Manual for a KB5 PPF-production

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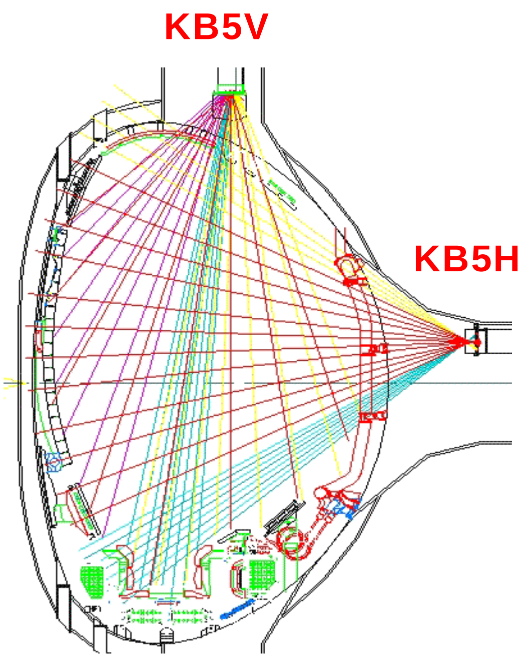
1 Introduction

Two new bolometer cameras (KB5) for horizontal and vertical views of the plasma cross section have been installed on the JET. These cameras replace previous cameras (KB1 and KB4) in operation and represent in combination with new electronics a substantial upgrade in capabilities: More viewing chords over a larger viewing angle, higher detectable energy range, higher sensitivity, lower noise level and therefore lower detectable signal (~2μW/cm^2 for integration time τ=2ms vs. ~70μW/cm^2 for τ =20ms). The detector element consists of a 20μm muscovite mica substrate, on one side of which an 8μm gold layer (the absorber layer has been increased in thickness from 4 to 8μm in order to extend sensitivity to 8keV) is deposited (absorber) and on the other are two interwoven gold meanders (resistors). When the absorber heats due to impinging plasma radiation, the meander resistances change. These changes can be related to the energy input. In order to compensate for temperature drifts as well as electromagnetic disturbances a 2nd reference bolometer is employed which is optically shielded from plasma view.

Each camera is comprised of 24 channels, with a particularly fine spatial resolution in the



Location:

- **Vertical camera KB5V on MVP octant 3 (replaces KB1).**
- **Horizontal camera KB5H on MHP octant 6**

Lines of sight:

•KB5V

16 channels cover all cross section (13-25cm separation at midplane);
8 channels dedicated to divertor (8 cm separation at top of divertor).
(+8 reserved channels w/ lower spatial resolution)

•KB5H

4 upper channels (vertical separation ~ 15 cm at R=3m);
+12 middle channels (separation 18-22 cm);
+8 lower channels for divertor (separation ~8 cm)

Fig1. The locations and line off-sight of KB5 cameras

divertor region of ~8cm. Definition of the lines-of-sight is attained by a collimator arrangement for the vertical camera and use of pinholes for the horizontal camera. The Fig.1 shows schematically the location and line off-sight of KB5 cameras.

All 48 bolometer signals are made available to the Real Time Control system for feedback/control purposes, with a maximum sampling bandwidth of 5kHz. The new software for calculation of total radiation power has been new written in FORTRAN90.

2 Overview of the new KB5 PPF-production program

2.1 Processing of bolometer signals

The main task of the program processing the bolometer signals is to process the raw JPF signal ΔU of the bolometers as a function of time t, which is proportional to the temperature rise of the bolometer foil due to incident radiation, by means of the bolometer equation

$$P(t) = \tfrac{\tau_C}{S \times G}\left(\frac{\mathrm{d}\Delta U(t)}{\mathrm{d}t} + \frac{\Delta U(t)}{\tau_C}\right) \tag{1}$$

to give the incident power P (in W),
where

ΔU(t) is the change in output signal from before radiation applied (V)

ΔU(t)=U(t)-U(0)

S is the sensetivity (Bolo bridge signal /incident power) (V/W)

G is the gain of used amplifier

τ_C is the cooling time constant (s).

The calibration factors are stored in the JPF (see Appendix A).

The incident power is traditionally expressed as a line-integral value P_{L} (in Wm^{-2}) by ,

$$P_{\mathrm{L}} = 4\pi P / E$$

where E is the étendue[1] of the detector and the factor 4π can be used because the plasma is assumed to radiate isotropically.

The current étendues for both KB5V and KB5H cameras have been calculated on the basis of the version-1 KB5 geometry by the pin3Danal3_linux.f90 program based on the data in the /home/ahuber/bolotomo/collimator and /home/ahuber/bolotomo/geomdir directories and also used for the geometric matrices.

Straightforward evaluation of the derivative in Eq. (1) would amplify noise. Therefore, regularization of Eq. (1) is required. Three regularization/filtering techniques have been implemented so far:

1. moving-window smoothing of the raw signal before processing,
2. processing by means of a Bessel filter (according to Ref. 2; the implementation of Jürgen Rapp) and
3. the *smotem* routine by Gottardi (i.e. the routine used in the KB194 program). This method appears to work well with the old parameter settings and is probably the preferred method at the moment.

2.2 Total radiated power calculation

The second task of the program is to provide an estimate of the total radiated power of the entire plasma and of the bulk. In the new program a static estimate (i.e. a fixed plasma shape is used) is made of the total radiated power by weighted summation, as described in Ref. 3. An estimate similar to the old BOLO/TOPO, which was shown in Ref. 3 to be incorrect during the X-point phase, is supplied for consistency with the past. This estimate is based on the "unscaled" weighted summation of Ref. 3, although an improvement has been made to scale the bulk plasma for better performance during the limiter phase. An improved estimate of the total radiated power during the X-point phase (lower X point only) is also produced by the "scaled" weighted summation of Ref. 3. In a similar way estimates of the bulk radiation are made from the outer channels of the vertical KB5V camera and the upper channels of horizontal KB5H camera.

2.3 Programming

The KB5 new program has been completely written in FORTRAN90 that is preferable programming language for Chain-1. All parameters used by the program are read from files and are stored in the PPF so that differences can be traced afterwards. The source code is available by calling the perl script,

/home/chain1/tools/scripts/privstepnew.perl bolo

which will put a copy of the source in /home/username/intershot/source/bolo/.

3 Details of the new KB5 PPF-production program

This section discusses the options and parameters of the program and some details of the calculation techniques, the program and the input files. A simple way to store many parameters in some arrays was adopted. This is not very elegant and has the disadvantage that renumbering may be needed if more parameters are inserted, but has the advantage of easy reading (structures with all the parameters would have been more elegant).

3.1 Selection of channels and geometric information

At this moment (January 2006) we have all channels (48 active and 8 reserve channels) in operation.

But from the experience in the past we know that several channels of KB1 have been broken or disconnected. So a means is required to select which channels should be processed. Also, for the calculation of the total radiated power and bulk radiated power the channels to be used have to be specified. For flexibility, the geometric information about the system is not hardwired into the program, but is supplied in a file. All this information (for a given geometry version, in this case version 6) is combined in the file *kb5data.dat*.[2] This file contains the number of cameras (the order must correspond to the order of the calibration factors read from the JPF comment blocks), the camera names (data types), the data type description string, the number of channels per camera, the origin of projection space[3] as used in this file, the string-length of the nodenames, and, for each channel: the JPF nodename, the camera number (not used), the channel number (not used, must be in correct order), whether the channel is to be processed (0: no; 1: yes), the étendue, the impact parameter p (in m), the angle ξ (in deg.),[3] whether the channel is to be used for the total radiated power calculation (0: no; 1: yes; vertical camera only), and whether the channel is to be used for the bulk radiated power calculation (outer channels of vertical and lower horizontal camera). The reading of the file is in fixed format, so the number of spaces between columns has to be strictly adhered to.

The projection-space coordinates are directional[3] (see Sec. 3.7) and are used in the calculation of the total and bulk radiated power. The angle is also supplied as the y variable of the two-dimensional signals per camera (channel and time). The selection of channels for the bulk power calculation should be on one side of $p = 0$; however, it is possible to chose one extra channel so that the interpolated value at is used (optional; recommended for the lower horizontal camera; see Sec. 3.8). Obviously, the channels selected for the vertical camera for the bulk radiated power calculation have to exclude channels that see divertor radiation.

3.2 Calibration factors

For KB5 the calibration factors (time constant and sensitivity) are stored in JPF comment nodes, so that the correct calibration factors are always available. These factors are written to the GAP tree whenever a KB5 calibration is done (see Appendix A for a description of the calibration procedure). Here is the list of JPF signals with calibration factors:

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[2] In this document filenames are given in the Courier font: upright type means that the filename is fixed and should not be changed, slanted type means that the default name is given but that the actual file used is determined by the name specified in an input file.

[3] For the definition of projection-space coordinates p and ξ see, for instance, Sec. 3.1 in L.C. Ingesson, *The mathematics of some tomography algorithms used at JET*, JET Report JET-R(99)08. There, also the definition of directional projection-space coordinates is given (see also footnote 8 on page 11). It is actually assumed in the program that for the vertical camera $\xi > \pi$; no test is made and incorrect results would be obtained if $0 \leq \xi < \pi$.

KB5V calibration factors as JPF signals:

Sensitivity:	DB/B5V-SENSI:001 … DB/B5V-SENSI:024
Cooling time	DB/B5V-TCONS:001 … DB/B5V-TCONS:024

KB5H calibration factors as JPF signals:

Sensitivity:	DB/B5H-SENSI:001 … DB/B5H-SENSI:024
Cooling time	DB/B5H-TCONS:001 … DB/B5H-TCONS:024

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3.3 Electronic settings

For KB5 the electronic settings (gains, filters and phases) are stored in JPF comment nodes, so that the correct information about electronics are always available. Here is the list of JPF signals with electronic settings:

KB5V electronic settings as JPF signals:

Gain:	DB/B5V-IGAIN:001 … DB/B5V-IGAIN:024
Filter	DB/B5V-FLTR:001 … DB/B5V-FLTR:024
Phase	DB/B5V-PHAS:001 … DB/B5V-PHAS:024

KB5H electronic settings as JPF signals:

Gain:	DB/B5H-IGAIN:001 … DB/B5H-IGAIN:024
Filter	DB/B5H-FLTR:001 … DB/B5H-FLTR:024
Phase	DB/B5H-PHAS:001 … DB/B5H-PHAS:024

3.4 Pre-processing of signals (offset, drift)

Although the KB5 amplifiers are balanced just before each discharge. This offset can easily be determined from the signal before the start of the plasma (at 40 s) and corrected for. In the old KB1 PPF production program a simple linear interpolation between the offset level and signal after the plasma is subtracted from the signal. This simple method has also been adopted in the new program. The input options (given in the *kb5jpf2ppf.par* file) and recommended values are given in Table I.

Table I: Options for processing of signals.

Option No.	Comment	Recommended value
1	Offset subtraction: 0: no; 1: yes	1
2	Time window at beginning of time vector for offset determination	0.5
3	Linear drift correction: 0: no; 1: yes	1
4	Time window at end of time vector for drift determination	0.1
5	Fudge factor to account for deficiency in-situ calibration	1.0

Note: The fudge factor which was used in the old KB1 PPF production program has been removed (set to 1.0) in the new program because the sensitivity measured with in situ method matches very well with the result using light source calibration.

3.5 Processing of bolometer equation

As indicated in Sec. 2, many methods exist to evaluate Eq. (1), and several of these have been implemented: 1) moving window smoothing, 2) Bessel filter, 3) Gottardi method. The selection of method is done in the *kb5jpf2ppf.par* file and the processing parameters and recommended values are given in Table II.

Moving window smoothing contains three type of windows:

1. Rectangular window
2. Median window
3. Triangular window

All these methods use FORTRAN90 routines, which requires the window size. The window size is set by the *time* parameter in the *kb5jpf2ppf.par* file.

