X-ray sources

Abstract

The reliability and its importance for x-ray sources is presented and analyzed where emphasis is given to the failure analysis for different ways of operating. X-ray sources availability and their component failure are presented and discussed.

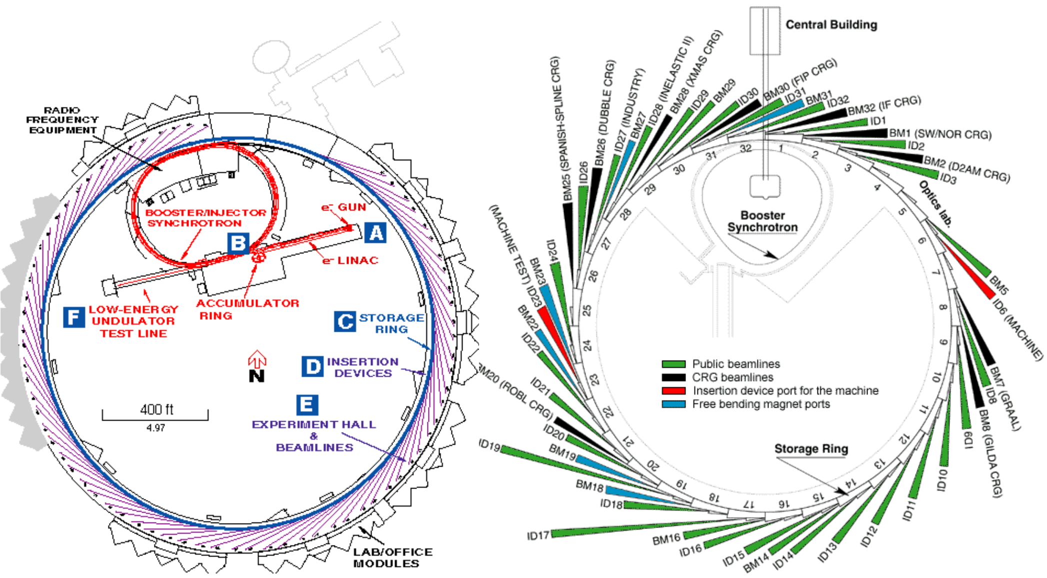
1. Introduction

Reliability is a very important aspect of any enterprise such as financial, scientific, commercial or other because it is strongly connected to trust.

Accelerators being a good combination of science, finance and commerce must be reliable too, meaning:

"The machine should function as much and as good as possible" i.e. reliability is strongly related to quality.

X-ray sources



are multi user storage rings that produce synchrotron radiation. There reliability has an increased importance exactly due to their nature i.e. many users work in parallel and plan their experiments long in advance (usually over one year). The demand for beam time is still unsaturated and new x-ray sources are emerging (e.g. Soleil , Diamond).

In these establishments work typically 600 - 6000 users per year for about 5000 hours of machine time for user operation.

Obviously a machine that breaks often or works badly will loose its users and radiation problems might arise that might lead to license retrieval

2. Reliability aspects

In general reliability depends upon:

- Budget (personnel, redundancy of equipment, (preventive) maintenance)
- Operations (operators, experts/on call, troubleshooting, modes of operation)
- Management (personnel, equipments, statistics)
- Planning (new installations, coordinating shut down work, careful control before start up)

and is measured with the (usable=beam with agreed quality) up-time (and the mean time between failures).

In the next, 3 x-ray sources (APS 7GeV, ELETTRA 2-2.4GeV, ESRF 6 GeV) will be considered for the only reason that they seem different since use 3 different modes of operating. Thus APS has full energy booster and top-up, ESRF full energy booster and ELETTRA injects from a linac at 1 GeV while the machine operates for the users at 2 or 2.4 GeV (22% of user time).

