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ΕΘΝΙΚΟ ΚΕΝΤΡΟ
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“ΔΗΜΟΚΡΙΤΟΣ”

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**Αδρονική θεραπεία: Μελέτη βάσεων δεδομένων σε
υπολογιστικά πλέγματα (Grid) και προσομοιώσεις Monte
Carlo**

ΜΕΤΑΠΤΥΧΙΑΚΗ ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

του

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Hadron Therapy: Study on Grid Databases and Monte Carlo simulations

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Απαγορεύεται η αντιγραφή, αποθήκευση και διανομή της παρούσας εργασίας, εξ ολοκλήρου ή τμήματος αυτής, για εμπορικό σκοπό. Επιτρέπεται η ανατύπωση, αποθήκευση και διανομή για σκοπό μη κερδοσκοπικό, εκπαιδευτικής ή ερευνητικής φύσης, υπό την προϋπόθεση να αναφέρεται η πηγή προέλευσης και να διατηρείται το παρόν μήνυμα. Ερωτήματα που αφορούν τη χρήση της εργασίας για κερδοσκοπικό σκοπό πρέπει να απευθύνονται προς τον συγγραφέα.

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Πιο συγκεκριμένα, έξι προτάσεις-λύσεις (projects) σε συγκεκριμένα προβλήματα ανά τον κόσμο μελετώνται, αναλύονται και σχολιάζονται. Τα δεδομένα που σε καθένα από αυτά τα projects λαμβάνουν χώρα, είναι από τα πεδία της γεωλογίας (“Nasa Earth Science Data Products”), της ιατρικής (“BioSimGrid”, “OncoGrid”), της πειραματικής φυσικής υψηλών ενεργειών (“Spitfire”, “Magda”) και της αστροφυσικής (“CasJobs”). Επιπλέον, το υπό μελέτη πρόβλημα σε κάθε περίπτωση ήταν διαφορετικό, όπως επίσης οι οικονομικές συνθήκες, τα θέματα ασφαλείας, οι τελικοί χρήστες, και τα εργαλεία που χρησιμοποιήθηκαν για την εκάστοτε υλοποίηση.

Σε αυτό το σημείο πρέπει να σημειωθεί ότι οι πληροφορίες από τις διαθέσιμες επιστημονικές δημοσιεύσεις ήταν “διασκορπισμένες”, με την έννοια ότι η δομή στις δημοσιεύσεις ήταν τελείως διαφορετική σε κάθε περίπτωση, ενώ διαφορετική έμφαση δινόταν στα επιμέρους τμήματα κάθε πρότασης. Στα πλαίσια της παρούσας εργασίας έγινε προσπάθεια να συγκεντρωθούν και να κατηγοριοποιηθούν οι πληροφορίες από κάθε πρόταση. Έτσι, συγκριτικοί πίνακες και συγκριτικά διαγράμματα παρατίθενται για όλα τα μελετηθέντα

προγράμματα σχετικά με:

- Το πρόβλημα που είχε να επιλυθεί σε κάθε περίπτωση
- Τον τρόπο με τον οποίο προσέγγισαν το πρόβλημα οι συγγραφείς
- Τις τεχνικές λεπτομέρειες της υλοποίησης, μεταξύ των οποίων το λογισμικό της Βάσης Δεδομένων που χρησιμοποιήθηκε, το “μεσισμικό” που χρησιμοποιήθηκε στην υποδομή GRID σε κάθε περίπτωση, τα εργαλεία επικοινωνίας GRID και Βάσεων Δεδομένων, καθώς και τα περιβάλλοντα διεπαφής με τον χρήστη
- Τον τρόπο με τον οποίο οι συγγραφείς αντιμετώπιζαν τα θέματα ασφαλείας που σε κάθε περίπτωση εγείρονταν

Το δεύτερο κομμάτι της παρούσας μεταπτυχιακής εργασίας, ασχολείται με μια πλήρη συστηματική μελέτη προσομοίωσης Monte Carlo πέντε διαφορετικών υλικών, τα οποία χρησιμοποιούνται στην κατασκευή των βασικών στοιχείων των επιταχυντικών διατάξεων και των θωρακίσεων που χρησιμοποιούνται στο CERN, αλλά και διεθνώς στις διάφορες επιταχυντικές διατάξεις. Τα υλικά αυτά είναι το αζωτούχο βόριο, που συχνά χρησιμοποιείται σαν στόχος τερματισμού της δέσμης, ο άνθρακας (γραφίτης) που συχνά αποτελεί υλικό κατασκευής κατευθυντήρων (collimators) και απορροφητών δέσμης (beam dumps), ο σίδηρος ο οποίος αποτελεί κύριο υλικό κατασκευής μαγνητών, ο χαλκός από τον οποίο κατασκευάζονται οι επιταχυντικές κοιλότητες (RF cavities), και το ανοξείδωτο ατσάλι το οποίο κανείς συναντά στους θαλάμους κενού (vacuum chambers). Τα υλικά αυτά, πολλές φορές είναι πιθανό να εκτεθούν σε τυχαία ακτινοβολία από την δέσμη που διατρέχει τον επιταχυντή, και να ενεργοποιηθούν. Σκοπός της παρούσας εργασίας είναι να μελετηθεί πλήρως ο αναμενόμενος τύπος ραδιονουκλιδίων που πιθανόν να παραχθούν από την ακτινοβολήση, καθώς η ισοδύναμη δόση (ambient dose equivalent) γύρω από το ακτινοβοληθέν υλικό, προκειμένου να γίνει μια εκτίμηση του ραδιοβιολογικού ρίσκου.

Στα πλαίσια της προαναφερθείσας συστηματικής μελέτης, δύο ξεχωριστά είδη προσομοιώσεων έλαβαν χώρα.

- Στο πρώτο είδος προσομοιώσεων, μοντελοποιήθηκε μια απλή γεωμετρία ενός συμμετρικού κυλίνδρου (ακτίνα ίση με το ύψος), η οποία κάθε φορά βομβαρδιζόταν, επί 9 συνεχόμενους μήνες με πρωτόνια. Στον περιβάλλοντα χώρο θεωρήθηκε ότι υπάρχει φυσικός αέρας, προκειμένου η προσομοίωση να προσεγγίζει όσο το δυνατόν περισσότερο πραγματικές συνθήκες. Η πυκνότητα της δέσμης πρωτονίων (beam intensity) ήταν ίση με $6 \cdot 10^{12} p/s$ ενώ οκτώ διαφορετικές ενέργειες εξετάστηκαν, ξεκινώντας από τα 50MeV και φτάνοντας μέχρι τα 400MeV ανά 50MeV. Το συγκεκριμένο εύρος ενεργειών επιλέχθηκε επειδή είναι πολύ συνηθισμένο όσον αφορά τους “μεσαίους” επιταχυντές πρωτονίων, οι οποίοι χρησιμοποιούνται ως “ακροφύσια” (injectors) σε μεγαλύτερες επιταχυντικές διατάξεις. Οι διαστάσεις του κυλίνδρου (ακτίνα και ύψος) διέφεραν κάθε φορά, ανάλογα με το μήκος διαδρομής των πρωτονίων, στο συγκεκριμένο υλικό και για την συγκεκριμένη ενέργεια. Η επικρατούσα ισοδύναμη δόση (ambient dose equivalent) $H^*(10)$, όπως αυτή ορίζεται από την διεθνή επιτροπή ακτινοπροστασίας (ICRP) καταγράφηκε συμμετρικά γύρω από

το στόχο, μέχρι την απόσταση ενός μέτρου από την κάτω, την πάνω και την παράπλευρη επιφάνεια του κυλινδρικού στόχου, για επτά χρονικά διαστήματα (cooling times), αμέσως μετά το τέλος της ακτινοβολήσης, μιας ώρας, μιας ημέρας, μιας εβδομάδας, ενός μήνα, τριών μηνών και έξι μηνών.

Επίσης, όλοι οι θυγατρικοί πυρήνες (residual nuclei) που παρήχθησαν στο στόχο για όλα τα παραπάνω χρονικά διαστήματα (λαμβάνοντας υπόψη την ραδιενεργό διάσπαση σύμφωνα με τους αντίστοιχους χρόνους ημιζωής) καταγράφηκαν, μαζί με την ενεργότητα του καθενός. Κατασκευάστηκαν χρωματικά διαγράμματα που δείχνουν την διαβάθμιση της ισοδύναμης δόσης, σαν συνάρτηση της απόστασης από το στόχο, καθώς και διαγράμματα τα οποία δείχνουν την εξέλιξη της ισοδύναμης δόσης, σε μια σταθερή απόσταση 50 εκατοστών από την παράπλευρη επιφάνεια του κυλίνδρου, σαν συνάρτηση του χρόνου.

- Στο δεύτερο είδος προσομοιώσεων, διατηρήθηκε η ίδια γεωμετρία, εφαρμόζοντας παράλληλα κάποιες τεχνικές μείωσης σφαλμάτων, και καταγράφηκε το φάσμα των διαφυγόντων νετρονίων από τον στόχο προς τον αέρα, σε διάφορα γωνιακά τμήματα, σε σχέση με την κατεύθυνση της δέσμης. Τα διαφεύγοντα νετρόνια είναι μεγάλης σημασίας, τόσο για την εκτίμηση του ραδιοβιολογικού ρίσκου, όσο και για θέματα ακτινολογικής θωράκισης. Κατασκευάστηκαν διαγράμματα με όλο το φάσμα ροής των διαφυγόντων νετρονίων, σαν συνάρτηση της ενέργειας τους και της πολικής γωνίας σε σχέση με την κατεύθυνση της δέσμης.

Επιπλέον, έγινε μια ξεχωριστή μελέτη μιας ιδιαίτερης ξεχωριστής περίπτωσης. Η περίπτωση της ύπαρξης ενός τσιμεντένιου θόλου (tunnel) γύρω από τον ακτινοβοληθέντα στόχο μελετήθηκε, και καταγράφηκε τόσο η ισοδύναμη δόση όσο και το φάσμα, τόσο των διαφευγόντων του στόχου νετρονίων, όσο και των νετρονίων που εμφανίζονται στον περιβάλλοντα του στόχου αέρα. Σύγκριση μεταξύ των δύο φασμάτων έδειξε μεγάλη αύξηση του πληθυσμού των θερμικών νετρονίων στον περιβάλλοντα αέρα, τα οποία προέρχονται από ελαστική σκέδαση στο τσιμέντο του θόλου, αλλά και αύξηση του πληθυσμού των διαφυγόντων του στόχου νετρονίων, γεγονός που οφείλεται στην επανείσοδο στο στόχο νετρονίων, που διέφυγαν αρχικά από αυτόν, σκεδάστηκαν στον θόλο και την επαναδιέφυγαν έχοντας χαμηλότερη ενέργεια.

Abstract

Hadron therapy is a novel technique of cancer radiation therapy using beams of energetic protons, neutrons, or positive ions for cancer treatment. In the context of this thesis, two individual projects have been performed, both of them having a direct relevance with Hadron Therapy.

The first part consists of a literature analysis of six different projects. The common characteristic of these projects is that they are dealing with the distribution of large amounts of data, among geographically distributed user teams. The solutions proposed are exploiting either Grid, or parallel databases implementations, or combinations of these two technologies. The objectives of the authors, the technical details of the implementations as well as the security issues of each proposal, have been extracted from the original papers, and are being juxtapositioned. Comparison tables between the different software and hardware choices of each implementation have been produced, while the benefits or the drawbacks of each choice, that are being stated by the authors, are also being quoted. The overall aim of the present study is to discuss the choice of certain software and hardware infrastructures in combination with the problem that has to be addressed each time. The scope of the present study, is to be used as a bibliographic reference for future studies, in order to be decided if these same infrastructures are proper and eligible to be used in PARTNER's rare tumor database platform, or other similar projects.

In the second part of the present thesis, a systematic Monte - Carlo simulation study of five typical accelerator materials (Boron Nitride, Carbon, Copper, Iron and Stainless Steel) is being presented. The overall aim of this study was to assess the radiological risk in case of accidental irradiation of the accelerators' surrounding materials. Using a simplified geometry of a right cylinder, the five materials were bombarded with a proton beam of energy in the range of 50MeV up to 400MeV. This range of energy is typical of intermediate energy proton accelerators used as injector to higher energy machines, as research accelerators for intermediate nuclear energy physics, and in hadron therapy. The ambient dose equivalent ($H^*(10)$) was scored in a distance up to 1 meter from the bottom, top and lateral surfaces of the cylinder, for seven different cooling times, as well as the residual nuclei inventory in the target. Moreover, the escaping neutron spectra were scored for all the materials and the aforementioned energies. Also, a case study of the neutron population variation with and without a concrete tunnel around the target was considered. The material of this thesis is going to be used as a handbook from the interested research teams in CERN.

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Chapter 1

Grid Databases: Terms and Definitions

1.1 Introduction

In this first chapter, an attempt will be done in order to introduce the reader to some basic concepts that will be appearing in the whole length of the present study. Of course, a lot of extended literature exists for the terms appearing in the present study, into which the reader may seek further information.

1.2 Database

In the broadest sense, a database is a collection of related files [1]. More formally, a database can be described as set of data that has a regular structure and that is organized in such a way that a computer can easily find the desired information. A database can generally be looked at as being a collection of records, each of which contains one or more fields (i.e., pieces of data) about some entity (i.e., object), such as a person, organization, city, product, work of art, recipe, chemical, or sequence of DNA.

1.3 Database Models

The relations between the data of a database is highly dependent on the database model being used. There are several models that describe the exact relations between these files in the international literature. The most important of them include:

- **The Hierarchical Model.** This is the earliest database model, and it requires that all files and all records, are and have to be related in a parent-child manner, similar to a single-parent household where each child has at most

one parent at any given time, but where each parent can have multiple children [1].

- **The Network Model.** It is an other early database model, in which the files are related as owners and members. This model resembles blended and extended families, where each owner (or each parent) can have multiple children (members) and each child can have multiple parents.
- **The Relational Database Model** [3, 4]. It is the most improved and widely used model since today. A relational database allows the definition of data structures, storage and retrieval operations and integrity constraints. In such a database the data and relations between them are organized in tables. A table is a collection of records and each record in a table contains the same fields. The purpose of the relational model is to provide a declarative method for specifying data and queries: we directly state what information the database contains and what information we want from it, and let the database management system software take care of describing data structures for storing the data and retrieval procedures for getting queries answered.
- **The Object Oriented Model (OO).** Object Database Systems have their origins in object programming languages [5]. And the basic idea is the same in both cases: namely that users should not have to wrestle with machine-oriented constructs such as bits and bytes, or even fields and records, but rather should be able to deal with objects, and operations on those objects, that more closely resemble their counterparts in the real world. A major benefit of this approach is the unification of the application and database development into a seamless data model and language environment. As a result, applications require less code, use more natural data modeling, and code bases are easier to maintain. Object developers can write complete database applications with a modest amount of additional effort. This one-to-one mapping of object programming language objects to database objects has two benefits over other storage approaches: it provides higher performance management of objects, and it enables better management of the complex interrelationships between objects.
- **The Object Relational Model (OR).** This model was developed with the objective of combining the concepts of the relational database model with object-oriented programming style [6]. This model adds new object storage capabilities to the relational systems at the core of modern information systems. These new facilities integrate management of traditional fielded data, complex objects such as time-series and geospatial data and diverse binary media such as audio, video, images, and applets. The OR model is supposed to represent the best of both worlds (relational and OO), although the OR model is still early in development.

1.4 The Database Management System (DBMS)

Between the physical database and the user, there is a layer of software widely known as the Database Management System. Each DBMS is based on a particular Database Model [5, 6]. One general function provided by DBMS is the “shielding”

of database users from hardware details. Using more technical terms, the DBMS accepts requests for data from the application program and instructs the operating system to transfer the appropriate data. Each DBMS should fulfil the following prerequisites [6]:

- Data should be stored on some hardware device and should persist after being accessed. Access methods include the creation of new data, modification of existing data, and deletion of data. This is referred to as **data persistence**.
- Multiple users should be allowed to access data simultaneously, called **concurrency**.
- Transactions are managed, allowing for the manipulation of data, and the ability to save a group of work.
- A query language should be available to retrieve data based on criteria supplied by the user.
- Data should be recoverable from a failure. If data is lost, the DBMS should have the capability to recover the data to any given state.

1.5 Web Databases

With the growth of the Web over the past decade, there has been a similar growth in services that are accessible over the Web. Many new services are web sites that are driven from data stored in databases [9]. Most web database applications consist of three layers of application logic. At the base is a database management system (DBMS) and a database. At the top is the client web browser used as an interface to the application. Between the two lies a special software, usually developed with a web server-side scripting language that can interact with the DBMS, and can decode and produce HTML used for presentation in the client web browser.

1.6 Parallel Databases

Databases serving a large volume of data use a great deal of disk space, and large amount of memory. This often leads to bottlenecks, mainly for hardware reasons. Combining the throughput of many processors and using many nodes, each with good cost performance communicating through the network (with good cost via high-volume components and bandwidth), many of the challenges can be addressed. Because the Grid does this with conventional commodity processors, memory, and disks, it allows a Grid database to be in an excellent position to exploit the massive numbers of CPU cycles and bandwidth and provide performance gains.

1.6.1 Parallel Database Management System

A **parallel database management system** can typically be defined as a homogeneous system, with tightly coupled processors, interconnected each other. More specifically, a parallel database management system (DBMS) is simply a DBMS that is implemented on a tightly coupled (shared memory) multiprocessor system.

1.7 Parallelism

In the framework of Parallel Databases, the term “parallelism” can be approached by two ways:

- Interquery Paralellism, which provides that nodes are divided across different queries, and
- Intraquery Paralellism, which can be further subdivided into **intraoperation parallelism**, where multiple nodes are working to compute a given operation, and **interoperational parallelism**, with each operator runs concurrently on a different site.

1.8 Metadata

Metadata is structured information that describes, explains, locates, or otherwise makes it easier to retrieve, use, or manage an information resource. Metadata is often called “data about data” or “information about information”. The term metadata is used differently in different communities. Some use it to refer to machine understandable information, while others use it only for records that describe electronic resources.

There are three main types of metadata [34]:

- **Descriptive metadata** describes a resource for purposes such as discovery and identification. It can include elements such as title, abstract, author, and keywords.
- **Structural metadata** indicates how compound objects are put together, for example, how pages are ordered to form chapters.
- **Administrative metadata** provides information to help manage a resource, such as when and how it was created, file type and other technical information, and who can access it. There are several subsets of administrative data in general; two of them, that sometimes are listed as separate metadata types are:
 - **Rights management metadata**, which deals with intellectual property rights
 - **Preservation metadata**, which contains information needed to archive and preserve a resource.

1.9 Grid & Database Systems

1.9.1 Grid

The term “the Grid” was coined in the mid-1990s to denote a (then) proposed distributed computing infrastructure for advanced science and engineering. Of course a lot of progress has been achieved since then, but even since today the real meaning of the word “Grid” is ambiguated. A lot of studies have been done to prove that the word “Grid” actually has a specific meaning, and a real and specific problem: **Coordinated resource sharing and problem solving in dynamic, multi-institutional virtual organizations** [7]. By the word “sharing” not only file exchange is described, but rather direct access to computers, software, data, and other resources, as is required by a range of collaborative problem-solving strategies emerging in industry, science, and engineering. This sharing is, necessarily, highly controlled, with resource providers and consumers defining clearly and carefully what is shared, who is allowed to share, and the conditions under which sharing occurs. A set of individuals and/or institutions defined by such sharing rules form is called “virtual organization (VO)”.

More technically, grids consist of computer clusters, that is groups of linked computers, sharing their resources and acting to the end user as a single computer, with total resource power, the sum of the resources of the member-computers.

Grid Architecture

Grid architecture is often described in terms of “layers” (tiers), where each layer has a specific function [41]. In general, grids consist of the following layers:

- **The Network Layer**, that consists of the network cables, the optic fibers, the routers, and in general the network equipment that is being used in order the computer clusters to be interconnected.
- **The Resource Layer**, that consists of the resources that all the computers can offer to the users, like the hard disk capacity, or the CPU power of the clusters’ member-computers.
- **The Middleware Layer**. In a distributed computing system, by the term “middleware” is defined a software layer that lies between the operating system and the applications on each site of the system [53]. The software consists of a set of services that allows multiple processes running on one or more machines to interact, like a “software glue” [49]. The origin of the name of this special software is because middleware sits “in the middle” between several application software that may be working on different operating systems.
- **The Application Layer**. It is the highest layer of the structure, which includes the applications, as well as the portals and development toolkits to support the applications. This is the layer that grid users interact with.

1.9.2 Grid Database Systems

As mentioned in several studies [12, 11, 8], the term “Grid Database System” is of highly ambiguous. Specifically, some studies assume that there is no infrastructure which can be defined “ad initio” as Grid Database System, but rather that existing databases require the provision of certain middleware components to make them available with a Grid Services setting. As there are several widely used database examples, there are several implementations of the software that will “Grid-ify” them [11, 33].

Chapter 2

The Present Study

2.1 Introduction

2.1.1 Hadron Therapy

Particle therapy is a form of external beam radiotherapy using beams of protons, neutrons, or ions for cancer treatment. The most common type of particle therapy is proton therapy. Although a photon, used in x-ray or gamma ray therapy, can also be considered a particle, photon therapy is not considered here. Additionally, electron therapy is generally put in its own category. Because of this, particle therapy is sometimes referred to, more correctly, as hadron therapy. A lot of projects exist worldwide that are involved with Hadron Therapy. Among them, a Particle Training Network for European Radiotherapy (PARTNER) has been established and being coordinated by CERN¹. The present study took place in the framework of PARTNER.

More specifically, design and implementation of a prototype common database and database services throughout the PARTNER network to facilitate the analysis of best practices and to provide for the necessary statistics treating rare tumors, using GRID infrastructures is one of the projects running presently in PARTNER.

In the present study, six scientific projects from different fields (Earth Science, Biology, Medicine, Physics) were revised, studied and evaluated. Each project is trying to address a different problem relative to management of large-volume and large-number scientific data, which had to be either distributed, stored or analyzed among the user teams being interested on these data, which in most cases were geographically spread. The solutions proposed are exploiting either Grid, or parallel databases implementations, or combinations of these two technologies.

