APPLICATION NOTE

RTI Electronics AB, Sweden

Revision A, July 2010

kVp and time measurements with the Barracuda or Piranha on a typical dental unit

Measurements of kVp and time on dental units with the Barracuda or Piranha may sometimes differ from the set values. The reason is definitions and number of preheat pulses that different manufacturers use in their systems.

This application note will highlight and explain why the difference between set and measured values may occur.

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Introduction

The Output from a typical Dental Unit

In this example we use a model that is a single-phase unit with 13 pre-heat pulses. The kVp and the tube current are fixed at 70 kV and 7 mA, respectively. The time is variable and set in milliseconds.

The waveform was recorded with the Barracuda and oRTIgo software. Typically the waveform appears as shown in figure 1.

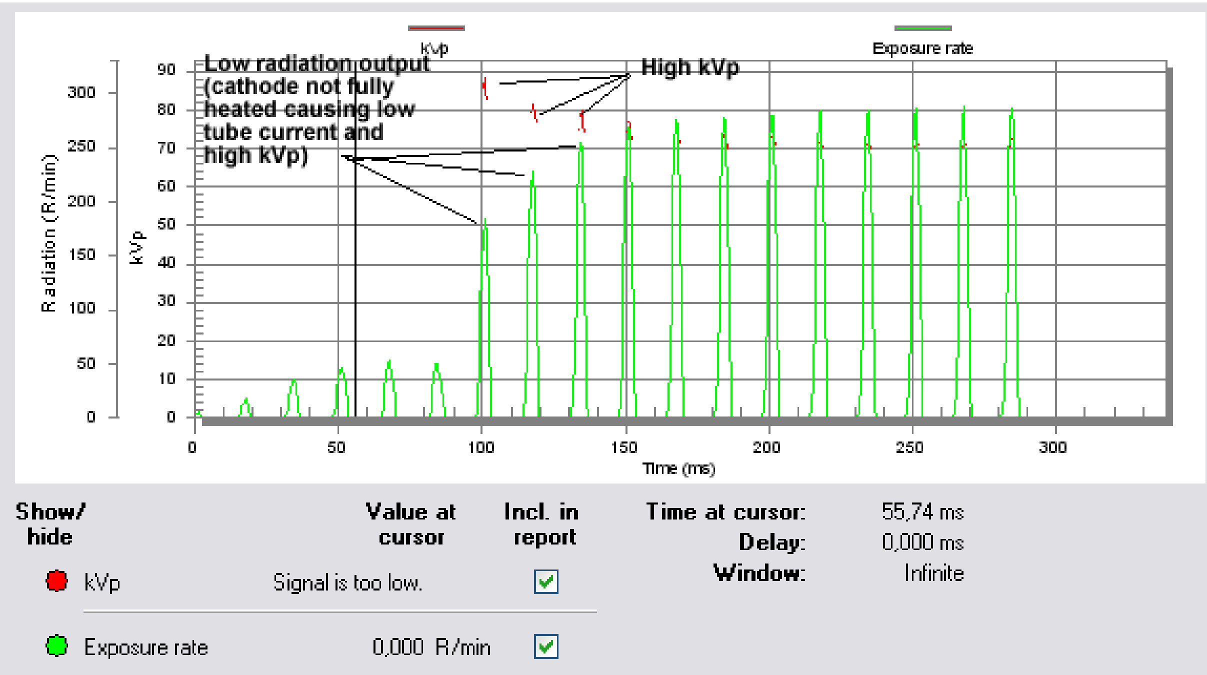

Figure 1. Exposure at 70 kV and 200 ms.

Note that all pre-heat pulses are not recorded since the output is very low. In this case 6 pre-heat pulses are "visible" and the exposure is 12 pulses. The waveform shows that the pre-heat pulses are low compared to the exposure pulses, typically 20% or less than the maximum output. As long as a trig level higher than 20% is used, the exposure time will be measured correctly. The standard trig level for the Barracuda is 50% (it can be set between 10% and 90% in 10% increments).

The waveform also indicates that when the exposure starts, the cathode is not yet fully heated during the pre-heat time. The tube current is therefore low during the first pulses and that leads to lower radiation output and higher kV during the first 3 to 5 pulses. The kV is almost 90 kV during the first pulse. This means that the kVp measured by a non-invasive meter depends upon when the meter measures the kVp - immediately when the exposure starts or after a specified delay. The measured kVp will also depend on whether the meter is taking the “peak value” of all peaks or an average of several peaks.

Definition of Exposure Time

There are two different standards that are used when defining the “exposure time”, the X-ray tube standard IEC60613:1989 defines the “loading time” and the X-ray generator standard IEC60601-2-7:1998 defines the “Irradiation time”.

Loading time is defined in the X-ray tube standard IEC60613:1989 as:

"Time, determined according to a specific method, during which the ANODE INPUT POWER is applied to the X-RAY TUBE."