The Gottardi method is a compression method by means of a hyperbolic tangent. According to this method, the line integrated signals by each detector can be expressed as

$$y_i^{smoothed} = \tfrac{1}{3}\sum_{k=i-1}^{k=i+1} y_k + \tanh\left[alevel \times \max\left(\left.\tfrac{dy}{dt}\right|_{x_i}, \left.\tfrac{dy}{dt}\right|_{x_{i+1}}\right) \times \max\left(\left.\tfrac{dy}{dt}\right|_{non-ELMy-phase}\right)\right] \times \left[y_i - \tfrac{1}{3}\sum_{k=i-1}^{k=i+1} y_k \right],$$

where $y_i^{smoothed}$ is the smoothed line integrated signal at time x_i and *alevel* is the compression factor for hyperbolic tangent defined in the kb5jpf2ppf.par file. To obtain effective smoothing of the signal noise, the *alevel* parameter has been set to 0.35. During the significant ELMs the argument of the hyperbolic tangent function is much larger than 3.0 and thus the hyperbolic tangent tends to1.0. From this it follows that no smoothing is applied during the ELMs ($y_i^{smoothed}=y_i$).

Sometimes in reprocessing the *smored* parameter (how many times you want to repeat the smoothing procedure) has been set to 20 to obtain more smoothing.

The Bessel filter method requires pre-calculated files (besfi######.dat3 in the specified directory; the #s indicate the six-digit integer sampling time in μs) that are produced by the program makebesfi.f. The sampling time is set in the parameter *deltat*, after which the makebesfi.f program has to be recompiled and run. Files have been produced for all required sampling frequencies, and their names are hardwired in SUBROUTINE *rdfilter* in the calcbolopow_bessel.f file. The way the Bessel filter has been set up, a variable sampling rate during the discharge (as is the case in the VME data-acquisition system of KB3 and KB4) is not supported. The amount of filtering is set by the *bandwidth* parameter, which has to have an integer value. A *bandwidth* of 1 means filtering at the Nyquist frequency, and a higher *bandwidth* value mean corresponding fractions of the Nyquist frequency. The maximum bandwidth value depends on what has been set for the *ixlim* parameter in makebesfi.f when the files are produced; 9 is the current maximum value which gives a lot of smoothing.

While Fig. 1(a) shows that all three methods give very similar results during a non-ELMy phase, except when the window smoothing uses a too short time window (not shown in the figure), Fig. 1(b) indicates that all methods that give acceptable results in a non-ELMy phase, apart from the Gottardi method, smooth away the ELMs too much. The oscillation of signal at 10Hz has been caused by ROG feedback control system.

Table II: Parameters for processing of bolometer equation.

Par. No.	*method*	Symbol	Comment	Recommended value
1	–		Method: 1: moving window smoothing 2: Bessel filter 3: Gottardi method	3
2	1	*type*	Type of window: 0: no window 1: rectangular window 2: median smoothing 3: triangular window	(3)
	2	*bandwidth*	Bandwidth of Bessel filter: 1…9: little…much filtering	(2)
	3	*smored*	Amount of smoothing	10
3	1	*time*	Smoothing window length (in s)	(0.1)
	3	*dnoise*	Threshold noise level; if <0 calculated internally	–1.0
4	3	*ibnois*	First point to calculate *dnoise*	20
5	3	*ienois*	Last point to calculate *dnoise*	50
6	3	*ibave*	Start points for averaged start point	3
7	3	*ieave*	End points for averaged last point	5
8	3	*alevel*	Compression factor for hyperbolic tangent	0.35
9	3	*cdno*	Modify level of noise	1.017
–	2	*path*	Path for besfi######.dat3 files	besfidir/

3.6 Philosophy of estimates of total radiated power

As described in Ref. 3 the total radiated power can be calculated in a straightforward way if one has a full vertical view of a poloidal cross-section of the plasma. Because this is not available at JET, one has to calculate the total radiated power by integrating over a tomographic reconstruction, or one has to make approximations. The former method is too slow to be applicable to many time slices (and would normally also require checking by hand). Techniques to estimate the total radiated power from the line-integral measurements include: 1) weighed summation [3], 2) statistical techniques [5], 3) neural networks and 4) Abel inversion[4]. The weighted-summation method was chosen because of its simplicity, robustness, physically meaningful parameters, and because the weights are likely to be similar to those obtained with the statistical techniques or neural networks.

[4] In the Abel inversion method one assumes the emissivity to be constant on flux surfaces and calculates the total radiated power from an Abel inversion. This method is not applicable at JET because of the X-point radiation and poloidal asymmetries that occur.

In the weighted summation one tries to approximate a full parallel view of a poloidal cross-section. The actual fan view therefore has to be projected to parallel lines. In projection space (Fig. 2) this can be seen as the projection of points on a tilted line (approximately straight) to points with constant angle ξ_{proj}. Ideally, the projection should be along contours of the sinogram. Because the sinogram is not available, the best one can do is to approximate the projection according to the expected sinogram as well as one can. One could do this for different plasma types, or even according to the plasma shape for the given shot. Because of the inevitable inaccuracies, it was chosen to use a fixed average geometry for all discharges. Furthermore, the variation of major radius for these lines of sight is neglected in the weighted summation.

3.7 Total radiated power

Two different total radiated power are output: TOPO which is similar to the old BOLO/TOPO, and TOPI, which is an improved version. TOPO is calculated according to "bulk" scaling, whereas TOPI uses "X-point" scaling. As discussed in Sec. 3.1, the channels to be used in this calculation are selected in the *kb5data.dat* file. It is important to de-select broken or non-connected channels (if they for evaluated shot exist). If the program detects that any of the selected channels is wrong (a test is made for zero signal, which indicates that the data-acquisition process failed), the affected radiated powers are not written to the PPF.[5][6]

3.7.1 Bulk scaling

The vertical KB5 camera does not cover the entire cross-section, so first one has to define the edge of the cross-section by introducing virtual (zero) edge points [red circle points in Fig. 2(b)].

Bulks scaling method$_{totrad2}$

The most straightforward way to project the KB5 vertical camera to ξ_{proj} [see Fig. 2(b)] is by $(p,\xi) \to (p',\xi') = (p,\xi_{\mathrm{proj}})$ (this will be referred to as *method*$_{\mathrm{totrad}}$ 2). For the edge points this is not good, as at ξ_{proj} they end up outside the vessel (blue area in Fig. 2).

Bulks scaling method$_{totrad1}$

[5] Automatic de-selection of channels is not desirable as the results may be unpredictable if essential channels are left out. Therefore it is better not to produce the data type to indicate that something is wrong and thus trigger a request for manual checking and re-processing.

[6] It should be taken into account in the production of PPFs that depend on the TOPO data type in the BOLO DDA that this data type may be missing on certain occasions.

A better projection is to scale p so that it fits within the vessel boundary at ξ_{proj} (parametrized by p_{u_1} and p_{u_2}). A linear scaling operation $(p,\xi) \rightarrow (p',\xi') = (p'',\xi_{\mathrm{proj}})$, where p'' is given by

$$p'' = \begin{cases} p_{\mathrm{mid}} + (p - p_{\mathrm{mid}}) \left| \dfrac{p_{\mathrm{u}_2} - p_{\mathrm{mid}}}{p_{\mathrm{e}_2} - p_{\mathrm{mid}}} \right| & p \geq 0 \\ p_{\mathrm{mid}} + (p - p_{\mathrm{mid}}) \left| \dfrac{p_{\mathrm{u}_1} - p_{\mathrm{mid}}}{p_{\mathrm{e}_1} - p_{\mathrm{mid}}} \right| & p < 0 \end{cases}$$

where $p_{\mathrm{mid}} = p_{\mathrm{e}_1} + (p_{\mathrm{e}_2} - p_{\mathrm{e}_1})(\xi_{\mathrm{proj}} - \xi_{\mathrm{e}_1})/(\xi_{\mathrm{e}_2} - \xi_{\mathrm{e}_1})$. This linear scaling is referred to as $method_{\mathrm{totrad}}$ 1. Fig. 3 shows scaled and projected impact parameter p_{proj} as a function of the unscaled impact parameter p (both with respect to the magnetic-axis origin). The solid points indicate actual channels. More advanced scalings (not implemented yet) would take into account that the scaling should depend on the distance $|\xi - \xi_{\mathrm{proj}}|$ or actually try to follow the contours of a sinogram.

The $method_{\mathrm{totrad}}$ 2 for bulk scaling corresponds to the "unscaled" method in Ref. 3; here the names bulk-scaling and X-point scaling for the total radiated power calculation are preferred as $method_{\mathrm{totrad}}$ 1 for bulk scaling is actually scaled. In the bulk power calculation (Sec. 3.8) similar scalings are used, but these have different characteristics controlled by $method_{\mathrm{bulkrad}}$ (of which the names may be confused with the present bulk scaling for the total radiated power).

The $method_{\mathrm{totrad}}$ 1 for bulk scaling has been selected as the preferred scaling: it is more physical than $method_{\mathrm{totrad}}$ 2 and gives much more reasonable values than $method_{\mathrm{totrad}}$ 2 in the limiter phase ($method_{\mathrm{totrad}}$ 2 give much too high values in that case). However, $method_{\mathrm{totrad}}$ 2 gives values closer to the old BOLO/TOPO in X-point plasmas, with $method_{\mathrm{totrad}}$ 1 the values during the X-point phase are always somewhat lower. The choice of $method_{\mathrm{totrad}}$ 1 is therefore a compromise between the quality of fit to the old BOLO/TOPO and the accuracy during the limiter phase (in which $method_{\mathrm{totrad}}$ 2 is much higher than BOLO/TOPO). Figure 6(a) illustrates these facts for the old and new BOLO/TOPO in a discharge which X-point phase between 12 and 63 s. In this particular case, the discrepancy between the old and new BOLO/TOPO is relatively large during the X-point phase.

3.7.2 X-point scaling

The rough bulk scalings are not adequate when there is X-point radiation. As is discussed in Ref. 3, it is very important to consider the X-point radiation by a horizontal projection in projection space with the origin in the (nominal) X point[7] [Fig. 2(d)]: in that case the sinogram contours of X-point radiation are nearly horizontal. projecting along the solid

[7] The change of origin of projection space [e.g. from $(x_{\mathrm{m}}, y_{\mathrm{m}})$ to $(x_{\mathrm{X}}, y_{\mathrm{X}})$] is given by: ξ is unchanged and $p \rightarrow -(x_{\mathrm{m}} - p\sin\xi - x_{\mathrm{X}})\sin\xi + (y_{\mathrm{m}} + p\cos\xi - y_{\mathrm{X}})\cos\xi$.

arrows. This horizontal projection is only applied to channels for which $p_{02} < p_X < p_{01}$ (the subscript X indicates that the X point is the origin of projection space). Outside this X-point region a scaling is applied that is characterized by the parameters indicated in Figs. 2(c) and (d), i.e. a squeezing from p_{11} to p_{21}, and from p_{12} to p_{22}. Various such scaling operations are indicated in Fig. 4. The details of the scaling operation can vary, but it is important that it is continuous at the transitions near p_{01} to p_{02}. It would also be preferable that the derivative $\mathrm{d}p_{\mathrm{proj}}/\mathrm{d}p$ were continuous, but no adequate scaling with that property has been found.

X-point scaling method$_{totrad1}$

In *method*$_{\mathrm{totrad}}$ 1 the scaling is linear (if $\alpha = 1$) or somewhat stretched close to the X-point . The projection (in projection space with the X-point as origin) $(p_{\mathrm{X}}, \xi) \to (p'_{\mathrm{X}}, \xi') = (p''_{\mathrm{X}}, \xi_{\mathrm{proj}})$ is given by

$$p''_{\mathrm{X}} = \begin{cases} p_{01} + (p_{21} - p_{01})\left|\dfrac{p - p_{01}}{p_{11} - p_{01}}\right|^{\alpha} & p_{\mathrm{X}} > p_{01}, \\ p_{\mathrm{X}} & p_{02} \le p_{\mathrm{X}} \le p_{01}, \\ p_{02} + (p_{22} - p_{02})\left|\dfrac{p - p_{02}}{p_{12} - p_{02}}\right|^{\alpha} & p_{\mathrm{X}} < p_{02}. \end{cases}$$

The function of α is to make the mapping non-linear with a weight towards close to the X point so that the slope changes less at p_{01} and p_{02}. This is similar to a scaling weighted with $|\xi - \xi_{\mathrm{proj}}|$.

