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The DELPHI Beam Dump

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Abstract

The DELPHI Beam Dump is designed to protect the vertex detector against extreme beam conditions, particularly in the new high energy operating regime of LEP, where the backgrounds may be unpredictable. In this note we describe the radiation monitoring systems which support the dump and the mechanism of the beam dump itself.

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1 Introduction

The purpose of the DELPHI beam dump is to provide protection for the vertex detector from extreme beam conditions. Radiation hardness tests [1, 2] have shown that the sensitivity of the vertex detector is limited by the radiation hardness of the readout electronics. Due to the design of the detector, which is based upon integrated coupling capacitors, it is principally sensitive to the integrated radiation, and additional damage is not expected to result from instantaneous bursts of radiation. The beam dump is therefore intended to protect against prolonged high background, which could integrate to a dangerous level, and reacts on a time scale of tens of seconds. In the next sections the radiation hardness of the detector is discussed, and the monitoring systems upon which the beam dump is based. The pattern of radiation received from LEP in the past is shown, and some beam dump results obtained by playing back the data. Finally the beam dump set-up is described along with the programs by which practical information is provided to the control room.

2 Radiation Hardness of the Vertex Detector

The 1995 vertex detector uses two different kinds of readout chips. MX3 chips are used for the Inner layer, at a radius of 9.0 cm, and are the least radiation hard. They will not be reused in the 1996 detector. MX6 chips are used for the readout of the closer layer, at a radius of 6.3 cm, and the Outer layer, at a radius of 10.9 cm. These chips will be reinstalled in the 1996 detector, with the Outer layer chips moved to the the Inner layer, and a new set of TRIPLEX chips will be used for the 1996 Outer layer. As the chips are irradiated their noise gradually increases, and at at some stage the efficiency for distinguishing m.i.p. signals from the background starts to decrease significantly. Radiation tests have shown that for the TRIPLEX and MX6 chips the signal over noise (S/N) is reduced by about 1% for every kRad of dose, with approximately a 20% error on this number. Using the S/N values registered in the detector, which vary between 11 and 17, and setting a lower value of 8 as a value of S/N for which the detector is still functional, we can define the 'lethal' dose for the MX6 chips as between 30 and 75 kRad. The corresponding lethal dose for the MX3 chips is around 15 kRad. Taking into account the total dose received before 1995 of between 2 and 4 kRad (most of which occurred before 1994) and assuming that we have 5 more years to run, we set a 'lethal' limit of about 5 kRad per year. If the dose is found to have a large variance in either the radial or the ϕ position, it may prove possible to preserve the S/N by changing the positions of some modules. On the other hand, in the unlikely scenario that LEP integrates such a background radiation in the next few years, some extra shielding may have to be envisaged.

3 Monitoring Systems

The monitoring system consists of two parts, an active region with continuous readout which triggers the beam dump, and passive monitors situated on the detector itself.

3.1 Active Monitors

The Active Monitors consist of low illumination solar cells [2] each having an active surface area of 5.5×1.4 cm^2. Four such cells are mounted on a plastic ring at a radius of 9.5 cm from the LEP beam and at $z = 1.455$ m in DELPHI, on the support bars of the new inner detector, on the C-side of DELPHI. In 1994 and previously they were mounted from the TPC laser box protection cover and hence were at $z = 1.955$ m. A current to frequency converter, mounted next to the solar cells inside DELPHI, digitises the solar cell currents, sending a pulse train to the Pythia scalers. The values are then read out (via SCALER_TALK) approximately every 10 seconds. The detector was absolutely calibrated to better than 2.5% with ^{137}Cs and ^{241}Am over a range of 0 to 100 rads/hour. The leakage current of the cells have a temperature dependence, and hence the pedestals are corrected with the temperature, monitored with a thermometer mounted on the detector support ring and read out together with the cells. In figure 1 we show the leakage current frequencies measured in the cells during a LEP shut-down period, plotted against temperature. The dependence is seen to be reasonably linear. In figure 2 we show the temperature corrected pedestal of monitor 1, normalised to the value at 21^o C. The gaussian fit corresponds to a sensitivity of 0.009 rads/hour. The corresponding values for the other monitors are 0.005, 0.016 and 0.007 rads/hour. The pedestals drift a little in the course of the year, but are always well within the accuracy required.

The active monitors have been running since 1991. In 1994 they accumulated doses of 12, 41, 8, and 38 Rad. The respective detectors were situated above, on the B side, below and on the D side of the beam pipe. The majority of the radiation was therefore accumulated in the horizontal plane.