- Normally this is the time the high voltage for the first time goes over a level (65 – 85 % of the peak value) and until it for the last time goes below the same level.

- If it is a 1- or 2-pulse system, the irradiation time is often used instead.

Irradiation time is defined in the X-ray generator standard IEC60601-2-7:1998 as:

"Duration of an IRRADIATION determined according to specific methods, usually the time a rate of a RADIATION QUANTITY exceeds a specified level "k.

- The irradiation time is often measured from the time when the high voltage has first climbed over 75% of the peak value and until it finally falls below the same level.

- If tube current and tube voltage is controlled simultaneously, then a 25 % level of the tube current may be possibly used instead.

Summary

There is no defined level for measurement on the radiation output. The standard refers to the actual high voltage or the tube current. None of those parameters are directly accessible for a non-invasive meter. However, all non-invasive meters that measure “exposure time” are measuring the irradiation time based on the measured radiation. For the Piranha and Barracuda the radiation signal we use for the measurement of time is in the range of 20 – 40% when the kVp is at 75% of its peak value. This indicates that a trig level of 30% would be suitable. Since this trig level easily can be selected, there is no problem to perform measurements with our meters.

A logical question is then: why has RTI chosen 50% as the default value for the trig level?
The answer to this is as follows: The meter is used on many different dental systems and by many users who are not knowledgably in how dental X-ray systems work. The 50% trig level minimizes the “risk” of catching pre-pulses and therefore measuring an incorrect time. The rising and falling edge of each pulse is very steep and a trig level at 50% instead of 30% will have little influence on the measured time.

IEC60613 is an older standard (1989) and is currently being revised by the IEC workgroup responsible for this standard. According to a member in this group, the revised IEC60613 will be more adapted to the IEC60601-2-7 standard.

The reason for this is not known, but a guess is that there is more interest in image quality, radiation safety and in what “comes out of the tube” instead of the performance of electrical parameters in the generator.

Examples of Time Measurements

The Piranha and Barracuda measure the irradiation time as defined in the generator performance standard IEC60601-2-7:1998.

In figure 2 are the results from the measurements.

Single Phase half wave rectified algorithm											
								Dose	Dose rate	Tot. Filtr.	HVL
kV	mA	Time	Trig	Delay	Window	kVp	Time (ms)	(mR)	(mR/min)	(mm Al)	(mm Al)
70	7	300	10	0	0	75,3	352,3	2,363	45913,2	2,0	2,0
70	7	300	20	0	0	75,4	287,3	2,390	56951,7	2,0	2,0
70	7	300	30	0	0	75,4	286,8	2,375	56689,2	2,0	2,0
70	7	300	10	50	50	71,2	352,8	2,316	44948,7	2,7	2,2
70	7	200	10	0	0	76,5	253,0	1,603	43377,0	2,0	2,0
70	7	200	20	0	0	76,2	187,5	1,618	59082,7	2,0	2,0
70	7	200	30	0	0	76,5	187,0	1,558	57040,9	2,0	2,0
70	7	200	10	50	50	75,0	252,5	1,566	42467,8	2,2	2,1
70	7	100	10	0	0	78,6	152,7	0,768	34438,5	2,0	2,1
70	7	100	20	0	0	78,4	87,2	0,816	64094,3	2,0	2,1
70	7	100	30	0	0	78,7	87,2	0,774	60824,0	2,0	2,1
70	7	100	10	50	50	76,2	152,2	0,751	33759,7	2,3	2,2
70	7	50	10	0	0	81,8	102,8	0,397	26438,3	2,0	2,2
70	7	50	20	0	0	81,7	51,9	0,392	51654,6	2,0	2,2
70	7	50	30	0	0	80,7	36,8	0,418	77749,8	2,0	2,2
70	7	50	10	50	50	74,0	102,8	0,377	25091,6	3,0	2,4

Figure 2. Measured data from our example unit.

Different trig levels (10%, 20% and 30%) were used. The results with 10% and 20% are not reliable since such a low trig level will cause pre-pulses to be measured. These exposures will be ignored in the further analysis. All measurements with 30% trig level have been done without any delay and with an infinite window. If we exclude the data measured with 10% and 20% trig level, we have the following results shown in figure 3.

				Time	Dose	Dose rate	Tot. Filtr.	HVL		Time Diff.
kV	mA	Time	kVp	(ms)	(mR)	(mR/min)	(mm Al)	(mm Al)		(ms)
70	7	300	75,4	286,8	2,375	56689,2	2,0	2,0		13,2
70	7	200	76,5	187,0	1,558	57040,9	2,0	2,0		13,0
70	7	100	78,7	87,2	0,774	60824,0	2,0	2,1		12,8
70	7	50	80,7	36,8	0,418	77749,8	2,0	2,2		13,2

Figure 3. Measured data with 30% trig level and without delay and with an infinite window.

We will use the exposure with 50 ms to show a possible explanation for the difference between measured time and set time. Figure 4 shows the waveform measured with the Barracuda for the measurement with a set time of 50 ms.