X-point scaling method$_{totrad2}$

In *method*$_{\mathrm{totrad}}$ 2 the scaling is actively proportional to $|\xi - \xi_{\mathrm{proj}}|$ and is given by the following formulae:

$$\xi_{\mathrm{unproj}} = \begin{cases} \xi_{11} + (p_{11} - p_{\mathrm{X}})\dfrac{\xi_{21} - \xi_{11}}{p_{11} - p_{01}} & p_{\mathrm{X}} > p_{01}, \\ \text{undefined} & p_{02} \le p_{\mathrm{X}} \le p_{01}, \\ \xi_{12} + (p_{12} - p_{\mathrm{X}})\dfrac{\xi_{22} - \xi_{12}}{p_{12} - p_{02}} & p_{\mathrm{X}} < p_{02}, \end{cases}$$

$$s = \begin{cases} -\dfrac{p_{11} - p_{21}}{\xi_{01} - \xi_{11}}\left|\dfrac{\xi_{21} - \xi_{\mathrm{unproj}}}{\xi_{21} - \xi_{11}}\right|^{\alpha} & p_{\mathrm{X}} > p_{01}, \\ \text{undefined} & p_{02} \le p_{\mathrm{X}} \le p_{01}, \\ \left|\dfrac{p_{12} - p_{22}}{\xi_{02} - \xi_{12}}\right|\left|\dfrac{\xi_{22} - \xi_{\mathrm{unproj}}}{\xi_{22} - \xi_{12}}\right|^{\alpha} & p_{\mathrm{X}} < p_{02}, \end{cases}$$

and

$$p''_{\mathrm{X}} = \begin{cases} p_{\mathrm{X}} + s\left|\xi_{\mathrm{unproj}} - \xi_{01}\right| & p_{\mathrm{X}} > p_{01}, \\ p_{\mathrm{X}} & p_{02} \le p_{\mathrm{X}} \le p_{01}, \\ p_{\mathrm{X}} + s\left|\xi_{\mathrm{unproj}} - \xi_{02}\right| & p_{\mathrm{X}} < p_{02}. \end{cases}$$

Again the function of α is to make the mapping weighted with $|\xi - \xi_{\mathrm{proj}}|$ and give a more continuous slope $\mathrm{d}p_{\mathrm{proj}}/\mathrm{d}p$. The results of *method*$_{\mathrm{totrad}}$ 1 with $\alpha = 1$ and *method*$_{\mathrm{totrad}}$ 2 with $\alpha = 0.25$ are very similar. So far, *method*$_{\mathrm{totrad}}$ 1 with $\alpha = 1$ is the recommended method.

Figure 6(a) shows that BOLO/TOPI calculated in this way is a little bit higher than BOLO/TOPO. Surprisingly BOLO/TOPO is more consistent with the most reliable method to determine the total radiated power, i.e. tomographic reconstructions of KB5 measurements [3].

3.7.3 Parameters

The input parameters (given in the *kb5jpf2ppf.par* file), dependence on *method*$_{\mathrm{totrad}}$ and recommended values are given in Table III. Note that some parameters should be given in directional projection space[8] to be in agreement with the general geometrical characterization of the JET bolometer systems (e.g. the *kb5data.dat* file). Some parameters should be given in projection space with the nominal magnetic axis as origin and some in projection space with the nominal X point as origin. Note also that in principle (p_{e_2}, ξ_{e_2}) and (p_{11}, ξ_{11}), (p_{e_1}, ξ_{e_1}) and (p_{12}, ξ_{12}), p_{u_2} and p_{21}, and p_{u_1} and p_{22} describe the same points in different coordinate systems. In addition, (p_{e_1}, ξ_{e_1}) and (p_{e_2}, ξ_{e_2}) define the virtual edge points [also the ones transformed to the X-point origin; these are not replaced by (p_{11}, ξ_{11}) and (p_{12}, ξ_{12})].

[8] When describing the geometry of the JET bolometer systems it is important to distinguish between lines of sight in opposite directions, in particular for the divertor bolometers in the Gas-Box divertor. Directional projection space does this by having unique points for the entire range $0 \le \xi < 2\pi$. For a detailed discussion of directional projection space, see L.C. Ingesson and R. Reichle, "Lines of sight for ITER bolometers," JET Report JET-R(98)03. For the present purposes it is sufficient to consider un-directional projection space (i.e. lines of sight viewing in opposite directions see the same) for which "Möbius periodicity" applies: $(p, \xi + \pi) = (-p, \xi)$.

Table III: Parameters for calculation of total radiated power.

Par. No.	Symbol	Comment	*method*	Recommended value
1	$method_{\rm totrad}$	1: recommended weighted summation 2: alternative weighted summation	–	1
2	$method_{\rm bulkrad}$	1: recommended weighted summation	–	1
3	$x_{\rm m}$	nominal R magnetic axis (m)	1/2	3.0
4	$y_{\rm m}$	nominal Z magnetic axis (m)	1/2	0.3
5	$x_{\rm X}$	nominal R of (lower) X point (m)	1/2	2.6
6	$y_{\rm X}$	nominal Z of (lower) X point (m)	1/2	–1.4
7	$p_{\rm e1}$	See Fig. 2(b) (directional value) (m)	1/2	1.044
8	$\xi_{\rm e1}$	See Fig. 2(b) (directional value) (deg.)	1/2	293.0
9	$p_{\rm e2}$	See Fig. 2(b) (directional value) (m)	1/2	–1.71
10	$\xi_{\rm e2}$	See Fig. 2(b) (directional value) (deg.)	1/2	219.0
11	$\xi_{\rm proj}$	See Fig. 2(b, c, e) (un-directional value) (deg.)	1/2	84.73
12	$p_{\rm u1}$	See Fig. 2(b) (directional value) (m)	1	0.91
13	$p_{\rm u2}$	See Fig. 2(b) (directional value) (m)	1	–1.2
14	p_{01}	See Fig. 2(e) (X-point value) (m)	1/2	0.005
15	p_{11}	See Fig. 2(e) (X-point value) (m)	1/2	2.7
16	p_{21}	See Fig. 2(c) (X-point value) (m)	1/2	0.95
17	ξ_{11}	See Fig. 2(c) (un-directional value) (deg.)	1/2	41.0
18	ξ_{21}	See Fig. 2(e) (un-directional value) (deg.)	1/2	81.29
19	p_{02}	See Fig. 2(e) (X-point value) (m)	1/2	–0.01
20	p_{12}	See Fig. 2(e) (X-point value) (m)	1/2	–2.03
21	p_{22}	See Fig. 2(c) (X-point value) (m)	1/2	–1.17
22	ξ_{12}	See Fig. 2(c) (un-directional value) (deg.)	1/2	112.0
23	ξ_{22}	See Fig. 2(e) (un-directional value) (deg.)	1/2	81.52
24	α	Power for squeezing/stretching operation	1/2	method 1: 1.0 method 2: 0.25

3.8 Radiated power in bulk plasma

The total radiated power in the bulk plasma is calculated in a similar way as the bulk scaling of Sec. 3.7.1. The parameters are shown in Fig. 5. So-far, only $method_{\rm totrad}$ 1 has been implemented. The projection to $\xi_{\rm proj}$ is linear (i.e. independent of $|\xi - \xi_{\rm proj}|$) and is done on one side of $p = 0$ only. Virtual points are introduced at both $p = 0$ and at the edge (cyan circles in Fig. 5. For the virtual edge point a signal value of zero is assumed, whereas for the virtual point at $p = 0$ a reasonable value has to be found. As discussed in Sec. 3.1, the channels to be used are selected in the *kb5data.dat* file. If any of the selected channels is wrong, the data types that depend on it are not written to the PPF. For the vertical camera it is important to leave out increased signal levels due to X-point radiation, an therefore the value at $p = 0$ is set equal to the value in the last point. For the horizontal camera this can be done in the same way, or the interpolated value with the next channel is taken. The projection and scaling is $(p_X, \xi) \rightarrow (p'_X, \xi') = (p''_X, \xi_{proj})$, with $p'' = p\, p_{proj} / p_{edge}$. This scaling is not ideal: the point where ξ_{proj} is intersected is scaled while there is no reason for it to be so, but this was the simplest linear scaling available. Note that the scaling squeezes the vertical camera and stretches the horizontal camera. The bulk radiated power on one side of the plasma then has to be extrapolated to the whole plasma. This is done by the $f_{stretch}$ parameter: the one-sided result is simply multiplied by $(1 + f_{stretch})$. This method is far from ideal, especially for the horizontal camera for which the X-point contribution has to be excluded at an arbitrary upper edge, but again the simplest. The input parameters (given in the *kb5jpf2ppf.par* file) and recommended values are given in Table IV.

Often, the estimates of bulk radiation from the vertical and horizontal camera are surprisingly similar. However, there are many occasions when the estimates are very different (especially during the limiter phase, and probably there is quite a large dependence on plasma position and shape which at present is not taken into account) [Figure 6(b)]. Therefore, if different, both values need to be considered with care. The values are also in excellent agreement with the radiated power within a normalized minor radius ρ of 0.95 from a tomographic reconstruction [Figure 6(b)]. A further important point to note is that the estimate from the upper channels of the horizontal camera will be unrealistically high when the GIM7 gas inlet is used (GIM7 is in its view).

Table IV: Parameters for calculation of total radiated power.

Par. No.	Symbol	Comment	*method*	Recommended value
2	$method_{bulkrad}$	1: recommended weighted summation	–	1
3	x_m	nominal *R* magnetic axis (m)	1	3.0
4	y_m	nominal *Z* magnetic axis (m)	1	0.3
25	p_{edge} (KB5V)	See Fig. 5 (undirectional value) (m)	1	1.044
26	ξ_{proj} (KB5V)	See Fig. 5 (undirectional value) (deg.)	1	99.03
27	p_{proj} (KB5V)	See Fig. 5 (undirectional value) (m)	1	0.93
28	$f_{stretch}$ (KB5V)	See Fig. 5	1	1.33
29	p_{edge} (KB5H)	See Fig. 5 (undirectional value) (m)	1	1.29
30	ξ_{proj} (KB5H)	See Fig. 5 (undirectional value) (deg.)	1	161.0
31	p_{proj} (KB5H)	See Fig. 5 (undirectional value) (m)	1	1.56
32	$f_{stretch}$ (KB5H)	See Fig. 5	1	1.16

3.9 BOLO DDA produced

The old KB1 PPF production program has produced two DDAs, BOLO and BOL4.
At present a PPF with only one DDA is produced, corresponding to BOLO (processed signals and total radiated power, estimates of total, bulk and divertor radiation) produced by the KB5 PPF program. The content of this DDA is listed in Table V and the corresponding JET Data Handbook pages are given in Appendix B. The actual name of the DDA is specified in the *kb5jpf2ppf.par* file, and may or may not correspond to BOLO. The *PPFUID*, to determine where the public or private PPF is written, is given in the kb5jpf2ppf.init file. The data type names and descriptions of the processed signals KB5V and KB5H are given in the *kb5data.dat* file, whereas all other data types are hardwired (in the subroutines *calctotradpow* and *writeppfs* in processtotpower.f90 and *writeppfs.f90,* correspondingly). To be compatible with previous PPFs the signal are two-dimensional: channel (per camera) versus time. Channels that were switched off in the *kb5data1.dat* file are given a zero value. Some characteristics of the channels (calibration, usage, étendue, gain, filter) are given for all cameras as one array with channels in the order KB5V and KB5H. The various total radiated powers are one-dimensional arrays as a function of time. The (old and improved) total and bulk radiated powers (TOPO, TOPI, TOBU and TOBH) are produced as described in Secs. 3.7 and 3.8, the estimates of the divertor radiation are obtained by TOXP = TOPO – TOBU and TXPN = TOPI – TOBU.

Table V: Contents of the PPF produced. Data types in bold type are for general use, the other ones are mainly for experts to be able to check the processing parameters afterwards. Data types in slanted type were not produced by the KB5 PPF production program.