3.2 Passive Monitors

In addition to the active monitors, each year about 30 passive TLD (Thermo Luminescent Devices) and RPL (Radio Photo Luminescent) monitors are attached to the vertex detector repeaters at radii of about 6 cm and 10 cm and at $z = \pm 20cm$. At the end of each year these are analysed to give the true dose very close to the detector. These values have been used each year to calibrate and gain experience with the active monitors. In 1994 the passive monitors registered between 0.1 and 0.9 kRad, depending on position. The three highest doses, of 0.9, 0.8 and 0.5 kRad, were seen in the horizontal plane, at small radius, and the remaining detectors (including a fourth also at small radius in the horizontal plane) received between 0.1 and 0.2 kRad.

4 Estimating the radiation received at the Vertex Detector

It is clear that although the monitors themselves are very accurately calibrated they only measure the dose at $z = 1.455$ m ($z = 1.96$ m until the end of 1994). The relative dose seen by the radiation monitors and that observed on the vertex detector and vertex detector readout electronics must be determined by comparing the doses registered in the active

[2] The detectors are Kodenshi Corp. SSC-9-5815 solar cells purchased from Sicovend Elecktronik, CH-8304 Wallisellen, Switzerland.

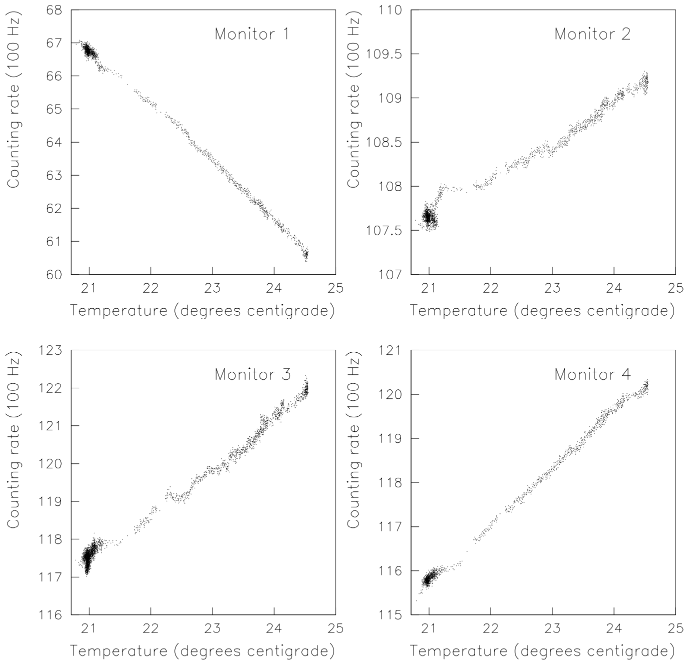

Figure 1: The counting rate plotted against temperature for the four monitors, during a period when there was no LEP radiation.

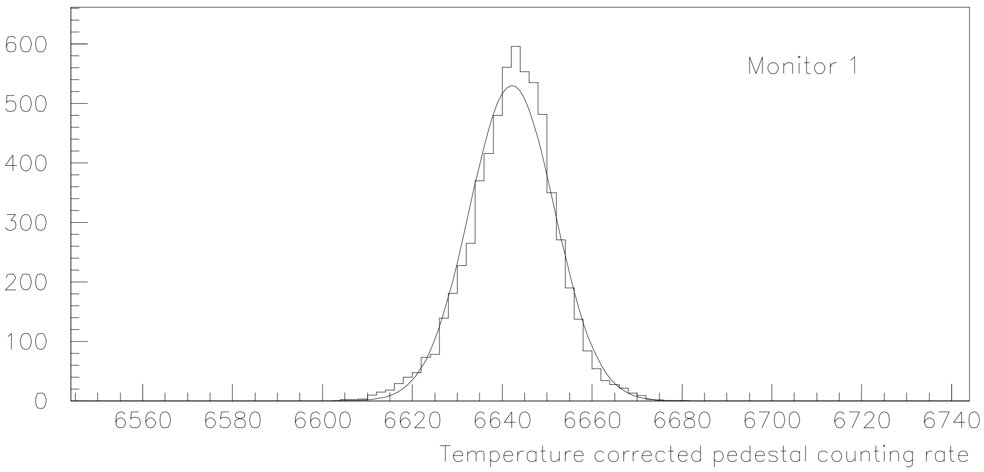

Figure 2: The pedestal counting rate for Monitor 1, corrected to the 21^o point. The spread corresponds to a sensitivity of 0.009 rads/hour.