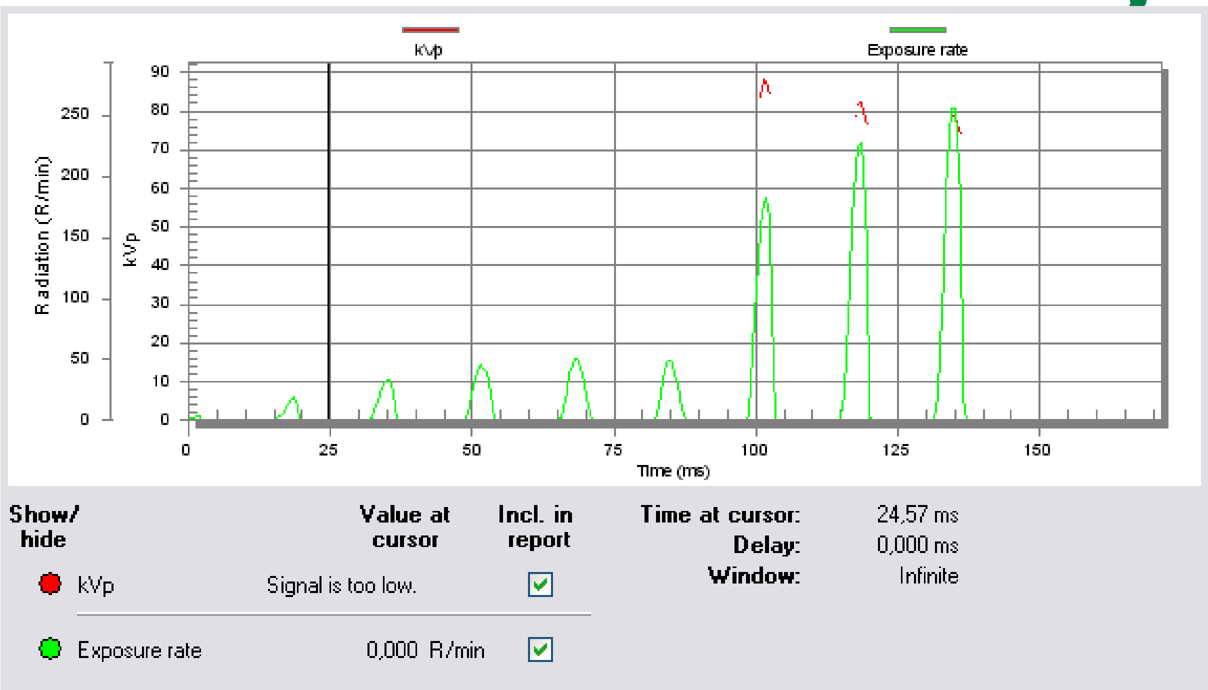

Figure 4. Typical waveform with set time = 50 ms.

The exposure is three pulses long and the Barracuda measured 36.8 ms. Based on the waveform and how irradiation time is defined in IEC60601-2-7:1998, it is obvious that the actual “exposure time” is shorter than the set time of 50 ms.

We can use the cursor in oRTIgo to measure the exposure time. See figure 5 and 6.