Using as a source the original published papers, information was mined about:

1. Each project's scope and the problem to be addressed in each case
2. The computing and (in general) infrastructure schema that was implemented from the authors in order to address the problem

¹For more information visit the official PARTNER site at <http://www.cern.ch/partner>

3. Technical details (in the magnitude that this was available in the original paper) about the computing implementation of each project's solution

The overall aim of the present study is to discuss the choice of certain software and hardware infrastructures in combination with the problem that has to be addressed each time. The scope of the present study, is to be used as a bibliographic reference for future studies, in order to be decided if these same infrastructures are proper and eligible to be used in PARTNER's rare tumour database platform, and possibly in similar data management projects, using GRIDS and database management systems.

2.2 Difficulties

In this study, there were several difficulties, concerning both the nature of the data, as well as the way that information was published by the authors. More specifically the issues which appeared during this study, are listed bellow.

- **Specific Problem - Specific Implementation**

The authors in each case, had to address a very specific problem, which, in most cases had to do with the nature of the data involved, and the specific community's users, who would be the end-users of the solution. Therefore, each approach proposed is unique, custom and fixed, and cannot be applied, without radical modifications even to a similar project. Moreover, in most of the projects, specific software was developed by the authors, like custom-made scripts or API's which of course, cannot be applied anywhere else except for the specific purpose that were developed for.

- **Lack of Information**

The published papers, from which information was mined for the projects, had neither the same structure, nor the same depth in the analysis and the presentation of the work done. Because of that, a number of aspects of each solution - infrastructure is being discussed in detail by the authors, while other aspects are not. Therefore, the comparison between every aspect of the projects is extremely difficult, because the necessary information for such a comparison, is not available.

- **Deprecated Infrastructures**

In some cases, the infrastructure developed, or the project itself is nowadays deprecated. The reasons for the deprecation usually are unknown, and the corresponding web sites are either not working at all, or are not updated recently. Therefore, information about possible updates of the software / hardware infrastructure, or about the users' experience and feedback, or the useful information about the reason of the deprecation, cannot be retrieved.

2.3 Framework

The six projects studied, are briefly described in the following chapters. A brief table of information about each project, containing the original paper's title, the author list and the year of publication is included, in order to help the reader find more information on each project easily.

The subsections of each chapter contain:

- A description of the problem to be addressed, the nature of the data involved, and the initiative of the authors for implementing their solution
- The schema, and the technical details that were available on the published paper
- The current status of the project, when that information could be retrieved

An effort has been done in order the detailed information from the original papers to be presented in a uniform way, and with the same order in all the chapters of the present study. Although, as mentioned before, that is not the case in the original papers, and therefore some sections are less analyzed than others, in each project.

Chapter 3

Distributed Generation of NASA Earth Science Data Products

3.1 Introduction

Brief information about this work can be described shortly in table (3.1)

Original Title	Distributed Generation of NASA Earth Science Data Products
Authors	Bruce R. Barkstrom, Thomas H. Hinke, Shradha Gavali, Warren Smith, William J. Seufzer, Chaumin Hu and David E. Corder
Year of publication	2004
Journal	Journal of Grid Computing
Keywords	Grid Mining, phenomena based subsetting, product generation

Table 3.1: Brief Information

3.2 Objectives and Initiatives

3.2.1 The Problem

NASA Data Centers store data archives from satellite-born instruments for observing the Earth. These data are being distributed to a great variety of users, for research purposes. These data, initially stored in files and directories format, depending on the time and the location of their acquisition, are being processed by application of several algorithms, in order some conclusions about several geophysical parameters to be extracted.

With the current configuration, user has to download large amounts of unneeded data and then use his own computing and storage resources in order to process these large data sets and extract the useful for him information. Also, there is a second set of problems arising from the fact that, simultaneous, collocated observations by different instruments may be located in different centers. Currently, a data user who wants a data product derived from data

stored in multiple archives, must order large amounts of data from each archive. Then, he has to combine this data using his own resources.

3.2.2 The Proposal

In the present work, the authors are proposing and implementing the idea of the creation of **customized data sets**, which are being created by users requests. With this approach, users are not forced to download useless data, but only data of their interest. Moreover, with the technique of creating **data subsets** to the clusters near to the original archives, and intelligently select computing resources which can combine the subsets into the data product requested by the user, one can deal with the problem of the collocated, simultaneous observations. More analytically, the approach consists of the following points:

1. Co-location of commodity linux clusters with Nasa Earth-Science data archives. These archives, using GRID Technologies are used by the clusters in order customized data products, that exactly fit the users needs to be created. Also, the clusters are equipped with high bandwidth connections to the tape-storage units and the attached disks that the archives are stored on.
2. Subsetting the archived data, depending on the users' requests in clusters, and selection of computing resources that combine the subsets into the data product requested by the users.

This subsetting operation is similar to a database creation, because it creates structures similar with rows and fields. In fact, the subsetting process creates joint catalogs of phenomena and the data associated with them. More analytically, when the subsetting process identifies data associated with a particular phenomenon, the software creates a catalog entry that identifies the phenomenon in question, computes summary properties for that instance, and provides pointers to the data within the files that appear to belong to the phenomenon. Because the data of interest are not image-like, the subsetting operation is similar to a database query involving selections of records based on the values of the parameters in the records.

3.3 Technical Details

3.3.1 Schema

For this work, an XML-Driven [29] subsetter was developed by ASDC¹, and was running on a Globus [24] Grid-Enabled Linux Cluster reading a test volume of CERES SSF data². The subsetter, reads the XML template file, which identifies the data file to be read and the location of the subset file, when the job is finished.

¹Atmospheric Sciences Data Center, <http://eosweb.larc.nasa.gov/>

²SSF stands for "Single Scanner Footprint". For more information on CERES format, visit the official website: <http://science.larc.nasa.gov/ceres/>

The XML template file identifies which parameters to read from the file, and it is intended to allow several kinds of operations to be performed iteratively and interactively on the data.

The incoming data from CERES SFF contain 131 parameters, organized in a singly dimensioned array, typically with about 150.000 independent observations, or footprints. The XML Template allows a user to specify an arbitrary fraction of these parameters. The template, also intended to allow the user to specify if they want some (or all) of the following:

- select footprints within a particular range of values
- produce a statistical summary
- compute a new parameter from the old set
- visualize relationships

3.3.2 Grid Environment

The following is the description of the GRID environment in which the test-run was made:

- Globus 3.0 alpha
- GridFTP [13] for all file transfers
- Secondary Storage (local disk) to store the Globus jobs (shell scripts)
- Tertiary Storage (disk on network attached computer) for data file and subsetter binary

For dealing with the problem of collocated and simultaneous data, stored in multiple archives, the authors are proposing use of a special software system, called GridMiner [14]. GridMiner is an agent-based mining system³, in which mining agents are sent to processors on the Grid to mine remote data that is accessible from the Grid and described in a mining database, that has been pre-loaded with the URL's of data to be mined.

The user is staging “thin” mining agents to the Grid processors that are to support the mining, along with the mining plan (written by the user), that is to guide the mining for desired phenomena. As the “thin” agent executes the mining plan, it identifies the operations that are to be used for the mining, and then uses the Grid to transfer the needed shared library executables from a mining operator repository to the Grid processors where the mining is to be performed. Once finished, the mining agent contacts the mining database to acquire the URL's of the files to be mined. Using the Grid, these files are transferred in the mining site and the mining is performed as specified in the mining plan. When the mining is completed, an XML document is created, and is sent to the subsetting engine. The XML document, includes indices to the original pixels in the data files that contribute to the object identifications, and the retrieval of the original data file is efficient also.

³There is plenty of bibliography about data mining that exceeds the framework of this report. For example, see [15]

3.4 Advantages of the approach

According to the authors, the advantages of the approach can be summarized as follows:

- Proved that GridFTP provides a reliable means of moving data between the various sites
- The Grid single-sign-on environment (user identifies and authenticates himself to one Grid system, and the Grid handles his access to all other Grid resources used) proved very useful.
- The SRB System provides seamless interface through which the Grid Miner could directly access data stored on mass storage tape silo, as much ease as accessing data stored in the filesystem of one of the Grid-accessible processors
- The Java based Globus CoG Kit provides a powerful capability to easily create a control program that coordinates file transfers and processing in two different Grid environments. No incompatibility of different versions was referred.

3.5 Current Status of the Project

The research approach discussed by the authors, is not dealing with the challenge of merging the technology that has been demonstrated in a small scale into more realistic operational environment. The ownership and operational costs need careful consideration. Since today, no full implementation of the proposal seems to have been done⁴.

⁴For more information about the ASDC, visit the official website at <http://eosweb.larc.nasa.gov/>

Chapter 4

BioSimGrid

4.1 Introduction

Brief information about this work can be described shortly in table (4.1)

Original Title	BioSimGrid: A Distributed Database for Biomolecular Simulations
Authors	Bing Wu, Kaishu Tai, Stuart Murdock, Muan Hong Ng, Steve Johnston, Hans Fangohr, Paul Jeffreys, Simon Cox Jonathan Essex, Mark S.P Sansom
Year of publication	2004
Journal	Proceedings of UK e-Science All Hands Meeting 2003
Keywords	Grid, Biomolecular Simulation, Molecular Dynamics, Protein, OGSA, OGSA-DAI, Distributed Database, Web Service, Middleware, Digital Certificate

Table 4.1: Brief Information

4.2 Objectives and Initiatives

4.2.1 The Problem

Biomolecular simulations provide data on the conformational dynamics and energetics of complex biomolecular systems. A large scale analysis of the results is of great interest, and with the present infrastructure, there are problems in comparing the results of multiple simulations, and in integrating simulation results with other (experimentally-derived) sources of data. Furthermore, it will be essential to provide data retrieval and analysis tools that are accessible to a wide community of scientists.

At present, simulation data reside in the “home” laboratories and are not accessible to other research groups. But even there, there are pressures on disk storage, that, once initial analysis and publications are complete, data are archived to tapes, and sometimes are lost. Proposals of creation of a centralized database,

such as the RCSB Protein data bank¹ are problematic due to the large amount of data exchanged. Also, there are problems of physically maintaining and curating a centralized database.

4.2.2 The Proposal

The overall aim of the project is to exploit the developing e-science infrastructure in the UK to enable large scale analysis of the results of biomolecular simulations. In particular, the BioSimGrid project will try to establish a formal database for biomolecular simulations within the UK, increasing collaboration via a distributed computing environment. The database will contain three types of data:

- **Raw Data**, which are the data generated by biomolecular simulations
- **First Level Metadata**, which are data describing the generic properties of raw simulation data, such as data location, simulator configuration, etc.
- **Second Level Metadata**, which are data describing the results of generic analyses of simulation data. This will be produced by a suite of generic analysis tools and will provide simulation data standards. A schematic approach of the project can be found at figure (4.1)[picture taken from the original paper].

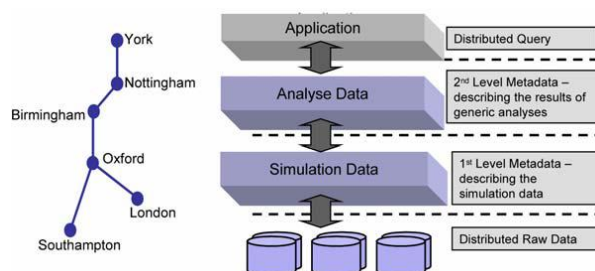


Figure 4.1: BioSimGrid Database Overview

Once all these data are in place, software tools will be developed for interrogation and data-mining across the entire distributed database. Also, new metadata will be provided, such as links to structural biology and genomics database entries, thus facilitating access to and understanding of biomolecular simulation results for non specialists.

4.3 Technical Details

4.3.1 Schema

The project is building an open software framework system based on OGSI [25] and OGSA [26], which are implemented in the middleware Globus Toolkit 3

¹For more information, visit the RCSB official website: <http://www.rcsb.org>

(GT3) [24], which provides a community based, open architecture, open source set of services and software libraries enabling applications to handle distributed and heterogeneous computing resources as a single virtual machine through Grid/Web services. The system architecture currently consists of the following components:

- **GUI:** An https-based web client provides user interaction with the system. The client can be either a standard web browser, or web-based application. This web client implementation offers easy interaction with the BioSimGrid from anywhere.
- **The service tier:** This tier is dedicated to deliver data analysis and data mining services to the user community through grid based web services. Also, there are supporting services such as monitoring, transaction and distributed query services. The protocols used here are XML [29] and SOAP [30].
- **Grid Middleware tier:** This tier contains the central element of the Grid Middleware, Globus Toolkit 3 Core, which provides the core services and capabilities required to construct a computational grid. On top of the GT3 Core, there is a set of components that implement basic services, such as security, resource, management, database access and communications.
- **Database/Data tier :** This tier contains the raw data and the database resources that are distributed across the collaborating sites. More information about the database distribution are given in the next section.

4.3.2 Database Distribution - OGSA-DAI

In order to address the challenges of distributed computing on large amounts of simulation data, the project uses a leading commercial database, namely IBM DB2 Universal Database Enterprise Server².

The distribution will be based on OGSA-DAI³. Through the OGSA-DAI interfaces, distributed and heterogenous data resources can be accessed and controlled as though they were a single logical resource. The concept of OGSA-DAI is based on delivering database as Grid/Web services.

The security, transaction management, distributed database access and job management, are integrated internally into the BioSimGrid applications. Furthermore, heterogenous databases can be used in the project without the need for any changes to the application code.

4.3.3 Example Work Flow

In the prototype described by the authors, two types of GUI clients are implemented: A web portal client and an application client. These will provide

²For technical information and documentation, visit the official product site at: <http://www-01.ibm.com/software/data/db2/9/edition-enterprise.html>

³Open Grid Service Architecture Database Access and Integration. For more information about the project, visit the official website: <http://www.ogsadai.org.uk>

software tools for interrogation and data mining across the entire distributed database, and a set of generic analysis tools for biomolecular simulations.

The user client uses a web-based front end to login to the system, authenticate and authorize. After that, the user can browse the available table trajectories in the BioSimGrid Database by selecting from a list of metadata options on a web form. After the input from the user selection, a set of variables, nicknamed “database query handler” is sent back from the client to the web server, which was an Apache/Tomcat Webserver⁴. The web server passes on this handler to the application server to start up an analysis. After the analysis is complete, the simulation results are displayed on the browser. A visualisation of the data is available also in the implementation, invoking a special visualisation software.

The current implementation of the prototype tools is based on Python⁵. Also, the popular biosimulation library MMTK⁶ which is written in Python is used for the calculations concerning the simulations. Furthermore, tools like Grace⁷ and VMD⁸ are implemented to the system in order to make it more useful for the end-user.

4.3.4 Security

The security implementation of the system will be based on three core components: Authentication, Authorization and Accounting.

- **Authentication** is achieved by Grid-certificate authentication mechanism, OpenCA-PKI⁹ and X.509 digital certificate technology [32]. When a user wants to access specific BioSimGrid services, the subject of his/her X.509 personal digital certificate is certified against the one stored in the corresponding database and only if the security check is successful, and a valid combination of username/password is entered correctly, the user obtains access to the data

All the web services are based on Secure Socket Layer (SSL) via HTTPS. The authentication is currently based on user credential delegation implemented using the opensource software MyProxy [18, 22].

- **Authorisation** is handled by the authorisation component of the system. This component queries the security database to retrieve information such as username, organisation and access level. Once this information is confirmed, the user gains access to his permitted area(s).

⁴For more information visit the official website: <http://tomcat.apache.org/>

⁵For more information about this object oriented language visit the official website: <http://www.python.org>

⁶Molecular Modeling Toolkit. A library for molecular simulations with a focus on biomolecular systems. For more information, visit the official website at: <http://sourcesup.cru.fr/projects/mmtk/>

⁷An Opensource design program. For more information visit the official website of the project: <http://plasma-gate.weizmann.ac.il/Grace/>

⁸Visualisation of Molecular Dynamics software. For more information visit the official website: <http://www.ks.uiuc.edu/Research/vmd/>

⁹For more information on the project, visit the official website at <http://www.openca.org/projects/openca/>

- **Accounting** is essential in order the security of the system to be enhanced, and system usage to be traced. This accounting component, has not still developed and implemented.

4.4 Advantages of the approach

The BioSimGrid project, using mainly opensource and widely known tools, is able to address the challenges of distributed computing on large amounts of simulation data, with an easy, and user friendly mechanism of authentication, and therefore offers easy and broad access to the data. Though, the official website of the project is not working, so no information about the latest status of the project can be obtained.

4.5 Current Status of the Project

The Project is still at an early stage of development, according to the authors. In particular, the database schema needs to be refined, with particular attention to simulation metadata, and development of methods for data deposition and for quality control of simulation data. This will enable comparative analysis to be done on complex simulations, in order to evaluate the strengths and weakness of the current prototypes in real world applications.

Chapter 5

OncoGrid

5.1 Introduction

Brief information about this work can be described shortly in table (5.1)

Original Title	Oncogrid: A Proposal of Grid Infrastructure for the Establishment of a National Health Information System on Childhood Cancer
Authors	Higor A. V. Alves, Moacir A. Campos. Jr., Francisco J. A. Fernandes, Marcia N. S. Kondo, Andre N. de Mello, Adilson Y. Hira, Marcelo K. Zuffo
Year of publication	2008
Journal	IEEE
Keywords	Cancer treatment, Grid Database, Kaplan-Meier Method, Cancer Registry

Table 5.1: Brief Information

5.2 Objectives and Initiatives

5.2.1 The Problem

As required by the Brazilian laws, health institutions directly involved in the cancer treatment have to register and consolidate cancer patients' data, valuable information for the management and evaluation of cancer treatment.

Among the generated statistical data, one of the most important is the cancer survival curve, that is the statistical picture of the survival experience of some group of patients in the form of a graph showing the percentage surviving versus the time between the starting event diagnosis of treatment start - and the exclusion event, death, recurrence, loss of follow up, etc. This type of graph has been widely used in the medical literature, because it is the best way to compare the different treatments for the same pathology.

Currently, taking into account the continental proportions of Brazil, cancer management is performed in an environment with data scattered among different locations and under different domains hindering the consolidation process.

5.2.2 The Proposal

The main objective of the project is to establish a Brazilian Telehealth Network for Oncology, integrating health and research institutions spread throughout the country using a high-speed backbone provided by the National Research and Study Network (RNP) of Brazil¹. By this way, each institution will maintain its own local health database in compliance with all legal requirements, and at the same time a national consolidation of this data will be enabled. In order to minimize the deployment costs and enable technology and vendors independence providing greater interoperability, open standards and tools are being used by the OncoGrid Project, and a total of five functional layers are being implemented.

5.3 Technical Details

5.3.1 The Security Layer

Due to the interoperability requirements for the proposed environment, it is necessary to use a security layer with high flexibility, offering the following functions [31]:

- Authentication
- Authorization
- Delegation
- Message Protection
- Access Control
- Certification Management

Technically speaking, the Security Layer for the OncoGrid architecture is based on the Grid Security Infrastructure, standard specified by Open Grid Forum (OGF) [21] using MyProxy [18, 22] and a custom made certification authority, based on OpenCA - PKI technology, using X.509 certificates [32] named “OncogridCA”.

5.3.2 User Access Layer

Authors selected two methods for user interface: Web Applications (Grid Portals) and Client Applications, so that, both the access through Internet and the best usability to be ensured.

¹For more information, visit the official web site of RNP Network at: <http://www.rnp.br/en/>

5.3.3 Application Services Layer

This level is responsible for services support. It is structurally composed by container's web services that store and deploy application services to the medical community. The importance of this layer is due to the possible insertion of new services whenever necessary in a standardized way and inter-operable with the other services. The interaction with this layer is carried through the service portals and standalone applications placed in the upper layer (User Access Layer)

5.3.4 Management and Information Grid Services Layer

The authors are proposing a separate layer that will be responsible for providing components that include information, allocation and resource management mechanisms, providing knowledge when necessary. The tools they are using in their implementation are the Monitoring and Discovery System (MDS), part of the Globus Toolkit [24] and the Grid Resource Allocation Management (GRAM)[19, 20] interface, also part of the Globus Toolkit.

5.3.5 Data Connection Services Layer

The authors are proposing this layer, which will be responsible for providing the homogenisation of the access to the distributed medical databases throughout the Brazilian territory.

In this layer, the OGSA-DAI interface and the GridFTP tool will be used enabling the movement and access to large datasets and databases.

5.3.6 Resource Layer

The Resource Layer is responsible for keeping the primary resources availability on the OncoGrid. The component set of this layer is composed by databases, processing resources and storage directories with large datasets.

5.3.7 Implementation

In order to validate the architecture, the authors developed a service that plots the survival plot by the Kaplan-Meier method [35]. This graph presents the survival expectation of a group of patients along a timeframe.

An initial environment was established between the Laboratory of Integrated Systems of the Polytechnic School of the University of Sao Paulo (LSI-EPUSP) and the Nucleus of Telehealth of the Federal University of Pernambuco (NUTES-UFPE), with the intention of evaluating the environment behaviour and to build a platform for application development.

The PostgreSQL Opensource Database Management System² was chosen, and

²For more information, visit the project page: <http://www.postgresql.org/>

used a random de-identified data subset generated from the childhood cancer database of the portal <http://www.oncopediatria.org.br/>. The final set, was divided into two databases, one hosted at LSI-EPUSP and the other at NUTS-UFPE, each one with about 3000 records.

In the final application, a Grid User asks through the Grid Web Portal for its Proxy Credential to the MyProxy Server, which searches its database of credentials and delegates it to the Grid Web Portal, allowing that user to access the resources of the OncoGrid. The single authentication eliminates the requirement of re-authentication for each available resource and the delegation of credentials allows the user to delegate permissions to the Web Grid Portal for access to all the resources of the computational grid through a Web Application.

To connect the application to the environment, the authors developed a JAVA API that authenticates and gives access to the data resources. Through this API, the user informs the application about the interval of months for plotting the graph and uses the proxy credential generated in the user's authentication to access the OGSA-DAI services, which will query the databases returning the values on a standardized form.

