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FROM DICOM TOGRID: A DOSIMETRIC SYSTEM FOR BRACHYTHERAPY BORN FROM HEP

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Abstract

In brachytherapy software defines the experimental configuration of radioactive seeds appropriate to achieve the desired dose distribution in the patient.We will show you how nowadays it is possible to develop a software for brachytherapy which achieves the goal of high accuracyand speed thanks to the combination of various software toolkits: Geant4 simulation toolkit, AIDA analysis toolkit, GRID and the web. Geant4-based brachytherapy application calculates dose distribution in tissues with great accuracy, in a realistic experimental set-up derivedfrom CT data. The AIDAanalysis toolkit provides the elaboration of simulation results. It is possible to run Geant4-based brachytherapy application through a web portal, sharing distributed computing resources thanks to the integration in the GRID, making possible even to modest size hospitals to profit of advanced treatment planning tools.

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1 Introduction

Brachytherapy is a widely used radiotherapic treatment; radioactive sources are employed to deposit therapeutic doses in treatment target, while preserving surrounding healthy tissues. One can distinguish three brachytherapy techniques: endocavitary (addressed to lungs, vagina and uterus treatment), interstitial (for prostate carcinoma) and superficial (for skin tumors). In clinical practice commercial software is used to define the patient's treatment planning: it calculates how to set radioactive sources in the treatment target in order to destroy tumor while preserving surrounding healthy tissues. Because of speed constraints, commercial software systems (i.e. *Variseed V 7*) calculate dosimetric quantities by applying approximated analytical methods and approximating patient's anatomy to water. The requirement of speed is a fundamental issue in clinical practice: medical physicists and physicians often should take quick decisions about therapeutic treatments. Commercial software does not exist for superficial brachytherapy. Each commercial software is addressed to a specific brachytherapic technique. Monte Carlo simulation is not used in clinical practice because it does not meet the speed constraint. A dosimetric system for brachytherapy has been developed using Geant4 Simulation Toolkit. The work presented in the following sections illustrates how this system achieves the goal of dosimetric precision and quick response.

2 Geant4 Brachytherapy application

The Geant4 dosimetric system developed following the *Unified Software Development Process* [1]: the adoption of a rigorous software process is essential for the reliability of a product addressed to radiotherapic treatments. The software process follows an iterative incremental model. The requirements of the system have been collected and analysed taking into account the functionality required for dosimetric evaluation as well as non functional requirement as speed constraint.

2.1 Requirements

In this session it is defined which functionality the brachytherapy application must satisfy. The application must calculate the energy deposit in the patient's treatment target due to the exposition of radioactive sources. It must be interfaceable with Computerised Tomography (CT) in order to model the patient's anatomy. Besides it must be addressed to all the brachytherapic techniques and it must offer a friendly user interface to allow any user and not just software specialists to use the application. The dosimetric system must produce quick results in order to be useable in clinical practice. It must be flexible in order to extend easily its functionality and open source: in this way everybody can access it and use it. In the following sessions the tools adopted to achieve the application purposes are introduced.

2.2 Tools

Geant4 [2] has been chosen as simulation tool because it offers both accurate physics and geometry description. Geant4 adopts an Object Oriented (OO) technology: as a consequence this simulation toolkit is characterised by both openness to extensions and flexibility. In particular, thanks to OO, a wide set of complementary or alternative electromagnetic and hadronic physics models is provided in order to allow the user to choose more appropriate models for his own application. The Geant4 *Low Energy Package* is more suitable for medical physics applications because it offers more accurate physics models at low energies (down to 250. eV). Geant4 provides flexibility to manage very complex geometrical structures and accurate descriptions of materials of bio-physics interest. Thanks to the presented features, Geant4 is a powerful Simulation Toolkit for brachytherapy applications because it unifies accuracy of physics models and detailed description of geometry. AIDA[3] has been chosen as analysis tool in order to produce histograms and ntuples containing simulation results. AIDA provides a set of abstract interfaces compliant with different analysis environments as Anaphe [4], JAS [5] and OpenScientist [6].