DDA	data type	Description	Type	Units
BOLO	*BONO*	Channels for bulk radiated power: 0: off; 1: on	channel (all)	–
	CAPA	Calibration “heat constant” and sensitivity	channel (all)	J
	ETEN	Étendue	channel (all)	sr m^2
	KB5H	Signals of KB5 horizontal camera	channel×time	W m^{-2}
	KB5V	Signals of KB5 vertical camera	channel×time	W m^{-2}
	ONOF	Channels for processing: 0: off; 1: on	channel (all)	–
	OPT	Program options (order of Table I)	index	–
	SENS	Sensitivity	channel (all)	V/W
	SPAR	Parameters for signal processing (order of Table II)	index	–
	TAU	Calibration time constant	channel (all)	s
	TOBH	Total bulk radiation (from horizontal camera)	time	W
	TOBU	Total bulk radiation (from vertical camera)	time	W
	TONO	Channels for total radiated power: 0: off; 1: on	channel (all)	–
	TOPO	Old total radiated power (bulk-scaling)	time	W
	TOPI	Improved total radiated power (X-point scaling)	time	W
	TOXP	TOPO – TOBU (old estimate divertor radiation)	time	W
	TPAR	Parameters for total and bulk radiated power calculation (order index of Tables III and IV)	channel (all)	–
	TXPN	TOPI – TOBU (improved estimate divertor radiation)	time	W

3.10 Running the program and input files

3.10.1 Simple running

The program can be run in various ways. The original files are in the /home/bolom/intershot/source/bolo directory. When using the default parameter files, it can be run in batch by calling the shell script

startkb5jpf2ppf shot PPFuid

The *PPFuid* is the PPF user-ID to which the PPF should be written (‘JETPPF’ produces public PPFs, if one has permission to do so). The output files of the batch job (*.out and *.err) are written to the batch subdirectory (as not to clog up the main directory); the *.err contains some innocent errors. In foreground, the program is executed by calling the shell script

runkb5jpf2ppf shot PPFuid

which is the shell script actually run by the batch job.

3.10.2 Background information on running and compiling

The runkb5jpf2ppf shell script writes the shot number, PPF user-ID for writing, dummy PPF user-ID for reading PPFs (not used so far) and parameter-file name (*kb5jpf2ppf.par*) to the fixed file kb5jpf2ppf.init; these parameters are read from the kb5jpf2ppf.init file by the subroutines read_init_file and readkb5jpf2ppfpara (in reads.f90) from the main program (main.f90).

To produce the running version (compile and link), one has to execute:

```
make bolo
```

The makefile provides control over all dependencies and the above command should be used whenever changes are made to FORTRAN90 routines.

The amount of information that the KB5 PPF program produces (on screen, or in the *.out file when run in batch) can be varied by means of the debug parameter set in the *kb5jpf2ppf.par* file: *debug* 1 gives normal output (a message that program started for which shot and a message that PPF produced and which sequence number), *debug* 0 is silent, *debug* 5 outputs much information to check the running of the program, and *debug* 10 outputs all information.

3.10.3 Input files

In this document the convention has been used that file names in upright font are unchangeable, i.e. hardwired in the program, whereas names in slanted type are variable, i.e. specified in input files and the name given is of an example file. There are three input files for the KB5 PPF production program, examples of which are shown in Appendix C:

1) kb5jpf2ppf.init: specifies the shot number, PPF user-IDs for writing and reading PPFs (the latter is dummy in the current program version) and parameter-file name; this file is produced by the shell script runkb5jpf2ppf;
2) *kb5jpf2ppf.par*: specifies the *debug* parameter (see Sec. 3.10.2), the DDA names (see Sec. 3.9), the file with the node names, selected channels and geometry, (*kb5data.dat*), the options for processing (see Sec. 3.4), the parameters for evaluation of Eq. (1) (see Sec. 3.5) and the parameters for the calculation of the total and bulk radiated power (see Secs. 3.7.3 and 3.8),
3) *kb5data.dat*: specifies the node names, selected channels and geometry of KB5 (see Sec. 3.1).

3.10.4 Multishot running

To process many discharges in one batch job with the same set of input files, the perl script runkb5jpf2ppfmulti and associated submission script startkb5jpf2ppfmulti were written. The shot numbers are specified in an input file of which the filename is the first parameter on submission (the second is the user name for PPF writing).

3.10.5 Implementation in Chain-1

The JET Intershot analysis runs after each plasma pulse in the torus. Intershot codes take data from the machine in the form of JET Pulse files (JPFs), and produces Processed Pulse Files (PPFs), containing physics variables such as plasma radiation. The PPF data is used in the control room to monitor JET performance, so prompt and reliable operation of the Intershot analysis is necessary for JET operations.

.3.10.5.1 Processing and Reprocessing a pulse

After each plasma shot, the intershot control system process this pulse <shotnumber> by running the following script /home/chain1/tools/scripts/run_pulse.perl -p <shotnumber>.
The whole pulse can also be reprocessed in a similar way by running, /home/chain1/tools/scripts/reprocess_pulse.perl –p <shotnumber>. from any JAC as userid chain1. This should be used for reprocessing an old pulse.

.3.10.5.2 Code Source

The KB5 new program has been completely written in FORTRAN90 that is preferable programming language for Chain-1. The source code can be found in /home/chain1/source/*bolo*/ and all subdirectories. The executable for *bolo* should be made by running make using the makefile /home/chain1/source/*bolo*/makefile .

.3.10.5.3 Binaries

Once made and tested, all source binary files are copied to /home/chain1/bin. This is the repository for all stable executables. For most steps, two binaries exist, *bolo* and *bolo*.bk . The binary *bolo* has been created with compiler options to trap floating point exceptions, and array bound errors (ie access to array elements outside the declared array size). This enables possible errors / flaws in the programs to be discovered, but prevents the program from completing if such an error occurs. The binary *bolo.bk* are run as a backup if the first executable fails. They have been compiled with these compiler options disabled, and should enable the executable to run to completion if at all possible.

.3.10.5.4 Input / output files

Output to standard output (unit 6 in fortran) is written to a temporary file fort.6 . Output written to another unit number x in Fortran will be written to file fort.x . Temporary output files for step *bolo* and pulse <*shotnumber*> will be written to directory /home/chain1/pulses/<*shotnumber*>/*bolo*/ - looking at these files can often be helpful in determining errors or problems which have occurred. The level of output written will usually vary with the debug level given when running the step (0 minimum output, 3, maximum). These temporary files remain for about 10 days before being automatically deleted.
Some steps write output to permanent logfiles. These files are written to directory /home/chain1/output/*bolo*/.
Input files for a bolo are contained in directories in /home/chain1/input/bolo/.
Old versions of the input files, and backups of all files which are links can be found in /home/chain1/archive/bolo.

.3.10.5.5 Development of the Code

The Bolo Code should be developed privately, in users own accounts (/u/bolom), before being copied to Chain1 for release.
To take a copy of the latest version of a Chain1 program, one should call the script

/home/chain1/tools/scripts/privstepnew.perl bolo,

Once this has been done, the user will have a directory **intershot/source/bolo** which contains the following
fortran: a subdirectory with the fortran source (the main program in main.f)
include: a subdirectory with the include files
makefile: a file to compile the code
bolo.*perl*: a script to link in input/output files and run the code

3.11 Description of program files

All the required files are listed and described in Table VI. These files are in the /home/bolom/intershot/source/bolo directory.

Table VI: Files used in the KB5 PPF production.

Filename	Description	Ref. Sec.
Shell scripts to run the program		
startkb5jpf2ppf	Shell script to start batch job	3.10.1
startkb5jpf2ppfmulti	Shell script to start batch job for multiple shots specified in a file	
runkb5jpf2ppf	Shell script to select shot number and *PPFuid* and start execution	3.10.2
runkb5jpf2ppfmulti	Shell script to select a file with shot numbers and *PPFuid* and start execution	3.10.2
Input files		
kb5jpf2ppf.init	Main parameter passing	3.10.3
kb5jpf2ppf.par	All processing parameters	3.10.3
kb5data.dat	KB5 camera data	3.10.3
Main FORTRAN90 program and routines		
main.f90	Main FORTRAN90 program	3
reads.f90	The specific routines for this program: *read_init_file*, *readkb5jpf2ppfpara_numbers*, *readkb5jpf2ppfpara, readkb5size*, *readkb5data*	
processdata.f90	The specific routines for this program: *proconekb5chan, calcbolopow*	
processtotpower.f90	The specific routines for this program: *calctotradpow*, *calcdeltap*, *calcdeltapscalbulk*, *trapsum* and *data_reduction*	3
tools.f90	The specific routines for this program: *sort, mean, sign_scalar, sign_1D_array,triangfilt, deriv, smooth, median*	0
The KB5 calibration procedure		3.2
xkb5cal	The KB5 in-situ calibration can be performed by users logged under the *spect* account on the DB diagnostic computer (alter kb4 from a gen-on machine).	
Routines for Gottardi processing		0
smotem_new.f90	The new FORTRAN90 program based on Gottardi smoothness method	

Routines for Bessel filter		0
calcbolopow_bessel.f90	Actual FORTRAN Bessel filter routine *calcbolopow_bessel* and the help routines *RDFILTER* and *MAKE_POWER*	
bol_str.h	Include file needed in calcbolopow_bessel.f	
(makebesfi.f)[a]	(Program to produce besfi######.dat3 filter files)	
Required directories		
batch	Directory to which batch-job information written	3.10.1
besfidir	Directory in which the besfi######.dat3 files stored	0
Supporting programs		
makefile	Makefile of all FORTRAN90 compilation	3.10.2

[a]Not actually used when preparing or running the program

References

[1] E.R. Müller and F. Mast, “A new metal resistor bolometer for measuring vacuum ultraviolet and soft x radiation,” J. Appl. Phys. **55**, 2635–2641 (1984)

[2] K.F. Mast *et al.*, “A low noise highly integrated bolometer array for absolute measurement of VUV and soft x radiation,” Rev. Sci. Instrum. **62**, 744–750 (1991)

[3] L.C. Ingesson, *Comparison of methods to determine the total radiated power in JET*, JET Report JET-R(99)06

[4] L.C. Ingesson *et al.*, "Radiation in impurity-seeded discharges in the JET MkI, MkIIA and MkIIGB divertors," accepted for publication in J. Nucl. Mat.

[5] M. Maraschek *et al.*, “Real-time determination of the total radiated power by bolometric cameras with statistical methods,” Rev. Sci. Instrum. **69**, 109–115 (1998)

Figures

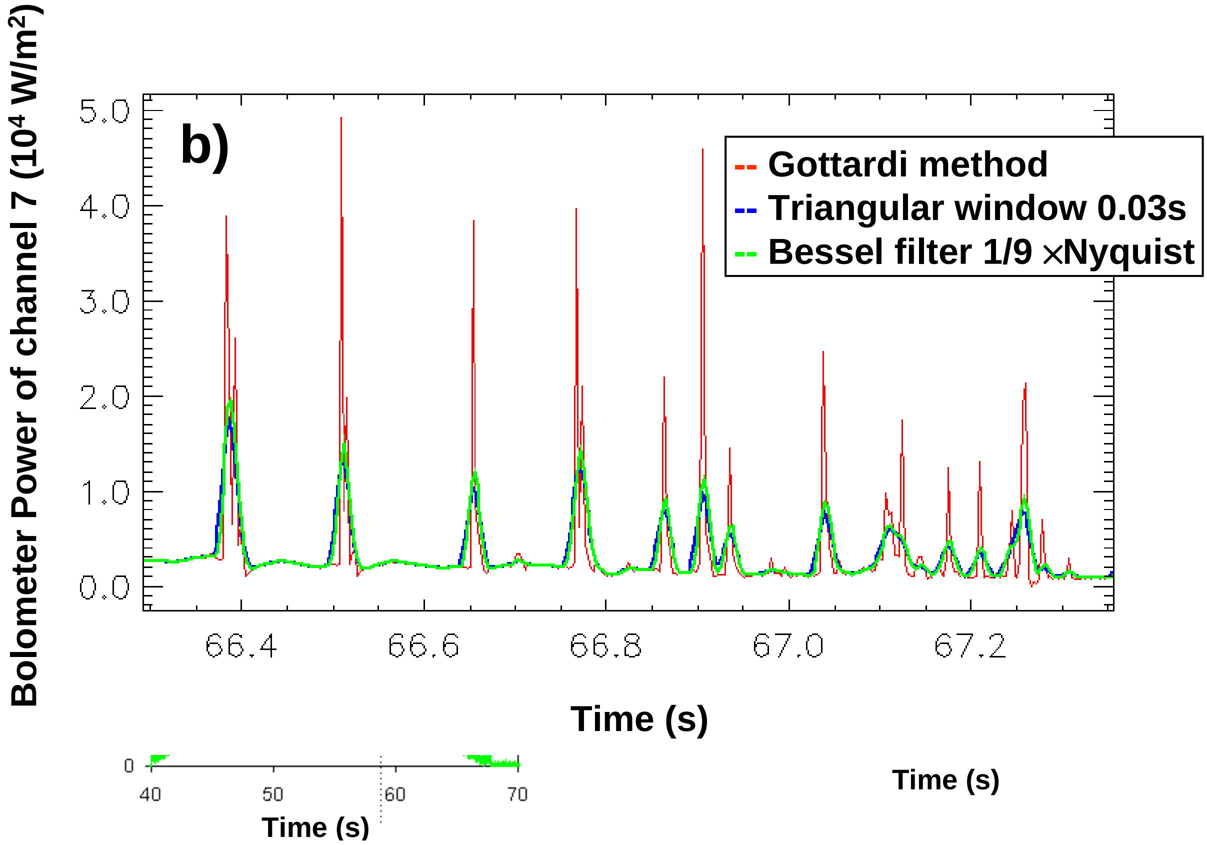


Figure 1: Time traces of a bolometer signal (channel V7) processed by different methods during the L-mode discharge #65363 (a) and during the ELMy-phase of the discharge #65555 (b). Clearly, the Gottardi method gives a signal identical to the one produced by the KB194 program.