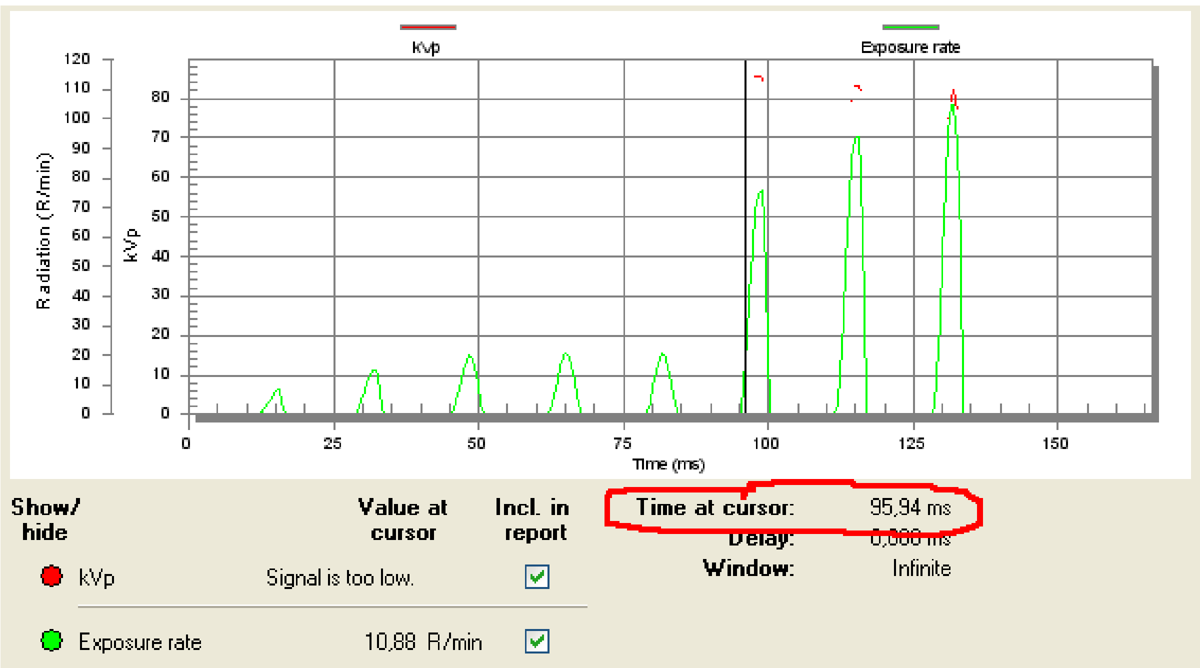

Figure 5. Start of the exposure at 95.94 ms.

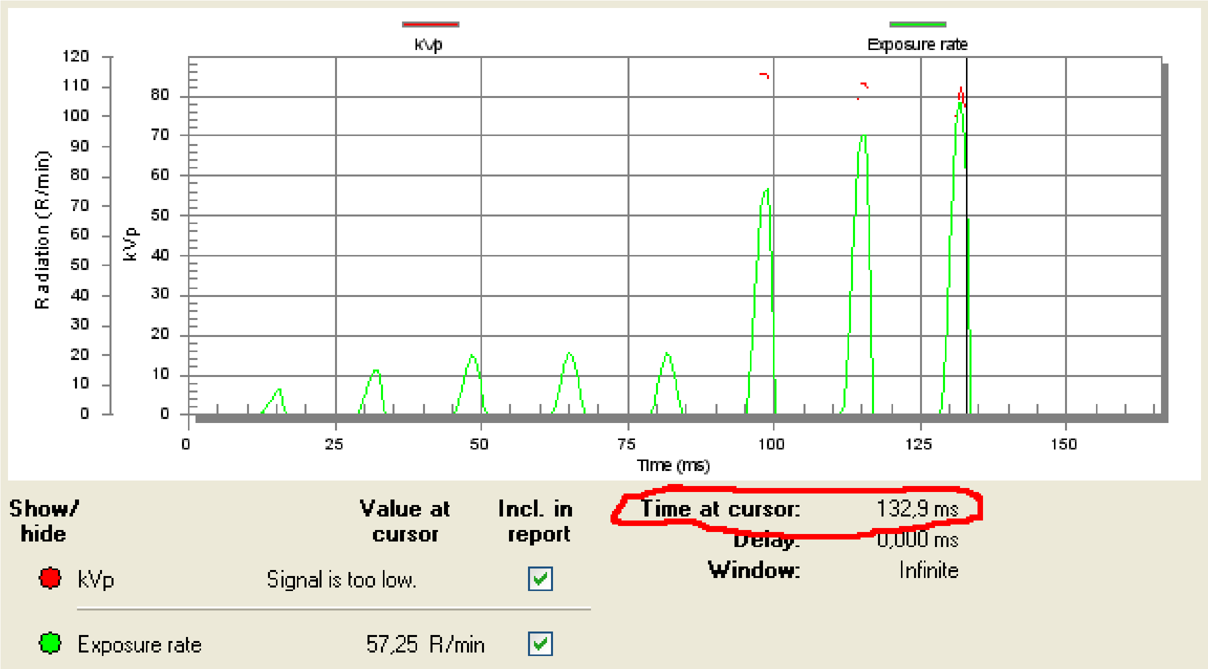

Figure 6. End of the exposure at 132.9 ms .

The time at the cursor position in Figure 5 and Figure 6 is 95.94 ms and 132.9 ms, respectively. Measured exposure time is: 132.9 – 95.94 = 37 ms. That corresponds well with 36.8 ms indicated in the test.

One explanation for the difference between set time and true “irradiation time” (many times called “exposure time”) is the following:

The set time shown corresponds to three cycles of the line power. This would give a time of 3 * 16.6666 ms = 50 ms. Figure 7 shows a theoretical waveform for the high voltage and the radiation coming out from the tube. The radiation output will not be a true sine wave since softer radiation will not penetrate the tube window and the aluminium filtration in the tube/collimator. For dental tubes the total filtration is typically 2.0 to 2.5 mm Al.

All non-invasive meters measure in some way the exposure time from the radiation output. The Piranha and Barracuda have a variable trig level and in this case 30% was used. The theoretical time when radiation is present is 3 * 16.6666 – 16.6666 / 2 = 41.7 ms, see figure 7. “Soft” (when kV is low) radiation will not come out from the tube and the actual time with radiation will be even shorter, see figure 7. Exactly what this time is can be calculated but is not done here. One can assume that a few milliseconds “disappear” in the beginning and in the end giving a shorter time when radiation is coming out from the tube. This is illustrated in figure 7.