2.1 Uptime statistics

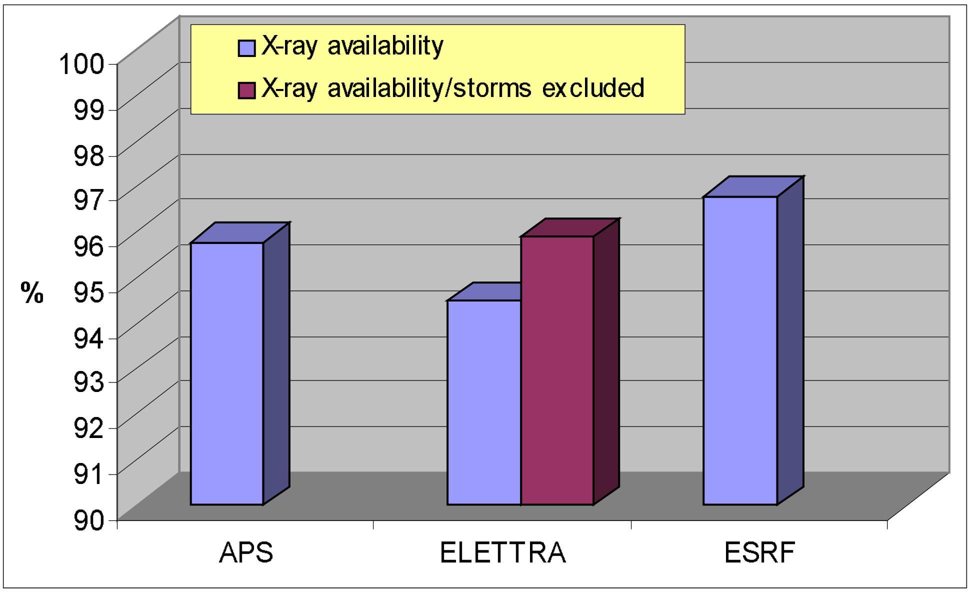


Figure 1: X-ray sources availability for 2001

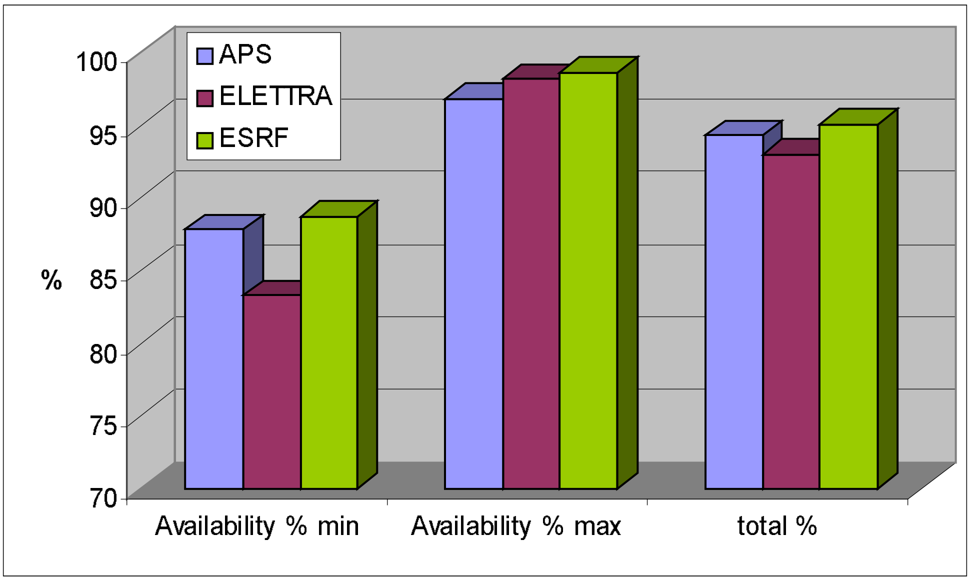


Figure 2: Maximum, minimum and average availability since 1995 (APS since 1997)