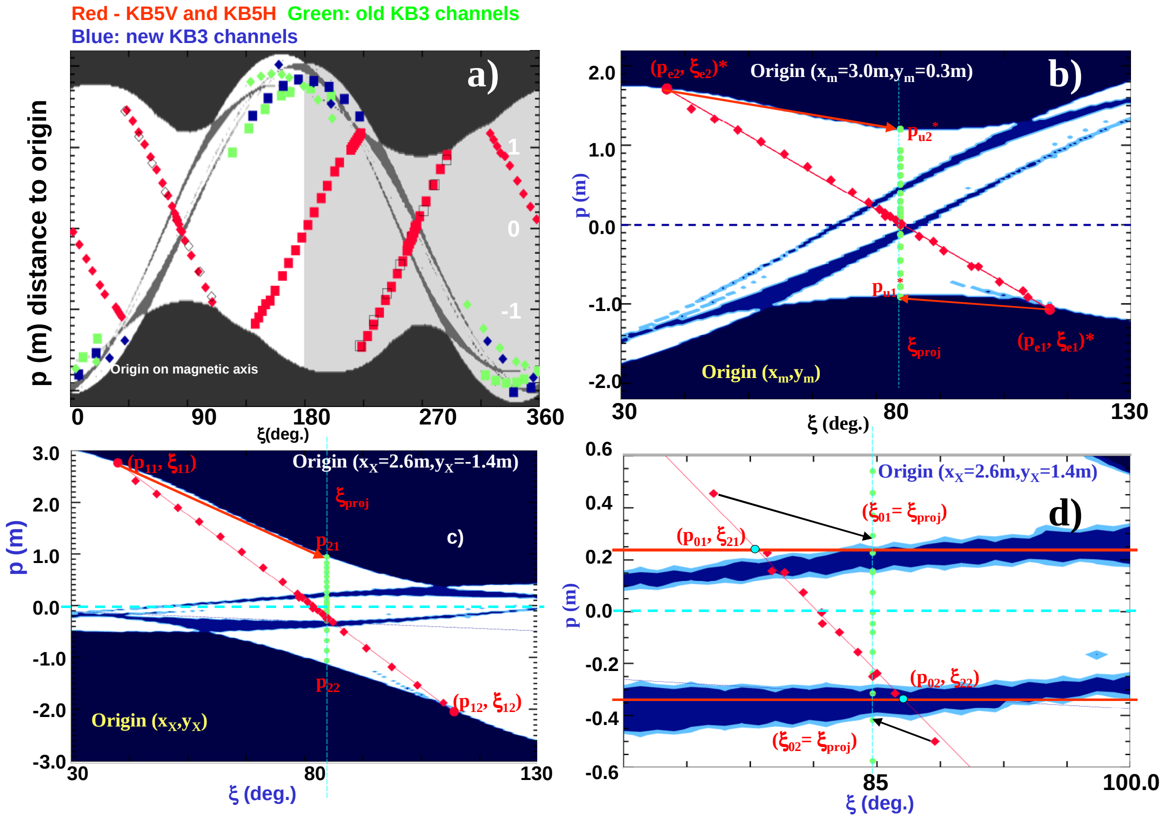


Figure 2: Overview of the scaling and projection operations in projection space, with the sinogram of typical plasma emissivity as contour plot. The quantities needed to define these operations are indicated in red. (a,b) Projection space with nominal magnetic axis $(x_{\mathrm{m}}, y_{\mathrm{m}})$ as origin. In (b) the quantities for the “bulk” scaling are indicated. (c,d) Projection space with nominal X-point position $(x_{\mathrm{X}}, y_{\mathrm{X}})$ as origin. In (c,d) the quantities for the X-point scaling are indicated. For a more detailed discussion see Fig. 7 in Ref. 3. The asterisks in (b) indicate that the values are assumed to be given as “directional” values, i.e. $(-p, \xi + \pi)$ with respect to the points indicated in the figure (see explanation in text). The grey area indicates line of sight that pass outside the innermost vessel wall (including limiters etc.).

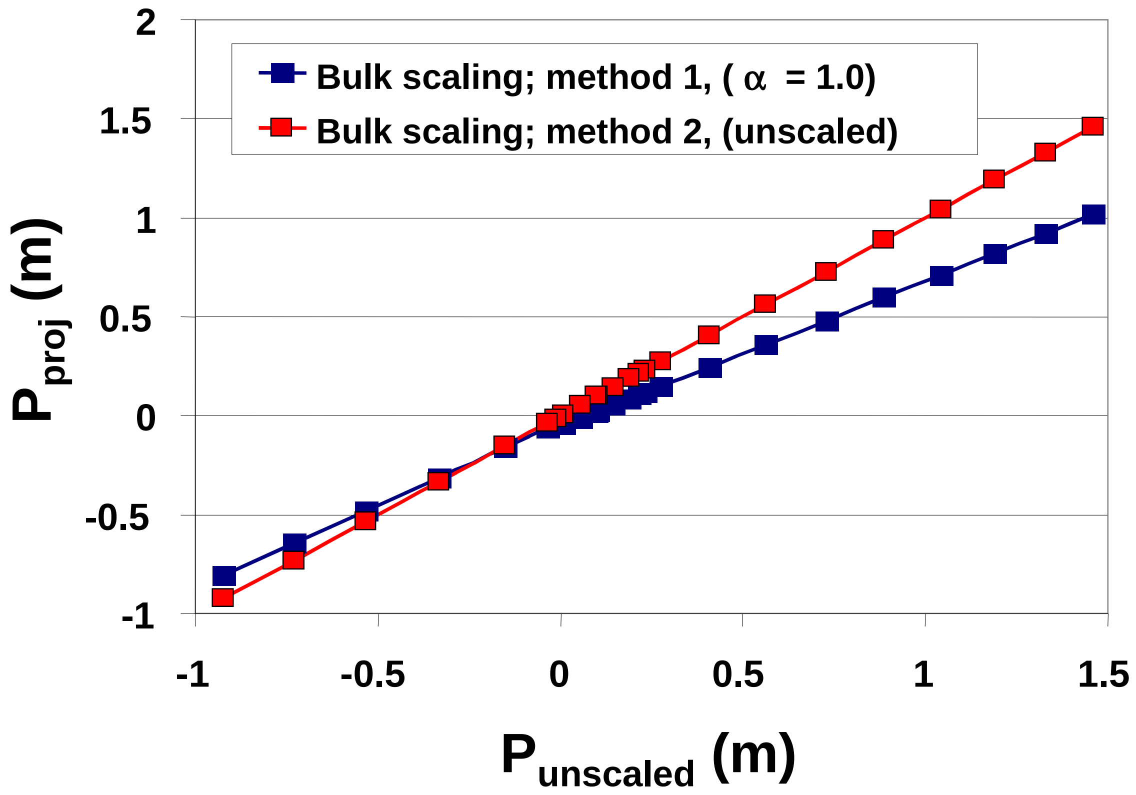


Figure 3: Scaled and projected impact parameter p_{proj} as a function of the unscaled impact parameter p (both with respect to the magnetic-axis origin). The solid points indicate actual channels.

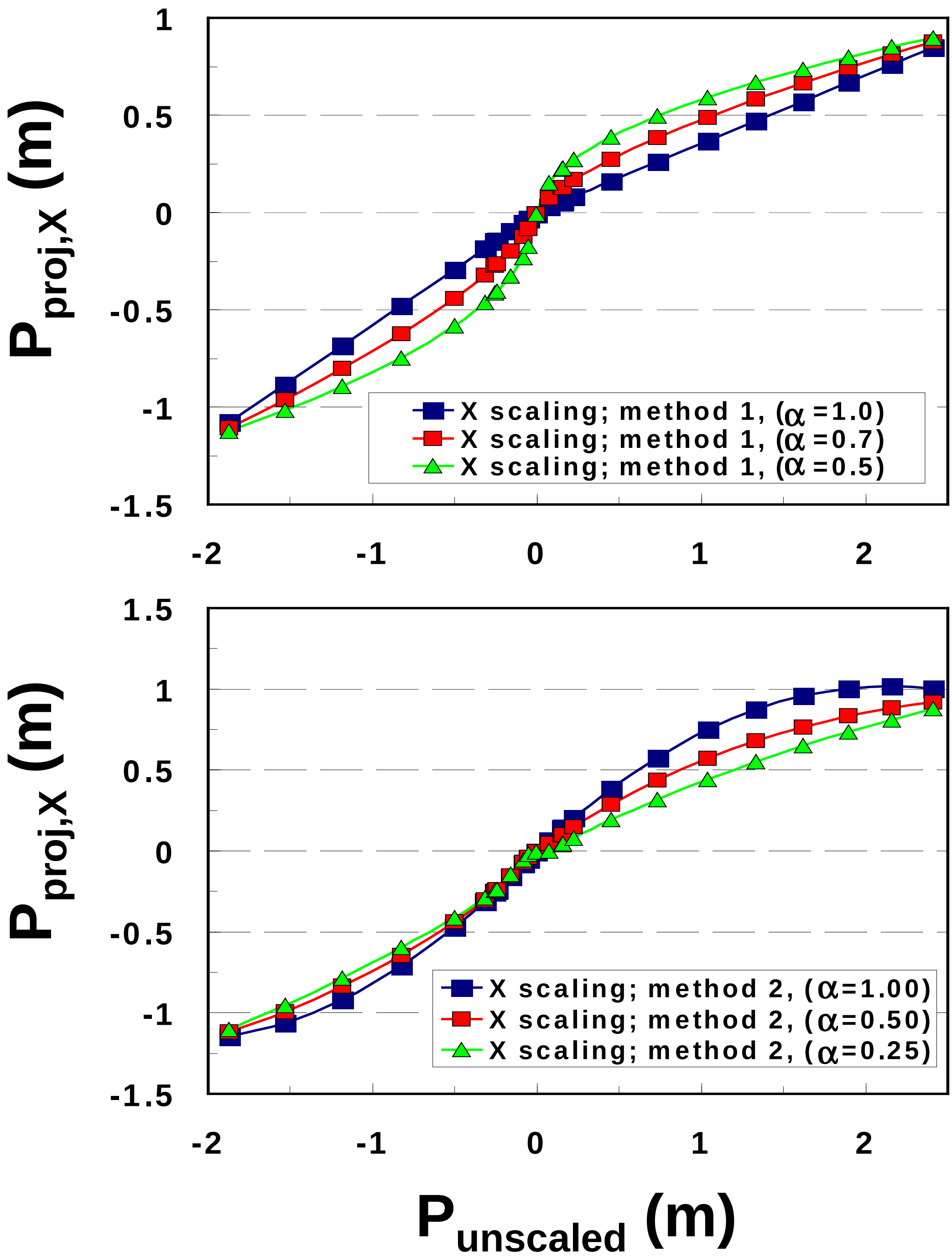


Figure 4: Scaled and projected impact parameter $p_{proj,X}$ as a function of the unscaled impact parameter p_X (both with respect to the X-point origin). Only scalings with special consideration for the X point (between p_{02} and p_{01}) are shown, with varying parameters (scaling method and the parameter α). The solid circles indicate actual channels.

