measurements of electron temperature and density

The requirements of spatial resolution in core plasma for JT-60SA is close to a/30 which is in agreement to that required for ITER. The spatial resolution of 5mm in edge and pedestal is in agreement as well with the requirements of ITER pedestal measurements. In Table D-3 Appendix D, a temporal resolution of ≈ms using Thomson Scattering is quoted on the pedestal measurements, while the Nd:YAG laser has 50Hz repetition rate (20ms).

3.2. q-profile measurements

The spatial resolution of MSE is close to a/10 in JT-60SA, while the requirements on measurements for ITER is a/20. The space resolution is linked to the required accuracy on the MSE measurement of the pitch angle. It could be important exploring the possibility of improving the space resolution for MSE measurements, given the importance of this measurement for the mission of the device.

In this context the option (as it is defined in the PID) of the measurement of the radial electric field (ErMSE) having two MSE working together could be reinforced with the aim of having the possibility of a certain redundancy between the ErMSE and the Er that can be deduced from CXRS measurements (ErCXRS) using the force balance.

3.3. CXRS measurements

The spatial resolution of CXRS/Tion measurements is close to a/20 for JT-60SA, while the requirements on measurements for ITER is a/10. The spatial resolution on rotation measurements is a/20 for JT-60SA, while it is required a/30 for ITER. The time resolution for CXRS measurements (Ti and Vrotation) is 1ms for JT-60SA, while the required time resolution for ITER is 100ms. In general the CXRS pedestal measurements are better in JT-60SA, with respect to that required for ITER.

3.4. Radiation profile

The requirement on measurements on radiation profile for JT-60SA are slightly better than in ITER: i) the space resolution between a/10-a/20, while in ITER are a/15 ii) the time resolution in JT-60SA is ≈ms, while in ITER 10ms is required.

3.5. Comments by JA/TROs on Technical specifications

Technical specifications of diagnostics will be updated following updates in each chapter in the later version.
4. **Real Time (RT) Control and Diagnostics (D Mazon)**

4.1. **observations on RT in SARPv2.1.**

- RT Control appears as a key element of the JT-60 SA Research Plan in order to perform RT experiments and predict the controllability of the plasmas in ITER and DEMO.

- **A full description of the envisaged RT network architecture is missing in the document.** Indeed from the experience gained at JET it is very important to consider since the beginning the full set of RT diagnostics all together with their interactions and different acquisition time.

- For plasma control a powerful RT infrastructure has to be designed capable to cope with slow (for example q profile) and fast control (for example MHD). This also has some consequence with the design of the network depending on the chosen system.

- **Particular emphasis is given to the control of MHD modes which are indeed crucial for ITER. But only classical SXR diodes are envisaged. New technology should be envisaged like SXR imaging.**

- **HXR diagnostic is not considered, but very useful for suprathermal deposition profile** (and simulation of transport).

From a general point of view no RT calibration are mentioned in the document and this could also have some implication on the design of the systems and should be taken into account from the beginning.

4.2. **proposals (for improvements)**

4.2.1. **A full chapter in the introduction should be dedicated to the description of RT infrastructure including a global picture of the synergy between the different diagnostics and their acquisition time.**

4.2.2. A contribution on the SXR field (measurement, analysis, inversion techniques, simulation for synthetic diagnostics...) is proposed for a better diagnose of the plasma; GEM detector (which is already an activity sustained by the EFDA since 2010) seems to be a very interesting candidate for the SXR measurement and presents the advantage to allow a discrimination in energy. It can also be used to measure and confirm the intrinsic rotation of the plasma and to perform spectroscopic analysis (impurity detection and Zeff determination). A contribution on this field could be also proposed.

4.2.3. The design of a tomographic HXR camera should be prepared for diagnosing the suprathermal electrons distribution function. This will be essential in particular during the Real time control of the sawtooth activity using ECCD for example.

4.3. **Comments by JA/TROs on RTC.**

We also recognize that the real time control is a key element of the plasma research in JT-60 SA. Research and issues related on the plasma control should be described in each chapter. Architecture and infrastructure of the real time control are in present not discussed in SARP.
5. Diagnostics for DEMO

The possibility of using JT-60SA to approach important issues of DEMO plasma control is mentioned in various part of SARPv2.1. An important requirement induced by DEMO device is the necessity of having the minimum set of sensors and actuators for plasma control and device safety.

The Table 2-2 in SARPv2.1 reports a summary on research needs for ITER and DEMO, with required device capabilities.

In DEMO the following control schemes are needed:

- Q-profile control (Off axis CD by N-NBI)
- RWM stabilization (by plasma rotation and external coils)
- NTM stabilization (ECCD)
- ELM control (pellet pacing)
- Radiative divertor and detachment (impurity seeding)
- Pedestal characteristics (fuelling)

These items bring the question about the minimum set of diagnostics useful for the mentioned control schemes in DEMO.