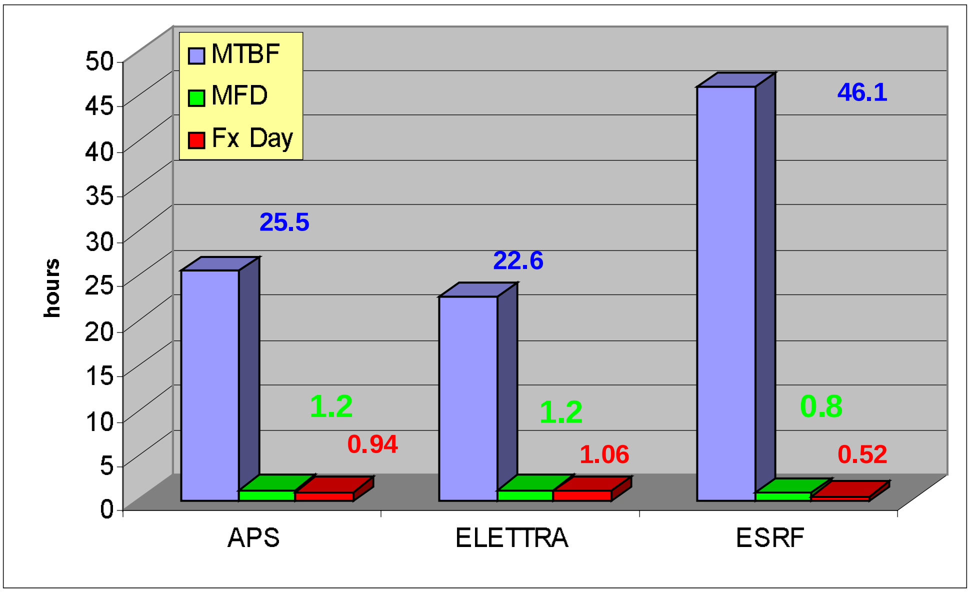


Figure 3: X-ray sources Mean Time Between Faults (MTBF) , Mean Fault Duration (MFD) and Faults per Day (FxD) for 2001

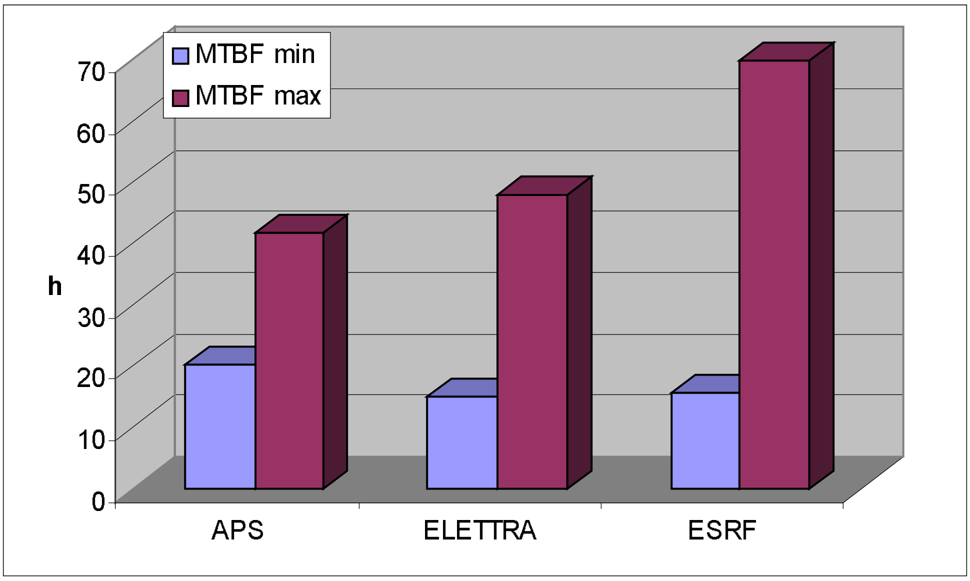


Figure 4: Maximum and minimum Mean Time between Faults since 1995 (APS 1997)

Considering the above statistics one immediately observes that all considered machines had a high reliability >95% in 2001. ELETTRA seems to be at 94.5% but excluding electricity micro-interruptions (due to storms or electrical network instabilities) the uptime is 95.9%. However extending the statistics over many years one sees that availability was not always above 95%. There were runs with uptime below 90% but in any case always above 80% and in general the average lays somewhere between 90-95%.

Another useful figure of merit is the mean fault duration and faults per day (mean time between faults). For 2001 APS and ELETTRA seems to lay close however ESRF seems to be a factor of two better. Seen all statistics since 1995 (APS 1997) whereas the minimum mean time between faults is in the order of 15-20 hours the maximum is still by 30% higher for ESRF.