This shows that the Piranha and Barracuda (the same is valid for all devices on the market) can never measure a time that corresponds to the set time on this typical mobile dental unit. This unit is not following the standard for how irradiation time is defined. The only way to measure the set time is to make a correction. The last column in Figure 3 shows the difference between the set time and measured time. From this follows:

Set time example unit = Measured time + 13 ms

This is valid for a trig level of 30%.

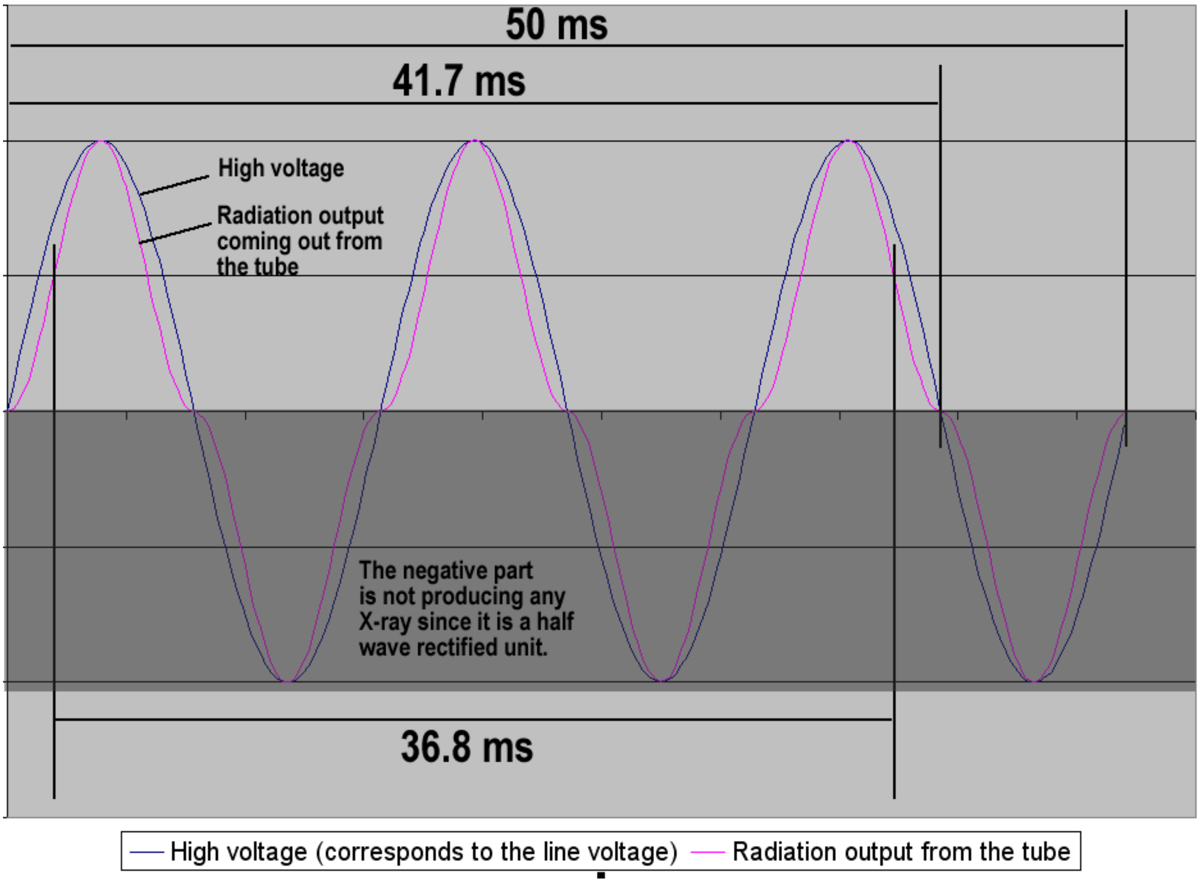

Figure 7. The theoretical waveforms.

Conclusion – Time Measurement

The set time on this example unit does not correspond to the irradiation as defined in the generator standard IEC60601-2-7:1998 and the time measured by non-invasive meters. However, this document is not discussing whether this unit's set values are accurately defined and does not discuss which standards that may be applied to the design of such a unit. We can, based on our 25 years of experience of QA on radiographic systems, foresee many complaints during QA sessions if the commonly used definition of "exposure time" is used. This may lead to some mobile dental units being "failed" and service being called in. This would be true not only when a Piranha or Barracuda is used, but with other non-invasive devices since all meters on the market measure time in a similar way. The other scenario is that users suspect their measuring equipment instead and complain to the meter manufacturer.

If the requirement is to measure according to the definition of "exposure time" used with this unit, the Barracuda can be used with the following settings:

Time trig level: 30% (the default 50% will probably give almost the same result)
Delay: Not relevant for the time measurement
Window: Not relevant for the time measurement

Calculate set time as:
Set time example unit = Measured time + 13 ms

Measurement of kVp

kVp can be difficult to measure on dental units since even if pre-heat pulses are used, the tube current is low in the beginning of the exposure causing the kV to be higher than the nominal (set) kVp. Figure 8 shows again the waveform recorded when the set time of 200 ms was used. The kV waveform is plotted in red. Note that the oRTIgo software only shows the part of the kV waveform that really can be calculated. This means that only a small portion (just around each peak) of the waveform is shown.