An important mission of JT-60SA is providing a useful answer to define this minimal set of sensors useful for the plasma control.

In particular the experiments on JT-60SA can help in defining whether

- using active diagnostics like MSE or Thomson Scattering and interferometry/polarimetry is a viable option in DEMO.
- Passive spectroscopy like X-ray crystal can help in providing informations on rotation
- IR systems can be used safely.

A study can be carried out and added to SARPv3 balancing the various options.

5.1. Comments by JA/TROs

Assessment of the minimum set of diagnostics and actuators to fulfill the plasma control and device safety will be mainly discussed in the chapter 3. Technical issues for implementing those diagnostics to DEMO will be discussed in the chapter 9 in future.
6. Conclusions and future work

In the report analysis of the diagnostics for JT-60SA is carried out.

The diagnostic set of JT-60SA has been compared to the ITER diagnostic set plan and indications were extracted from this analysis, jointly with the specificity of the device.

The comments of JA/TROs reported on each chapter support in general the analysis and the key proposals made by EU WG.

From the comments it can be observed that important fields where further investigation is needed and where EU contribution can be sensible, are the following:

- Q-profile diagnostics
- Kinetic diagnostics (in particular Thomson Scattering)
- Fast particle diagnostics
- Divertor diagnostics
- Disruption Diagnostics
- Real Time Control
- Diagnostics for DEMO
ANNEX I

SARPv2.1 REVISION: Appendix D and Diagnostics of JT-60SA

Contribution related to Diagnostics of JT-60SA.
Ref document is the DRAFT v2.2 (ref. FO/SARPv3/7/2.2/131011).
Authors: F P Orsitto and Diagnostics WG (see DRAFT v2.2 for membership)
Ref FO/SARPv3/7/2.2.1/091111

1. The tables I,II,III,IV,V are proposed to be inserted in the App D, since they give a complete comparison between the ITER Diagnostics set plan and that of JT-60SA as it appears from App D and the PIDv2.7 (sept 2011).
2. Table I.1 is proposed to be inserted in the Appendix D as defining the technical specifications on Fast particle diagnostics.
4. The following comment is related to App D 2 Port allocation: In Appendix D, A Divertor Thomson Scattering system (DTS) is mentioned with attractive requirement on measurements (10mm space resolution along the leg, 10 ms time resolution), but the layout is not described neither in SARPv2.1 nor in the PID2.7. The ITER divertor Thomson Scattering system is projected to measure the outer leg of the divertor. It is planned for measurements of the electron temperatures between 0.3 and 200eV, at electron densities above $10^{19} \text{m}^{-3}$, every 1 ms, with a space resolution of 50mm along the leg and 3mm across the leg, and accuracy of 20% on electron density and temperature.
5. The following comments are related to App D 2 Port allocation and they could refer to fig D-2 (collection optics of Thomson Scattering): Sec 1.2. Optical systems/Comments on measurements of temperature and density by TS.
6. sec. 1.3.1. Comments on q profile measurement: to be inserted as a separate paragraph in ch 3.
7. sec 1.4.1 Comments on Electron Cyclotron Emission: to be inserted in sec 5 of ch 4 MHD stability
8. sec 1.4.2. Comments on diagnostics for fluctuations (and transport): to be inserted in the section on ‘Measurements’ of Ch 5 Transport and Confinement.
9. sec.1.5.2. Diagnostics for Disruptions: to be inserted in the sec 4 (Disruptions) of Ch 4 MHD Stability and Control.
10. The following comments can be inserted in the Ch 8 Divertor, SOL and PWI as separate paragraph: The dust and erosion monitors can be object of a focused research on JT-60SA also in preparing solutions for ITER. Divertor erosion monitors can measure the changes in thickness of the inner and outer divertor target plates during plasma operations. There are two techniques under consideration for ITER: i) speckle interferometer and ii) laser radar. The use of the Thomson Scattering system to detect dust generated in disrupting discharges has been recently mentioned in a review paper on JT-60U by A Isayama. Dust microbalances are considered for ITER, measuring the local dust concentration under divertor targets. There is some experience on quartz microbalances on JET.
11. Sec.1.5.1. Comments on PWI diagnostics: to be inserted in Ch 8 as separate paragraph.
12. Sec2. Require measurements and essential diagnostics for scenario evaluation: to be inserted in Ch 3 Operation Regime Development.
13. Sec.3 Comments on technical specifications of diagnostics : to be inserted as notes in the tables of App D.
14. Sec.4 Real Time (RT) Control and Diagnostics : to be inserted as a separate paragraph in Ch 4 MHD Stability and Control.
15. Sec.5 Diagnostics for DEMO: to be inserted as separate paragraph in Ch 9 Fusion Engineering