2.3 Validation

The Geant4 brachytherapy application has been validated in terms of adopted physics models (microscopic validation) and in terms of experimental setup (macroscopic validation). In the microscopic validation tests of electrons and photons models have been performed in order to guarantee the reliability of physics processes adopted in the brachytherapy dosimetric system. In figure 1 and 2 some results are shown: more tests are available at www.ge.infn.it/geant4/analysis/TandA/index. The results of tests have been compared with medical physics reference data[7]. The macroscopic validation consists in calculating the dose distribution along the perpendicular axis to the major axis of the radioactive source. The results have been compared with protocol data [8] and with experimental dosimetric measurements performed at the National Institute for Cancer Research (IST, Genova)[9] and at San Paolo Hospital in Savona [10] with ionisation chambers and films. In figure 3 results are shown for a 192^Ir source used in endocavitary brachytherapy [9]. The test has been performed also for Bebig Isoseed I-125 addressed to interstitial brachytherapy.

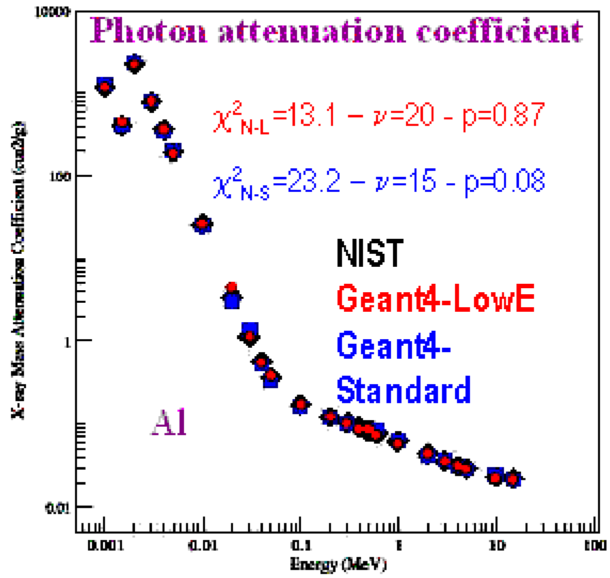

Figure 1: Results about Geant4 photon physics models validation

2.4 Geant4 brachytherapy application implementation

The brachytherapy dosimetric system calculates the energy deposit of brachytherapic sources in a phantom. Thanks to the introduction of the design pattern *Abstract Factories*, shown in figure 4, it is possible to implement any brachytherapic source (present in trademark or new) without affecting the software code. The application of the design pattern *Abstract Factory* has been based on the fact that radioactive sources differ just in terms of geometrical structures, composition, energy spectra of the gamma delivered by the radioactive core, while the physics models adopted describe the particle interactions accuratly for all the brachytherapic devices. The scope of the application -calculation of energy deposit in the patient's treatment area- is the same for all brachytherapic sources. The radioactive sources are defined in terms of geometry (materials and volumes involved) and of energy spectrum of photons delivered by the radioactive core; in figure 5 the structure of Bebig-Isoseed I-125 is shown. Geant4 Low Energy Physics Package has been adopted in order to model all physics processes involving photons, electrons, positrons. The energy deposit is collected in a phantom gridded in voxels 1.0 millimeter wide. The user can choose to calculate dose distributions in a phantom filled up with absorber material for specific dosimetric studies or in a patient's anatomy modeled through a Geant4 DICOM Interface. The application is provided of a user-friendly interface to allow its simple use. The user can choose interactively the radioactive source to simulate,