		Monitor 1	Monitor 2	Monitor 3	Monitor 4
1994	Dose received in rads	12.4	41.5	7.8	37.8
	% during physics conditions	2.4	0.5	3.0	2.5
1995	Dose received in rads	26.7	20.5	25.4	14.6
	% during physics conditions	3.2	9.4	2.3	19.0

Table 1: Radiation received in 1994 and in 1995 (up until the end of the Z^0 run) *at the radiation monitors*.

and passive monitors. Comparing with the numbers given in Section 3.2, it can be seen that the dose seen on the vertex detector electronics in 1994 is typically 10 to 20 times greater than that registered in the active monitors, which is consistent with the experience from previous years. This factor varies by a up to a factor of two depending on different azimuthal positions. Hence the real limitation on the precision with which it is possible determine the dose accumulated by the vertex detector and its readout electronics is limited by such an extrapolation and not the intrinsic accuracy of the radiation monitors themselves. In 1995, due to the closer proximity of the active monitors to the detector itself, the factor is probably closer to 10 than to 20. Taking 20 as the upper limit, and taking into account the radiation tolerances discussed above, a limit is set, *at the radiation monitors*, of 250 rads/year.

5 Pattern of LEP Background Radiation

The pattern of radiation seen at the radiation monitors in 1994, and for the period up until the end of the Z^0 run in 1995, integrated for the year, is shown in figure 3. (For the rates per day, see figures 4, 5. In 1994 the maximum dose seen was about 40 rads, i.e. over five times lower than the lethal limit. The radiation was also quite uneven, being mainly concentrated in the horizontal plane. The vast majority of the radiation was collected during the LEP ramp and squeeze, with very little during stable running conditions. Even during these periods the radiation was delivered quite evenly, and it is hard to single out particular spikes where it would have been possible to save significant radiation by dumping the beam. Towards the end of the year the radiation increased due to the bunch train developments, and had this rate been constant throughout the year the total dose would have gone up by a factor of four. The doses received are summarised in table 1.

In 1995 the radiation was more evenly distributed between the four monitors, but the maximum dose seen was very similar to that seen at the same time of year in 1994. A larger fraction of the total dose was also seen during stable beam collisions, in contrast to 1994.

The data was looked at in playback mode to investigate the role that the beam dump might play. A number of different algorithms were tried, each with different levels of sensitivity to a rise in radiation. It was assumed that each time the beam would have been dumped, the detector would not have received the high radiation immediately following the time of the dump. It must also be remembered that although DELPHI was to some

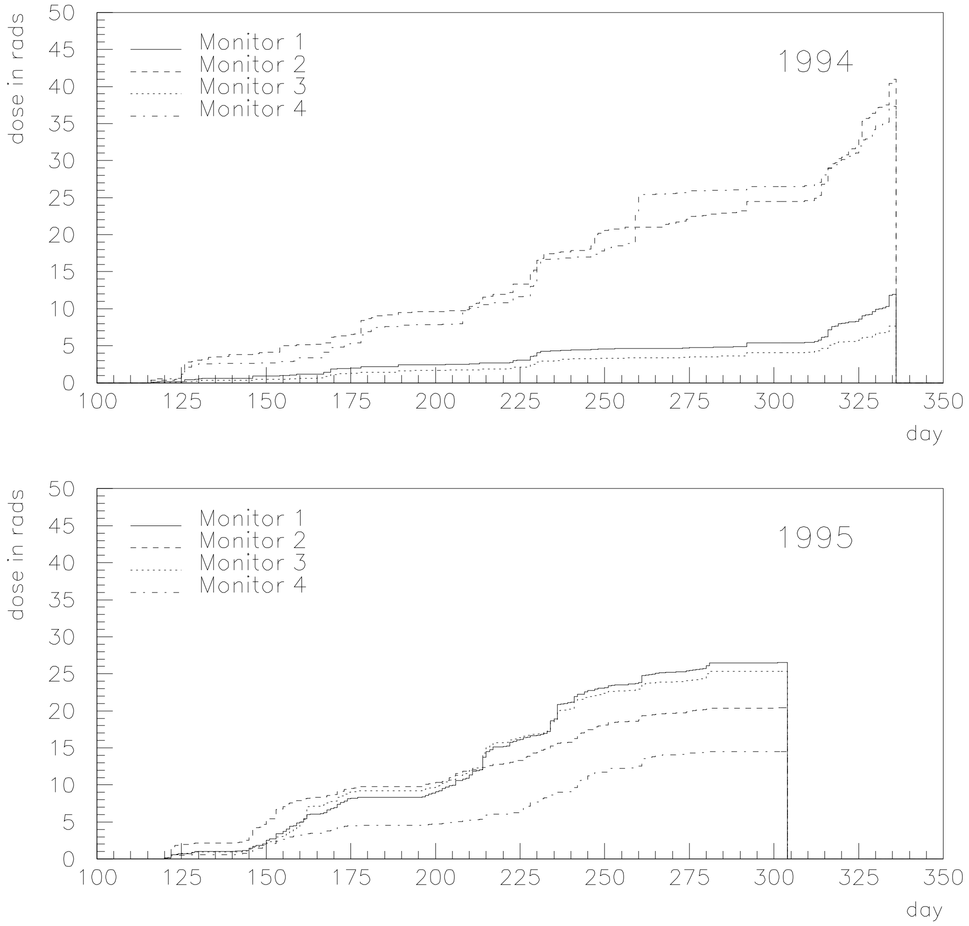

Figure 3: The integrated dose registered at the radiation monitors in 1994 and 1995. The positions of the monitors are: Monitor 1 – above beam pipe, Monitor 2 – B side, Monitor 3 – below beam pipe, Monitor 4 – D side.