5.4 Advantages of the approach

According to the authors' view, the environment allows nationwide access to the information, consolidating the geographically distributed databases. It can also selectively query a specific data resource, as evidence of how this environment can provide a highly flexible logical topology for information access. The architecture proposed by the authors, allows the consolidation of distributed databases stored at health care units by the Oncogrid platform, yielding statistical analysis and other fundamental services to aid in the control policies, prevention and fight the cancer in the country. Furthermore, the architecture of OncoGrid can also include components in the resource layer, offering a High Performance Computer (HPC) environment and opening perspectives for using other types of applications. Moreover, the architecture based in open standards and Web Services will create the conditions for the integration and interoperability of the legacy systems in the hospitals and health units.

5.5 Current Status of the Project

By the time that these lines were written, no information about the status of the project were found published.

Chapter 6

Magda

6.1 Introduction

Brief information about this work can be described shortly in table (6.1)

Original Title	Magda: Manager for Grid-Based Data
Authors	Wensheng Deng, Torre Wenaus
Year of publication	2003
Journal	Computing in High Energy and Nuclear Physics
Keywords	Data Manager, Grid-Resident data, Atlas Experiment, BNL Laboratory

Table 6.1: Brief Information

6.2 Objectives and Initiatives

6.2.1 The Problem

The computer power required for the data analysis of the LHC, is huge. The produced data, stored in major computer centers in Europe, America and Asia, should be easily located, and conveniently retrieved by the researchers' community throughout the world. That was the challenge that the authors wanted to cope with, and their motivation for creating "Magda".

6.2.2 The Proposal

"Magda" is a distributed data manager prototype for the ATLAS experiment. It has been in stable operation since May 2001.

The authors are re-defining, in the framework of the project, the concepts of "site", "location" and "host". More particularly:

- The concept "**site**" is used to abstract the storage facilities

- The concept “**location**” is used to denote data locations within a “site”
- The concept “**host**” is used to represent a collection of computers that have access to a defined set of “sites”.

Thus, one Magda service, having knowledge of the host it is running on, is automatically aware of all the data locally accessible to it.

The principal components of the system, organized as tables in a relational database, are:

- File Catalog, with logical and physical file information and metadata
- “site”, “location” and “host” catalogs
- Logical files can optionally be organized into collections
- Replication Operations are organized into reusable tasks

6.3 Technical Details

6.3.1 Scripts and Schema

Magda makes use of the MySQL open source relational database, Perl, C++ and Java. The core of the system is one MySQL database, and the main components of the system, which are:

- File Catalog, with both logical and physical file information and metadata
- “site”, “location” and “host” catalogs
- Collections of Logical Files¹
- Tasks of Replication Operations

are implemented as MySQL tables.

More specifically, the interaction with the database is done via Perl, C++, Java and CGI (Perl) scripts. Specifically, Perl scripts are building and filling the database with metadata, as well as are responsible for the crawling of the data sources and the catalog filling. On the other hand, C++ and Java API's are autogenerated by Perl Scripts using the database schema as obtained from MySQL metadata, which support the database queries, and the processing of returned results. The use of Perl programming language, due to its pliability assures that no need of code auto-generation is required, as far as generic Perl code provides full access to all databases.

¹Logical file is a type of file that provides a view of the data stored into the Physical file. It does not contain data. A logical file contains only an index to the data stored into the physical file

6.3.2 User Interface

A special web interface for interaction with the users was implemented by the authors, that uses the above scripts in order to perform the following operations:

- Database browsing, in the broad sense of catalog, “site”, “location”, “host”, as they are defined in the framework of the project.
- Catalog querying, by date, type, location, filename, owner
- Entries modification, in the sense of adding and editing sites, locations, hosts, collections as well as replication tasks.

Special command line tools also were developed by the authors, which are provided for users to query the catalog, archive files, validate files and fetch files for use.

6.3.3 Bulk Data Replication

Special attention was given by the authors to the task of automated file replication. A set of scripts drives also the replication tasks. Also, replication of files between different computing centers is being supported.

6.4 Current Status of the Project

By the time that these lines were written, no information about the current status of the project were found published, neither on the official site, nor in other references found in the original publications. The project was tested on US Atlas Grid [27] and EDG [28] testbeds, which are now deprecated.

Chapter 7

CasJobs

7.1 Introduction

Brief information about this work can be described shortly in table (7.1)

Original Title	When Database Systems Meet the Grid
Authors	Maria A Nieto-Santisteban, Jim Gray, Alexander S. Szalay, James Annis Aniruddha R. Thakar, William J.O' Mullane
Year of publication	2005
Journal	Proceedings of the 2005 CIDR Conference
Keywords	Very large databases, Grid Applications, Data Grids, e-Science, Virtual Observatory

Table 7.1: Brief Information

7.2 Objectives and Initiatives

7.2.1 The Problem

The authors, intending to evaluate the benefits of combining database and Grid technologies, are implementing with the use of SQL technologies an existing file-based Grid Application, MaxBCG [36]. The MaxBCG algorithm¹, which works in a 5-dimensional space (uses 5 parameters) and calculates the cluster likelihood of each galaxy, has been used to search the SDSS² catalog [37] for galaxy clusters. The algorithm includes six steps:

1. Getting the galaxy list, i.e extracting the five dimensions of interest from the catalog
2. Calculating the BCG likelihood for each galaxy, and discarding of unlikely galaxies

¹MaxBCG stands for Maximum-likelihood Brightest Cluster Galaxy

²Sloan Digital Sky Survey

3. Cheking neighbours, i.e weighting the BCG likelihood with the number of neighbors
4. Determining whether it is the most likely galaxy in the neighborhood to be the center of the cluster
5. Discarding of compromised results
6. Reitreiving the galaxies that the algorithm determined as part of the cluster

Originally, the MaxBCG was implemented as Tcl scripts, orchestrating the SDSS Astrotools package [38], and running on a dedicated cluster, specifically tuned to solve this type of problem. The same application code was integrated with the Chimera Virtual Data System [39].

The algorithm is following a divide-and-conquer strategy which breaks the sky in 0.25 deg^2 fields. Each field is being proccessed as independent task. Two files are being created, the “target” file ($0.5 \times 0.5 \text{ deg}^2$), that contains galaxies that will be evaluated, and the “buffer” ($1 \times 1 \text{ deg}^2$) with the neighbouring galaxies needed to test for a cluster. Ideally, the buffer file whould be of $1.5 \times 1.5 \text{ deg}^2 = 2.25 \text{ deg}^2$. But, with the current implementation and infrastructure, the time to search the larger buffer file is unacceptable because the cluster nodes did not have enough RAM storage to hold the larger files.

Once the Buffer and the Target files are loaded into RAM, the algorithm is CPU bound. The cluster nodes, old enough, (600 MHz) could proccess a “target” field of 0.25 deg^2 in about 1000 seconds. The processing of many target fields is parallel and the whole cluster (5 nodes, 600 MHz each, 1GB RAM) could process 10 target fields in parallel. Once the Buffer and the Target files are loaded into RAM, the algorithm is CPU bound. The cluster nodes, old enough, (600 MHz) could proccess a “target” field of 0.25 deg^2 in about 1000 seconds. The processing of many target fields is parallel and the whole cluster (5 nodes, 600 MHz each, 1GB RAM) could process 10 target fields in parallel.

7.2.2 The Proposal

The authors are implementing the same MaxBCG algorithm, using a custom made relational DBMS, the SDSS Cas³ Database [40]. The SQL application is able to process much larger pieces of the sky, all at once. Using a database and database indices allows that, because the database scans the areas using high speed sequential access and spatial indices rather than keeping all the data in the RAM.

More particularly, the SQL application uses the database system to SELECT the necessary data and to do some processing and filtering inside the database. Tha processing requires basically one SELECT statement to extract the 5 parameters of interest from the General Galaxy Table, and each of these rows or galaxies is JOINED with the 1000 row redshift lookup k-correction table to compute the BCG likelihood.

³Catalog Archive Server

As far as the neighbors counting is considered, the authors used the techniques described in relevant papers (for example, see [42]) to perform the neighborhood searches. More specifically, a special technique of Zone Indexing was finally implemented, because it offered better performance. The concept behind that technique is the mapping of the celestial sphere into stripes of certain height, called Zones. The objects are uniquely defined into each zone, depending on their position. For more specific information on that, see [43].

Grid Implementation

Authors, in order to reduce the huge amount of files transferred over the network, in order the computations to be achieved, they implemented the SDSS Batch Query System (CasJobs)[44]. CasJobs allows users to submit long-running SQL Queries on the CAS databases. The query output can be stored on the server-side in the user's personal relational database, named "MyDB". CasJobs is a set of .NET Web applications and services implemented with ASP.NET and C# that provides an asynchronous batch query work-bench interface to the SDSS CAS. The main functionalities of CasJobs are:

- **MyDB:** Each user has a personal, 500Mb SQL Server Database that query output is stored.
- **Contexts:** CasJobs introduces the concept of a context as an abstraction of the database layer. Contexts let the users select from multiple mirrors of the same data set, as well as run queries and joins between multiple different data sets.
- **Query Execution:** Users can submit queries in one of two modes on the query page: Either a synchronous mode for quick queries, or an asynchronous batch mode for long queries.
- **Job history and management:** A detailed Job History page is available to users for viewing all the jobs they have ever submitted along with their original queries.
- **Table Import:** Users can import their own data as tables in MyDB via the CasJobs Import page, so that cross-match queries can be executed, on several datasets.
- **Shared data with groups:** Users can create or join one or more groups to which they can publish their MyDB tables. This makes the tables visible to all members of that group in their MyDB's.
- **User Login and account management:** Users' authorization is obligatory in order to be able to run batch queries, but they can run quick queries without logging in.
- **Data Extraction:** Users can download copies of MyDB tables to their home machines. The expectation is that users typically download their tables after they have refined their queries and results to their satisfaction, thus minimizing network traffic.

- **Annotation:** Users can leave comments on any database object in any visible context. Such comments are then visible to all users who can view that object. This lets people leave descriptions and usage details that might benefit other users and collaborators.
- **Access Control:** It is possible to restrict access to contexts to a certain group, so that only group members can query that context. In this case, the group's administrator controls the group's member list.
- **Programmatic Access:** The Web Services API's facilitate the development of third-party access tools for programmatic access to CasJobs. A Java command line access tool that we developed using these API's is currently available.

7.3 Technical Details

The SQL Implementation of the MaxBCG, can run either on a single SQL Server or on a cluster of SQL servers. As described above, the distribution of Zones among several servers allows parallel execution of the algorithm on different partitions of the target area. In addition to that, the data distribution is arranged so each server is completely independent from the others.

A benchmarking of the system was done, using a Microsoft SQL Server 2000 cluster, composed of 3 nodes, each one a dual 2.6 GHz Xeon with 2GB of RAM. Mainly, the algorithm consists of 3 tasks:

- The task that arranges the data into Zones, so the neighborhood searches are efficient
- The main task, that includes the BCG likelihood computations, and the main searches of the neighborhood for the proper estimation of the BCG likelihood.
- The selection task, that decides whether a "candidate" is a galaxy cluster.

7.3.1 Web Application

The CasJobs Web application's back end interfaces with SQL Servers to execute user queries in a distributed manner. More particularly, the CasJobs web site is based on a set of SOAP services, so any user can access these services directly using a SOAP tool-kit in his or her preferred programming language.

Also, a command-line package for accessing CasJobs in Java that serves as an example of how to programmatically access the services provided by CasJobs was written by the authors.

The authors have not implemented any Web service or Grid technology in order to track state in SOAP calls. Also, a database of jobs belonging to a particular user is being maintained, so privileges and authorization can be managed in individual basis.

7.3.2 Job Service

Apart from short jobs, everything in the CasJobs system is asynchronous and requires job tracking. Every job is registered in a “Jobs Table”. A Windows service (named “the procrastinator”) runs a thread that wakes up periodically and scans the Jobs table for new jobs for each target.

The procrastinator creates output files, updates job entries, and scans the HTTP directory in which files are written and removes files older than a configurable time.

7.3.3 Load Balancing

CasJobs uses the SQL-Server-linked server mechanism to execute queries remotely on different database servers. All servers, are linked bidirectionally, to allow a query running on one server to read or write results to a different server. This allows multiple copies of the same databases to be kept in different servers, and different queries to be applied on the same dataset in each server, and therefore a load balancing to be successfully achieved. This can easily scaled out as necessary by simply adding servers with more copies and creating query contexts for them.

7.4 Advantages of the approach

According to the authors’ view, the Zone Indexing technique in combination with the Relational Database has two important benefits. Firstly, the algorithm is “joining” a zone, and discards those objects that are beyond some radius. So the Spatial Searches, that are time and cpu intensive, are not needed. Secondly, by assigning different zones to each SQL server, full parallelization can be achieved.

The Benchmarking of the SQL Implementation showed gave a 2x speedup in the processing times, at the cost of 25% more CPU and I/O resources.

Also, the SQL implementation was, according to the authors, considerably simpler than the TCL-Astrotools old implementation of the algorithm, because it leveraged the features of the SQL system for data access, indexing and parallelism.

7.5 Current Status of the Project

According to a newest publication of the authors [45], currently CasJobs has become the mainstay and workhorse of the SDSS data-access system. It’s in use at SDSS mirror-sites worldwide and has also been adapted for non-SDSS astronomical archives. The technologies that CasJobs employs are universally applicable and inescapable for query management in very large online databases.

Chapter 8

Spitfire

8.1 Introduction

Brief information about this work can be described shortly in table (8.1)

Original Title	Project Spitfire - Towards GRID Web Service Databases
Authors	William H. Bell, Diana Bosio, Wolfgang Hoschek, Peter Kunszt, Gavin McCance, Mika Silander
Year of publication	2002
Journal	Informational Document, Global Grid Forum 5, Edinburg, Scotland, Jul. 21-24, 2002
Keywords	RDBMS, Grid Databases, Spitfire Project, EDG project

Table 8.1: Brief Information

8.2 Objectives and Initiatives

8.2.1 The Problem

In Data Grids, many small and large services spread over multiple loosely coupled organizations are working together to provide access to and management of massive amounts of distributed data [46]. A lot of Grid Services, like Replica Location Service [47], Hyper Registry [48] Job Scheduler [50] and Performance Monitor [51] maintain, in general, persistent metadata in databases.

There are mature, opensource as well as commercial implementations of Relational Database Management Systems (RDBMS), which are well established in the IT industry. Although, existing RDBMSs are neither grid enabled nor web service enabled. No Grid standards exist for uniform database interfaces, data model, network protocols and security, adversely affecting cross-organisational interoperability and reuse. In addition, the complexity of RDBMSs is often prohibitive for commodity usage.

8.2.2 The Proposal

The framework of the EDG Data Management work package (<http://cern.ch/grid-data-management>)(nowdays deprecated) addresses these issues with “Spitfire” project (<http://cern.ch/hep-proj-spitfire>) the motivation of which is to provide a secure grid enabled database service to permit access to a wide range of relational database systems through standard Grid protocols and well-published Grid interfaces. The Spitfire middleware is inserted into the control and data path between client and RDBMS. Spitfire, “grid-enables” a wide range of relational databases by introducing a uniform service interface, data model, network protocol and security model. These, are based on widely accepted standards (eg: OGSA [26], WSDA [52], URIs [54], HTTP [55], TLS [56], GSI [57], XML [29], SOAP [30], WDSL [58]) and neutral with respect to the programming language, platform and database product.

8.3 Technical Details

8.3.1 Overall Architecture

The Spitfire middleware is placed between client and RDBMS. The Spitfire Server, the client, and RDBMS can run on the same machine but can also run on three different machines separated by the LAN or WAN. Of course, in that case special security measures like use of the HTTPS protocol should be taken into account. The Spitfire server can be called from remote command line tools (jwget, wget, curl, ...), even from custom client applications, for example libwww-perl¹ or httpplib².

Moreover, the Spitfire server can be accessed by a browser client. In this case, the Spitfire server returns Result sets as formatted HTML tables instead of XML. The Spitfire server is implemented as Java servlet running within a “container” of a virtual hosting environment such as Apache Tomcat servlet container.

For the communication of Spitfire middleware with the RDBMSs, the JDBC API [59], based on Sun Java technology is being used. This API, defines a uniform vendor independent way to communicate with a wide range of RDBMSs. It is a thoroughly accepted industry standard and optimized drivers exist for a great range of RDBMSs. However, JDBC is Java specific and it does not specify a standard network protocol. The architecture can be summarized as follows:

1. The Client communicates with the Spitfire Server through XML/HTTPs protocols.
2. The Spitfire server, using JDBC API with specific drivers, contacts the RDBMS (even over a Grid Database) and mines the information that the client requested
3. The information, are being transferred, again through the JDBC API to the Spitfire Server

¹For more information, visit <http://ftp.ics.uci.edu/pub/websoft/libwww-perl/>

²For more information, visit <http://docs.python.org/library/httpplib.html>

4. The Spitfire Server transmits the Data to the requesting Client, through HTTPS/XML.

So, the program achieves to “Grid-ify” the RDBMS, by means that makes the data accessible from a remote (but authorized) client.

8.3.2 Grid Database Administration

According to the authors the year of publication, they were in progress of developing Spitfire as a Grid Service. The XML protocol will be replaced by SOAP in the case of Grid Web Service.

8.3.3 Data Model

The Spitfire client and server communicate relational data in canonical XML format ³. Canonical XML defines an 1:1 mapping from relational tables to XML format and vice versa: a relational table corresponds to an XML ROWSET element, and a row corresponds to a nested XML ROW element, and a column is mapped to a nested element with the same name, filled with the value of the row’s column.

8.3.4 Network Protocol

Spitfire is designed so that clients can read and write over HTTP(s) into any RDBMS. The project configuration is fully GSI enabled and compatible by using CoG, the Java port of the Globus Toolkit developed at Argonne National Laboratories.

8.3.5 Web Service Interface

Spitfire provides an abstract function invocation interface based on URL encoding [54] of function names and parameters for SQL standard functions such as query, insert, delete and update, as well as encoding of custom functions. Currently, the project runs on the Axis web service engine using the HTTP servlet binding. The main interaction of the client with the system is being done through a custom made API, the “Sptifire” API, which contains five independent interfaces, to one of which the user has to authenticate in order to be accepted as a “Spitfire” client.

8.3.6 Performance

Java servlets were chosen by the authors because of their high efficiency. In order to minimize the number of connection setups, persistent HTTP(S) 1.1

³For more information please visit the official site at: <http://www.w3.org/TR/xml-c14n>

connections are used. For similar reasons, the services use thread and JDBC connection pooling, and advanced catching.

8.3.7 Security

The security mechanism in Spitfire is performed in two steps:

1. User Authentication. This takes place with the x.509 certificate technology, and the issue of special digital certificates. The verification of the user's digital certificate validity is made in two phases: first the certificate's signature is verified against the set of trusted Certificate Authorities' certificates. Next, the certificate is checked against a Certificate Revocation List. If both test are passed, the client is properly authenticated.
2. User Authorisation. This procedure is being completed by the core servlet of Spitfire, Oracle XSQL Servlet. This servlet selects the XSQL file corresponding to the client's request. The file itself describes a data base operation. These files, are protected by embedding a XML tag. When the servlet encounters this tag, a special class is being called, which checks against the role database if the client is authorised to act in the given role. The verification is done using the certificate subject name of the client's x.509 certificate.

8.4 Advantages of the Approach

According to the authors, "Spitfire" offers a uniform service interface, data model, network protocol and security model in order to grid-enable a wide range of relational database systems. It is based on widely accepted standards and neutral with respect to the programming language, platform and database product. Also, according to the authors' view, "Spitfire" performs transparent translation of the input query and output result set to and from the target database backend.

8.5 Current Status of the Project

The project seems deprecated today. The official site (<http://hep-proj-spitfire.web.cern.ch/hep-proj-spitfire/share/spitfire/doc/>) seems broken, and the European Data Grid (EDG) project, is now deprecated and replaced by EGEE. No further information could be mined for the current status of the project, or possible updates. The authors are mentioning that their current work is to upgrade Spitfire to a Grid Web service.

Chapter 9

Summary

The projects studied in the present report were specific solutions in specific problems, using specific techniques. In the following sections the technical details of the approaches and the implementations are going to be put together and discussed.

9.1 Type of Data

In the six projects studied, there were several and different type of data that had to be managed, processed or distributed between the user teams engaged each time. The type of the data involved in each project can be found concentrated in the Table (9.1).

Table 9.1: Type of data involved in the projects

Project	Data Type
Nasa Earth Science Data Products	Geological
BiosimGrid	Medical
OncoGrid	Medical
Magda	High Energy Physics
Casjobs	Astronomical
Spitfire	High Energy Physics

The above mentioned users teams (Medical Doctors, High Energy Physicists, Astronomers, Earth Scientists) are rather representative user teams who are handling large amounts of data. For example, medical data are always data of increasing volume, because of the medical records that are of essential importance in diagnosis, apart from the large resolution always needed in medical imaging of every type; volume of data that are going to be produced by LHC at CERN is predicted enormous, because of the rare nature of the requested Higgs Boson; astronomical research requires usually large amounts of data to be processed, because of the density of the astronomical objects being observed by earth; the satellite born images used for earth science research is nowadays of increasing volume because of the escalating interest on the environmental factors affecting

humans.

In all the studied papers, the authors decided that the only way to deal with their large amounts of data, that had either to be processed or distributed, or both, among the geographically spread users, was to accept the view that: “Applications including collaborative visualization of large scientific datasets (pooling of expertise), distributed computing for computationally demanding data analyses (pooling of compute power and storage) and coupling of scientific instruments with remote computers and archives” [60] must exploit GRID technologies along with database application [61] in order to achieve the most effective solution.

The format of the data used in each project was totally different. Although, in all the implementations, the GRID infrastructures and database system used, were not “format-dependent”. The format-dependancy in the majority of the projects studied was implemented at the application layer, or directly in the user interface, or, where this was necessary, was taken into account in the data processing procedures, where each project implemented its own methods, adapted to its users needs.