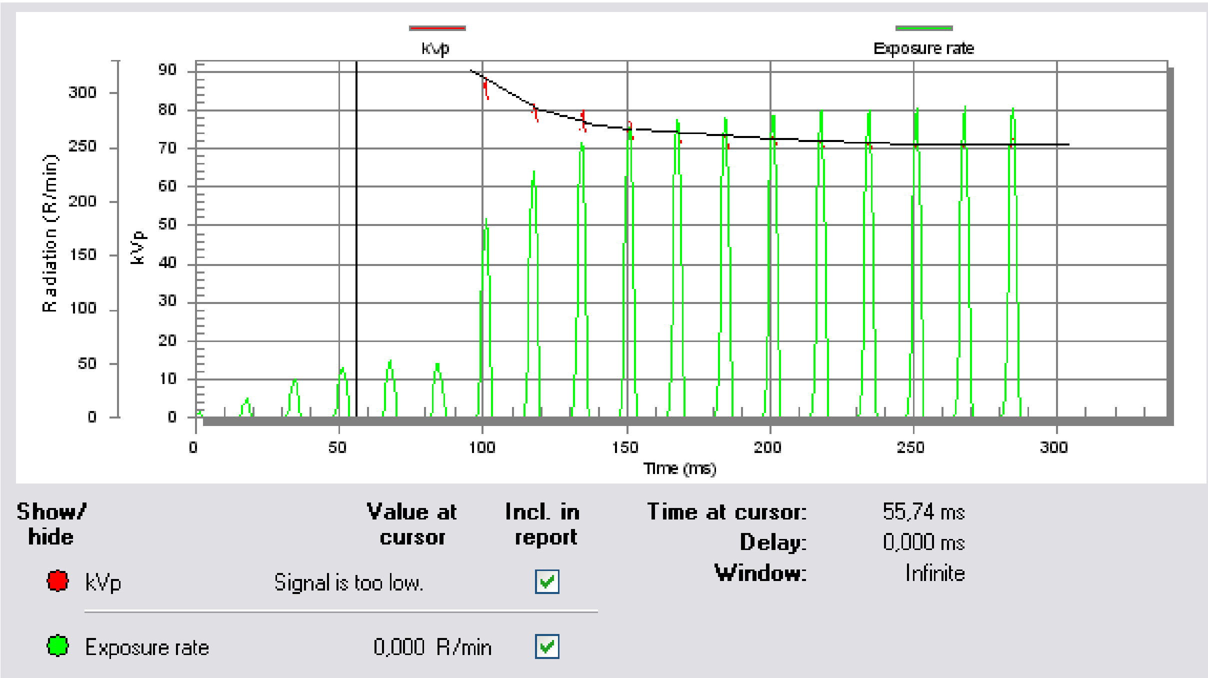

Figure 8. The trend of the kV peaks is marked by the black curve.

The kV waveform clearly shows that the pre-heat pulses are not fully heating the cathode to give the maximum tube current. This causes the first pulses to have much higher kVp than the nominal kVp, see figure 1. The waveform in figure 8 shows that the kVp is almost 90 kV during the first pulse, the second is approximately 83 kV, the third 80 etc. After approximately 100 ms (of the exposure, not including the pre-pulses) the kVp reaches its stable nominal value.

The Piranha and Barracuda have **Delay** and **Window** functions (see figure 9) that gives the possibility to select where during the exposure the kVp should be measured. In this case we could use:

Delay: 100 ms
Window: Infinite (not necessary to limit the time, allowing the Piranha/Barracuda to measure kVp as long as the exposure is on).

With a delay of at least 100 ms the correct kVp will be measured. If no delay is used, the first part of the waveform will influence the results and show a higher kVp value.

Figure 9 shows how the **Delay** and **Window** are defined.