From the presented analysis one sees that the examined x-ray sources (and in general any) (should) have a reliability higher than 90%. The examined machines with the passage of time tend to go above 95% which is practically a non stop mode. At the same time the faulty 5% should be smoothly distributed through the year (otherwise might happen that certain group of users do not work at all since 5% of 5000 is about 10 days) the figure of merit being MFD.

Many factors are involved that help in keeping the reliability as high as possible one of which is the statistics of the machine components that have failed. Let us see if some general trends exist.

2.2 Equipment failures

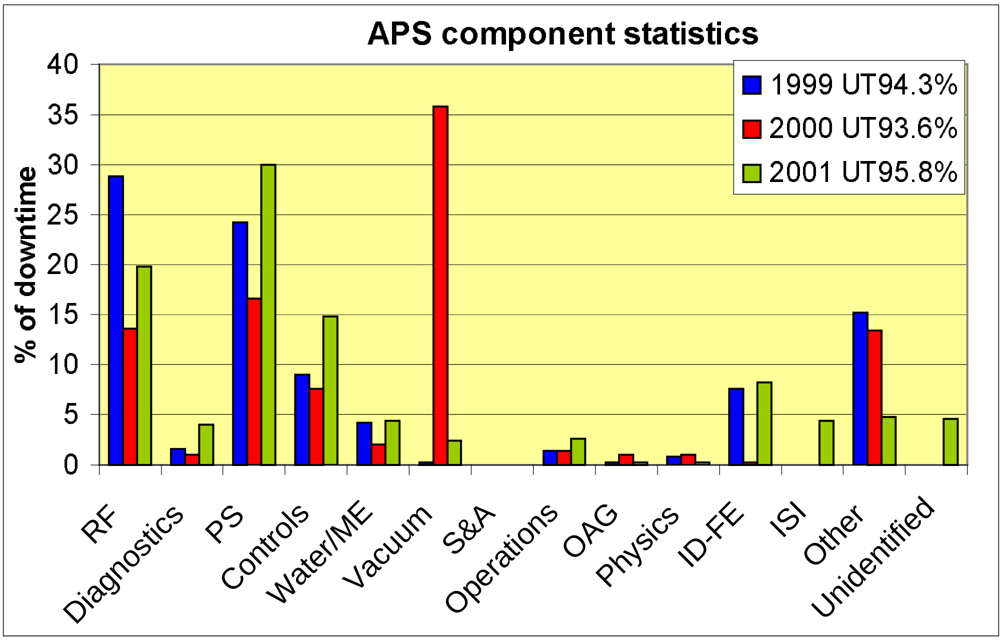


Figure 5: Three years of component failure analysis for APS

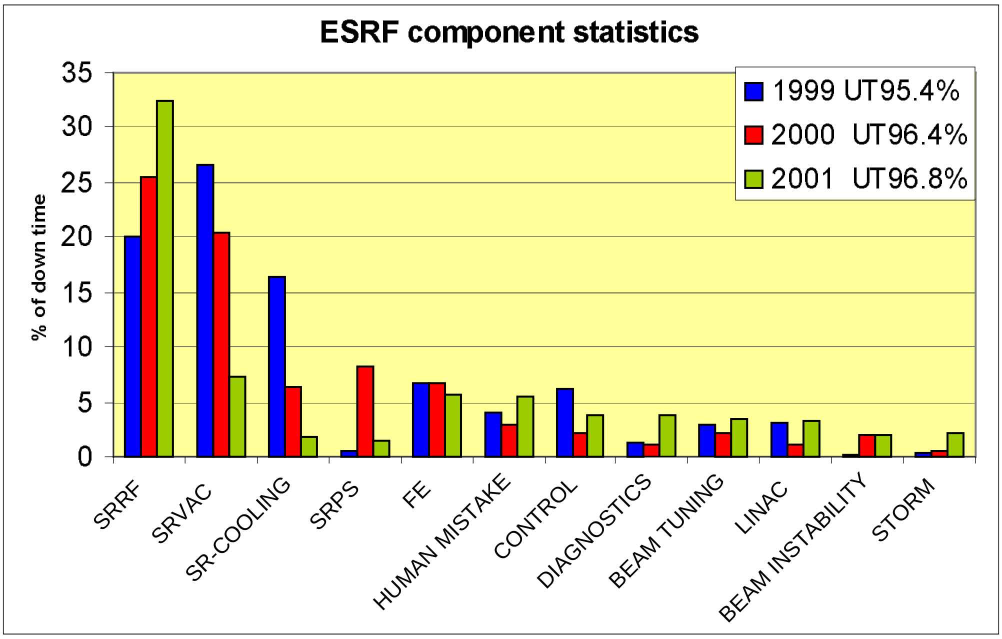


Figure 6: Three years of component failure analysis for ESRF

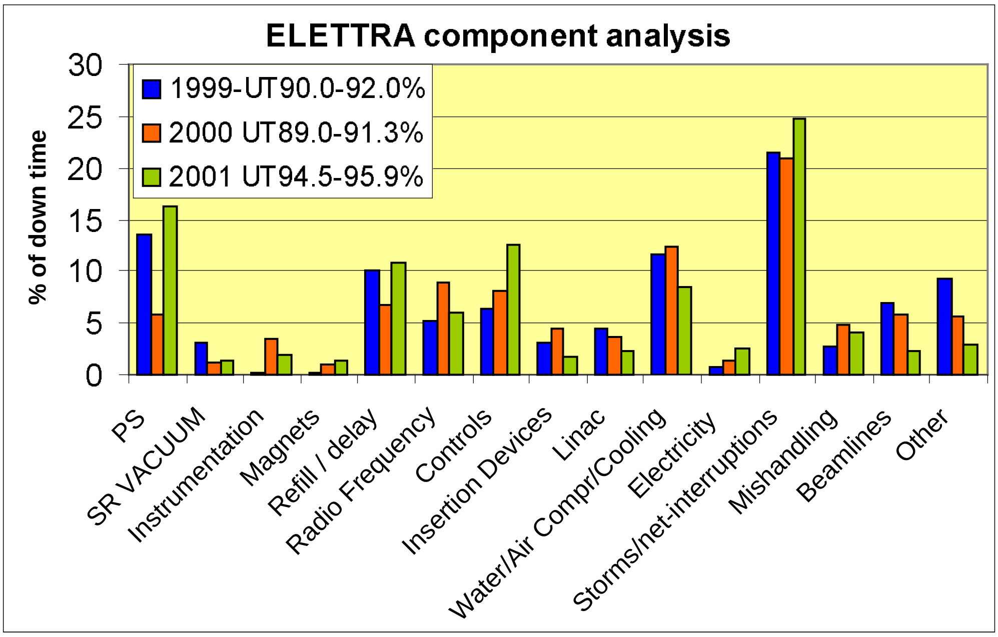


Figure 7: Three years of component failure analysis for ELETTRA

A concise view is summarized in the next table (% shown are the max. values):

	PS	**RF**	**CONTRS**	**VAC**	**Cooling**	**other**	**BL**	**refill**
APS	>15%	>15%	>10%	>35%	<5%	>10%	>5%	
ELETTRA	>15%	>5%	>10%	<5%	>10%	> 5%	>5%	>10%
ESRF	> 5%	>20%	> 5%	>25%	>15%	<5%	>5%	

Amongst the many different reasons that a subsystem can fail it can be seen that there is one related to the energy of the x-ray source and another to the operating mode. Thus ESRF and APS both high energy storage rings suffer from failures of the rf system, whereas from failures of the power supplies suffer APS (top-up mode) and ELETTRA (ramping to the final energy). This mode of operating is prone to faults during refills since the main ring power supplies and all other systems are stressed. In fact over 50% of failures happen during this period. The high energy machines have suffered at least once from major vacuum failures, which is not the case for ELETTRA. The control system failures appear independent being almost the same for all machines. Human error can contribute also in a non-direct manner. For both ELETTRA and ESRF the evident mishandling is around the 5% relatively low no statistics exist for the indirect mishandling. “Other” is something to be eliminated, ELETTRA works towards this direction and no unspecified fault is tolerated. Finally all machines suffer from the users, the percentage is low >5% for all tree machine and peaks when new lines are installed.

Storms contribute to about 2% of the downtime. ELETTRA suffers from storms and network micro-interruptions with MDT of less than 2 hours. However although one could discuss whether it is worth spending some million to get continuity generators for just a 2% , many (including management) ignore that these interruptions can provoke major equipment failures.

