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HOW ROBUST ARE EXISTING MEDICAL LINACS IN CHALLENGING ENVIRONMENTS? A STUDY OF DOWN TIME AND FAILURE CAUSES

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Abstract

There is a severe lack of radiotherapy linear accelerators (LINACs) in Low- and Middle-Income countries (LMICs), limiting capacity for cancer care in these regions. Anecdotally, operating high tech accelerators in environments with power fluctuations, harsh climatic conditions and geographic isolation leads to large failure rates and downtime. To guide future developments, this study presents a data-driven approach to collect statistical data on LINAC downtime and failure modes, comparing to a simple availability model.

INTRODUCTION

There is a current lack of around 5000 radiotherapy LINACs in Low and Middle-Income (LMIC) countries, a shortfall which is due to rise to 12,400 by 2035. The incidence of cancer is rapidly increasing in these areas, and far from closing the gap by building new centres, the problem is in fact increasing [1]. A number of reports have highlighted that the LINACs themselves “do not function well in the adverse conditions encountered in LMICs” [2] because of ”regular interruptions to energy supply, lack of air temperature control in buildings, and weak health systems” [3].

An initial study conducted in 2018 gathered the first statistical data of the downtime and failure modes of medical LINACs in Nigeria and Botswana, and compared this to the downtime and failure modes in a High Income Country, namely the UK [4]. Reliability issues are experienced for a variety of reasons (including the lack of appropriately skilled staff, environmental stresses and intermittent power supplies). This work was carried out in the context of a new collaborative research program initiated through a number of workshops co-ordinated by CERN, STFC and ICEC. Subsequent studies of accelerator technology needs an underpinning dataset to inform future interventions.

The initial failure rate study had limited statistics, collecting data from just two LMICs (Botswana and Nigeria) and one HIC (United Kingdom). A major barrier to data collection is the time-consuming nature of analysing digital or print log-books, due to the lack of automated recording and categorisation of fault data. This issue should be addressed in future, with an extended study and potentially in collaboration with vendors.

Some of the issues faced regarding LINAC downtime in LMICS may be addressed by: improving the robustness of design for certain LINAC subsystems such as vacuum and control system electronics, improving system tolerance to power failure, improving maintainability to reduce the skill requirements on maintenance staff and thereby reduce downtime as well as the risk of making errors during complex processes and providing a readily accessible supply of spare parts.

To elucidate the impact of different aspects of the challenge, a simple model has been developed to compare potential future interventions. The tool is based on a reliability analysis for a generic (i.e. non vendor-specific) LINAC. A simple high level reliability model should provide an objective tool to determine the benefits that may be expected from simple changes to design or spares holdings. For instance, we can ask the question of whether the machine downtime is dominated by time to failure, lack of spare parts, time to repair, or other factors. Will a ready availability of spare parts allow the machines to have availability equal to the HIC equivalent, or is it better to incorporate ’hot spares’ at additional cost, so that the machine can continue running even in the case of a subsystem failure?

Any reliability analysis is only as good as the input data, so this model is kept simple in nature to reflect the nature of the Mean Time Between Failure data which has been ascertained from data collected in an earlier study [4], but can be updated in the availability tool as more information is obtained.

AVAILABILITY MODEL

A simple availability modelling tool has been developed to guide future design developments. The most important input into any such tool is the Mean Time Between Failure (MTBF) data, which has been estimated from the earlier study. Additional data input from this study includes the percentage of repairs requiring spare parts and the typical re-stocking time of spare parts, which is usually 1-2 days for most parts in Europe.

Since it is not useful to build a model which is more sophisticated than the input data, a number of limitations exist in the current model, the primary one being that no dependencies are assumed between subsystems.

This simple availability tool extends our previous work in analysing LINAC downtime [4] and availability and takes a subsystem view of the whole machine. The current tool has broken down the machine into 18 systems, as shown in Fig. 1.