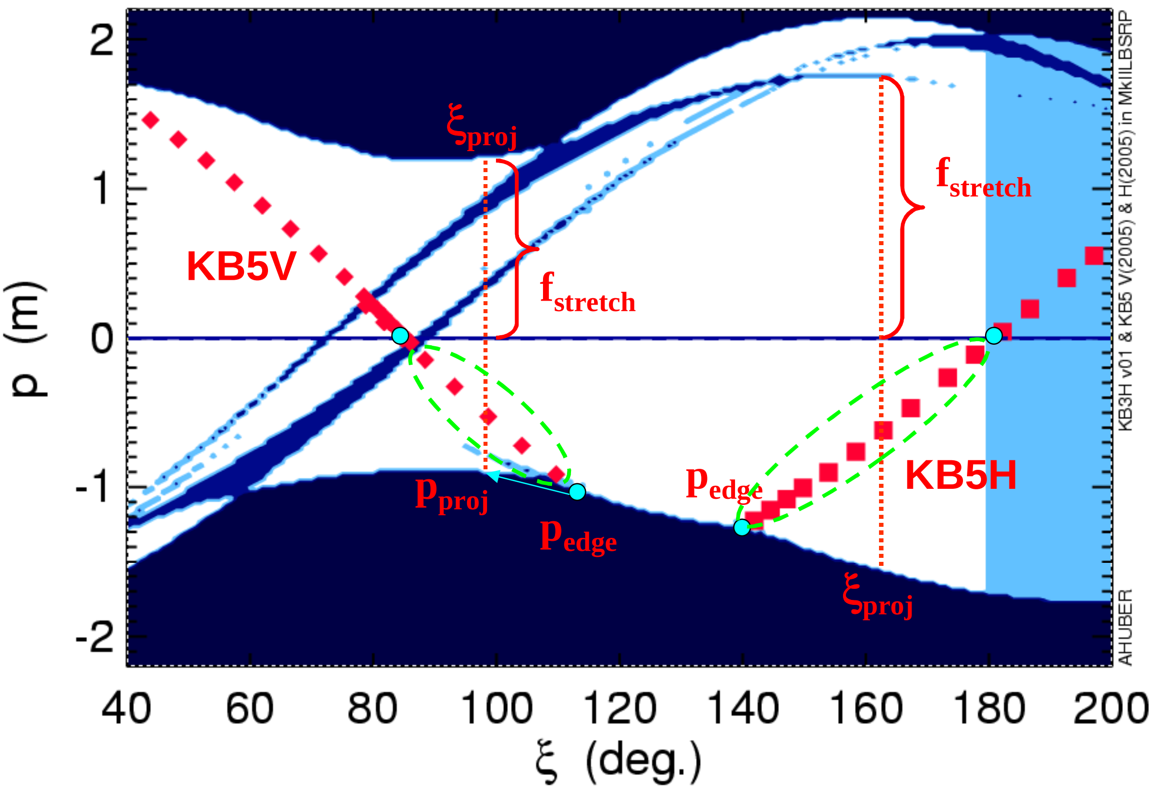


Figure 5: Projection space showing the characteristic points for the calculation of the total radiated power in the bulk plasma. A typical sinogram is given as a contour plot. The used points of the vertical KB5V (filled red diamond) and-horizontal KB5H (filled red square) cameras are located below $p = 0$ (inside marked green dashed ellipse). Filled cyan circle points are the virtual channels outside the plasma and at $p = 0$. The various parameters used in the calculation are indicated in red.

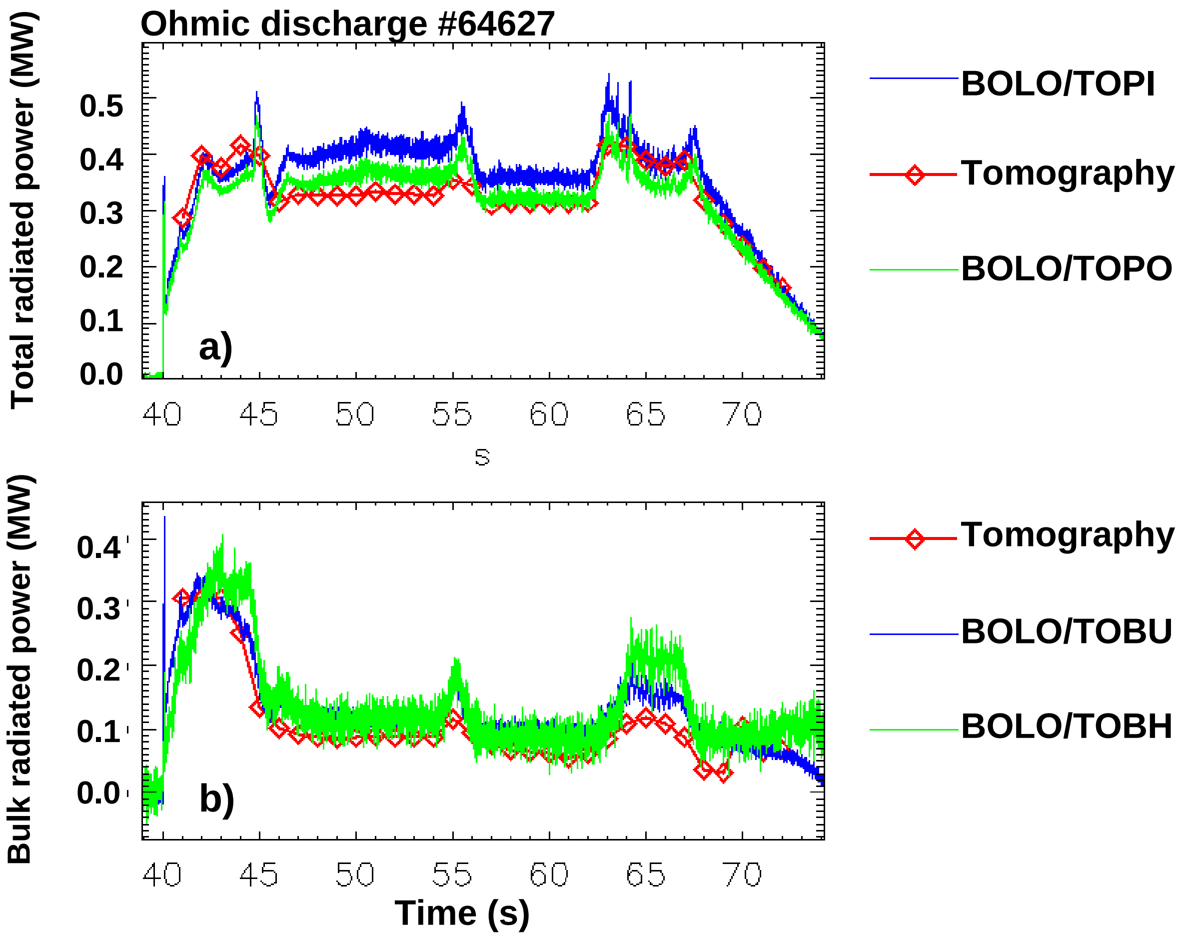
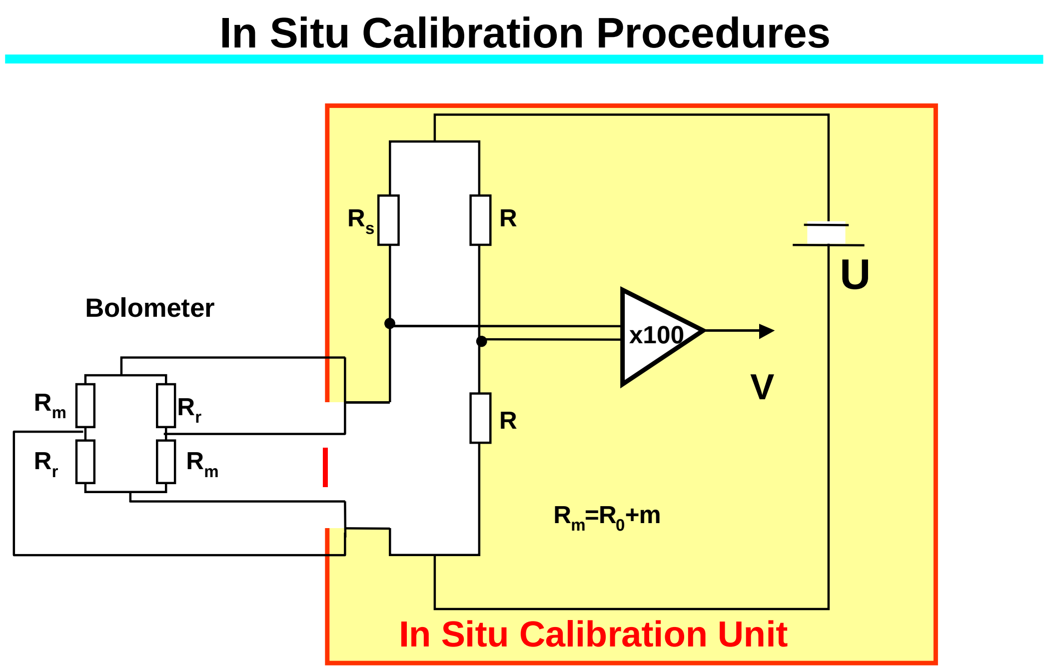


Figure 6: Comparison of various ways to determine (a) the total radiated power and (b) the power radiated from the bulk plasma.

Appendix A: KB5 calibration procedure

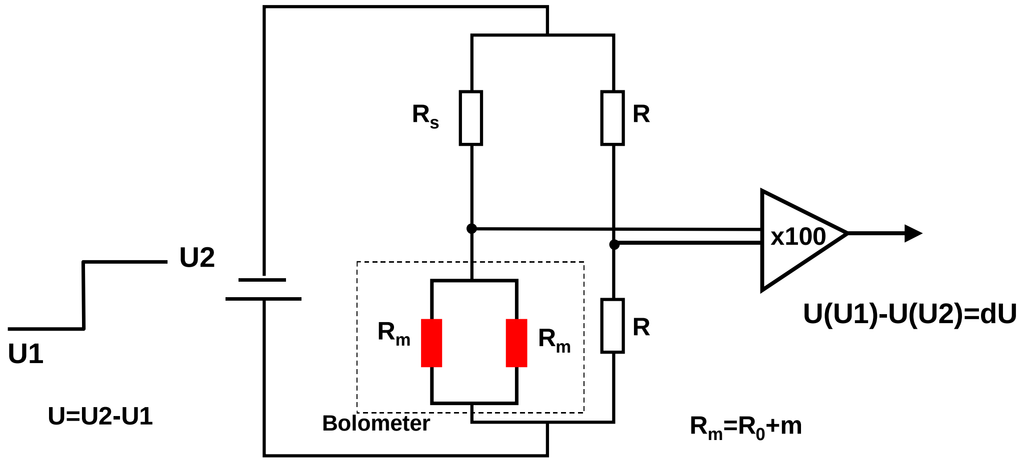
The KB5 in-situ calibration can be performed by users logged on under the *spect* account on the DB diagnostic computer (alter kb4 from a gen-on machine). The KB5 control program and calibration procedure were written by Simon Dalley (CODAS).

During the in situ calibration two reference bolometer resistance were short-circuited as shown in the figure below. In situ calibration unit contains a Wheatstone bridge and the calibrated bolometer is included in this bridge as measurement resistor. When the lower Voltage U1, in this case 0.5V is supplied to the bridge, the output signal is balanced by using 128 step adjustable resistors (2.37kOhm to 8.72kOhm). The remaining output voltage is set to zero by a DAC.



Then the higher voltage U2, in this case 5V is supplied to the bridge in order to simulate the absorption of plasma irradiated power through the bolometer Joule heating. After 450µs the output voltage U(U1) is measured in order to avoid an incorrect value because of an offset jump.

After 1450ms the temperature rise has reached its final value and the output U(U2) is measured. The difference DU=U(U2)-U(U1) will be calculated. The cooling time is measured by calculating 63% of the temperature rise curve. Both dU and cooling time are displayed on the LCD.



The dissipated electrical power P at the bolometer resistance Rm leading to dU is:

$$P_{OH} = \frac{(\frac{U_2}{2})^2 - (\frac{U_1}{2})^2}{(R_m \| R_m)} = \frac{U_2{}^2 - U_1{}^2}{4 \times (R_m \| R_m)}$$

NOTE: Calibration Unit from IPT gives R_m value, what is measured at R_m resistance and correspondingly is equal to (R_m|| R_m).