9.2 Objectives

Different objectives had to be dealt by each one of the projects. Summarized, the problems that the proposals had to solve, can be found in the table (9.2).

These problems are different, in the sense that they are dealing with different types of data, different user teams, different constraints in each case, but, the overall aim is similar in all of them: Distribution and/or process of large amounts of scientific data.

Table 9.2: Objectives of the projects

Project	Problem to be solved
Nasa Earth Science Data Products	Large amount of data have to be downloaded by the users, from which only a small amount of useful fields must be extracted. Also there is a great collocation of useful data, that users have to collect, combine and process explicitly.
BiosimGrid	Large amount of Biological Simulation data have to be shared among the researchers in order to enable a large scale analysis of these simulation data.
OncoGrid	In Brazil, the patients cancer/health data are geographically spread among different locations and under different domains. Law requirements enforces these data to be registered and consolidated. An infrastructure that eases and accelerates this procedure must be implemented.
Magda	The amount of LHC data, and the process computing power is expected enormous, while these data must be available to researchers throughout the world. Therefore, the need of data retrieval and process in the home institutes is essential.
Casjobs	The MaxBCC algorithm checks astronomical data in order to find galaxy clusters. With the (then) current infrastructure of a dedicated cluster, the processing of files was very slow.
Spitfire	A lot of useful metadata from various GRID services worldwide are being kept in relational databases. A lot of times, these metadata have to be retrieved. This retrieval is extremely difficult due to the large distribution of the

9.3 Proposals

In the following paragraphs, a schematic summary of the basic parts of each proposal is being presented.

- Distributed Generation of NASA Earth Science Data Products

Schematically, the proposal of the authors for the Distributed Generation of Nasa Earth Science Data Products can be found in Figure (9.1).

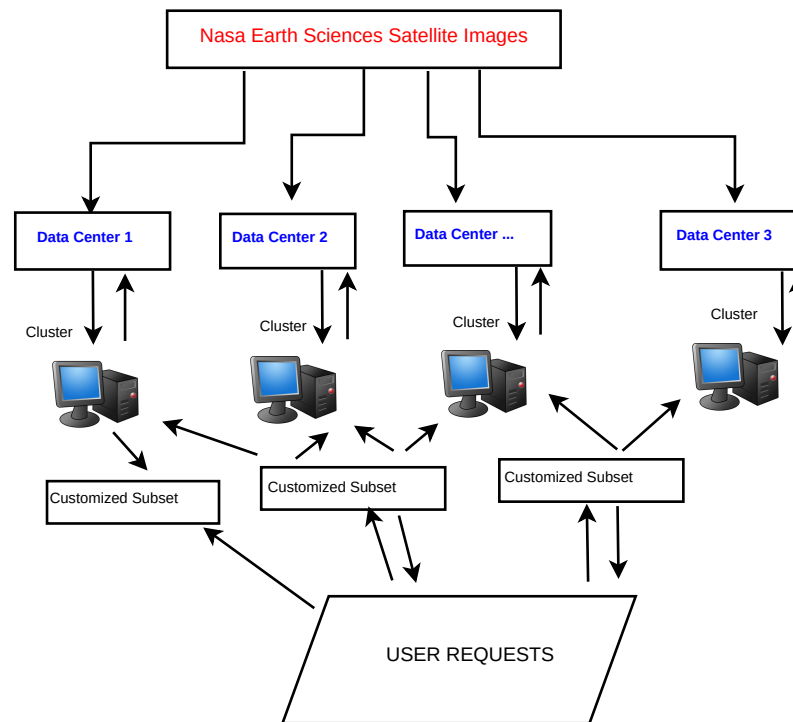


Figure 9.1: NASA Data Products Proposal Schema

The clusters, interconnected in a GRID, and connected with the tape archives of the satellite data, using a custom made subsetting program, are preparing the **custom** data set that user needs. At a second step, the clusters are communicating and are mining the information that the user asked for from all the interconnected archives. When the mining of the information is finished from all the archives, the data are being transferred to the original site, and from there are being sent to the user.

- BioSimGrid

Schematically, the proposal of the authors for the BioSimGrid project, can be found in Figure (9.2).

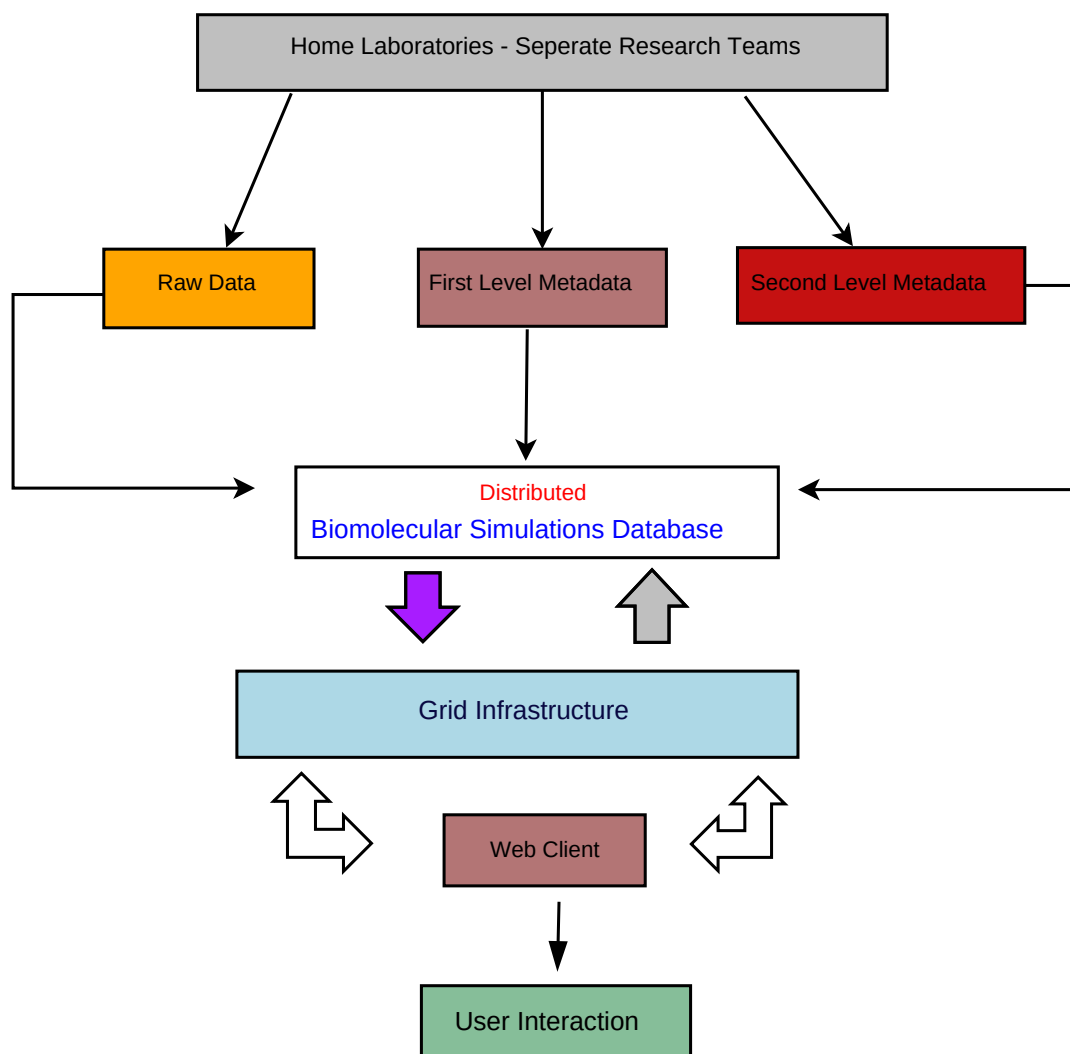


Figure 9.2: BioSimGrid Proposal Schema

The raw simulation data from the home laboratories, along with the first and second level metadata are imported into the distributed database systems. The corresponding GRID infrastructure, interacts with the database system from which is mining the information that the user asks for, through a web interface. When the desired data are concentrated, they are being sent to the user through the web interface.

- OncoGrid

Schematically, the proposal of the authors for the BioSimGrid project, can be found in Figure (9.3).

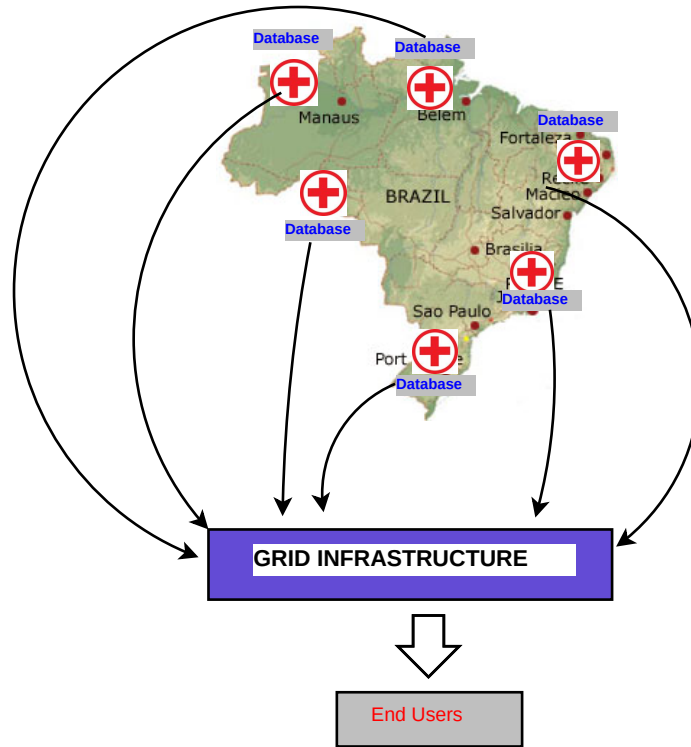


Figure 9.3: Oncogrid Proposal Schema

The main proposal of the OncoGrid project, is based on the existence of relational databases in each Hospital, which will keep its own medical records, and through a GRID infrastructure, a communication between these databases and therefore a national consolidation of these data will also be available. In order to get the cost reduced, the whole proposal is based on opensource software.

- MAGDA

Schematically, the proposal of the authors for the MAGDA project, can be found in Figure (9.4).

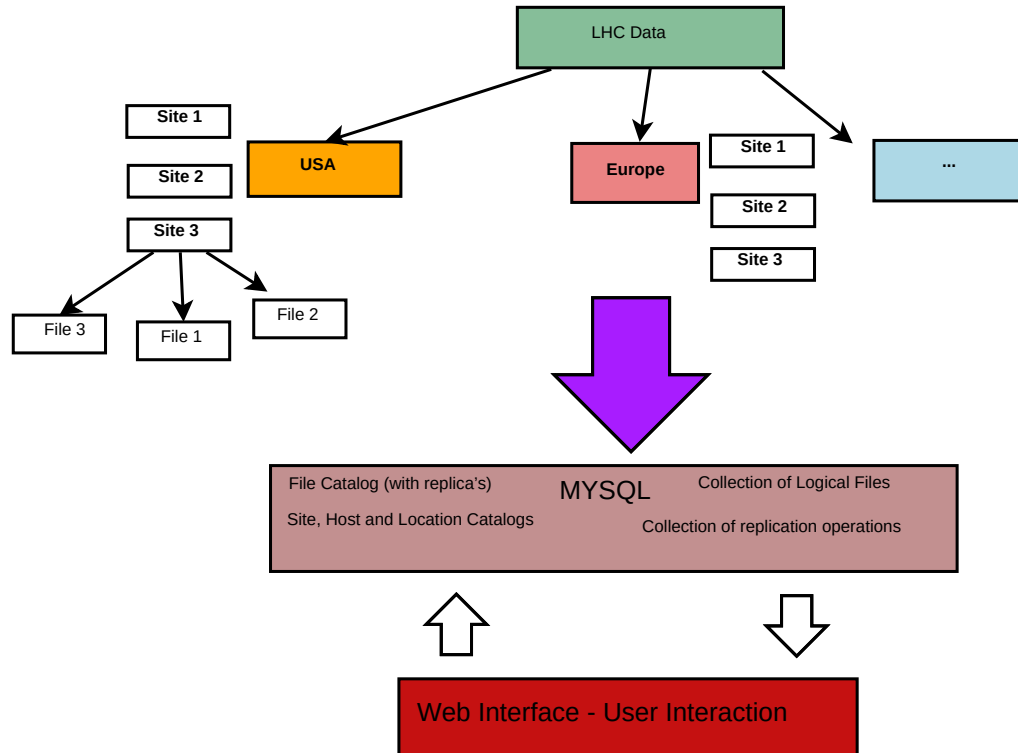


Figure 9.4: MAGDA Proposal Schema

All the information about the sites, the hosts and the locations of the geographically spread files are being stored in the MySQL database. The interaction of the user with the database is being done by special scripts and API's, and through a Web Interface. The difference between MAGDA and the other proposals, is that the project is not trying to interact with several distributed databases through the GRID, but to put the information from the GRID into one Database Management System, with which the end user will interact.

- CasJobs

Schematically, the proposal of the authors for the CasJobs project, can be found in Figure (9.5).

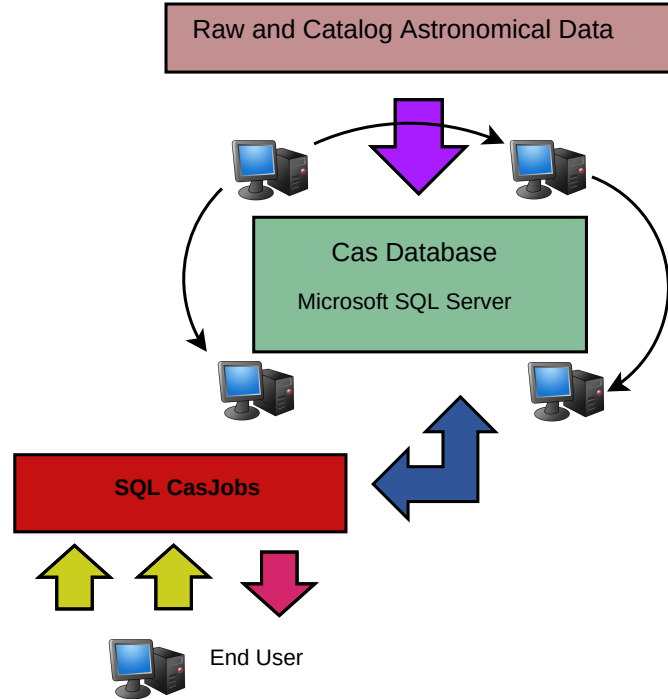


Figure 9.5: CasJobs Proposal Schema

In the proposal for the Grid Implementation of the MaxBCC algorithm, the CAS Database[40] will interact with the user through the custom made SQL application. The implementation of the CAS Database can be done either in a single machine, or a cluster of SQL Servers, where, simultaneous queries and processing can be achieved through the CasJobs SQL application. The final data are being sent to the user through a web interface.

- Spitfire

Schematically, the proposal of the authors for the Spitfire project, can be found in Figure (9.6).

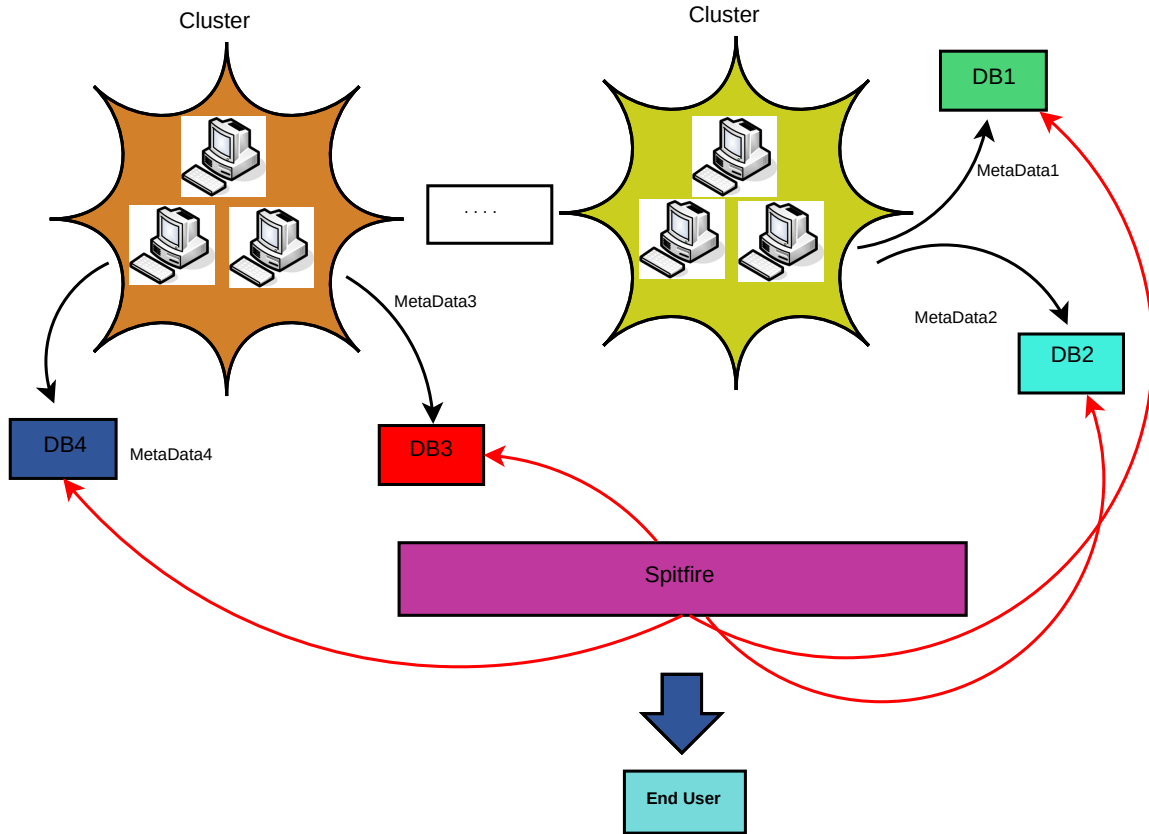


Figure 9.6: Spitfire Proposal Schema

The difference of “Spitfire” from the other projects presented in this study, is that it is dealing with the metadata (and not with the actual data) stored in several, geographically spread DBMS, and it addresses a way of communication between the end user and the remote databases. “Spitfire”, the year of the publication, according to the authors, it was intended to be developed as a Grid Service.

9.4 Technical Details

The different nature of the projects, as well as the different structure of the papers describing the proposals and the different depth on the analysis of the details of each project, does not allow a fully structured discussion about the technical details of the corresponding implementations. Nonetheless, in the following sections an attempt of juxtaposition and discussion of technical elements concerning the Database Management Systems, GRID infrastructures used, the interaction with the user and the security issues of each implementation will be done.

9.4.1 Database Management Systems

The Database Management Systems used in the six studied projects were chosen by the authors for different reasons in each case. In some cases the budget constraints were forcing the use of open source software only, while in other cases, the warranty of a commercial software was chosen in order to ensure the long time integrity of the database. In some cases, technical details enforced the use of a specific database management system. The database systems chosen, and the reason stated by the authors for their choice, can be found in table (9.3).

Table 9.3: DBMS used in the projects studied

Project	Database System Used	Reason given by the authors
Nasa Earth Science Data Products	-	No specific Database Management System was used in this project's approach. The subsetting operation of the data being implemented in the specific approach is similar to a database, since it creates rows and fields.
BioSimGrid	IBM-DBS UDES	"In order to address the challenges of distributed computing on large amounts of simulation data" is the only statement being done by the authors regarding the choice of the specific DBMS software.
OncoGrid	PostgreSQL	Open standards and tools were chosen in order to minimize the deployment costs.
Magda	MySQL	- (Authors are not stating why they chose the core of the system being a MySQL database)
Casjobs	(for the CAS Database) - Microsoft SQL Server	Microsoft offered the authors support and one of the authors was already intimately familiar with the software. So the MS-SQL server dictated over the other option that was the (also commercial) IBM-DB2 Server
Spitfire	MySQL (more to be supported soon)	In an example implementation, the authors used the MySQL database, without stating any specific reason. But also they are stating that a variety of vendors (DB2, Oracle, etc) are going to be supported.

From the above table, one can see that the choices of the core database system are being dictated by the specific conditions taking place in each problem. Excluding the "Spitfire", which the databases are not part of the implementation but they have to be supported by the project, and "Nasa Earth Science Data Products" which does not actually use a DBMS, in the other 4 projects, the choices

were limited either to the broad used commercial Microsoft SQL Server and IBM-DB, mainly because of the support offered from the developing companies, but also because of their proven stability in handling large amounts of data. As far as Oncogrid is concerned, the budget constraint was significant, so the DBMS software was chosen with the coefficient of the cost to play the most significant role, and an opensource DBMS was chosen. However, the authors are not stating why they chose PostgreSQL instead of some other opensource DBMS, like, for example, MySQL.

9.4.2 Grid Infrastructure Software

In all the projects studied, a grid computing infrastructure is deployed. In the five out of the six projects (“Nasa Earth Science Data Products”, “BioSimGrid”, “OncoGrid”, “Magda” and “Spitfire”), the computer clusters deployed were either dedicated (“Nasa Earth Science Data Products”, “BioSimGrid”, “OncoGrid”) or clusters of the public domain (“Magda”, “BioSimGrid”), in the sense that are broad-use clusters in the framework of the EDG or US-GRID Projects (Now replaced by EGEE). Of course, in each implementation several differences exist, for example custom-made scripts (the subsetter software in “Nasa Earth Science Data Products”, or the custom SQL application software in the case of “CasJobs”). However the main software tools being used so in the dedicated clusters as in the more public ones, was the tools of the Globus Toolkit [24] [Version 3 or 4], with the exception of the “CasJobs” project, in which the authors are not mentioning specific information about the dedicated cluster used in their implementation. The main grid middleware used in the projects studied can be found concentrated in the table (9.4).