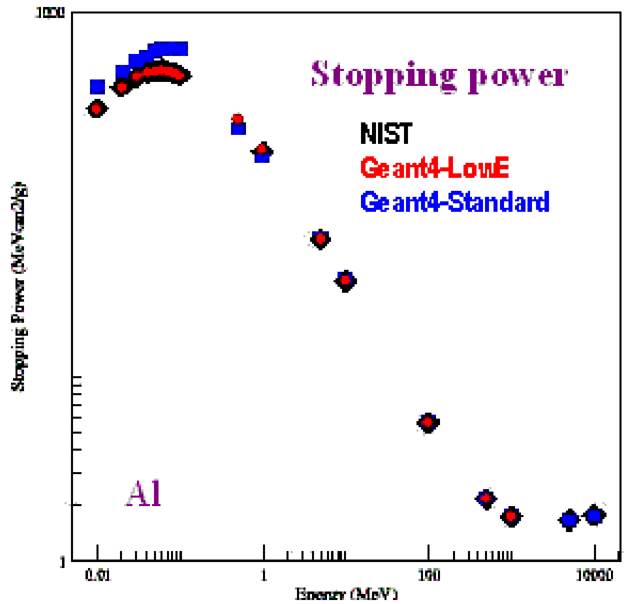

Figure 2: Results about Geant4 electron physics models validation

the absorber material of the phantom, the number of photons delivered by the radioactive core. The user can decide to visualise the experimental set-up and particle tracks with alternative visualisation packages. The energy deposit in the phantom is stored in a ntuple containing spatial coordinates of a voxel and related energy deposit. The user can elaborate the results and visualise graphically dose distributions and isodose curves.

2.5 Results

Dose distributions have been calculated for all the
brachytherapic sources available in the application; in figure 6 an example of experimental configuration is illustrated; figure 7 and 8 show the related results of the simulation in terms of dose distributions and isodose curves. The results can be generalised to more sources.

2.6 Integration in a distributed computing environment

The time required for running the brachytherapy application in sequential mode is not pratically conceivable for clinical applications: the software response should be produced in maximum few minutes, because treatment planning could be defined before or during the patient radiotherapic treatment. Table 1 shows the performance of an *average* PIII machine, as an *average* hospital may own. The solution is given by running the system

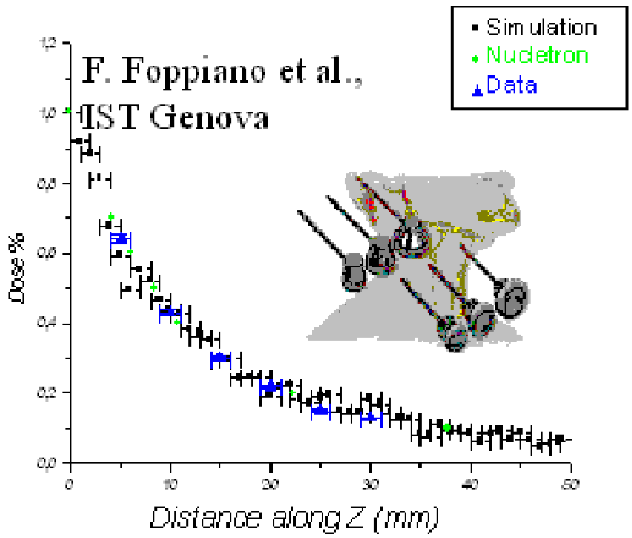

Figure 3: Results about experimental set-up validation

Table 1: CPU time for all brachytherapic devices running in sequential mode

device	number of gamma	execution time
endocavitary brachytherapy	1M events	61 minutes
superficial brachytherapy	1M events	65 minutes
interstitial brachytherapy	1M events	67 minutes

in parallel mode. The results (shown in table 2) were obtained running the brachytherapy dosimetric system on a dedicated cluster of 50 machines (PIII machines, 500-1000 MHz). The performance improved drastically in respect to parallel running mode but no *average* hospital usually owns 50 machines to dedicate to treatment planning. The idea to access to distributed resources was born from the evidence of real computing resources owned by singular hospitals: the brachytherapy dosimetric system, or more in general, a Monte Carlo simulation addressed to medical physics, could be used in clinical practice if hospitals , institutes , etc., put in common their own CPU resources and run their own particular application on shared distributed computing resources; this goal has been achieved running the brachytherapy dosimetric system on the GRID [11]. Running in sequential or parallel mode or using distributed computering resources is completly transparent to the user thanks to the introduction of the intermediate layer DIANE [12]: thanks to this tool the software is not affected by running mode choice. Figure 9 shows a job running in