extent protected from radiation by the OPAL beam dump, the radiation can be quite localised. It was found that in order to reduce the dose by 50% it would have been necessary to dump the beam between 100 and 120 times[3]. If the algorithms are tuned so as to just cause one dump, then this dump would have occurred on May 5th and would have saved just one rad. From the DELPHI point of view it is not advantageous to save 50% of the radiation at the expense of so many beam dumps, as we are significantly below our lethal limit. However it is of interest to protect the VD from prolonged high backgrounds, where tens of rads may be dumped into the vertex detector in a few minutes. Such a dose may reduce overall lifetime of the detector in LEP. This is particularly important as LEP enters the new period of high energy running, and the background may be unpredictable. The beam dump should also be controlled in an automatic way.

6 The Beam Dump Algorithm

The beam dump algorithm aims to gather together the information from the active monitors and provide just one number, which instantaneously indicates the danger level. Placing a ceiling on this number provides a convenient method of signalling a beam dump. The algorithm should react fast to an increase of radiation in any one of the detectors, and react more quickly the higher the background. It should also react quickly to a decrease in background levels, so that as soon as LEP brings the background to safe levels, the algorithm responds and the beam is saved. Finally the algorithm should be relatively simple, so the levels given are intuitively understandable. The algorithm chosen works by updating a running counter. This counter is updated approximately every 10 seconds as follows:

```
IF ( radiation rate > a .AND. integrated dose in last minute > b ) THEN
        counter = counter + 1 + c × rate
    ELSE
        counter = counter  × d
ENDIF
```

This loop is repeated for each monitor, with the proviso that the counter is not allowed to decrease if any of the other monitors are above the threshold given in the first line. The settings of a,b,c and d control the sensitivity of the counter, with a and c being particularly important parameters. As the radiation arrives the counter starts to increase. There are then several levels of warning. The first level warning indicates some background radiation, and the third level warning requests that the shifter should phone LEP to inform them that the rates are high in DELPHI. There are three more levels before the level that will trigger a dump. For testing the beam dump the data was played back with different values of parameters in the beam dump itself, and threshold values for the warning levels. The values for the 'slow' and 'fast' modes and for the 'normal' and 'sensitive' settings are shown in table 2. Note that the integrated dose includes that taken in the last 10 seconds, so theoretically the beam dump could trigger on the first cycle.

[3]This is consistent with OPAL's estimate of how much radiation was saved by dumping the beam 94 times in 1994 [3]

parameter	a	b	c	d	threshold	Phone LEP	Dump Beam
‘slow’ algorithm	10	0.1	0.01	0.9	‘normal’ settings	100	400
‘fast’ algorithm	5	0.05	0.1	0.9	‘sensitive’ settings	50	200

Table 2: Values of parameters and thresholds for ‘slow’ and ‘fast’ modes and for the ‘normal’ and ‘sensitive’ settings. The units are rads or in rads/hour, where applicable.

year	algorithm	settings	beamdumps	beamdumps during physics	‘Phone LEP’ alarms
1994	‘fast’	‘normal’	7	0	21
		‘sensitive’	12	1	32
	‘slow’	‘normal’	2	0	11
		‘sensitive’	0	n/a	8
1995	‘fast’	‘normal’	2	0	16
		‘sensitive’	11	1	32
	‘slow’	‘normal’	0	n/a	5
		‘sensitive’	0	n/a	2

Table 3: Summary of the performance of the beam dump algorithm run in playback onthe 1994 and 1995 data. In normal operation the dump is run in the ‘fast’ mode with ‘normal’ threshold settings.

Figure 4 shows the integrated radiation for each day in 1994, with a scatter plot showing the values that would have been registered for the counter, in the ‘fast’ mode. The counter is seen to reflect well the amount of radiation received. If the beam dump had been activated with normal settings, the beam would have been dumped by DELPHI 7 times during 1994. Most of these dumps would have occurred during the bunch train commissioning [4].

Figure 5 shows the equivalent plot for 1995. If the beam dump had been operational throughout the year DELPHI would have dumped the beam 2 times. The statistics for the different settings are summarised in table 3. The beam dump was put into operation in the ‘fast’ mode with ‘normal’ settings in the last week of running during the Z^0 scan, and has been continuously in operation since. In the worst case, with the figures given, the VD could receive about 10 Rad of localised dose, before dumping the beam. If however we receive little radiation it is anticipated that the threshold for dumping the beam could be gradually raised.