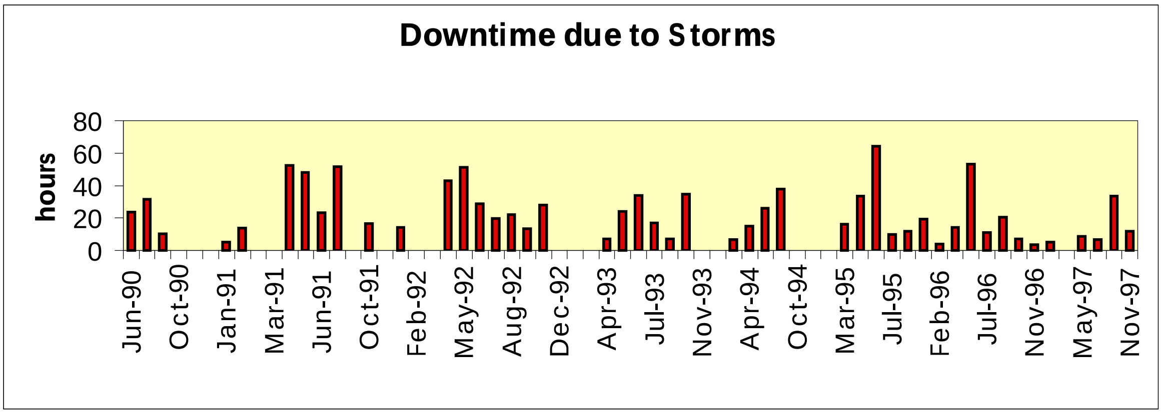


Figure 8: Downtime due to Storm occurrence at ELETTRA

3. Some reliability considerations

Many factors are getting involved in keeping the reliability as high as possible, for some factors there can be a substantial improvement with time for other less.

First thing to be done is to carefully evaluate the wished reliability level. The reliability cut-off to our experience for a x-ray sources is about 92% , below this the users start getting uneasy. As we have seen it is also important the way the downtime is distributed. Very short and frequent or very long MFD are not well accepted. A difference of 3% in reliability might mean a 30% difference in budget. When at ELETTRA the on-call service stopped, the machine uptime got reduced by this amount. Still the machine suffers from unnecessary delays although there is a (still) small team of operators that can fix many faults, those that statistically were the most frequent.

Another important aspect is the way one operates. Machines that do not do exotic things are prone to work better. Top-up mode seems to be more prone to faults although with the passage of time the operations learned the weak points and take the right measures. Ramping the ring itself does not help either however also at ELETTRA we have learned to fix via preventive maintenance the weak points.

Few bunch operation mode in high energy machines can also create problems, as ESRF can confirm, extracts for L. Hardy notebook, March 99:

"The by far most important event of the week occurred on Wednesday morning at 07:10. At that time the pressure rose in ID11 followed by a lifetime reduction and a beam kill. Attempts to store beam again were in vain. Careful diagnostic lead to the conclusion that there was an RF finger break down at the entrance of the ID11 straight section. It was decided to carry out a vacuum intervention at noon. Indeed an RF finger was bent downwards from the upper part into the beam and was melted at its end. The origin of this breakdown lies in the fact that the in-vacuum undulator of ID11 was installed in the winter shutdown about 15 mm too far downstream. To recuperate the missing length the bellows of the upstream vessels were stretched. As a consequence the corresponding RF fingers were drawn too far and lost their contact with the sleeve. The 16 bunch delivery lead to a heating up and final bending of the RF finger. Given the large pumping speed available on that zone it was possible to go back to operation in 16 bunch at midnight of the same day. This means that only two shifts were lost due to this vacuum intervention."

This led to 18 hours interruption due to 1 broken RF finger. The total number of hour lost for all equipment was 180 hours (meaning that this only incident represented 10 % of the time lost). And, there were 5488 hours of scheduled beam for Users (meaning that this incident alone, decreased the availability by 0.33 % in that year! There was another RF finger event, in Nov. 1997: 50 hours stop due to 1 broken RF finger. The total number of hour lost for all equipment was 252 hours (meaning that this only incident represented 20 % of the time lost). And, there were 5170 hours of scheduled beam for Users (meaning that this incident alone, decreased the availability by 1 % in 1997 !
Thus they have learned how not to burn rf-fingers.