Table 9.4: Grid Middleware used in the projects studied

Project	Grid Middleware Used
Nasa Earth Science Data Products	Globus Toolkit 3
BioSimGrid	Globus Toolkit 3
OncoGrid	Globus Toolkit 4
Magda	Globus Toolkit [no version specified]
Casjobs	- [non specified by the authors]
Spitfire	Globus EDG [Globus Toolkit ancestor]

As one can clearly observe from the table (9.4), Globus Toolkit is the dominant choice as the middleware for the Grid Infrastructures used, even if the application layer (above the middleware layer) is totally different in each case, or different tools of the toolkit are being exploited in each implementation. The choice of Globus Toolkit 4 for the “Oncogrid” project is being supported by the authors, as a decided choice after several evaluations [62, 63, 64, 65], and because of its support of multiple applications, the standardized communication, the free binary opensource code and because of its frequency of usage for GRID computing implementation[66]. For the “BioSimGrid” the choice of the authors for the Globus Toolkit was because of its opensource and open-architecture set

of services and software libraries, which enable the handling of distributed and heterogeneous computing resources as a single virtual machine. In the rest of the studied projects, no specific reason is being stated by the authors to support the choice of Globus Toolkit as the Grid Middleware.

9.4.3 Interaction With the Databases

A very important part of the present study, is to summarize the way that the Grid Middleware, or in general the Grid infrastructure interacts with the databases. Of course, this layer presents significant differences between the implementations. However, a project-by-project juxtaposition will be done in the next paragraphs and some comments in each one (if available in the original papers) will be presented.

- **Nasa Earth Science Products**

As far as this project is concerned, no database management system was used by the authors, in the sense of a specific autonomous software as in the other cases. Although, the raw data were sub-setted by an XML driven subsetter, which, creates structures similar with rows and fields. In order to deal with the problem of collocation of data stored in different archives, the authors are using a specific software which is sent to the Grid processors to mine the requested information.

- **BioSimGrid**

In the BioSimGrid, the main tool used for the interaction of the grid with the databases, is the OGSA-DAI [67], a framework for accessing and integrating data resources over the Grid. The authors are supporting their choice by stating that the open standards and service interfaces were ideal for accessing and controlling heterogeneous database resources as they were a single logical resource. Therefore, the BioSimGrid applications will deliver services based on several distributed queries with the minimal programming effort. Moreover, heterogeneous databases can be used in the project without any needs of changing the application code.

- **OncoGrid**

In this project, the OGSA-DAI framework was again used in the communication between the middleware and the databases. The authors are stating that they decided to use OGSA-DAI because it is an opensource tool already used in different research initiatives, such as CaBIG [68], BioSimGrid [69] and UniProt [70]. The authors considered that as an evidence of the middleware stability. They are stating also that the use of OGSA-DAI framework would solve the problem of the non-homogeneous database systems of the hospitals, and enabling the sharing of data among them.

- **Magda**

In the Magda project, there is no need of interaction of a Grid infrastructure with the database, in the sense that this was discussed in the previous projects. The interaction of the information with the MySQL database implemented in this project, is done by C++, Java and Perl APIs that are

also used from the users to access the database components, while special custom made Perl scripts are filling in the database with the information crawled from all the sites and locations. In the original paper, the authors are not commenting on the reasons of their choices at all.

- **CasJobs**

In the CasJobs implementation, that is the interaction over the GRID with the CAS Database, the authors are stating that only a custom solution should work for their case. They are discussing of custom implementation in each cluster of their CasJob database, and they are looking forward in using in the future more official (in the sense of grid-services) implementations.

- **Spitfire**

The communication between the Spitfire server and the remote RDBMS's is being implemented by the authors with the use of Java JDBC API [59]. For the communication with each remote DBMS a different JDBC driver is being used. The JDBC API was chosen, because all the Spitfire server software is mainly a Java servlet running into a virtual container of Apache Tomcat. Authors are supporting their choice of JDBC API by declaring that the JDBC API defines a uniform vendor - independent way to communicate with a wide range of RDBMSs. It is a thoroughly accepted industry standard and optimized drivers exist for every serious RDBMS.

9.4.4 User Interaction

A very important part of each implementation, is the way that the underlying layers are interacting with the end user. The user interface should be easy-to-use and the end user should be totally isolated from the underlying technical details, at the magnitude that this is feasible.

- **Nasa Earth Science Data Products**

Since the goal of this project was just to test the possibility of implementing Grid technologies in an already working situation, the authors in the original paper don't give much details on how exactly did the user interaction work. They are just referring that the user imported the information for the files he wanted to mine in a specific, XML template file, which was subsequently "driving" the special subsetter developed for the application, to mine the specific files and information from the archive. XML files are driving the subsetter in the second case that data are mined from multiple archives, geographically spread from the end-user.

- **BioSimGrid**

Special attention has been paid in the user interaction in the BioSimGrid project. Through an Apache web server, a https based client interacts with the system. The client can be either a standard web browser or web-based application. The use of the web interface eliminates development and maintenance of client software. The user can interact with the BioSimGrid from anywhere and with "anything" (laptop, PDA, etc.) This gives to the system great portability while it allows to the scientists without a lot of

“special procedures” to interact with the database and mine the information they want. The web server interacts with the database through XML/SOAP protocols.

- **Oncogrid**

The authors of “Oncogrid” project, take also up the view that “Like in the power lines infrastructure, the Grid-Computing user must use the available resources transparently, without noticing the complexity in the environment composition” [66, 71]. So, they implemented for their project two methods for user interface:

1. Web Applications (known as Grid Portals).

This kind of user interface, was selected by the authors because it offers mobility to the users and allows access to the environment through an Internet web browser. The Grid Portals, allow through a single login procedure access to the whole infrastructure, without requiring from the user to authenticate at every step.

2. Client Applications

According to the authors view, the client applications may not offer much mobility since they require a more controlled environment to access the available resources in the grid, but on the other hand they have better usability and interaction facilities when compared to Web Applications.

Both interactions with the end user seem to have implemented by the authors, as a proposal for the project. Although, in the implementation that the users are describing as a testbed for their application, a Grid Web Portal is used for the interaction with the users.

- **Magda**

Authors of the “Magda” project, are giving minimal information about the user interaction of their project, except from that the main way of user interaction with the MySQL database is a web interface and several Perl, C++ and Java scripts. From the web interface, the user is able to browse the whole database (“catalogs”, “locations”, “site”, “hosts”), to query the system and modify its entries. Moreover, the collection of the command line tools, according to the authors are there to provide catalog query, file archiving and validation as well as file transfer from the database locally.

- **CasJobs**

The “CasJobs” Web site is based on a set of SOAP services, so any user can access these services directly using a SOAP toolkit in his or her preferred programming language. The authors are discussing about the implementation of the web site hosted at the Johns Hopkins University, where Python, Java and Perl has been used. Because currently the CAS database is being hosted in different organizations, the access policy that they apply to the database is different. Nevertheless, the authors are stating that CasJobs is accessible not only through the web interface but also through several web services. For more information, see [45].

The innovative implementation of user interaction that appears in “CasJobs” is the personalized database that the system offers to its users. More specifically, the query output can be stored on the server-side in the user’s

personal relational database, to which the authors are giving the name “MyDB”. Users are therefore able to upload and download data to and from their MyDB. Corellation, filtering and search in the main database are also offered. Also, the project provides a collaborative environment where users can form groups and share data with others. Also, a job history for each user is available through a special page. For more information, the reader may see [45].

- **Spitfire**

In the Spitfire project, the communication between the Spitfire Server and the client takes place through the XML/HTTPS protocols, through a special API, named by the authors “Spitfire API”. This API is partitioned over five independent interfaces, in one of which the client has to be authenticated, in order to use the infrastructure. The five layers of the API are:

1. **Grid Database Administration Interface**

This interface provides administrative functionality over the Grid-enabled databases upon the RDBMS, allowing authorized clients to create, drop and alter databases and tables.

2. **User Management Interface**

Administrators are permitted to remotely change roles and permission level of users associated to these roles.

3. **Database Information Interface**

From this interface, authenticated clients are permitted to extract information about the database, its associated tables and their schema.

4. **Core SQL Functionality**

From this interface, the common insert, update, delete, and select functionality upon the remote database is implemented.

5. **High-level functionality**

Authors are stating that no higher-level services are being implemented by now, although future work includes functionality that will permit possible replication of database views, distribution and load balancing, and automated clean up services to remove stale meta-data.

9.5 Security

In the six studied projects, the security, either played a very significant role (for example in the projects dealing with medical data, where the preservation of personal data has to be taken into account), or the authors didn’t care at all about the security, which was the case, for example, in CasJobs, because the astronomical data can be freely available to everyone. In the following sections a summary of all the security features, in the detail depth of information that can be offered from the original papers.

- **Nasa Earth Science Data Products**

In that specific project, the authors are minimally discussing security issues. Probably, the reason for that is that from one hand the specific data are

not “sensitive” in the sense that special security meters have to be taken in order to be protected from un-authorized users, and from the other hand, the specific project was just “test-implemented”, in the sense that authors are discussing several issues before exporting their proposal to production stage, so the security was of not an important issue in that’s project’s case.

- **BioSimGrid**

In the BioSimGrid case, the authors are implementing a three-core security mechanism, based on authentication, authorization and accounting. More specifically:

- Authentication

The authentication mechanism consists of two levels. At the first level, the user authenticates using a digital certificate, which is verified through the certificate-based authentication that has been implemented to the system (OpenCA). More specifically, the authentication mechanism based on Public Key Infrastructure (PKI) and X.509 digital certificate technologies, verifies the X.509 user’s digital certificate against the one stored in the corresponding database, and only if the security check is successful, the user grants access to the services.

The second level includes a user/pass based authentication. This is designed for those users who cannot use the digital certificate technology, due to software restrictions. This level of authentication enables web access of the system via a public pc anywhere in the world. The authors are explicitly stating that all the web accesses are based on Secure Socket Layer (SSL) via HTTPS. The authentication mechanism is currently based on user credential delegation implemented using MyProxy [18, 22]. Although, the authors are not further discussing why they chose these tools among others.

- Authorisation

The authors have implemented an internal security database containing the necessary user account information, in order the users of the portal to be verified against that database. This security database is being queried by the authorization component of the system to retrieve the user account information such as username, organization, and access level. Once this information is confirmed, the user will have access his/her permitted area(s).

- Accounting

Authors implemented a full logging of the transaction taking place from and to the database. In their future plans, is the design of a distributed accounting mechanism in order to enhance the security as well as to trace the system usage. User activities will be stored, while for the retrieval of the accounting information of a particular user, an accounting component based on distributed queries will be developed by the authors.

- **OncoGrid**

Since the “OncoGrid” project is dealing with Medical Data, the security layer of the project is enhanced and being analytically discussed by the authors. The comment of the authors is that due to the nature of the data involved,

a security level with high flexibility offering the functions of authentication, authorization, delegation, message protection, access control and certification management should be implemented [72].

The GSI (Grid Security Infrastructure) standard is being used by the authors of the paper. As in “BioSimGrid”, a special certification authority, the OncogridCA, delegates the users’ digital certificates, while the credential delegation is being done with the MyProxy package, using the Single Sign On method, which enables the user to access the whole infrastructure with a single login. The authors are giving some details on their implementation:

- OncoGridCA

Under this section the authors are explaining why the use of X.509 digital certificate in combination with the PKI is essential and applies both at Grid Portals and Client Applications. As far as the Grid Portals are concerned, more mobility is offered since a Single Sign On login takes place, and the user grants access to the whole infrastructure without further authentication procedures. For the Client Application case, there is less mobility because the authentication should take place in a more controlled environment, but they are offering better usability and interaction facilities when compared to web applications.

- MyProxy

The authors are supporting their choice of “MyProxy” because it offers on-line credential repository and allows access control, delegation, authentication and safe storage of the private keys. According to the authors’ view, this tool provides the means for compatibility between the security protocols used on the web and the specifications from OGF [21] through the delegation of credentials and SSO.

- **Magda**

The authors of “Magda” in the original paper don’t at all comment on the security of the project. No information about possible security issues or implementations.

- **CasJobs**

The authors of “CasJobs” are making on their original paper only the comment that “we are working on the issues of security”. In general the whole project seem to be publicly available, and the issues of security don’t seem to interest the authors.

- **Spitfire**

The security layer of “Spitfire” is similar with “BioSimGrid” and “OncoGrid”. Valid digital certificates signed from trusted Certification Authorities (spread worldwide, in order to serve the user community), are being transported via SSL to the security layer of the infrastructure. The certificate is being checked for validity and revocation. Afterwards, and if this check is succesful, the name of the user, extracted from the digital certificate, is used in order to authorize the client under a role. If a role is explicitly requested, the certificate is checked for the permissions of that role, in the backend database.

Chapter 10

Simulations: Introduction

10.1 Radioactivity

The term “radioactivity” refers to those spontaneous transformations that involve changes of the nuclei of atoms. The energy released in such transformations is emitted as photons and/or other radiations [73]. Radioactivity is a stochastic process; the whole atom is involved in this process because nuclear transformations also can affect the atomic shell structure and cause emission of electrons, photons or both.

Atoms are subdivided into nuclides. A nuclide is a species of atoms having a specified number of protons and neutrons in its nucleus. Unstable nuclides, that transform to stable or unstable progeny, are called “radionuclides”. The transformation results in another nuclide or in a transition to a lower energy state of the same nuclide.

The **decay constant**, λ , of a radionuclide in a particular energy state is the quotient of dP by dt , where dP is the probability that a given nucleus undergoes a spontaneous nuclear transformation from that energy state in the time interval dt , thus:

$$\lambda = \frac{dP}{dt} \quad (10.1)$$

The unit of λ is s^{-1} .

The quantity $\frac{\ln 2}{\lambda}$, commonly called the “half life”, $T_{1/2}$, of a radionuclide, is the mean time taken for the radionuclides in the particular energy state to decrease to one half of their initial number.

The **activity**, A , of an amount of a radionuclide in a particular energy state at a given time, is the quotient of dN over dt , where dN is the number of spontaneous nuclear transformations from that energy state in the time interval dt , thus:

$$A = \frac{dN}{dt} \quad (10.2)$$

where the unit of activity is $[s^{-1}]$, which has the special name Becquerel (Bq)

The activity, A , of an amount of a radionuclide in a particular energy state is equal to the product of the decay constant λ , for that state, and the number N of nuclei in their state, thus:

$$A = \lambda \cdot N \quad (10.3)$$

10.1.1 Serial Radioactive Decay

Substituting the equation (10.2) to (10.3) and solving the corresponding differential equation, the well known law of exponential decay occurs:

$$N = N_0 e^{-\lambda t} \quad (10.4)$$

where N is the number of nuclei N_0 the initial number of nuclei, λ the natural constant of decay and t the time ¹.

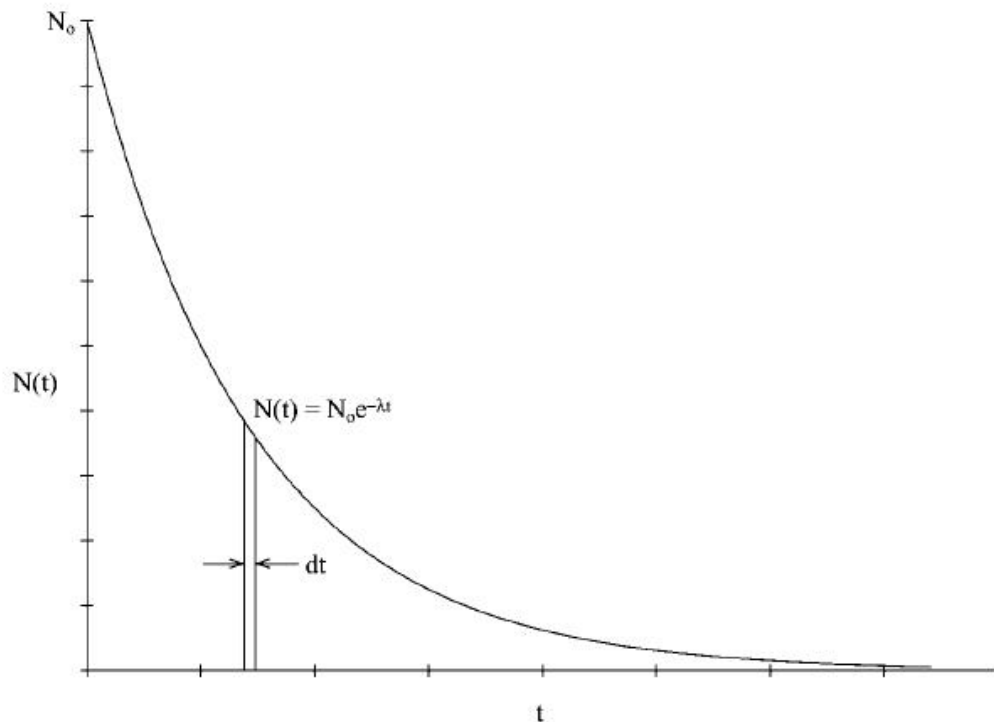


Fig. 3-33 Mean life τ of a radioactive substance is obtained by determining a value τN_0 that equals the total area under the curve, or the sum of the differential areas $N(t)dt$ from $t = 0$ to $t = \infty$.

Figure 10.1: Image source: [84]

¹The minus symbol is just to “declare” that the number of nuclei is decreasing

Series Decay Calculations

The radioactive transformation of many radionuclides often yields a product that is also radioactive. The radioactive product in turn undergoes transformation to produce yet another radioactive product and so on until stability is achieved. The number of atoms of each member of a radioactive series at any time t can be obtained by solving a system of differential equations which relates each product $N_1, N_2, N_3, \dots, N_i$ with corresponding disintegration constants $\lambda_1, \lambda_2, \lambda_3, \dots, \lambda_i$.

Each series begins with a parent nuclide N_1 , which has a rate of transformation:

$$\frac{dN_1}{dt} = -\lambda_1 N_1 \quad (10.5)$$

The second nuclide in a radionuclide series will be produced at a rate of $\lambda_1 N_1$ due to the transformation of N_1 , but as soon as atoms of N_2 exist, they can undergo transformation if they are radioactive; Thus, the rate of change of atoms of N_2 is the rate of production minus the rate of removal of N_2 atoms, or:

$$\frac{dN_2}{dt} = \lambda_1 N_1 - \lambda_2 N_2 \quad (10.6)$$

Similarly, for atoms of N_3 , which are produced by transformation of N_2 atoms and subject to removal as a function of the disintegration constant λ_3 ,

$$\frac{dN_3}{dt} = \lambda_2 N_2 - \lambda_3 N_3 \quad (10.7)$$

Generalizing the above,

$$\frac{dN_i}{dt} = \lambda_{i-1} N_{i-1} - \lambda_i N_i \quad (10.8)$$

If the end product is stable, the atoms of the stable end product appear at the rate of the last radioactive precursor, and of course are not removed since they are stable.

Solving that system of differential equations, one can obtain the following equations. For the number of atoms N_1 ,

$$N_1 = N_1^0 e^{-\lambda_1 \cdot t} \quad (10.9)$$

where N_1^0 is the number of atoms of parent at $t = 0$. This expression for N_1 can be inserted into (10.6) to give:

$$\frac{dN_2}{dt} = \lambda_1 N_1^0 e^{-\lambda_1 \cdot t} - \lambda_2 N_2 \quad (10.10)$$

which can take the form:

$$\frac{dN_2}{dt} + \lambda_2 N_2 = \lambda_1 N_1^0 e^{(\lambda_2 - \lambda_1)t} \quad (10.11)$$

This type of equation can be converted into one that can be integrated directly by multiplying through by an appropriate factor, which in this case is $e^{\lambda_2 t}$ [84]. So, the equation (10.11) becomes:

$$\frac{d}{dt}(N_2 e^{\lambda_2 t}) = \lambda_1 N_1^0 e^{(\lambda_2 - \lambda_1)t} \quad (10.12)$$

which can be directly integrated to give:

$$N_2 e^{\lambda_2 t} = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1^0 e^{(\lambda_2 - \lambda_1)t} + \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1^0 (e^{-\lambda_1 t} - e^{-\lambda_2 t}) \quad (10.13)$$

where the last term of the sum corresponds to the integration constant, that was calculated by the initial conditions ($t = 0, N_2 = 0$).

Therefore, the solution for N_2 as a function of time, is:

$$N_2(t) = \frac{\lambda_1}{\lambda_2 - \lambda_1} N_1^0 (e^{-\lambda_1 t} - e^{-\lambda_2 t}) \quad (10.14)$$

Following exactly the same procedure for the numbers of atoms of the third kind, after the integration and the calculation of the integration constant, the equation for the number of atoms of N_3 with time is:

$$N_3(t) = \lambda_1 \lambda_2 N_1^0 \left[\frac{e^{-\lambda_1 t}}{(\lambda_2 - \lambda_1)(\lambda_3 - \lambda_1)} + \frac{e^{-\lambda_2 t}}{(\lambda_1 - \lambda_2)(\lambda_3 - \lambda_2)} + \frac{e^{-\lambda_3 t}}{(\lambda_1 - \lambda_3)(\lambda_2 - \lambda_3)} \right] \quad (10.15)$$

And the same procedure is being followed for every series involved.

The solutions for the numbers of atoms of radioactive series yields a recursion of similar terms, which has been generalized into a series of expressions known as the Bateman Equations, if it is assumed that at $t = 0$ only the parent substance is present. For more information, see [84].

Radioactive Equilibrium

The relative activities of a radioactive parent and its radioactive product (commonly referred to as “the daughter”) can be determined from the equation for the number of atoms for the second member of series by multiplying both sides by λ_2 . Then one has:

$$A_2(t) = \frac{\lambda_2}{\lambda_2 - \lambda_1} A_1^0 (e^{-\lambda_1 t} - e^{-\lambda_2 t}) \quad (10.16)$$

Therefore, the time of maximum activity $A_0(t)$, t_m , can be determined by differentiating the equation (10.16), setting it equal to zero, and solving for t_m :

$$t_m = \frac{\ln(\lambda_2/\lambda_1)}{\lambda_2 - \lambda_1} \quad (10.17)$$

The time of maximum activity occurs at the same time that the activities of the parent and daughter are equal if, and only if, the parent has only one radioactive product. Two special cases of radioactive equilibrium are Secular Equilibrium and Transient equilibrium.