7 The Beam Dump setup

The beam dump control system is based on a current loop system, illustrated schematically in figure 6. The current from LEP is passed through the DELPHI beam dump control

[4]The causes of the extra radiation seen during the bunch train running have now been studied and are largely understood [4]

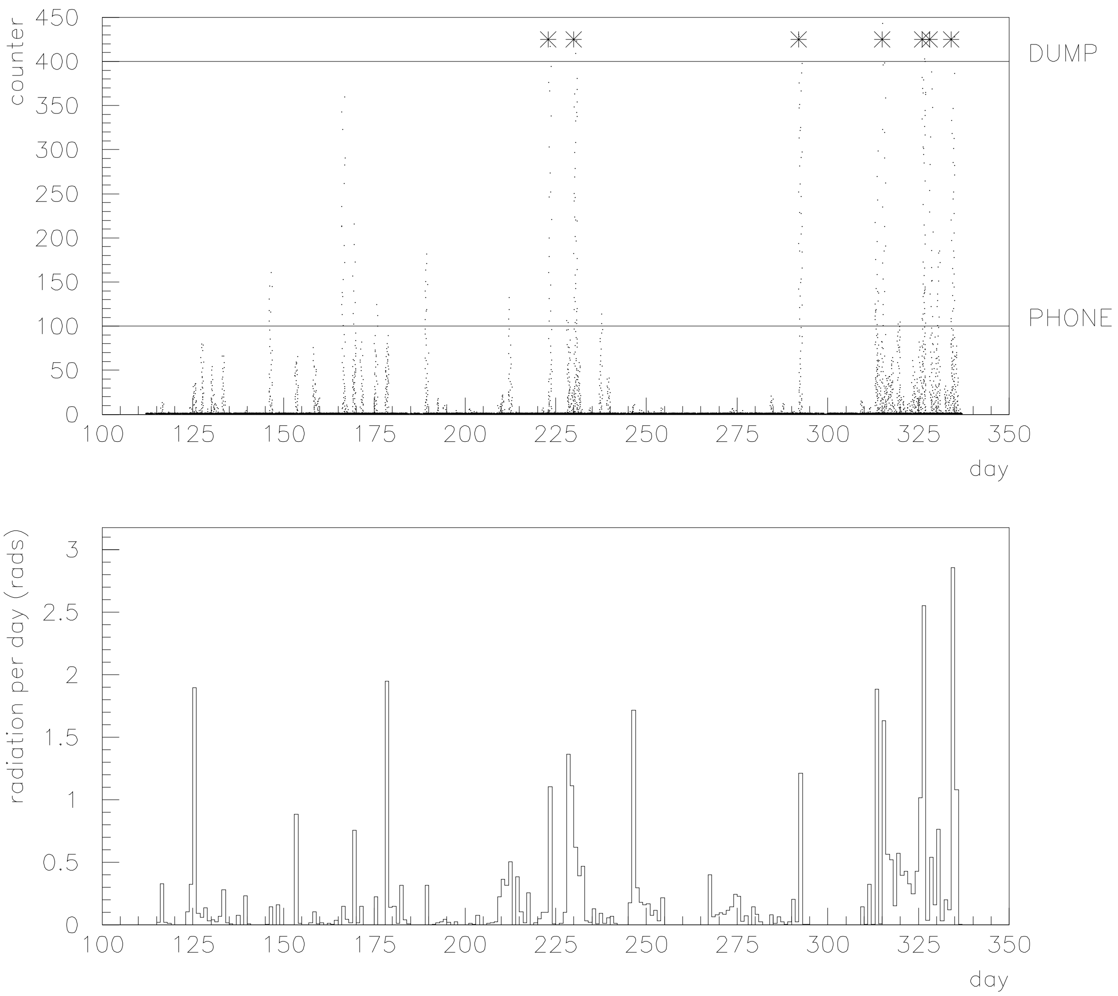

Figure 4: Value of counter controlling dump, and integrated radiation per day, at monitor two, for the whole of the 1994 running. The lines indicate the thresholds for phoning LEP and for dumping the beam. The stars show the times of the beam dumps which would have occured. None were during physics collisions, and most occurred at the end of the year when the bunch train running was being commissioned and the amount of background radiation increased by a factor of four.