Based on knowledge of the system, three subsystems are further broken down closer to component level, these are the RF Power Control (split into Thyratron, Cabling, Modulator and Other), Electron Gun (split into Gun, the high voltage

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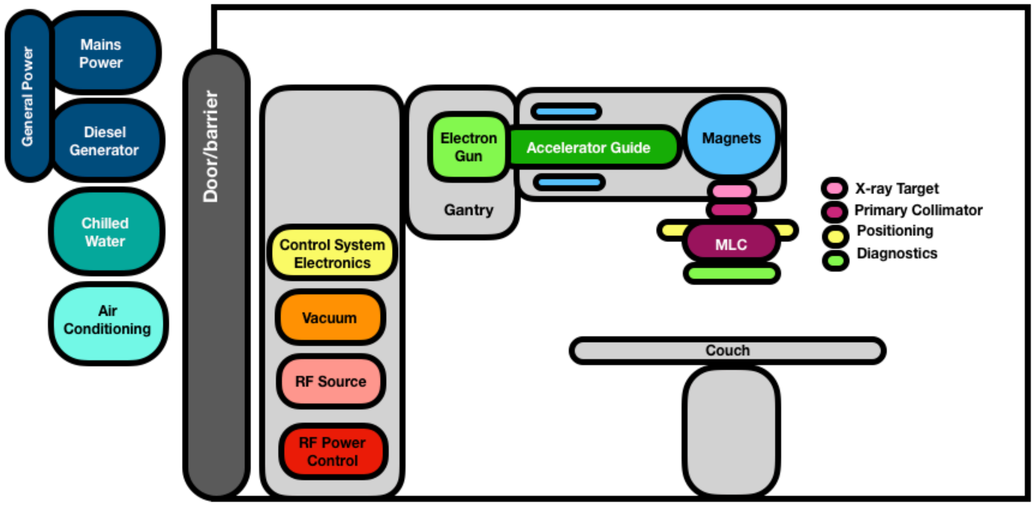

Figure 1: Generic layout of LINAC and its subsystems for the purposes of availability analysis and modelling.

electron gun control, low voltage electron gun control and other) and X-Ray Target (split into Target and Other which includes any movable actuators).

The tool takes into account the number of each subsystem installed, required for functioning, the number normally running (allowing for 'hot spares'), the failure to start probability, the Mean Time Between Failure (MTBF) and the mean downtime if it fails excluding time waiting for spare parts.

Results

Based on the MTBF data previously obtained, the subsystem availability can be analysed for its contribution to the overall machine availability. Usually in such an analysis, one would find that individual subsystems dominate the downtime, however this isn't so clearly shown in this case as shown in Fig. 2. The primary reason is the immense amount of effort expended by both vendors and on-site engineers in retaining optimum availability, which is 99.34% in the HIC dataset analysed (downtime of 0.66%).

To make a prediction of the availability in LMICs, we learn from the previous study and adjust the following parameters. Case (1) all parts take 5 times longer to arrive, Case (2) all repairs take twice as long, Case (3) a number of subsystems fail roughly twice as often (a conservative assumption), which here includes the air conditioning, cooling, generator, control system electronics, vacuum (MTBF=2000 hrs) RF power control, couch and door (MTBF=3000 hrs), and MLC (MTBF=1000 hrs) subsystems, where MTBF data is estimated from our previous work. As there is no data on vacuum downtime in HIC data, we assume the downtime from this failure is 20 running hours (in fact, it could be much longer in reality). Finally, Case (4) includes all of these factors simultaneously. The contribution of each factor to availability is shown in Table 1. In Case (3) and (4), the availability drops more dramatically and is dominated by failures in the air-conditioning and vacuum subsystems, as shown in Fig. 3 which correlates with the preliminary results of the the previous study and demonstrates the use of this simple modelling tool in this context.

Table 1: Impact of Factors in LMICs on LINAC Availability

Factor	Availability	Unavailability
Baseline from HIC data	99.34%	0.66%
Case 1	99.21%	0.71%
Case 2	98.69%	1.31%
Case 3	96.56%	3.44%
Case 4	93.72%	6.28%

CONCLUSION

The results shown here illustrate that a concerted effort must be undertaken to improve all aspects affecting availability of radiotherapy LINACs in LMICs. Purely focusing on spare part provision and training of engineers will not equalise the situation between different environments (Case 3), and improving availability requires a technology intervention alongside a multi-disciplinary systems approach. The primary focus highlighted in these results is that individual subsystems need to be more robust to failure, and that the decreased MTBF esimated from previous work dominates the overall availability of the LINAC, particularly for the air conditioning, vacuum, MLC, door/barrier, chilled water and RF power control systems.