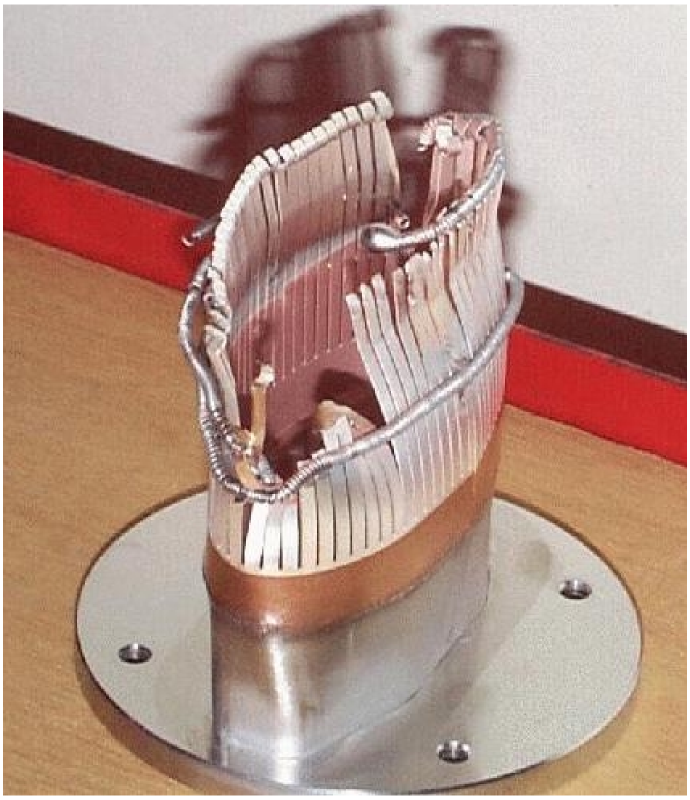


Figure 9: An ESRF burned rf finger (courtesy L. Hardy)

All machines are in evolution and during major evolution steps uptime suffers because not all aspects are known and usually not well analyzed. The ESRF finger case enters into this aspect as well although in a lower energy machine this kind of mishandling would have been probably less critical.

Problems can also arise when decisions on installations and innovations are taken ignoring users and operations. Starting in late 1998 and fully during 1999 and 2000, 4 low gap aluminum vacuum chambers and the corresponding light exits were installed at ELETTRA. The experience with stainless steel was excellent but for many reasons it has been decided to use extruded aluminum. To meet deadlines the machine was opened each shut down either for a major installation or for adding other pieces thus venting the aluminum chambers. Aluminum needs a long time to condition (also after venting) (100 Ah or about 30-40 beam days) and conditioning has been decided to take place during machine physics and in extend during user shifts. The result was that the ELETTRA up time for 2 years was suffering a further 3-4% reduction due to this decision (let alone the machine physics output), the levels of radiation were higher and new shielding was necessary while the users were very unhappy. Finally the message was received by the management and all installations stopped, the machine returned to its usual reliability (in 1998 was 94%) and this year, the installation of a new low gap aluminum Neg coated vacuum chamber was meticulously prepared. The conditioning with the synchrotron radiation finished within 10 Ah i.e. 3 days allowing anyway the use of the machine for machine physics experiments because already from the beginning we had lifetimes of the order of hours where before we had minutes.