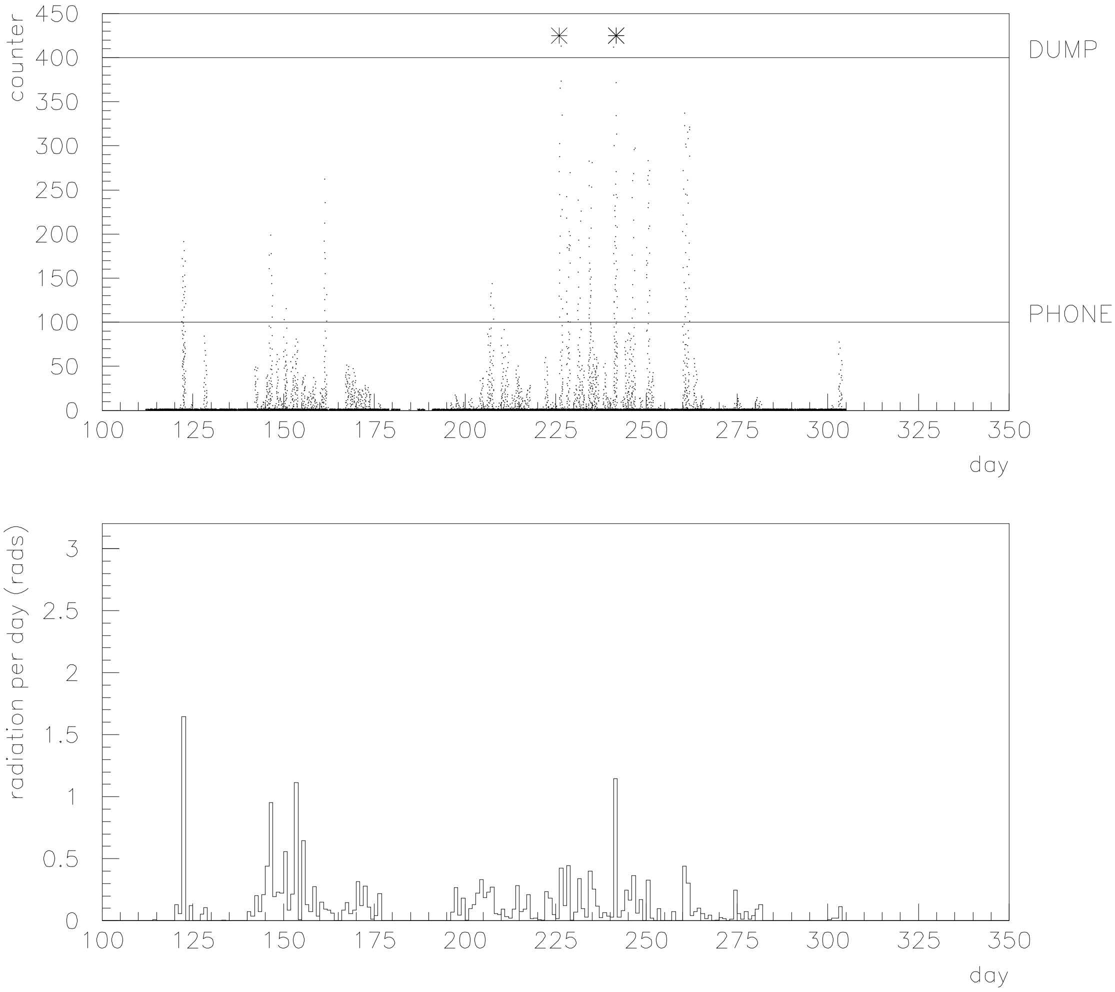

Figure 5: Value of counter controlling dump, and integrated radiation per day, for the whole of the 1995 running up until the start of the high energy run. The times when the radiation would have provoked a beam dump are marked with a star.

system located in B2. The loop is normally closed, as soon as it is opened the current is interrupted and the beams are dumped automatically.

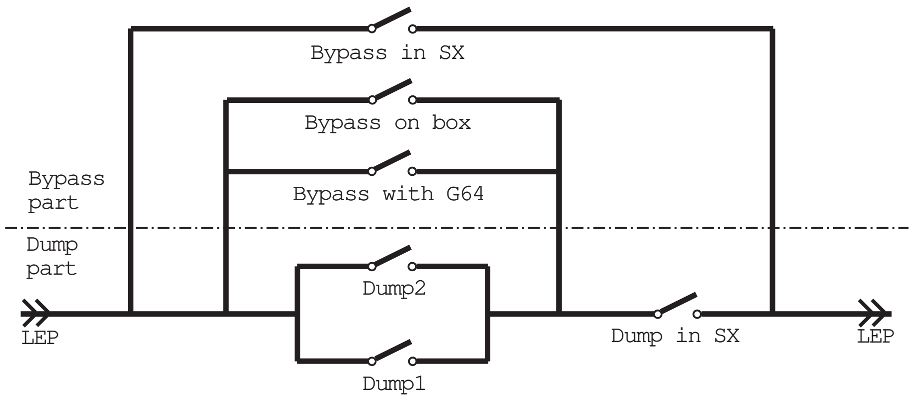

Figure 6: Schematic illustration of the DELPHI beam dump control system

The beam dump control system consists of a control box and a G64 monitoring system. In addition there are two buttons (dump and bypass) located in the control room. The control box itself is illustrated in figure 7. Note that in the control box there are in fact two current paths, both of which must be simultaneously cut to force a dump.