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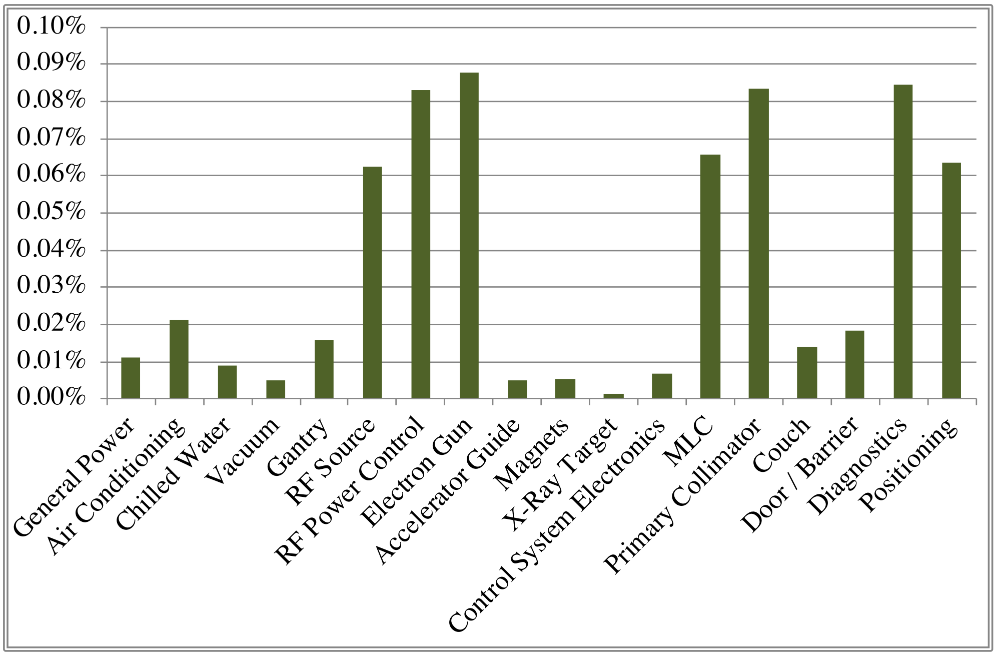

Figure 2: LINAC subsystem contribution to unavailability for HIC data. Overall availability is 99.34%.

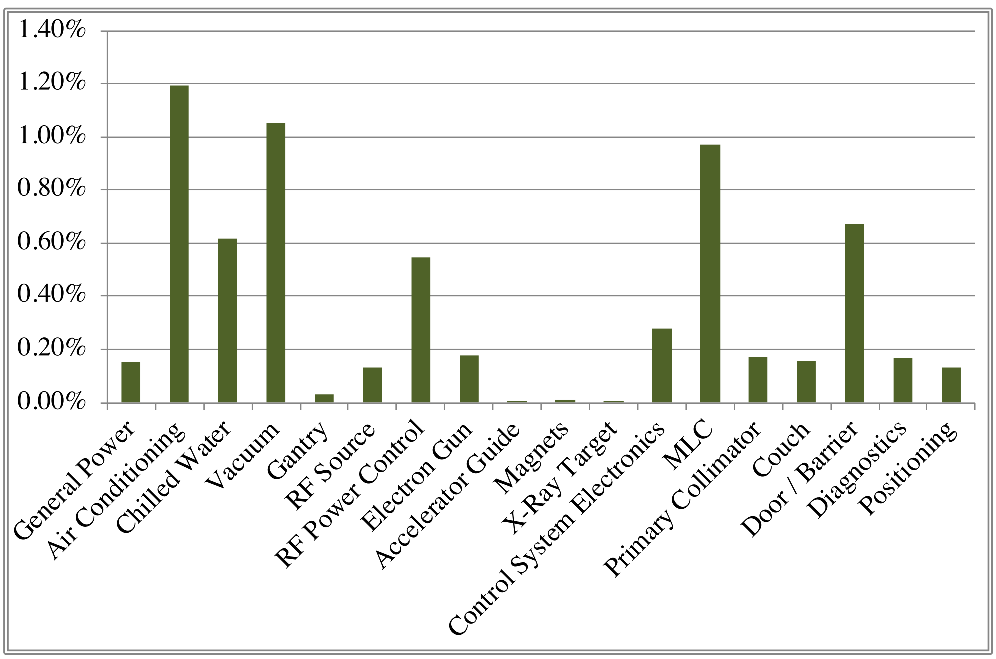

Figure 3: LINAC subsystem contribution to unavailability for assumptions around LMIC data assuming Case 4 (described in text). Note the vertical scale is much larger than the previous figure.

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