- If the period of observation (or calculation) is such that the activity of the parent nuclide remains essentially unchanged, i.e is much longer lived than the product, then the activity of the radioactive product in the equation for the second member of a radioactive series can be simplified as follows:

$$A(t) = A_1^0(1 - e^{-\lambda_2 t}) \quad (10.18)$$

When the above described condition is satisfied, the product activity will grow to a level that is essentially identical to that of the parent, and the activities of the parent and the product show no appreciable change during many half-lives of the product. This condition is called **secular equilibrium**.

- A condition called **transient equilibrium** results between a radioactive parent and a radioactive product if the parent is longer-lived than the product ($\lambda_1 < \lambda_2$), but the half-life of the parent is such that its activity diminishes appreciably during the period of consideration. If no product activity exists at $t = 0$, the activity of the product is given by:

$$A_2(t) = \frac{\lambda_2}{\lambda_2 - \lambda_1} A_1^0 (e^{-\lambda_1 t} - e^{-\lambda_2 t}) \quad (10.19)$$

For values of t above 6.7 half-lives or so, $e^{-\lambda_2 t}$ becomes negligible compared with $e^{-\lambda_1 t}$ and the activity of the product is essentially:

$$A_2(t) = \frac{\lambda_2}{\lambda_2 - \lambda_1} A_1^0 e^{-\lambda_1 t} \quad (10.20)$$

Thus, the product eventually diminishes with the same half-life as the parent. When this condition exists, the two nuclides are said to be in transient equilibrium

10.2 Nuclear Interactions

As nuclear interactions are defined those processes that involve a bombarding particle and a target nucleus. Projectiles used in nuclear interactions can be alpha particles (a), protons (p), deuterons (d), neutrons (n), or light nuclei such as tritium (3H) or helium (3He). Interaction of a projectile with a target atom (the reactants) yields first a compound nucleus which then breaks up to produce the final products.

The total charge (total Z) and the total number of nucleons (total A) are the same before and after the reaction, and momentum and energy must be conserved in each reaction.

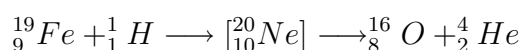
Three categories of interactions can occur between the incident particles and the target particles.

1. **Scattering**, in which the projectile bounces off the target nucleus with a transfer of some of its energy. Scattering reactions produce a decrease in the energy of the projectile by elastic or inelastic scattering. If the residual nucleus is left in its lowest or ground state, the scattering is elastic; if left in an excited state, the scattering is called inelastic.
2. **Pickup and stripping reactions** in which a high-energy projectile either collects (picks up) or loses (strips) nucleons from a target atom. These reactions usually occur when the projectile has high energy, and in such reactions the nucleon enters or leaves a definite “shell” of the target nucleus without disturbing the other nucleons in the target
3. **Absorption** of the projectile into the target nucleus to form a new (or excited) atom that then undergoes change. Absorption reactions occur when the incident projectile is fully absorbed into a target atom to form a new compound nucleus which lives for a very short time in an excited state and then breaks up. The new nucleus only exists for 10^{-16} s or so; thus, it cannot be observed directly, but this is much longer than the 10^{-21} seconds required for a projectile to traverse the nucleus. It is therefore assumed that the compound nucleus does not “remember” how it was formed, and consequently it can break up any number of ways depending only on the excitation energy available

Each type of interaction will produce recoil of the nucleus and deceleration (or stopping) of the particle, which alters its momentum and energy.

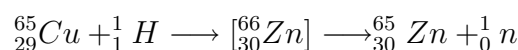
10.2.1 Proton-Alpha Particle (p, α) Reactions

Irradiation of various target materials with protons yields alpha particles; for example:



10.2.2 Proton-Neutron (p,n) Reactions

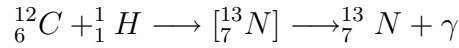
Protons can be used to produce neutrons in certain target elements through interactions that are mostly endoergic. The effect of these transmutations is to increase the charge on the target nucleus by one unit, moving it above the line of stability on the chart of the nuclides with no change in the mass number. Such reactions are usually endoergic because mass changes are negative. For example:



where the proton reacts with the nuclei to produce a neutron. For example the Q-value of the (p,n) for ^{65}Cu is €“2.13 MeV and the threshold energy is €“2.16 MeV. Protons incident on foils of ^{56}Fe , also yield neutrons by the $^{56}\text{Fe}(p, n)^{56}\text{Co}$ reaction.

10.2.3 Proton-Gamma (p,γ) Reactions

Some proton interactions produce an excited state of the target nucleus which is relieved by emission of a gamma photon. Example of a (p,γ) reaction is:



10.3 Neutrons

The comprehensive treatment of neutron interactions is vast in the international literature [85, 87, 88]. The energy of neutrons, has extensively studied and several classes of neutron energies exist. The most basic ones appear in table (10.1).

Table 10.1: Neutron Energy (temperature)

Energy (eV)	Energy designation
10^{-3}	cold
0.025	thermal
1	slow
10^4	epithermal
10^6	fast

10.3.1 Neutron Interaction

Three main interactions of neutrons with other nucleons exist:

- Neutron - Neutron ($n - n$).
Elastic or inelastic scattering may occur between the interaction of two neutrons. One must note at this point that this scattering should be free of the effects of Coulomb Interactions, since the neutrons are neutral in terms of charge. Although there are many experimental difficulties in studying that kind of scattering [86].
- Neutron - Proton ($n - p$)
- Neutron - Electron ($n - e$)

10.3.2 Neutron Reactions

Although neutrons are not charged particles, i.e themselves they don't consist ionizing radiation, they interact highly with the other nucleons, often

producing ionizing radiation. The main nuclear reactions that neutrons are involved, are the following:

- Elastic or Inelastic Scattering ($A(n, n)B$)
- Radiative capture ((n, γ))
- Charged particle emission ($A(n, p)B$, $A(n, \alpha)B$)
- Fission ($(n, f)B$)

10.4 Quantities and Units of Radiometry

10.4.1 Ionizing Radiation

The term “ionizing radiation” refers to charged particles (e.g. electrons or protons) and uncharged particles (e.g. photons or neutrons) that can produce ionization. Since in some cases the difference between the excitation and ionization can become blurred, a pragmatic approach for dealing with this ambiguity is to adopt a threshold for the energy that can be transferred to the medium, and therefore define cut-off energies below which charged particles are not considered to be ionizing. Hence, the choice of the cut-off energies does not materially affect the spatial distribution of energy deposition, except at very small distances.

10.4.2 Stochastic and Non-Stochastic Quantities

Differences between results from repeated observations are very common in physics. These can arise from imperfect measurement systems, or from the fact that many physical phenomena are subject to inherent fluctuations. Thus, one distinguishes between a non-stochastic quantity with its unique value and a stochastic quantity, the values of which follow a probability distribution. In many instances, this distinction is not significant because the probability distribution is very narrow.

10.4.3 Scalar Radiometric Quantities

The scalar radiometric quantities used in the framework of the present thesis are:

- The **particle number**, N is defined as the number of particles that are emitted, transferred or received. The unit of particle number is 1 (dimensionless quantity). The distribution

$$N_E = \frac{dN}{dE} \quad (10.21)$$

is also defined, where dN is the number of particles with energy between E and $E + dE$. [73]

- The **fluence**, Φ , is defined as the quotient of dN by $d\alpha$, where dN is the number of particles incident on a sphere of cross-sectional area $d\alpha$, thus:

$$\Phi = \frac{dN}{d\alpha} \quad (10.22)$$

The unit of fluence is $[m^{-2}]$.

- The **Double Differential Particle Yield** can be defined as the distribution of particles propagating within a solid angle $d\Omega$ around a specified direction, in respect to their energy. Thus:

$$Y = \frac{dN}{d\Omega dE} \quad (10.23)$$

By dimensional analysis, the unit of this quantity is $[sr^{-1} \cdot J^{-1}]$.

- The **absorbed dose** D , is the quotient of $d\bar{\epsilon}$ by dm , where $d\epsilon$ is the mean energy imparted to matter of mass dm , thus:

$$D = \frac{d\bar{\epsilon}}{dm} \quad (10.24)$$

The unit of the absorbed dose is $[J \cdot kg^{-1}]$, which has the special name Gray (Gy). More specifically, one gray deposits one joule of energy in a kilogram of irradiated tissue.

10.4.4 Individual Monitoring

Absorbed dose makes no distinction between several types of radiation (ie. alpha, beta gamma etc) or between types of tissue or organ irradiated, some of which are more sensitive to irradiation than others (ie thyroid, ovaries etc). The International Commission on Radiological Protection (ICRP), after revising several publications [78], introduced in 1985, in report 39 [75] which was revised on 1991, on report 60 [73] the quantity that is considered to be of interest, which is the absorbed dose averaged over a tissue or organ (rather than at a point) and weighted for the radiation quality. This weighted absorbed dose is called the **equivalent dose** in a tissue or organ, using the symbol H_T . Thus:

$$H_T = \sum_R W_R \cdot D_{T,R} \quad (10.25)$$

where $D_{T,R}$ is the absorbed dose averaged over the tissue or organ T , due to Radiation R . The factors W_R are dimensionless and tissue-dependend.

10.4.5 Area Monitoring

The quantities in for area monitoring, as recommended in ICRU Report 39 [75], are defined using a spherical phantom, the “ICRU Sphere”. This is a 30cm diameter, tissue equivalent sphere with a density of $1 g \cdot cm^{-3}$, and a mass composition of 76.2% oxygen, 11.1% carbon, 10.1% hydrogen and 2.6% nitrogen.

Two quantities for area monitoring are specified in ICRU Report 39, which were completed by Report 43 [77] and revised in a later publication, Report 47 [76]:

- The **Ambient Dose Equivalent**, $H^*(d)$, at a point in a radiation field, is the dose equivalent that would be produced by the corresponding expanded and aligned field, in the ICRU Sphere, at a depth d , on the radius opposing the direction of the aligned field. The unit of this quantity is $[J \cdot kg^{-1}]$ which has the special name Sievert (Sv), and it is equal to an energy absorption of 1 Joule per Kilogramme. ICRU notes [76] also the following:
 1. Any statement of ambient dose equivalent should include a specification of the reference depth, d . For strongly penetrating radiation the currently recommended depth is $10mm$.
 2. In order to simplify the notation, d should be expressed in mm . Then, $H^*(10)$ is understood to be ambient dose equivalent for a depth of 10 mm.
 3. Measurement of $H^*(d)$ requires that the radiation field be uniform over the dimensions of the instrument, and that the instrument has an isotropic response.
 4. When $d = 10$, $H^*(10)$ may be written as H^* .
- The **Directional Dose Equivalent**, $H'(d, \Omega)$, at a point in a radiation field, is the dose equivalent that would be produced by the corresponding expanded field in the ICRU sphere at a depth d , on a radius in a specified direction Ω . The unit of this quantity is Sv .

10.5 Monte Carlo Method

10.5.1 General and History

Monte Carlo methods are a class of computational algorithms that rely on repeated random sampling to compute their results. They are especially useful in studying systems with a large number of coupled degrees of freedom, and in general, for modeling phenomena with significant uncertainty in inputs.

The term “Monte Carlo method” was coined in the 1940’s by physicists working on nuclear weapon projects in the Los Alamos National Laboratory [79].

Monte Carlo is now used routinely in many diverse fields, from the simulation of complex physical phenomena such as radiation transport in the earth’s atmosphere to the simulation of the esoteric sub-nuclear processes in high-energy physics experiments. Its name does not mean to imply that the method is either a “gamble” or “risky”. It simply refers to the manner in which individual numbers are selected from valid representative collections of input data so they can be used in an iterative calculation process. These representative collections of data are some sort of a Frequency Distribution that is converted to a Probability Distribution. Monte Carlo Simulations could be regarded as True Stochastic Simulations in that they describe the

final state of a model by just knowing the frequency distributions of the parameters describing the beginning state and the appropriate metric that maps or transforms the beginning state to the final state [80].

One interesting point of the method is that it allows one to obtain the values of certain given operators on functions obeying a differential equation, without the point by point knowledge of the functions that are solutions of the equation.

There is no single Monte Carlo method; instead, the term describes a large and widely-used class of approaches. However, these approaches tend to follow a particular pattern:

1. Definition of a domain of possible inputs.
2. Generate inputs randomly from the domain using a certain specified probability distribution.
3. Perform a deterministic computation using the inputs.
4. Aggregate the results of the individual computations into the final result.

10.6 The FLUKA Monte Carlo Code

FLUKA is a FORTRAN simulation code used to calculate particle transport and interactions with matter. The development of FLUKA since its first appearance has seen many advances that cover an extended range of applications. A more detailed historic review of FLUKA can be found in [81], or in the official site <http://www.fluka.org>.

FLUKA can simulate with high accuracy the interaction and propagation in matter of about 60 different particles, including photons and electrons from 1 keV to several thousands of TeV, neutrinos, muons of any energy, hadrons of energies up to 20 TeV (up to 10 PeV by linking FLUKA with the Dpmjet ([82]) code) and all the corresponding antiparticles, neutrons down to thermal energies (with a special neutron library) and heavy ions. FLUKA can handle even very complex geometries, using an improved version of the well-known Combinatorial Geometry (CG) package.

Another feature of FLUKA, probably not found in any other Monte Carlo program [81], is its double capability to be used simultaneously in biased mode and in a fully analogue mode. That means that while it can be used to predict fluctuations, signal coincidences and other correlated events, a wide choice of statistical techniques are also available to investigate punch through or other rare events.

In the present study, the Fluka2009 version of the code was used, running on the clueet cluster², located in Preveessin site of CERN, Geneva.

²For more information on the cluster, visit the site: <http://ab-atb-eet.web.cern.ch/ab-atb-eet/Computing/Cluster/>

Chapter 11

The Present Study

11.1 Introduction

As mentioned in several studies [89], Proton Accelerators in the intermediate energy range (from few tens to a few hundreds of MeV), being continuously used for nuclear physics research, since several years find increasing application in cancer radiation therapy. Machines in this energy range are being used as injectors for high energy accelerators (which work on the GeV region or above). An example is the 160MeV linac accelerator presently being designed at CERN to replace the existing 50MeV proton injector[90]. Therefore, particular attention has to be given to the materials being irradiated during the operation of these accelerators, either due to the large beam intensities required as injectors, or, in the case of radiation therapy, because of the high populated area, and for the radiation dangers for the patient being treated himself.

The main radiation dictating the surrounding area is the neutron field produced by the interaction of the proton beam with the structures of the accelerator, of the beam transfer lines, or (in the case of medical machines) of the beam delivery system used to irradiate the patient (such as collimators and field-shaping devices), and with the patient himself. Similar data in this intermediate energy are not abundant in literature and are usually limited to specific condition, geometries and energy values.

To overcome this lack of information, a systematic simulation study of accelerator materials is being performed. More specifically, investigation of the expected type and amount of radionuclides generated by irradiation is being provided. Moreover, the ambient dose equivalent ($H^*(10)$) rates around the irradiated material, so as the radiological risk to be assessed, are being systematically recorded and presented. The whole study is done by using a simplified, reference geometry, in the proton energy range 50MeV's to 400 MeV's, with a step of 50MeV's. Also, with a different set of simulations, the double differential neutron spectra of each material, and in each energy, in several angular bins in respect to the beam axis was obtained, and is being presented. Finally, a special situation was studied, that of an iron target being enclosed into a concrete tunnel. The differences in the neutron spectra and the ambient dose equivalent are evaluated.

11.2 Materials

The materials iron, stainless steel, boron nitride, copper and carbon(graphite) were selected to be examined in this study. These are common materials which make up main accelerator components. For example, iron is being commonly used in magnets; copper is the main component of the RF cavities; stainless steel exists in the vacuum chambers; boron nitride and carbon graphite can be used in collimators, dumps and beam stopper components.

The exact composition of the materials used as target of the beam in the present study can be found concentrated in the tables (11.1) - (11.5). In the table (11.5) the compounds BN, SiO₂, B₂O₃ were simulated as having the composition that appears in the table (11.6). For the elements that were not predefined into the FLUKA code, the atomic properties used in the simulations can be found in the table (11.7).

11.2.1 Composition Tables

Table 11.1: Carbon(graphite)[Mass % composition] ($\rho = 2.00g/cm^3$)

element	percentage
C	100

Table 11.2: Iron [Mass % composition] ($\rho = 7.86g/cm^3$)

element	percentage
Fe	99.77
Mn	0.06
C	0.01
P	0.01
S	0.01

Table 11.3: Copper [Mass % composition] ($\rho = 8.98g/cm^3$)

element	percentage
Cu	99.9596
O	0.0004
Ag	0.01
Mo	0.01
Si	0.02

Table 11.4: Stainless Steel [Mass % composition] ($\rho = 7.90g/cm^3$)

element	percentage
Fe	69.1924
Cr	18.62
Ni	8.32
Si	0.648
Mn	1.52
P	0.0302
S	0.037
Mo	0.567
Cu	0.393
Al	0.277
Co	0.172
V	0.0704
W	0.0407
Ca	0.0368
Na	0.033
Mg	0.0166
Sn	0.0147
Nb	0.0083
As	0.0029

Table 11.5: Boron Nitride [Mass % composition] ($\rho = 1.92g/cm^3$)

element	percentage
BN	92.9
SiO ₂	0.2
O	4.0
B ₂ O ₃	0.4
Ca	2.5

Table 11.6: Atom Composition of Compounds used in BN material [Atom % composition]

element	percentage
BN	50% B, 50% N
SiO ₂	66.6% O, 33.3% Si
B ₂ O ₃	40% B, 60% O

Table 11.7: Non predefined FLUKA elements atomic properties [Source: <http://physics.nist.gov/PhysRefData/Handbook/>]

element	Atomic Number	Atomic Weight	Density [g/cm^3]
Arsenic (As)	33	74.92	5.73
Boron (B)	5	10.81	2.34
Chromium (Cr)	24	51.99	7.14
Cobalt (Co)	27	58.93	8.90
Manganese (Mg)	25	54.93	7.21
Molybdenum (Mo)	42	95.94	10.22
Niobium (Nb)	41	92.9	8.57
Phosphorus (P)	15	30.97	2.20
Sulfur (S)	16	32.066	2.06
Vanadium (V)	23	50.94	6.00

Table 11.8: Air [Mass % composition] ($\rho = 0.00120484g/cm^3$)

element	percentage
C	0.1248
N	75.5267
O	23.1781
Ar	1.1704

11.3 Neutron Treatment

11.3.1 Low Energy Neutrons

The FLUKA code does a special treatment on Low Energy Neutrons. Transport of neutrons with energies lower than a certain energy is performed in FLUKA by a multigroup algorithm. The energy boundary below which multigroup transport takes over depends in principle on the cross section library used: in the ENEA 72-group library which is distributed with the code this energy is 19.6 MeV, and in the 260-group library, 20 MeV [81]. The multi-group technique, widely used in low-energy neutron transport programs, consists in dividing the energy range of interest into a given number of intervals (“energy groups”). Elastic and inelastic reactions are simulated not as exclusive processes, but by group-to-group transfer probabilities forming a so-called “downscattering matrix”.

In the present simulations, all the materials involved in the composition of the compounds, were contained into the group libraries, so the low energy neutrons were transported with the correct cross sections.

11.3.2 Variance Reduction

Several Variance reduction techniques have been proposed and used in Monte Carlo Methods (see for example, [92]). In the present study, and in order to improve the statistics of the neutron spectra, the techniques of Geometry Splitting and Russian Roulette are being applied in the set of simulations that scores the escaping neutron yield. In order to apply the techniques, a “computational artifact” was invented. The solid cylinder was “transmuted” to 3 coaxial cylinders, which, starting from the base one, had increasing height and radius. The outer one, was exactly of the same dimensions as the solid one used in the set of simulations for the ambient dose equivalent and the residual nuclei distribution. Increasing importance was assigned to the cylinders, starting from the inner one which had importance 1.0, the middle one was assigned importance 2.0, the outer one importance 4.0, and the surrounding air also was assigned with importance 4.0. More discussion about the variance reduction techniques in Monte Carlo Methods, or the exact way that are implemented into the FLUKA code is overcoming the framework of the present study, and one should refer to the literature [92, 93, 81].

11.4 Geometry

11.4.1 First Set

The geometry chosen for the first set of simulations in this study is a simplified geometry of a right, solid cylinder with its radius equal to its height, located at the (0,0,0) point of a Cartesian coordinate system. The dimensions of the cylinder were varying as a function of the material, and the energy of the beam. Although, in all cases the height of the cylinder

was chosen to be slightly larger than the proton range in the material as a function of the beam energy, corresponding to proton-energy tables[91]. The corresponding dimensions of the cylinders used in the simulations are concentrated in the tables (11.9) - (11.13). The target was simulated to be located into a sphere of Natural Air (which composition can be found in Table (11.8)), of radius 10^6 cm, with the purpose to simulate a human environment.

11.4.2 Second Set

The geometry chosen for the second set of simulations, as described above, was exactly the same, solid, right cylinder, with the difference that contained other two, smaller cylinders, made up from the same material as the outer one. The dimensions of all the cylinders, for each material and energy, can be found to the tables (11.14)-(11.18).