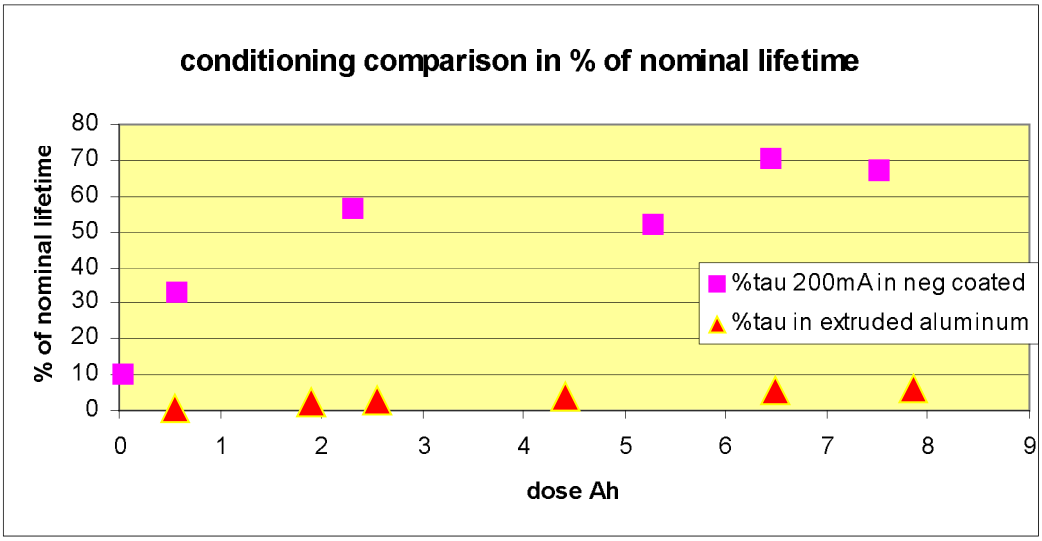


Figure 10: Lifetime percent to nominal for a extruded and one neg coated aluminum low gap chamber

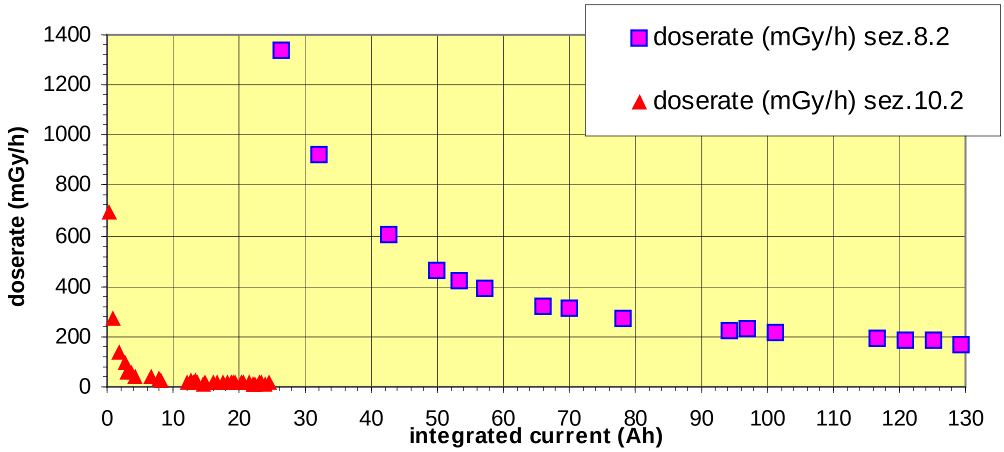


Figure 11: Dose rates for an extruded (sez. 8.2) and a neg coated (sez. 10.2) aluminum low gap chamber

4. Conclusions

X-ray sources should (and have) high reliability levels i.e. above 92% Three examined sources for 2001 had more than 95% which is the aim of any operations group. One should not overlook the MFD also an important parameter to keep users happy. Seems that power supplies, radio frequency systems and controls are the major constant contributors of downtime followed by vacuum, cooling and beam lines depending on various factors such as the operating mode and the energy. Downtime due to cooling is decreasing for both ELETTRA and ESRF due to a large preventive maintenance program. The mode "run it until it breaks" does not help the reliability. Storms is a 2% downtime contributor one should evaluate (i.e. budget vs. uptime) to see if spending millions justifies the cost.

Reliability heavily depends on budget but not only. Actions that appear of administrative nature like seriously programming any activity, regular operations meetings, good statistical analysis not allowing for unspecified events, experienced and good operators team, good personnel management can help to maybe gain a 2-3% in up-time.

Maintenance and especially the preventive one is very important too(but enters into the budget question).

At these high levels of reliability seemingly not relevant actions can reduce it, thus one should be very careful when taking a decision to install something (equipment or mode). Evolution at the beginning works against reliability, experts and users should learn to accept this.

Acknowledgments

Pleased to thank L. Hardy for numerous suggestions and material on ESFR statistics.