Since we have two measurement resistances at the bolometer which double the unbalancing of the bridge we have to consider a factor of 2 and also we must divide the signal by the gain factor of 100. The effective capacity is:

$$C = P_{OH} / 2 \times \tau_C \times U_2 / dU \times 100$$

where τ_C is the cooling time.

The bolometer equation can be expressed by sensitivity S:

$$P = C\left(\frac{dU}{U_{ef}\, dt} + \frac{dU}{U_{eff}\, \tau_C}\right) = \frac{\tau_C}{S}\left(\frac{dU}{dt} + \frac{dU}{\tau_C}\right)$$

where the sensitivity is defined as S=dU/P when the steady state form of the equation is considered. In the case of KB5 a 40V peak-to-peak sinusoidal voltage at 50kHz is applied to the Wheatstone bridge and the effective voltage is thus $U_{eff} = 14.14V$.

The sensitivity could be expressed as:

$$S = U_{ef} \times \tau_C / C$$

The possible status and comment values:

- Not connected. No comment
- Ok –if the variation in resistance is less than 200Ω. Comment:
  - No comment – if the variation in resistance is less than 40Ω.
  - R+Nohm – if the variation in resistance is between 40Ω and 200Ω, where N is the variation
- ? –if the variation in resistance is more than 200Ω. Comment:
  - - R+Nohm –where N is the variation
- 1p –if one pin or connection is broken, which results in three undefined resistance values
- 2p –if two pin or connection is broken, which results in five undefined resistance values
- bad –if all pins are broken, which results in all undefined resistance values

The variation N is defined as:

$$N = \max(R_1, R_2, R_3, R_4) - \min(R_1, R_2, R_3, R_4)$$

Example of KB5 calibration output Parameter (on air)

R1 [Ohm]	1037.8	
R2 [Ohm]	1038.8	
R3 [Ohm]	1028.3	
R4 [Ohm]	1028.8	
Rac [Ohm]	1347.3	
Rsig [Ohm]	1346.5	
Rm [Ohm]	678.3	
Rr [Ohm]	668.5	
INS_ACP	>26MOhm	
INS_ACN	>26MOhm	
INS_SIGP	>26MOhm	
INS_SIGN	>26MOhm	
Insitu_Rm [Ohm]	678.3	must be used for Power calculation
U1 [V]	0.5	must be used for Power calculation
U2 [V]	4	must be used for Power calculation
U[U1] [V]	-0.0014	
U[U2] [V]	0.2602	
dU [V]	0.26154	must be used for heat capacity calculation
tau [s]	0.099	must be used for heat capacity and sensitivity calculation
Insitu_Rr [Ohm]	668.6	
U1 [V]	0.5	
U2 [V]	4	
U[U1] [V]	0.0118	
U[U2] [V]	0.2644	
dU [V]	0.25269	
tau [s]	0.096	
Power [W]	0.005804954	
Heat Capacity [J]	0.384533228	
Gain [1/W]	0.257454994	
Sensitivity [V/W]	3.640413619	
Status		
Comment		
Before		
Vessel Temp. [grad]	200	
Date of calibration	16/02/2005	
Channel	KB5V/01	

Appendix B: JET Data Handbook reference pages for KB5

Diagnostic: KB5 Bolometer System	**JET name:** KB5

Short description:

Total radiation power, Radiation profiles through tomographic reconstruction

ROs	**Ext.**	**Bleep**
A. Huber	4941	6520
P. Beaumont	4515	6464

Location: Ex-vessel, octant 6 (horizontal camera, KB5H) and 3 (vertical camera, KB5V)

Subsystem: DB

JPF Node names: B5H-UBOL<RAW:001…B5H-UBOL<RAW:024, B5V-UBOL<RAW:001…B5V-UBOL<RAW:024

All channels are used for real-time feedback signals

JPF Node Names for RTCS:

B5HR-UBOL<RAW:001…B5HR-UBOL<RAW:024, B5HR-PBOL:001…B5HR-PBOL:024,

B5VR-UBOL<RAW:001…B5VR-UBOL<RAW:024, B5VR-PBOL:001…B5VR-PBOL:024,

PPF Production: automatic

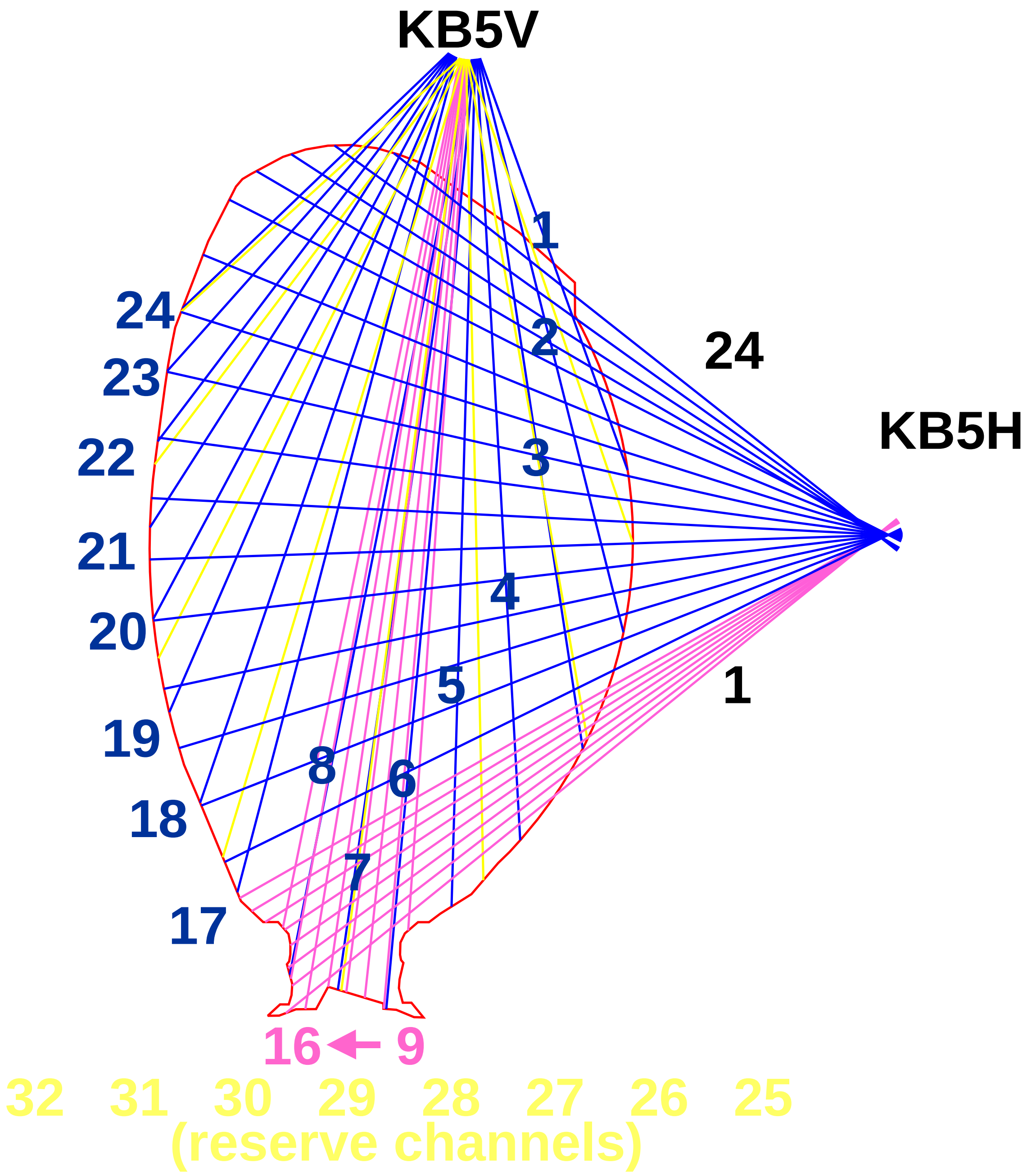
DDA names: BOLO
BURA (Abel inversion of upper channels of KB5H camera) on request
On request tomography information in BOLT and BARA.

Related diagnostics: KB3 and KB4.

Timing information: The data acquisition is predefined by a number of slow and fast windows (see control mimic). The time resolution is typically 1ms and up to 0.2 ms to study faster events. The total recording window is 100s

Data check: to check data for excessive noise or power failure on electronic crates: check BOLO/TOPI, look at JPF data with JETDSP.

Lines of sight:



1. The full-width-half-maximum of the viewing beams extends roughly to halfway the neighbouring channels.

Other information:

KB5H camera measurement strongly influenced by gas injection from GIM7; for reliable tomographic reconstructions and Abel inverses GIM7 must be off in the phase of interest.

Trouble shooting: ROs or other members of the Plasma Imaging Group

References:

K.F. Mast, J.C. Vallet et al., “A Low Noise Highly Integrated Bolometer Array for Absolute Measurement of VUV and Soft X Radiation”, Rev. Sci. Instrum. 62 (1991) 744

R. Reichle *et al.*, “Bolometer for ITER” in *Diagnostics for Experimental Thermonuclear Reactors*, Ed. P.E. Stott *et al.* (Plenum Press, New York, 1996), pp. 559

L.C. Ingesson, “Comparison of methods to determine the total radiated power in JET,” JET Report JET-R(99)06

K. McCormick, A. Huber, C. Ingesson et al., “New bolometry cameras for the JET Enhanced Performance Phase” Fusion Engineering and Design 74 (2005) 679.

BOLO

1. PPF DDA NAME: BOLO

2. DVRO: A.Huber

3. The Diagnostic (KB5), the Program (KB5 PPF program) and the Data Produced (BOLO)

4. Various PPF Signals for BOLO

PPF Type	Unit	Description	Normal Level of Accuracy
BONO		0/1: Channels off/on for bulk rad. calc.	
CAPA		Calibration gain and heat capacity used	
ETEN	m^2sr	Étendue used for geometry	
KB5H	$W\ m^{-2}$	KB5H horizontal camera	10%
KB5V	$W\ m^{-2}$	KB5V vertical camera	10%
ONOF		0/1: channel off/on in processing	
OPT		Program options	
SENS	V/W	Sensitivity	
SPAR		Parameters for smoothing	
TAU	s	Calibration time constants used	
TOBH	W	Total bulk radiation (from horizontal camera)	20%
TOBU	W	Total bulk radiation (from vertical camera)	20%
TONO		0/1: channel off/on for total radiation calc.	

TOPI	W	Total radiated power (from KB5V; improved calculation)	10%
TOPO	W	Total radiated power (old estimate)	10–30%
TOXP	W	Total X point and divertor rad. (old estimate)	30%
TPAR		Parameters for total radiation calc.	
TXPN	W	Total X point and divertor rad. (improved estimate)	20%

Notes:

4.1 KB5H, KB5V, TOBU, TOBH, TOXP and TXPN contain the processed line-integral bolometer signals as a function of channel number and time.

4.2 TOPI is an estimate of the total radiated power calculated from the vertical KB5V camera, which for a wide range of discharges is similar to the more-accurate value determined from tomographic reconstructions. For consistency with the past, the BOLO quantity is still output, which nearly always is too low by 10% (but for certain discharges TOPO is far too low).

4.3 The quantities ONOF, TONO, TAU, SENS, CAPA, ETEN, OPT, SPAR and TPAR are for expert use. ONOF, TONO, TAU, CAPA, ETEN are in the order of channels of KB5V and KB5H.

5. Data on which BOLO is Dependent:

Only the B5 JPF node.

6. Additional Information on BOLO

In the processing of the data a smoothing over typically 10 points in time is applied. During significant ELMs no smoothing is applied.

The measurements are assumed to be line-integral measurements, whereas the channels view the plasma with significant beam widths. One has to take particular care when interpreting the processed signals of lines of sight that view the divertor and edge of the plasma.

7 Data Complementary to BOLO

The PPFs of the KB3 and KB4 bolometers, B3D4 and B3E4, are partly complementary to BOLO.