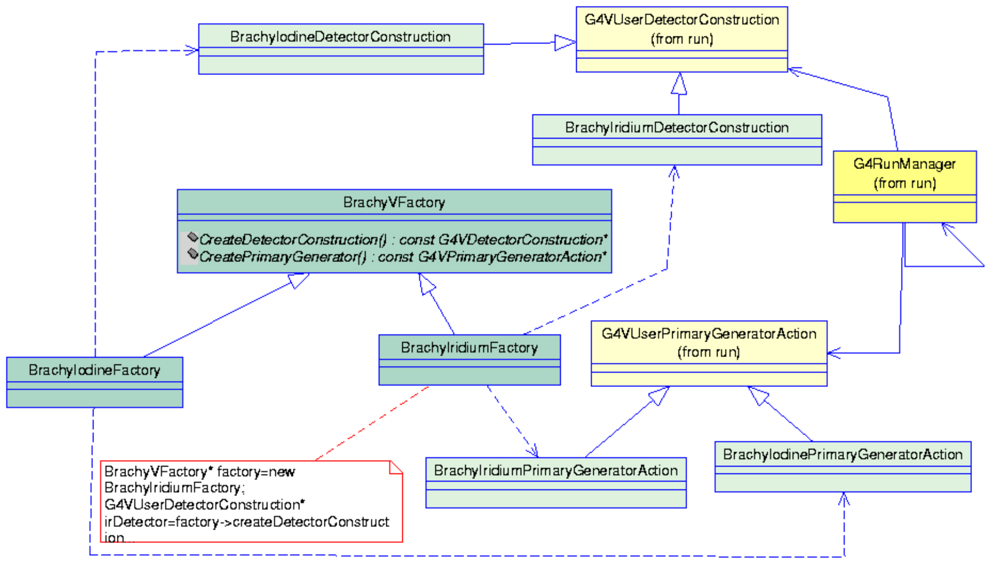

Figure 4: Design pattern *Abstract Factory*

Table 2: CPU time for all brachytherapic devices running in parallel mode (preliminary results)

device	number of gamma	execution time
endocavitary brachytherapy	1M events	4 minutes, 34 seconds
superficial brachytherapy	1M events	4 minutes, 25 seconds
interstitial brachytherapy	1M events	4 minutes, 36 seconds

parallel mode on computers located in institutes of different countries. The results shown are preliminary.

2.7 Web Interface

It is possible to run the dosimetric system through a web interface and to retrieve a two-dimensional histogram with the dose distribution in the plane containing the source. The user must define interactively the configuration of the application in term of type of the source, phantom absorber material, number of gamma delivered by the radioactive core. At that point the user has got to submit the job. The result of the simulation will appear on the screen. The user can run the application in different modes: he can choose to run the demo version, or to run it in parallel on a cluster (under test), or on the GRID (under development).

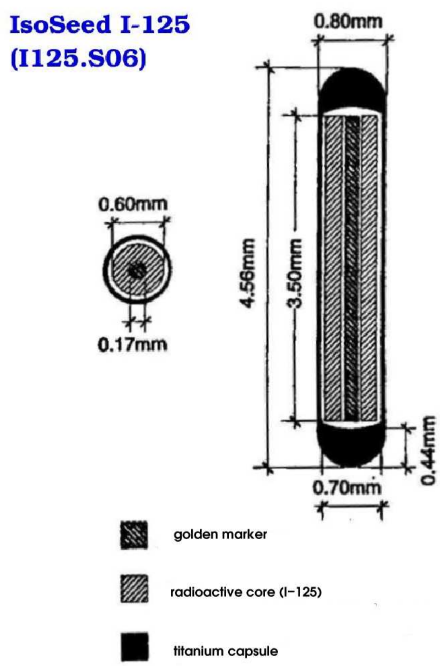

Figure 5: Bebig Isoseed I-125 structure

3 Conclusions

This work shows how nowadays it is possible to develop a general purpose dosimetric system addressed to all brachytherapy techniques, achieving both the goals of calculation accuracy and quick response. Monte Carlo is not used in clinical practice for speed contraints. Now it is realistic to think that a hospital is not required to own and mantain extensive computering resources to exploit the scientific advantages of Monte Carlo simulation for radiotherapy thanks to the access to distributed computing resources.