In normal operation all bypass switches are open and all dump switches are closed. The beam can be dumped by either

- Opening BOTH dump1 and dump2. This can be done only by software, either via a command given by and operator or automatically without any operator intervention. Both dump swithes are controlled from the G64.
- Opening the dump switch in the control room with a key.

The beam dump system can be bypassed on three levels:

- By closing the bypass switch in the control room, bypassing the entire control box in B2, and the dump switch in the control room.
- By closing the bypass switch on the control box in B2.
- By closing a bypass switch in the control box controlled by the G64 [5].

In normal operation the dump1 and dump2 switches are closed, and the beam dump system works in full automatic mode, taking as a software input the thresholds of the counter described above.

Some details of how to get information about the status beam dump system, and the background radiation, and the programs which need to be running for the system to be operational, are given in the Appendices.

[5]This switch is closed when the G64 is reset or powered off.

Figure 7: Schematic of the control circuitry for the beam dump control box.

8 Conclusion

The beam dump system has been operational in DELPHI since the beginning of October, 1995. It relies on a system of solar cells which are continuously monitored. The sensitivity of the system is limited not by these cells but by the error in extrapolating from the radiation recieved at the monitors to that received at the VD electronics. The system protects the VD from the possibility of integrating radiation doses which would take it close to the lethal limit.

9 Acknowledgements

We would like to thank Michel Ferrat, who built the beam dump box.

Many members of the DELPHI DAS group were helpful in setting up the online monitoring systems.

We would also like to thank members of the VD group who contributed, in particular Hans Dijkstra who suggested the beam dump algorithm which was eventually used.

References

[1] V. Chabaud *et al.*, "The DELPHI Silicon Strip Microvertex Detector with Double Sided Readout", CERN-PPE/95–86, 14 June, 1995.

[2] H. Dijkstra *et al.*, "Radiation hardness of Si strip detectors with integrated coupling capacitors", Proceedings of IEEE Nuclear Science Symposium, IEEE trans. nucl. sci: 36 (1989) 591-592.

[3] J. Lauber, "OPAL Radiation Monitoring", Transparencies presented at the DELPHI forum, 13th December 1994.

[4] G. Von Holtey *et al.*, "Off-energy electron background with bunch trains in LEP", CERN–SL–95–86; Bovet *et al.*, "Final report of the 1994 bunch train study group", CERN–SL–94–95.

A Information on background levels

The information on the background radiation levels can be accessed in three different ways, by a summary table, by trace plots and by running the software.

A.1 Summary Table

The summary table can be viewed with a simple dui command on any x terminal. It contains the following information:

- The rates accumulated every ten seconds, which indicates that the monitors are alive
- The pedestal corrected instantaneous radiation rates, in rads per hour, calculated at a local level, and the rates sent to the LEP control room. The rates sent to LEP are different in that they are forced to be greater than or equal to zero, and may be combined with information from other detectors
- The integrated rates accumulated in the last 10 minutes and in the last 24 hours
- The value of the counter described in this note, and a line of text showing the warning level

There are also some help files, and a display showing how long the program has been running (so the shifter can tell if the dose accumulated in the last 24 hours is in fact meaningful).

Some workstations at the pit have an option to display these tables from a pull down menu. They may also be displayed with the following command on the online cluster:

```
@disk$user:[vd_operator.motif.dui]DISPLAY_RADMON
```

(remember to direct the display to your X-terminal).

A.2 Traceplots

The trace plots are permanently displayed above the DAS workstation and on the WS-DEVD station. They show the instantaneous radiation rates for the four monitors for the last 3 hours, and in coarser detail on another plot for the last 27 hours. In addition, the display on WSDEVD shows the value of the counter in the last 3 and 27 hours. They may be displayed on any x terminal with the following command:

```
@disk$user:[vd_operator.motif.dui]DISPLAY_RADTRACE
```

A.3 Software

A facility exists to calculate the radiation seen at the solar cells in the last 24 hours and provide plots in HBOOK format. The pedestal calculation used in this program is slightly more sophisticated than that used for the running total, which accounts for small diffreneces seen with the numbers in the table. It is operated from the VD_OPERATOR account by typing RADINT. It produces an HBOOK file with the differential and integrated radiation seen in the last 24 hours. This may be seen, after running RADINT, simply by going into PAW and typing EXEC RAD.