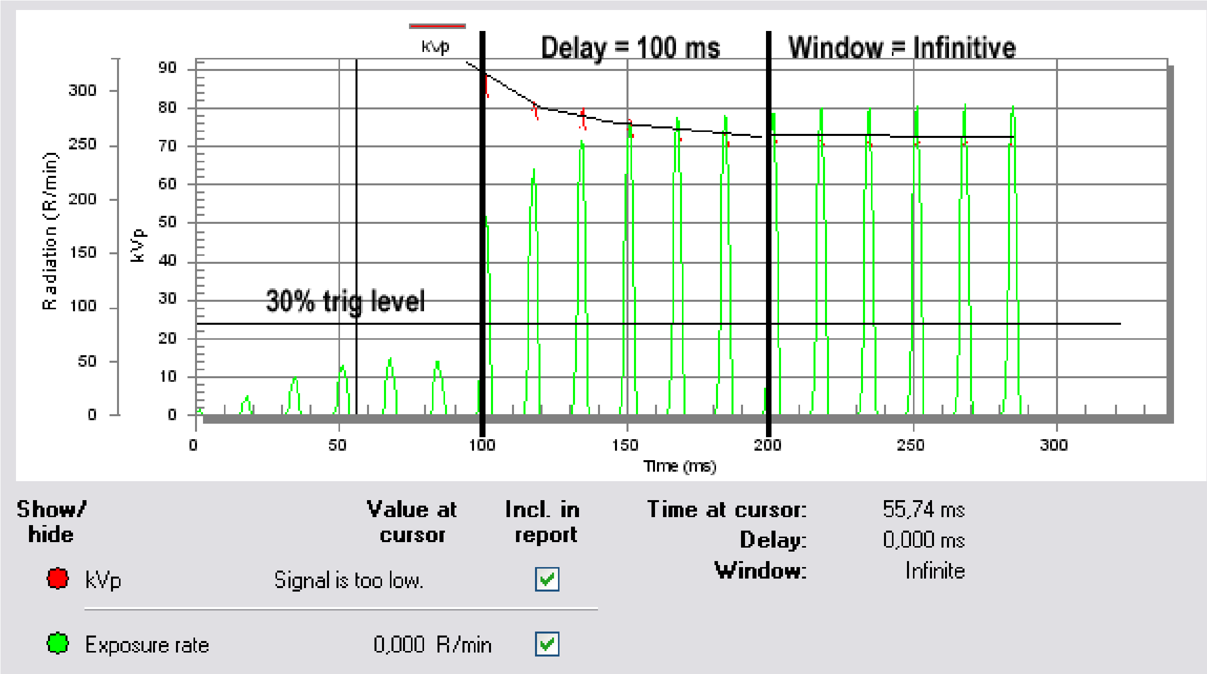

Figure 9. Waveform with delay of 100 ms and an infinite window.

When measuring kVp with set time = 50 ms, a delay of 100 ms cannot be used. In this case, delay = 0 ms must be used since the radiation time is just 50 ms and the Piranha/Barracuda must measure during the 50 ms to collect enough data. The measured kVp will in this case be higher than the nominal kVp. This is correct since the exposure is only the first three pulses which display a higher kVp than the nominal set value.

If a detailed study of the kV is to be done the **Delay** and **Window** functions can be used. See figure 10.

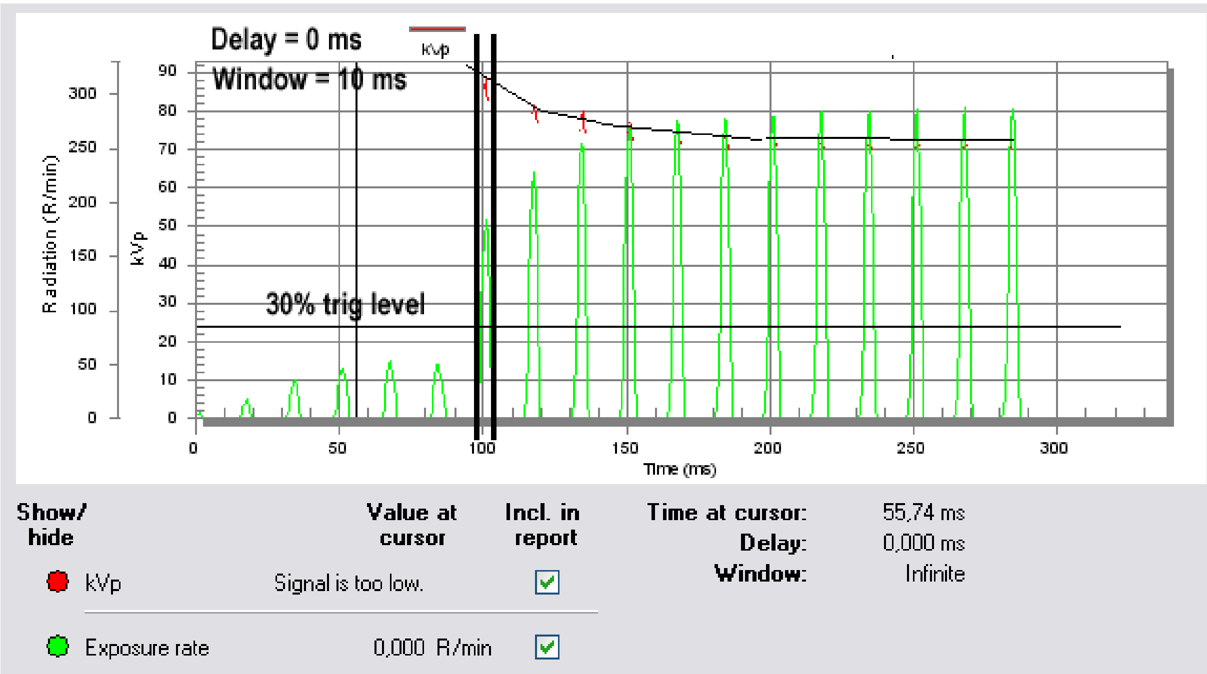

Figure 10.