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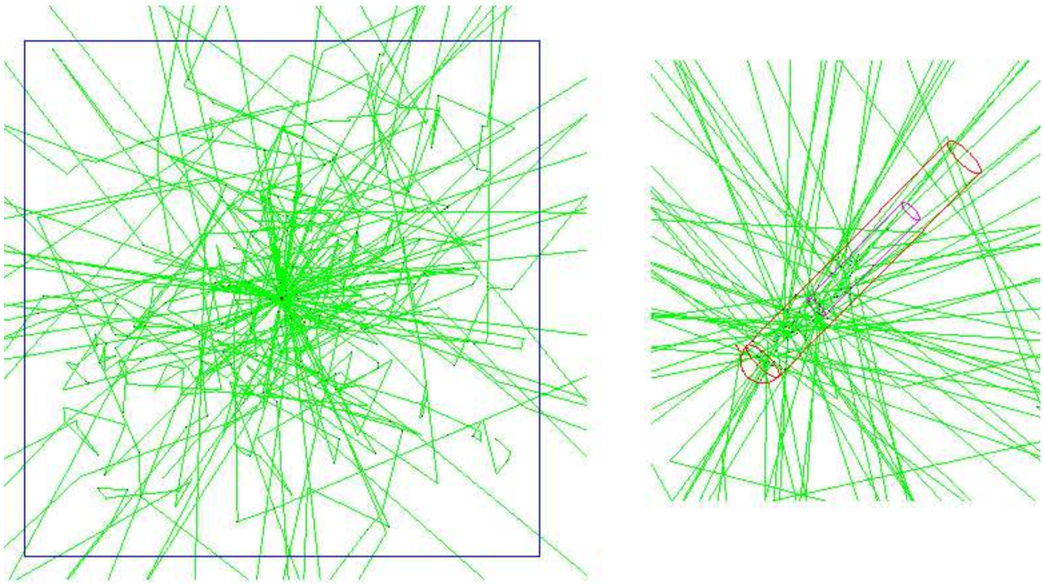

Figure 6: Visualisation of the experimental set-up: the source is set in the center of a phantom filled with soft tissue; the gamma (green tracks) are delivered from the radionuclide.

References

[1] G. Booch, *et al.*, The Unified Modeling Language User Guide, (Ed. Addison Welsey)

[2] http://geant4.web.cern.ch/geant4

[3] G. Barrand, *et al.*, Abstract Interfaces for Data Analysis -Component Architecture for Data Analysis Tools, Proceeding CHEP 2001

[4] O. Cuet, *et al.*, Anaphe-OO Libraries and Tools for Data Analysis, Proceeding CHEP 2001

[5] http://www.jas.freehep.org

[6] http://www.lal.in2p3.fr/OpenScientist

[7] http://www.physics.nist.gov/

[8] R. Nath, *et al.*, (Department of therapeutic Radiology, Yale University School of Medicine, New Haven, Connecticut), Dosimetry of interstitial brachytherapy

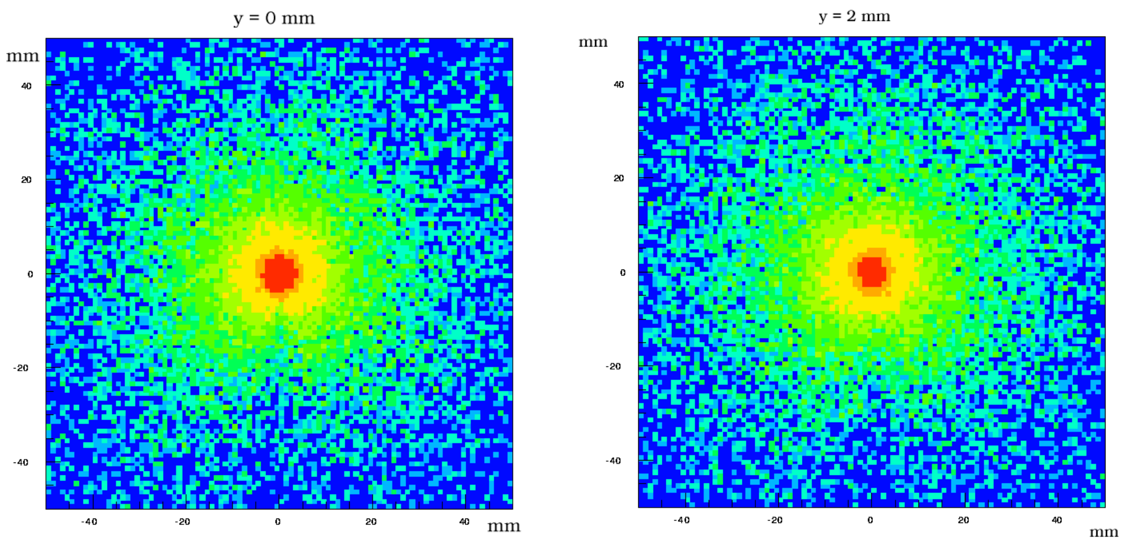

Figure 7: Dose distribution for Ir_{192} source used in endocavitary brachytherapy [9]

sources: Reccomendations of the AAPM Radiation Therapy Commettee Task Group, N.43, Med.Phys. 22 (2), February, 1995.