B Information on the Beam Dump System

B.1 SMI

To display the actual status of the beam dump control system the smi display can be used. Here the state of the system in 1995 is described, it may be changed in some aspects for the 1996 run. To start the SMI use the command bd_disp when logged in as CP_OPERATOR or SC_OPERATOR This command will show you the smi display for the beam dump domain. Apart from the menu you will see the following objects:

- CL - Allows the input for the automatic dump to be taken from either RAD_MON_SMI (CL is CENTRAL) or RADMON_TEST (CL is TEST). All input is inhibited when CL is in state LOCAL, operator software commands are still possible in this case. CENTRAL is the normal state.

- RADMON_TEST - Used for testing the automatic dump procedure. Will be used as input for the automatic dump when CL in TEST. NOT_ACTIVE is the normal state, during tests it can show the same states as the object RAD_MON_SMI.

- RAD_MON_SMI - The normal input for the automatic dump, this input is selected when CL in CENTRAL. This shows the actual state of the radiation. The possible states (with increasing radiation) are: QUIET, SOME, QUITE_HOT, HIGH, VERY_HIGH, REQUEST_DUMP. The last state will trigger the automatic dump, there is no action on the other states, they are there only for information. There is no normal state, but it should be as low as possible (QUIET)

- BEAMDUMP - Shows the state of the beam dump system. The normal state is ARMED or BYPASSED depending if the system is bypassed or not. When ARMED an automatic beam dump can be triggered. Other states are: AUTO_DUMP: the automatic dump has fired, will be cleared when beams are dumped and radiation back to normal. CONFIRM_DUMP1,CONFIRM_DUMP2,CONFIRM_DUMP_ALL: waiting for confirmation after manual software command to open one or both dump switches. CLEAR_DUMP: wait for radiation level to go back to normal or wait for command to close both dump switches.

- CURRENT_LOOP - Shows if there is any current in the loop. Normal state is CURRENT_OK. When no current is going the state is BEAMS_DUMPED and LEP beams are dumped automatically.

- BYPASS - Shows what bypass is active. NONE is the normal state. Note that one bypass might mask out another one.

- DUMP_SIGNALS - Reflects the state of the two dump switches. NO_DUMP is the normal state. Will show DUMP1_FIRED, DUMP2_FIRED or BOTH_DUMPS_FIRED when one or both dump switches are opened.

- DUMP_CURRENT - Shows the current through the two dump switches. CURRENT_OK is the normal state. Will show NO_CURRENT_DUMP1, NO_CURRENT_DUMP2 or NO_CURRENT_BOTH_DUMPS when no current is going through one or both dump switches. Note that due to lower resistance in the bypass chain the state NO_CURRENT_BOTH_DUMPS will be shown when one or more of the bypasses are closed.

The following commands can be given (commands are given to objects via the menu in the smi display, see below how to do so):

- SET_TEST - on object CL to switch from CENTRAL to TEST
- SET_LOCAL - on object CL to inhibit any input
- SET_CENTRAL - on object CL to switch from TEST or CENTRAL
- BYPASS_WITH_G64 - on object BYPASS to close the G64 controlled bypass switch in the control box.
- REMOVE_BYPASS_WITH_G64 - on object BYPASS to open this switch.
- DUMP1 - on object BEAMDUMP open dump1 switch.
- DUMP2 - on object BEAMDUMP open dump2 switch.
- DUMP_ALL - on object BEAMDUMP open both dump switches.
- CLR_DUMP - on object BEAMDUMP close both dump switches.
- CONFIRM - on object BEAMDUMP to confirm the command to open one or both of the dump switches.
- CANCEL - on object BEAMDUMP to cancel the command to open one or both of the dump switches.

Note that the availability of the commands depends on the status on the object (eg. SET_TEST is not available when CL already in TEST).

To give commands use the menu. With the cursor on 'Object Control' (use up and down cursor keys to move) in the 'MAIN MENU' hit return. The 'Object Selection' menu will be shown. Select one of the three top objects (BEAMDUMP, BYPASS or CL), select '–Exit–' to go back to the main menu, ignore the other menu items. After selection of an object the 'Action Menu' will be shown, select one of the commands and hit return (or select –Exit– to get back to the main menu). In the 'Action menu' NEVER use any of the commands starting with 'X_SET_' these are internal smi commands and migh lead to unpredictable results.

B.2 Batch Jobs

For the whole system to be operational, three programs should be running:

- RADMON – on WSDEVD (queue WSDEVD$USER_CONTROL), logfile: delphi$joblog:[vd]radmon.log
- EP_BD_CTRL – on VSDEOP (queue WSDEVD$SLOW_CONTROL), logfile: delphi$joblog:[tp]ep_bd_ctrl.log
- SMI_BEAMDUMP on VSDEOP (queue WSDEVD$SLOW_CONTROL), logfile: delphi$joblog:[tp]smi_beamdump.log