11.4.3 Dimension tables - first set

Table 11.9: Boron Nitride

Beam energy (MeV)	50	100	150	200	250	300	350	400
Radius (cm)	0.67	2.34	4.80	7.86	11.52	15.66	20.16	25.02
Height (cm)	1.34	4.69	9.60	15.72	23.04	31.32	40.32	50.04

Table 11.10: Carbon(Graphite)

Beam energy (MeV)	50	100	150	200	250	300	350	400
Radius (cm)	0.65	2.25	5.00	7.50	11.00	15.00	20.00	25.00
Height (cm)	1.30	4.50	10.0	15.0	22.00	30.00	40.00	50.00

Table 11.11: Copper

Beam energy (MeV)	50	100	150	200	250	300	350	400
Radius (cm)	0.23	0.78	1.58	2.58	3.75	5.06	6.50	8.00
Height (cm)	0.46	1.57	3.16	5.16	7.50	10.12	13.00	16.00

Table 11.12: Iron

Beam energy (MeV)	50	100	150	200	250	300	350	400
Radius (cm)	0.25	0.85	1.72	2.81	4.09	5.53	7.10	8.79
Height (cm)	0.50	1.70	3.44	5.62	8.18	11.06	14.20	17.59

Table 11.13: Stainless Steel

Beam energy (MeV)	50	100	150	200	250	300	350	400
Radius (cm)	0.25	0.85	1.71	2.80	4.08	5.50	7.02	8.70
Height (cm)	0.50	1.70	3.43	5.60	8.16	11.01	14.04	17.40

11.4.4 Dimension tables - second set

Table 11.14: Boron Nitride

Beam Energy(MeV)	50		100		150		200		250		300		350		400	
radius/height (cm)	r	h	r	h	r	h	r	h	r	h	r	h	r	h	r	h
Inner Cylinder	0.13	1.12	0.46	3.91	0.96	8.00	1.57	13.10	2.30	19.20	3.13	26.10	4.03	33.60	5.00	41.70
Middle Cylinder	0.47	1.23	1.64	4.30	3.36	8.80	5.50	14.41	8.06	21.12	10.96	28.71	14.11	36.96	17.51	45.87
Outer Cylinder	0.67	1.34	2.34	4.69	4.80	9.60	7.86	15.72	11.52	23.04	15.66	31.32	20.16	40.32	25.02	50.04

Table 11.15: Carbon(Graphite)

Beam Energy(MeV)	50		100		150		200		250		300		350		400	
radius/height (cm)	r	h	r	h	r	h	r	h	r	h	r	h	r	h	r	h
Inner Cylinder	0.13	1.10	0.45	3.80	1.00	7.80	1.50	12.90	2.20	18.90	3.00	25.60	4.00	33.00	5.00	41.00
Middle Cylinder	0.45	1.21	1.57	4.18	3.50	8.58	5.25	14.19	7.70	20.79	10.50	28.16	14.00	36.30	17.50	45.10
Outer Cylinder	0.65	1.30	2.25	4.50	5.00	10.00	7.50	15.00	11.00	22.00	15.00	30.00	20.00	40.00	25.00	50.00

Table 11.16: Copper

Beam Energy(MeV)	50		100		150		200		250		300		350		400	
radius/height (cm)	r	h	r	h	r	h	r	h	r	h	r	h	r	h	r	h
Inner Cylinder	0.04	0.39	0.15	1.31	0.31	2.64	0.51	4.30	0.75	6.25	1.01	8.44	1.29	10.83	1.60	13.40
Middle Cylinder	0.16	0.42	0.55	1.44	1.10	2.90	1.80	4.73	2.62	6.87	3.54	9.28	4.54	11.91	5.62	14.74
Outer Cylinder	0.23	0.46	0.78	1.57	1.58	3.16	2.58	5.16	3.75	7.50	5.06	10.12	6.50	13.00	8.00	16.00

Table 11.17: Iron

Beam Energy(MeV)	50		100		150		200		250		300		350		400	
radius/height (cm)	r	h	r	h	r	h	r	h	r	h	r	h	r	h	r	h
Inner Cylinder	0.05	0.42	0.17	1.42	0.34	2.87	0.56	4.69	0.81	6.82	1.10	9.22	1.42	11.84	1.75	14.66
Middle Cylinder	0.17	0.46	0.59	1.56	1.20	3.15	1.96	5.15	2.86	7.50	3.87	10.14	4.97	13.02	6.15	16.12
Outer Cylinder	0.25	0.50	0.85	1.70	1.72	3.44	2.81	5.62	4.09	8.18	5.53	11.06	7.10	14.20	8.79	17.59

Table 11.18: Stainless Steel

Beam Energy(MeV)	50		100		150		200		250		300		350		400	
radius/height (cm)	r	h	r	h	r	h	r	h	r	h	r	h	r	h	r	h
Inner Cylinder	0.05	0.42	0.17	1.42	0.34	2.86	0.56	4.67	0.81	6.80	1.10	9.18	1.40	11.70	1.74	14.50
Middle Cylinder	0.17	0.46	0.59	1.56	1.20	3.14	1.96	5.13	2.85	7.48	3.85	10.09	4.91	12.87	6.09	15.95
Outer Cylinder	0.25	0.50	0.85	1.70	1.71	3.43	2.80	5.60	4.08	8.16	5.50	11.01	7.02	14.04	8.70	17.40

11.5 Beam Parametres

A flat, pencil beam, without any divergence, with an intensity of $6 \cdot 10^{12}$ protons/s was chosen to be simulated in the present study. The beam was

impinging in the center of bottom side of the cylinder, beginning from the position $z = -1\text{cm}$ towards the positive direction of the z axis.

The irradiation profile was 9 months constant irradiation of the target.

11.6 Scoring

11.6.1 First set

In the first set of simulations, the residual nuclei distribution on the target, after seven cooling times, was scored. Also, the ambient dose equivalent ($H^*(10)$) was scored to a cylindrical “scoring grid”, up to a distance of 1m from the bottom, upper and lateral sides of the cylindrical target. The steps for the scoring were chosen to be 1 cm for the scoring along the z -axis, 1 cm for scoring along the radius, and a step of 30° for the azimuthal angle ϕ .

The cooling times chosen were:

- EOB, scoring was done immediatly after the end of the bombardment (0 s)
- 1h, scoring was done after 1 hour after the end of the bombardment (3600 s)
- 1d, scoring was done after 1 day after the end of the bombardment ($24 \cdot 3600 = 86400$ s)
- 1w, scoring was done after 1 week after the end of the bombardment ($24 \cdot 3600 \cdot 7 = 604800$ s)
- 1m, scoring was done after 1 month after the end of the bombardment ($24 \cdot 3600 \cdot 30 = 2592000$ s)
- 3m, scoring was done after 3 months after the end of the bombardment ($24 \cdot 3600 \cdot 90 = 7776000$ s)
- 6m, scoring was done after 6 months after the end of the bombardment ($24 \cdot 3600 \cdot 180 = 15552000$ s)

The radioactive decays were activated in the code, in order to simulate the real conditions, up to 3 replicas of each nuclei. The time evolution is calculated analytically by the code and all daughter nuclei and all associated radiation are considered [81].

11.6.2 Second set

In second set of simulations, only the prompt double differential neutron yield was obtained, i.e the prompt neutrons escaping from the surface of the target to the air, as a function of their energy and their angular direction, in respect to the beam axis. Six different angular beams were defined, and the neutron yield was scored for each of them separately. The angular beams defined were:

- $0^\circ - 15^\circ$
- $15^\circ - 45^\circ$

- $45^\circ - 75^\circ$
- $75^\circ - 105^\circ$
- $105^\circ - 135^\circ$
- $135^\circ - 180^\circ$

Chapter 12

Results and Plots

12.1 Ambient Dose Equivalent Color Plots

In the following pages, the ambient dose equivalent color plots are being presented. The plots were created with the opensource program gnuplot ¹. The scoring mesh was an R- ϕ -Z mesh, up to the distance of 1m from the target. The following plots are Z-R plots, integrated over ϕ . More specifically, the x-axis of the plots corresponds to the z-axis of the actual geometry, while the y-axis of the plot corresponds to the radial distance from the center of the cylinder. All distances are in cm. FLUKA gives the results for the ambient dose equivalent in pSv/s , so, the normalization factor $3.6E-03$ ² was applied in order for the results to be presented as $\mu Sv/h$.

In the following plots the color scale changes, often in subsequent plots. So the reader should be careful in order to avoid any misunderstanding of the ambient dose equivalent.

¹for more information, visit the official gnuplot page: <http://www.gnuplot.info/>