[9] M. Tropeano, Master Degree in Physics- Brachiterapia HDR: procedure di calibrazione e simulazioni Monte Carlo con Geant4, University of Genova, 2001.

[10] S. Guatelli, Master Degree in Physics- Brachiterapia interstiziale con I-125: misure sperimentali e simulazione Monte Carlo, University of Genova, 2002.

[11] http://grid.web.cern.ch/grid

[12] J. Moscicki, DIANE– Distributed Analysis Environment for GRID-enabled Simulation and Analysis of Physics Data, Proceeding NSS2003.

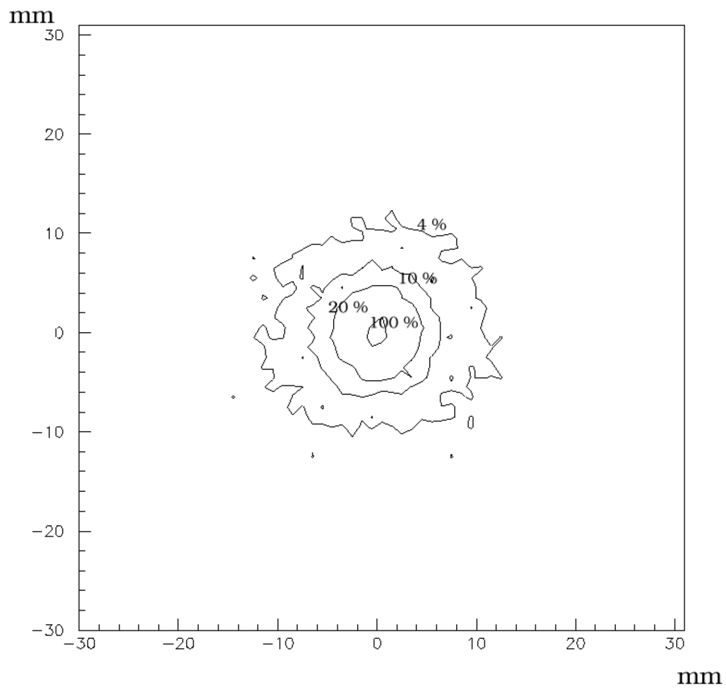

Figure 8: Isodoses for MicroSelectron source

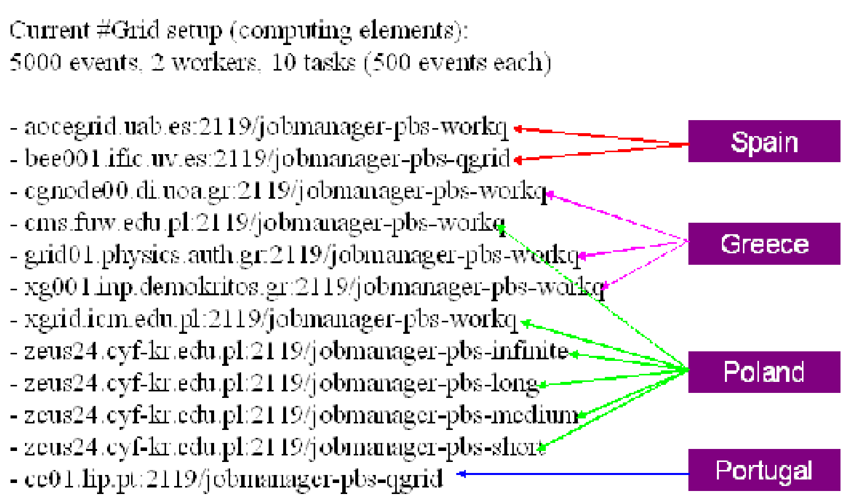

Figure 9: Trace back of brachytherapy application job running on different computers