Appendix C: Input files

kb5jpf2ppf.init:

```
65483
bolom
JETPPF
kb5jpf2ppf.par
! This initialization file for KB5 PPF production contains on separate lines:
! shot number, PPFuid for writing PPF, PPFuid for reading (not used at present)
! and the name of the parameter file
```

kb5jpf2ppf.par: Note that comment lines start with “!”. The reading routine skips these fixed lines [but no checks are made whether a line starts with an “!”, so one cannot arbitrarily add comments (except at the end of the file)].

```
! Parameter file for KB5 processing (kb5jpf2ppf) valid for MkIILBSRP
1  ! debugging level (0: no output ... 10: all output)
! DDA name for 'BOLO' production and actual name for 'BOLO'
BOLO
! DDA name for 'BOLO' production and actual name for 'BOLO'
BOLO
! filename with on/off channel information, etendues, nodenames etc.
kb5data.dat
! Options for processing
5     ! number of options in this file
1     ! 0/1 no/yes offset subtration
```

```
0.5   ! time window at start of time vector for offset determination
1     ! 0/1 no/yes linear drift correction
0.1   ! time window at end of time vector for drift determination
1.0  !1.15   ! fudgefactor to account for difference between optical and electrical calibration
! Parameters for evaluation of bolometer equation
9     ! number of parameters in this file
3         !3     ! filtering method: 1: window; 2: Bessel; 3: Gottardi
50 !20    ! method 1: 0: no window; 1: rectangular; 2: median; 3: triangular; method 2: bandwidth (1..9: little..much smooting); method 3: smored: amount of smoothing
-1.0      !-1.0   ! method 1: smoothing window (in s); method 3: dnoise (if <0: calculated internally)
20        !20    ! method 3: ibnois first point to calculate dnoise
50 !30    ! method 3: ienois last point to calculate dnoise
3     ! method 3: ibave start points for averaged start point
5     ! method 3: ieave end points for averaged last point
0.25     !0.35  ! method 3: alevel compression factor for hyperbolic tangent
1.017 ! method 3: cdno modify level of noise dno
! path name (end in '/') for besfi files (needed when bessel filter: method 2)
/u/bolom/intershotboloproc/besfidir/
! Parameters for calculation of total radiated power
32    ! number of parameters in this file
1     ! method total radiated power calculation 1: summation with weights from fixed magn. axis and X point; 2: idem but exactly as in report
1     ! method bulk radiation calculation 1: summation with weights from magn.axis
3.0   ! method total 1/2 and/or bulk 1: xm: nominal R magnetic axis (m)
0.3   ! method total 1/2 and/or bulk 1: ym: nominal Z magnetic axis (m)
2.6   ! method total 1/2: xX: nominal R of (lower) X point (m)
```

```
-1.4  ! method total 1/2: yX: nominal Z of (lower) X point (m)
1.044  ! method total 1/2: pe1: directional p value of extrapolated edge point vertical camera ("channel 0")
293.0 ! method total 1/2: ksie1: directional ksi (deg) of extrapolated edge point vertical camera ("channel 0")
-1.71 ! method total 1/2: pe2: directional p value of extrapolated edge point vertical camera ("channel 15")
219.0 ! method total 1/2: ksie2: directional ksi (deg) of extrapolated edge point vertical camera ("channel 15")
84.73 ! method total 1/2: ksiproj: projection angle (deg) of vertical camera
0.91  ! method total 1: pu1: directional p value of projected extrapolated edge point vertical camera ("channel 0")
-1.2  ! method total 1: pu2: directional p value of projected extrapolated edge point vertical camera ("channel 15")
0.005   !0.23  ! method total 1/2: (scaled method:) p01: p value above which outside special divertor region
2.70  ! method total 1/2: p11: p value of edge (up,original) to describe divertor stretching operation
0.95  ! method total 1/2: p21: p value of edge (up,squeezed) to describe divertor stretching operation
41.0  ! method total 1/2: ksi11: ksi value (deg) of edge (up) to describe divertor stretching operation
78.0  ! method total 1/2: ksi21: ksi value (deg) of edge (up,second) to describe divertor stretching operation
-0.01    !-0.34 ! method total 1/2: p02: p value below which outside special divertor region
-2.03 ! method total 1/2: p12: p value of edge (down,original) to describe divertor stretching operation
-1.17 ! method total 1/2: p22: p value of edge (down,squeezed) to describe divertor stretching operation
112.0 ! method total 1/2: ksi12: ksi value (deg) of edge (down) to describe divertor stretching operation
86.6  ! method total 1/2: ksi22: ksi value (deg) of edge (down,second) to describe divertor stretching operation
1.00  !0.25 ! 1.00! mehtod total 1/2: squeezepower: power of squeezing operation (NOTE: important to change when method_totrad changes!!!)
1.044  ! method bulk 1: pedge (KB5V): p value of vertical virtual line of sight outside plasma
99.03 ! method bulk 1: ksiproj (KB5V): ksi of projection angle vertical camera (not used)
0.93  ! method bulk 1: pproj (KB5V): p value at projection angle of vertical virtual line of sight outside plasma
1.2   ! method bulk 1: fstretch (KB5V): stretch factor inboard plasma for vertical calculation
1.29  ! method bulk 1: pedge (KB5H): p value of horizontal virtual line of sight outside plasma
161.0 ! method bulk 1: ksiproj (KB5H): ksi of projection angle lower horizontal camera (not used)
```

```
1.56  ! method bulk 1: pproj (KB5H): p value at projection angle of horizontal virtual line of sight outside plasma
1.2   ! method bulk 1: fstretch (KB5H): stretch factor lower half plasma for horizontal calculation
```

kb5data.dat: Note that comment lines start with "!". The reading routine skips these fixed lines [but no checks are made whether a line starts with an "!", so one cannot arbitrarily add comments (except at the end of the file)].

```
! KB5 characterization file
2     ! number of cameras
KB5V
KB5V vertical camera
32    ! number of channels camera 1 (KB5V)
KB5H
KB5H horizontal camera
24    ! number of channels camera 2 (KB5H)
3.0000  0.3000         !(R,Z) of origin projection space for (impact,angle)
19    ! length nodenames
!   node          cam chan on/off etendue  impact(m)  angle(deg) on/off(TOPO,TOBU)
DB/B5V-UBOL<RAW:001 1  1 1    6.15668E-08   0.92336   289.70401  1  1
DB/B5V-UBOL<RAW:002 1  2 1    4.84012E-08   0.73020   284.13300  1  1
DB/B5V-UBOL<RAW:003 1  3 1    4.83687E-08   0.53332   278.65399  1  1
DB/B5V-UBOL<RAW:004 1  4 1    4.67045E-08   0.33242   273.19901  1  1
DB/B5V-UBOL<RAW:005 1  5 1    3.45285E-08   0.15189   268.40601  1  1
DB/B5V-UBOL<RAW:006 1  6 1    2.39133E-08   0.01215   264.72601  1  0
```

DB/B5V-UBOL<RAW:007	1	7	1	2.34426E-08	-0.10188	261.74600	1	0
DB/B5V-UBOL<RAW:008	1	8	1	2.29296E-08	-0.21560	258.76300	1	0
DB/B5V-UBOL<RAW:009	1	9	1	1.00381E-08	0.03650	266.04700	1	0
DB/B5V-UBOL<RAW:010	1	10	1	1.06444E-08	-0.00768	264.97800	1	0
DB/B5V-UBOL<RAW:011	1	11	1	1.00351E-08	-0.05420	263.84500	1	0
DB/B5V-UBOL<RAW:012	1	12	1	1.01474E-08	-0.09906	262.75699	1	0
DB/B5V-UBOL<RAW:013	1	13	1	1.01552E-08	-0.14343	261.70401	1	0
DB/B5V-UBOL<RAW:014	1	14	1	9.99120E-09	-0.18803	260.62100	1	0
DB/B5V-UBOL<RAW:015	1	15	0	1.03578E-08	-0.23330	259.51700	0	0
DB/B5V-UBOL<RAW:016	1	16	0	9.81484E-09	-0.27587	258.48499	0	0
DB/B5V-UBOL<RAW:017	1	17	1	3.00301E-08	-0.40727	255.31100	1	0
DB/B5V-UBOL<RAW:018	1	18	1	3.65520E-08	-0.56179	251.12300	1	0
DB/B5V-UBOL<RAW:019	1	19	1	3.70868E-08	-0.72751	246.52800	1	0
DB/B5V-UBOL<RAW:020	1	20	1	4.18292E-08	-0.88708	241.97900	1	0
DB/B5V-UBOL<RAW:021	1	21	1	5.12869E-08	-1.04215	237.42300	1	0
DB/B5V-UBOL<RAW:022	1	22	1	6.00174E-08	-1.18973	232.86700	1	0
DB/B5V-UBOL<RAW:023	1	23	1	6.82730E-08	-1.32941	228.32001	1	0
DB/B5V-UBOL<RAW:024	1	24	1	7.60144E-08	-1.46037	223.77901	1	0
DB/B5V-UBOL<RAW:025	1	25	0	6.72606E-08	0.84326	288.76001	0	0
DB/B5V-UBOL<RAW:026	1	26	0	6.92535E-08	0.53653	280.00500	0	0
DB/B5V-UBOL<RAW:027	1	27	0	7.16996E-08	0.21510	271.20200	0	0
DB/B5V-UBOL<RAW:028	1	28	0	7.50217E-08	-0.11012	262.44101	0	0
DB/B5V-UBOL<RAW:029	1	29	0	7.95187E-08	-0.45003	253.21800	0	0
DB/B5V-UBOL<RAW:030	1	30	0	7.92650E-08	-0.80693	243.12100	0	0
DB/B5V-UBOL<RAW:031	1	31	0	7.91635E-08	-1.14059	232.94800	0	0

```
DB/B5V-UBOL<RAW:032 1 32 0   8.02508E-08  -1.45116   222.26100  0  0
DB/B5H-UBOL<RAW:001 2  1 1   8.90301E-09   1.19461   218.95900  0  0
DB/B5H-UBOL<RAW:002 2  2 1   9.12827E-09   1.12260   216.31700  0  0
DB/B5H-UBOL<RAW:003 2  3 1   9.33704E-09   1.04823   213.67599  0  0
DB/B5H-UBOL<RAW:004 2  4 1   9.52863E-09   0.97152   211.03101  0  0
DB/B5H-UBOL<RAW:005 2  5 1   9.68336E-09   1.15909   217.60300  0  0
DB/B5H-UBOL<RAW:006 2  6 1   9.79748E-09   1.08567   214.95599  0  0
DB/B5H-UBOL<RAW:007 2  7 1   9.89023E-09   1.00966   212.30000  0  0
DB/B5H-UBOL<RAW:008 2  8 1   9.96062E-09   0.93185   209.65601  0  0
DB/B5H-UBOL<RAW:009 2  9 1   2.14143E-08   0.84873   206.24200  0  0
DB/B5H-UBOL<RAW:010 2 10 1   2.28223E-08   0.69682   201.50301  0  0
DB/B5H-UBOL<RAW:011 2 11 1   2.34906E-08   0.53894   196.72800  0  0
DB/B5H-UBOL<RAW:012 2 12 1   2.33642E-08   0.37896   192.00101  0  0
DB/B5H-UBOL<RAW:013 2 13 1   2.37417E-08   0.19471   186.64700  0  0
DB/B5H-UBOL<RAW:014 2 14 1   2.45627E-08   0.03005   181.90500  0  0
DB/B5H-UBOL<RAW:015 2 15 1   2.45637E-08  -0.13555   177.14200  0  1
DB/B5H-UBOL<RAW:016 2 16 1   2.37442E-08  -0.29908   172.41200  0  1
DB/B5H-UBOL<RAW:017 2 17 1   2.34785E-08  -0.47483   167.25999  0  1
DB/B5H-UBOL<RAW:018 2 18 1   2.36090E-08  -0.63345   162.51199  0  1
DB/B5H-UBOL<RAW:019 2 19 1   2.29375E-08  -0.78765   157.76601  0  1
DB/B5H-UBOL<RAW:020 2 20 1   2.15184E-08  -0.93571   153.04401  0  1
DB/B5H-UBOL<RAW:021 2 21 1   1.89998E-08  -1.01460   149.62500  0  1
DB/B5H-UBOL<RAW:022 2 22 1   1.86667E-08  -1.08979   146.99200  0  1
DB/B5H-UBOL<RAW:023 2 23 1   1.81219E-08  -1.16319   144.34000  0  1
DB/B5H-UBOL<RAW:024 2 24 1   1.73497E-08  -1.23374   141.70200  0  1
```

! Etendues from geometry v01