If using delay = 0 ms and window = 10 ms, the Piranha/Barracuda will only measure the kV during the first pulse. This would probably give a result of approximately 90 kV.

The window can then be moved by increasing the delay time with 16.7 ms, see figure 11.

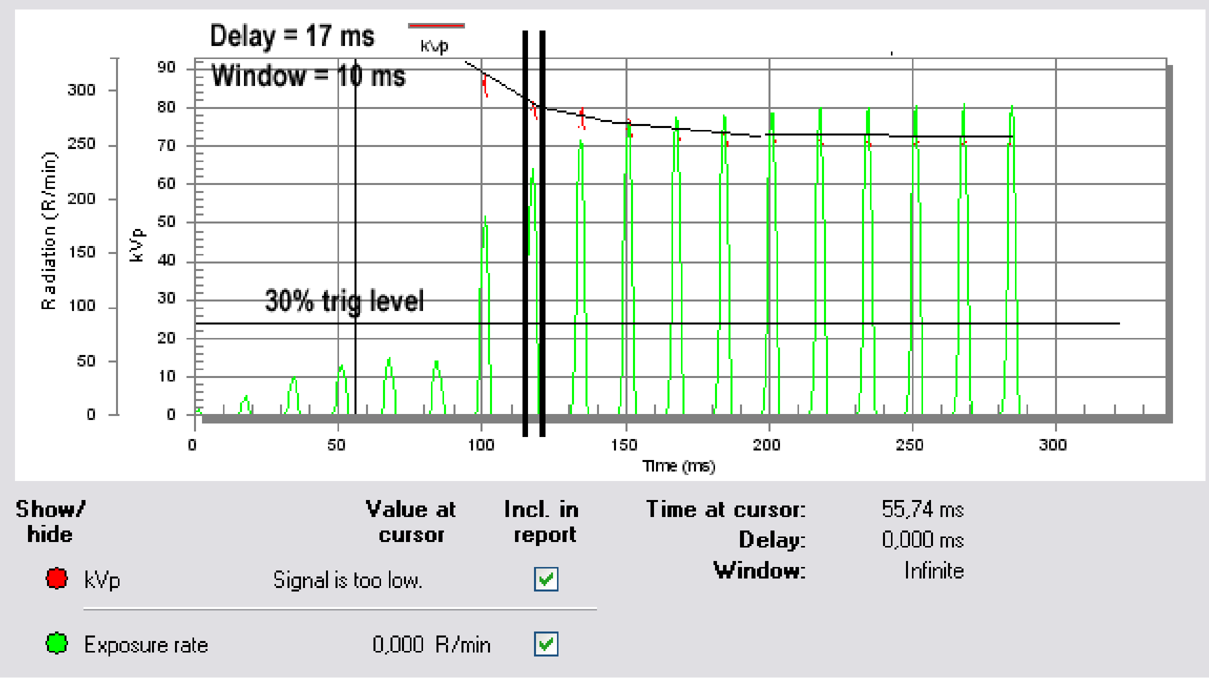

Figure 11.

If we now make a new exposure, the measured value would be approximately 82 kV. We could again move the window by increasing the delay and measure the third pulse and see approximately 80 kV etc. This measurement would clearly show that the kVp is dropping for each pulse measured until it reaches a stable value close to the nominal kVp.

Conclusion - kVp Measurement

This example unit has higher kVp in the beginning of the exposure since the cathode is not fully pre-heated when the exposure starts. This causes a lower tube current in the beginning of the exposure and hence a higher kVp. During the first 100 ms of the exposure the cathode is fully heated, the tube current increases and the kVp drops and reaches its nominal value.

The longer the exposure time is the less influence the first pulses have on the measured kVp. When using shorter times, especially 50 ms, the kVp is higher than the nominal kVp. Also when using 100 ms set time, the major part of the pulses will have a higher kV and the measured kVp will be higher than the nominal kV. The actual measured value will depend on the delay time used.

For the 50 ms exposure with delay of 0 ms, the Piranha/Barracuda will measure the three first pulses. The shown tube voltage, 80.7 kV, is the average of the first three pulses. The nominal kVp can never be measured when the exposure time is 50 ms since the kV never reaches its stable (nominal) value. This will be true for a 100 ms exposure time even when using a delay of 50 ms. The measured kV will be closer to the (nominal) value however it is clear by the waveform that the measured kV will be higher than the (nominal) kV value. When using a Piranha/Barracuda it is recommended that exposure times of 150 ms or longer and using a delay of at least 100 ms should be used to ensure that kVp is measured on the stable part of the waveform in order to measure and produce an accurate kV value.