² $pSv/s \times 10^{-6} \mu Sv/pSv \times 3600 s/h$

12.1.1 Boron Nitride - 50MeV

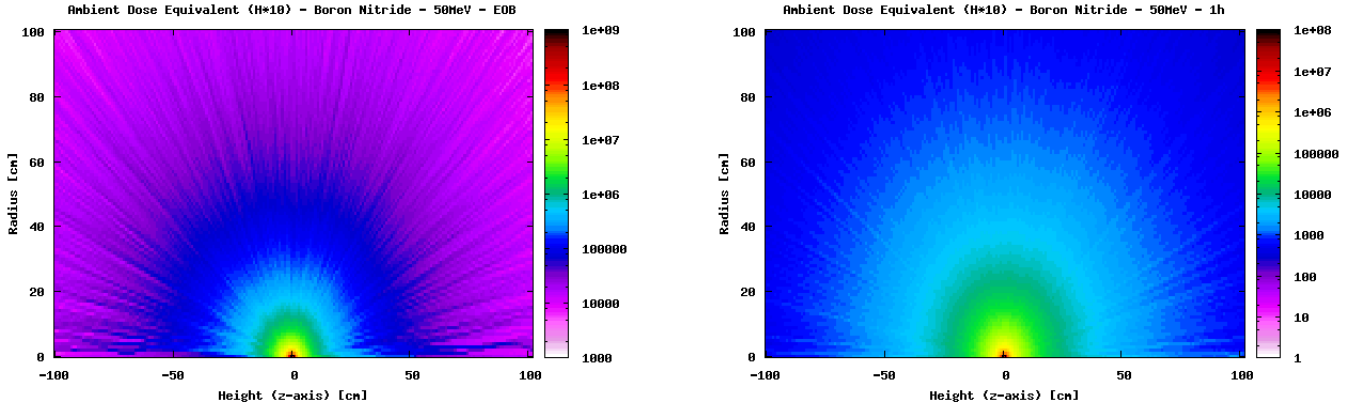


Figure 12.1: cooling times: EOB and 1h

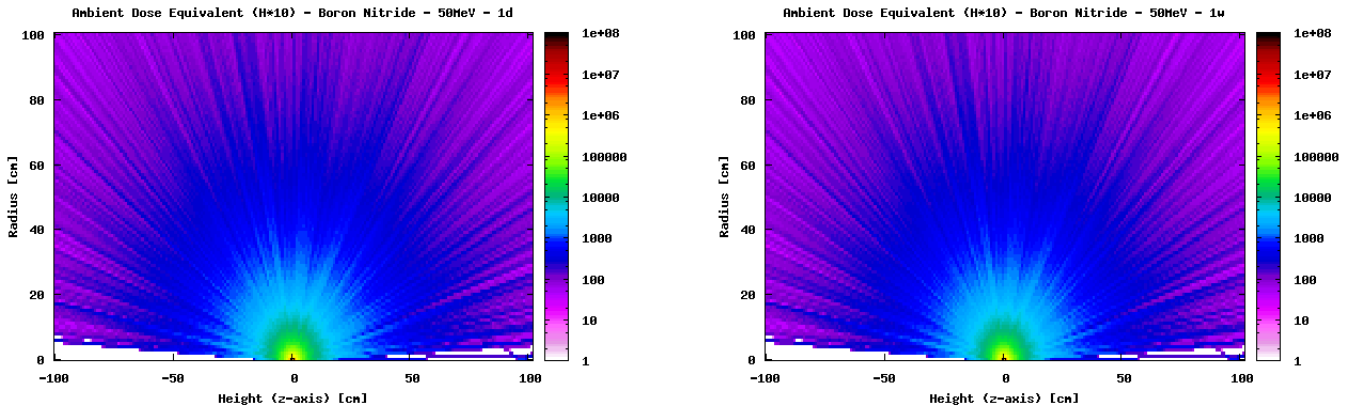


Figure 12.2: cooling times: 1d and 1w

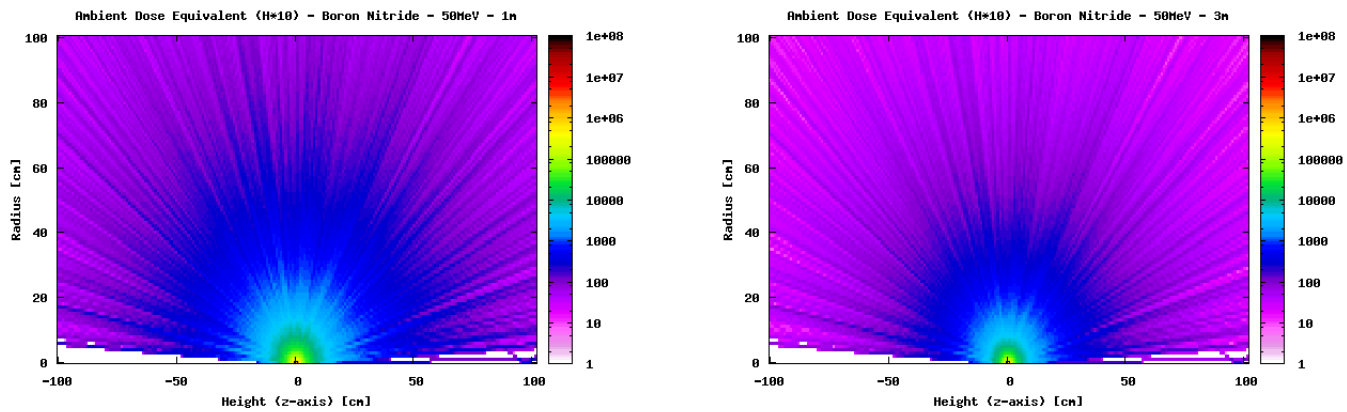


Figure 12.3: cooling times: 1m and 3m

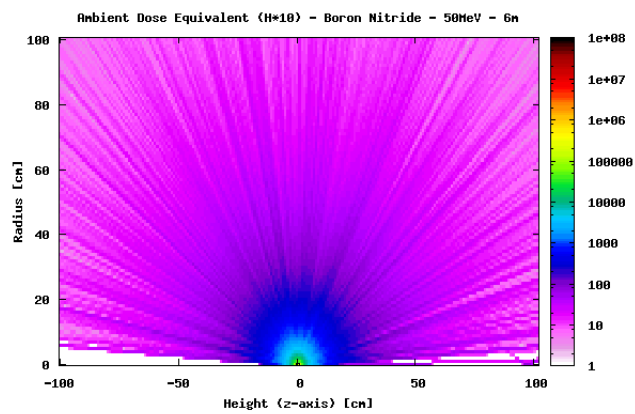


Figure 12.4: cooling time: 6m

12.1.2 Boron Nitride - 100MeV

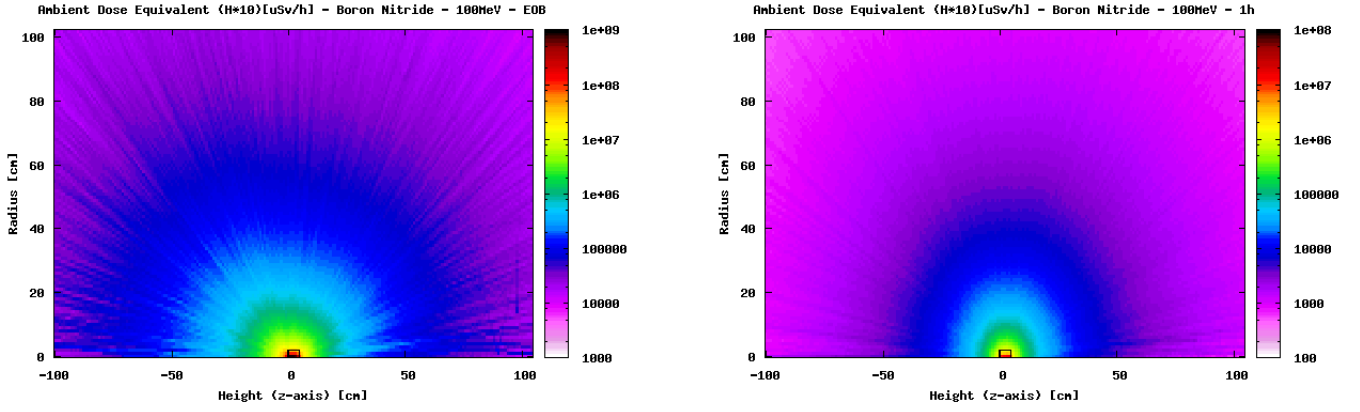


Figure 12.5: cooling times: EOB and 1h

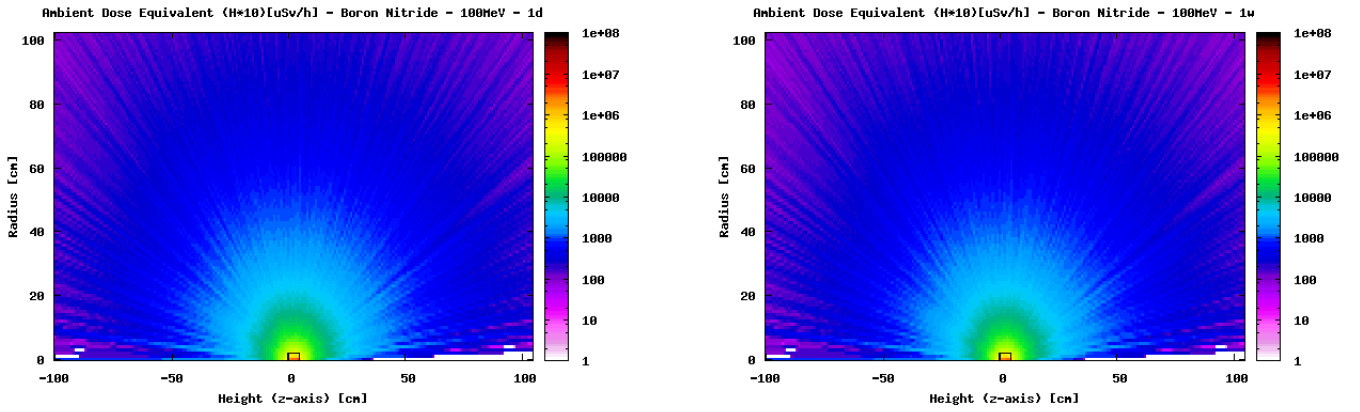


Figure 12.6: cooling times: 1d and 1w

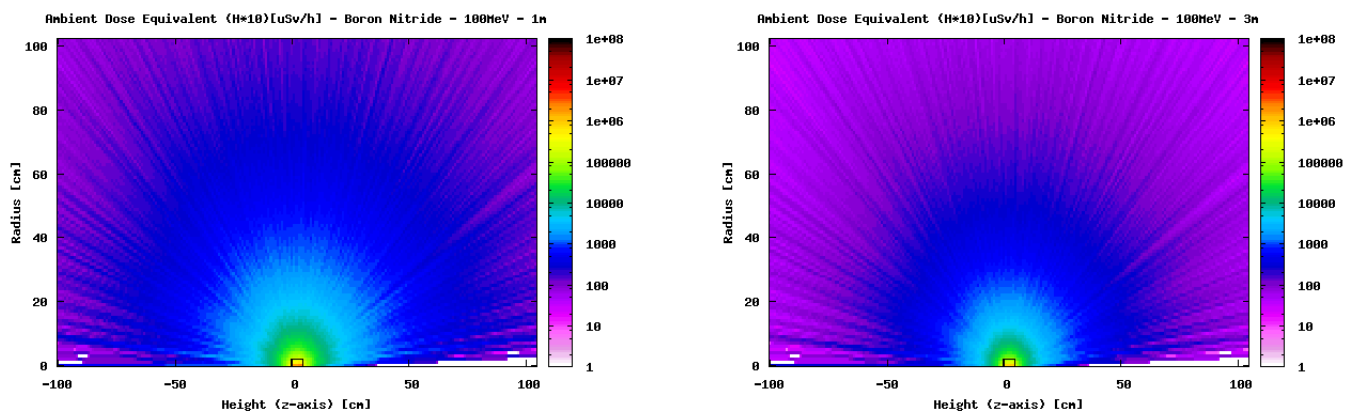


Figure 12.7: cooling times: 1m and 3m

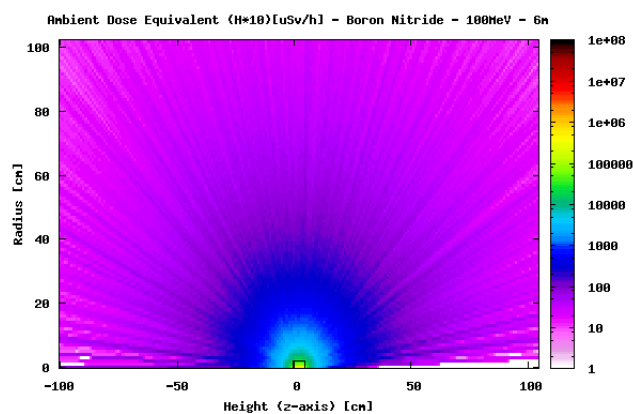


Figure 12.8: cooling time: 6m

12.1.3 Boron Nitride - 150MeV

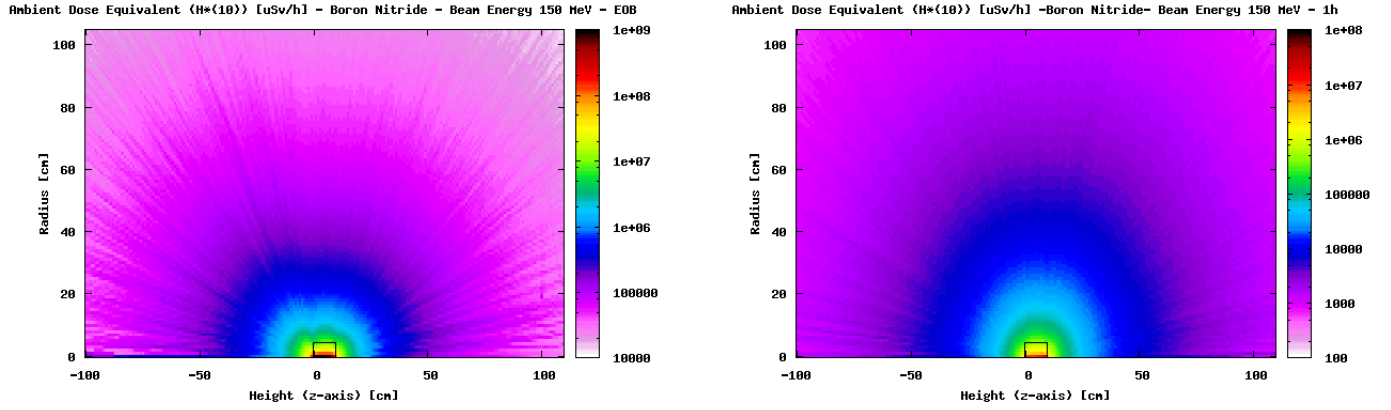


Figure 12.9: cooling times: EOB and 1h

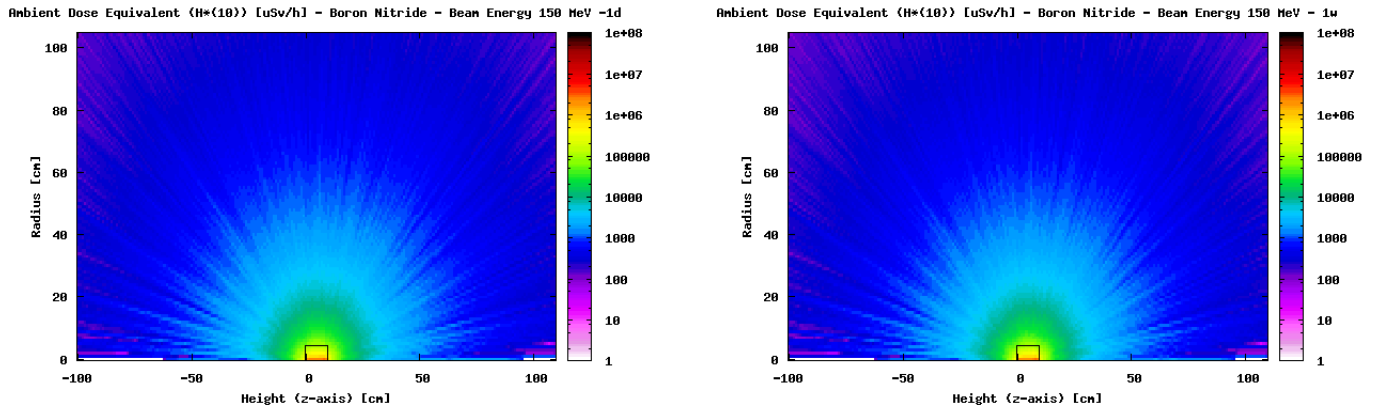


Figure 12.10: cooling times: 1d and 1w

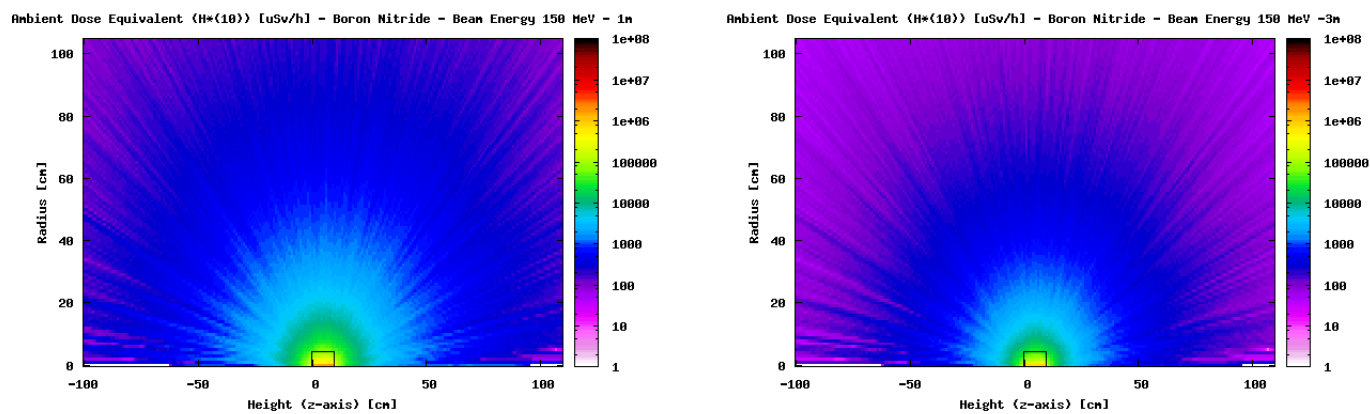


Figure 12.11: cooling times: 1m and 3m

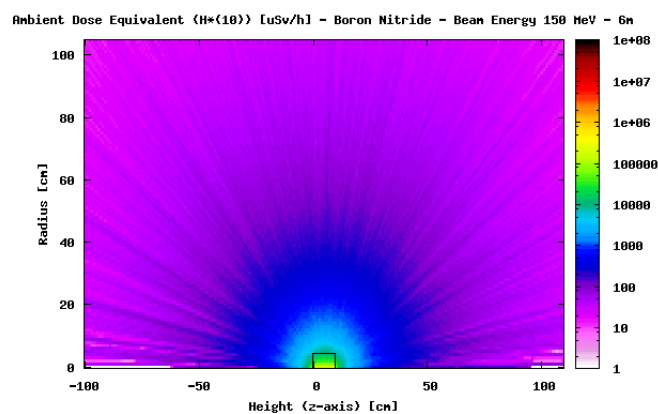


Figure 12.12: cooling time: 6m

12.1.4 Boron Nitride - 200MeV

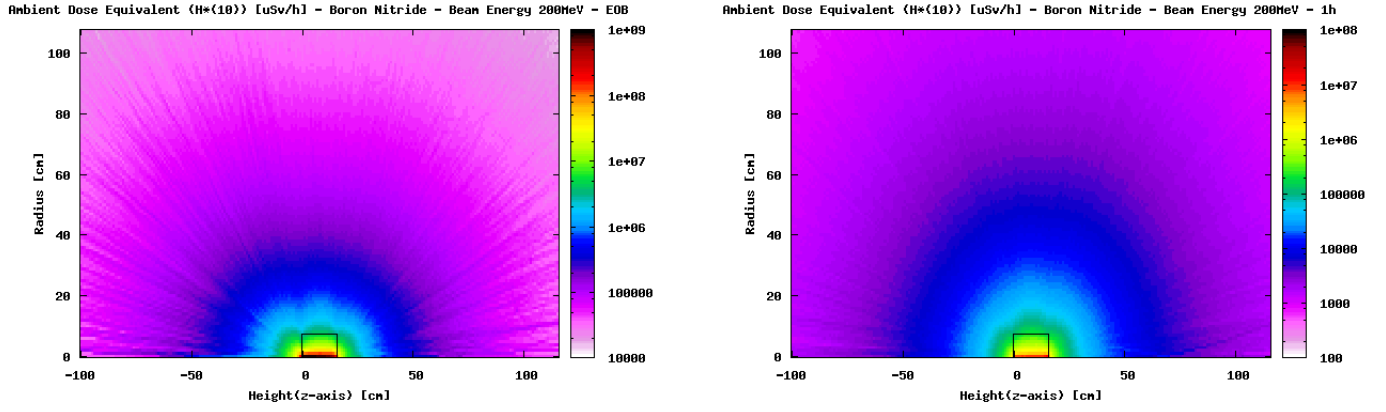


Figure 12.13: cooling times: EOB and 1h

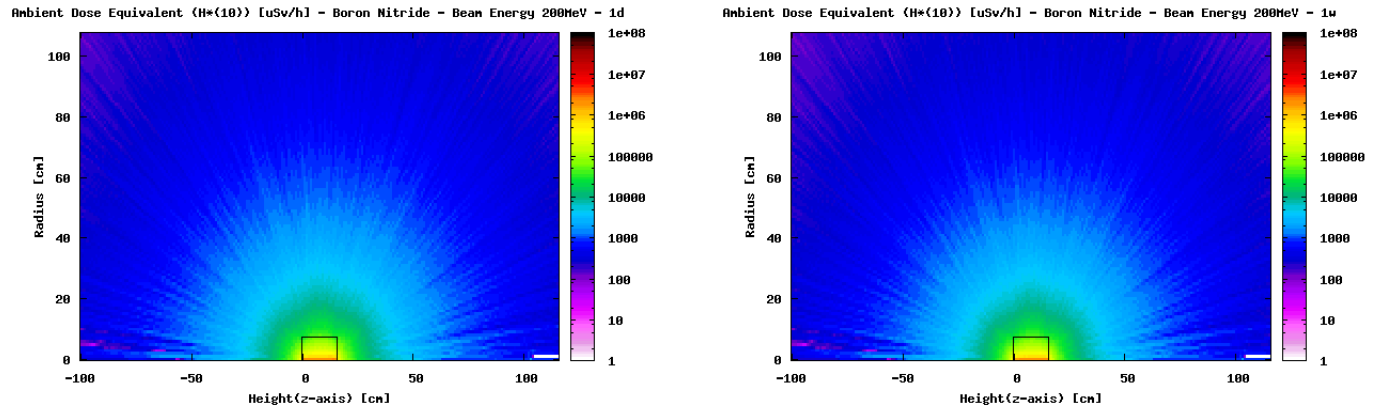


Figure 12.14: cooling times: 1d and 1w

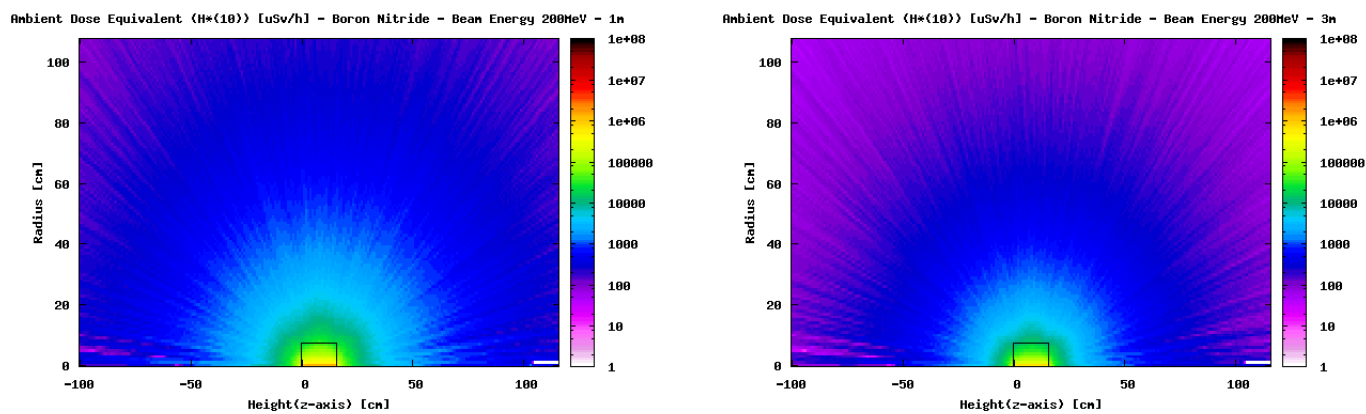


Figure 12.15: cooling times: 1m and 3m

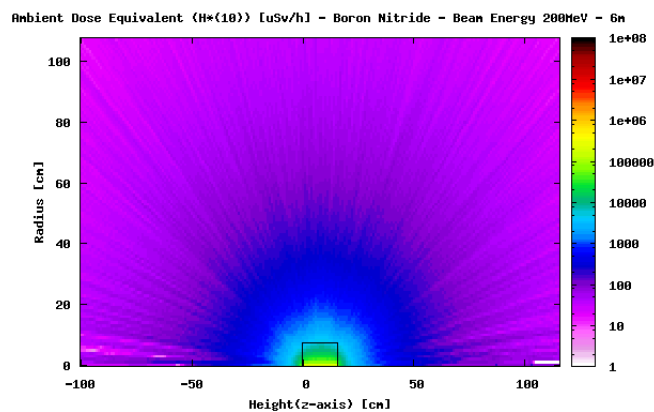


Figure 12.16: cooling time: 6m

12.1.5 Boron Nitride - 250MeV

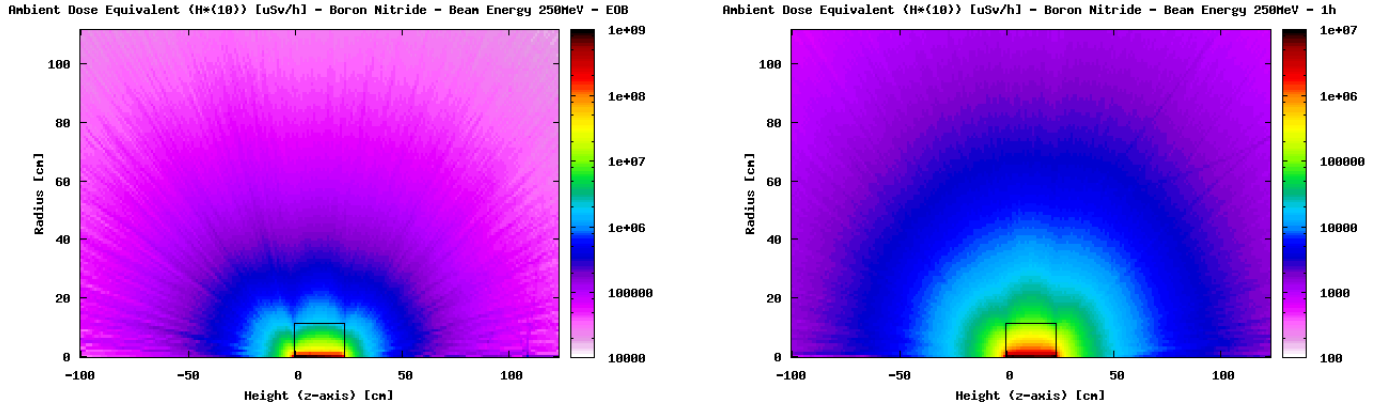


Figure 12.17: cooling times: EOB and 1h

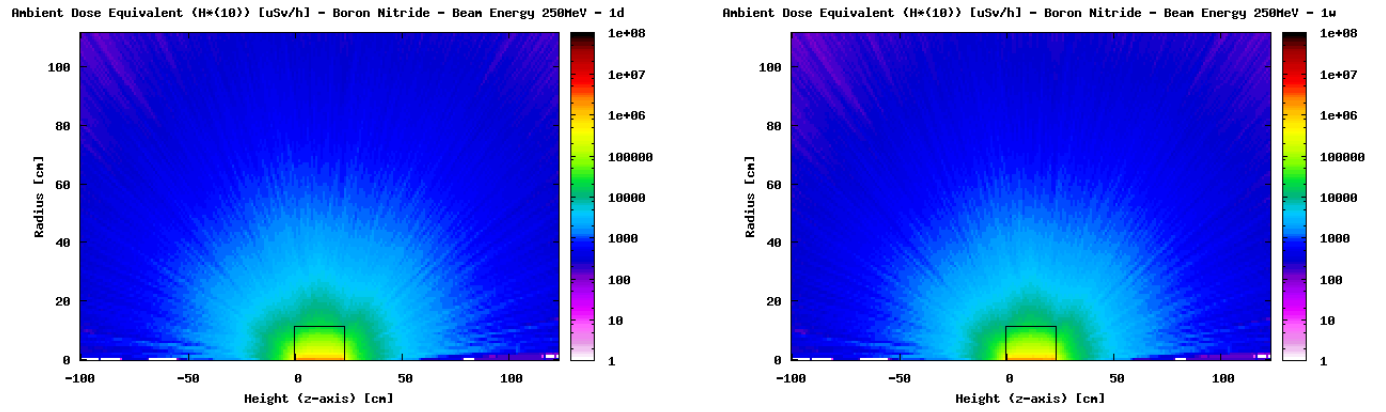


Figure 12.18: cooling times: 1d and 1w

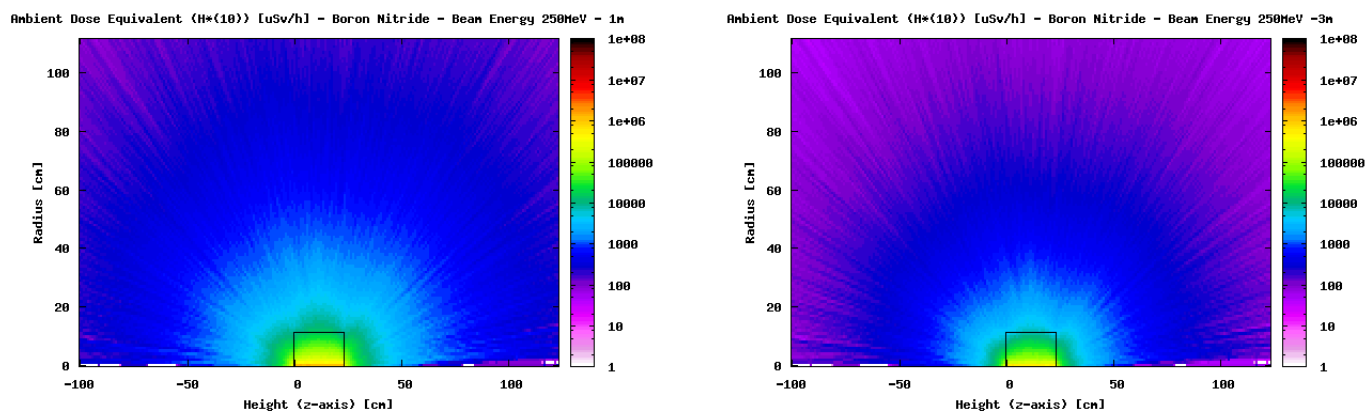


Figure 12.19: cooling times: 1m and 3m

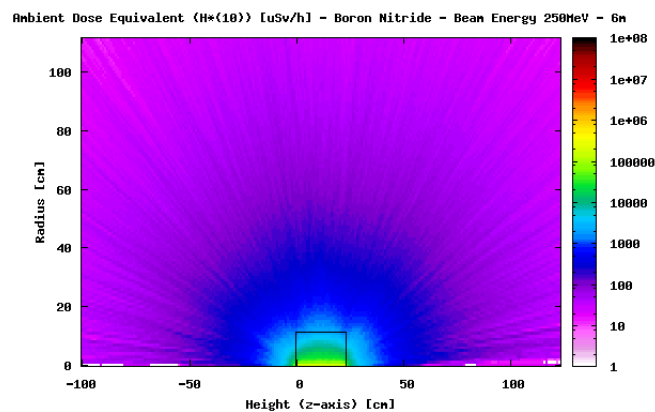


Figure 12.20: cooling time: 6m

12.1.6 Boron Nitride - 300MeV

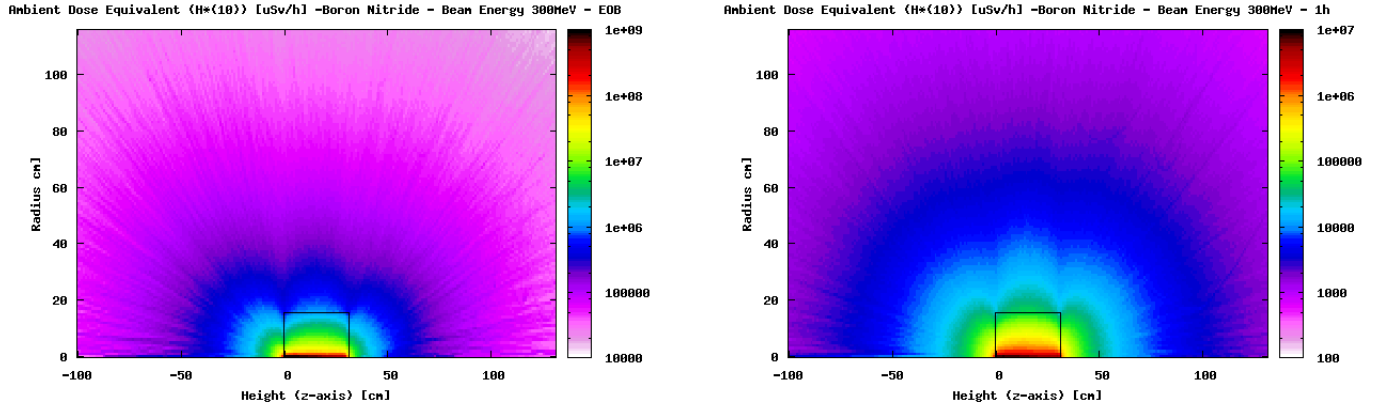


Figure 12.21: cooling times: EOB and 1h

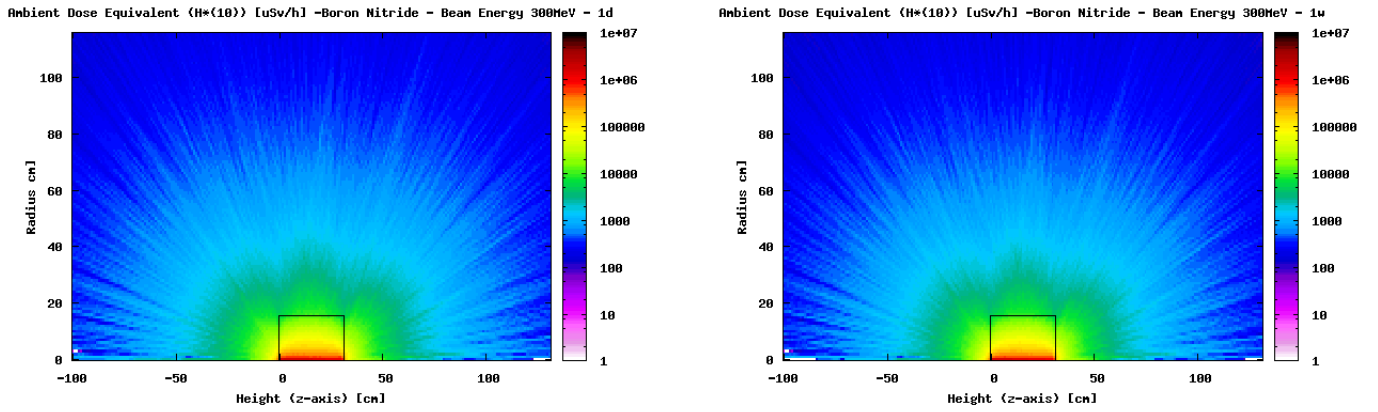


Figure 12.22: cooling times: 1d and 1w

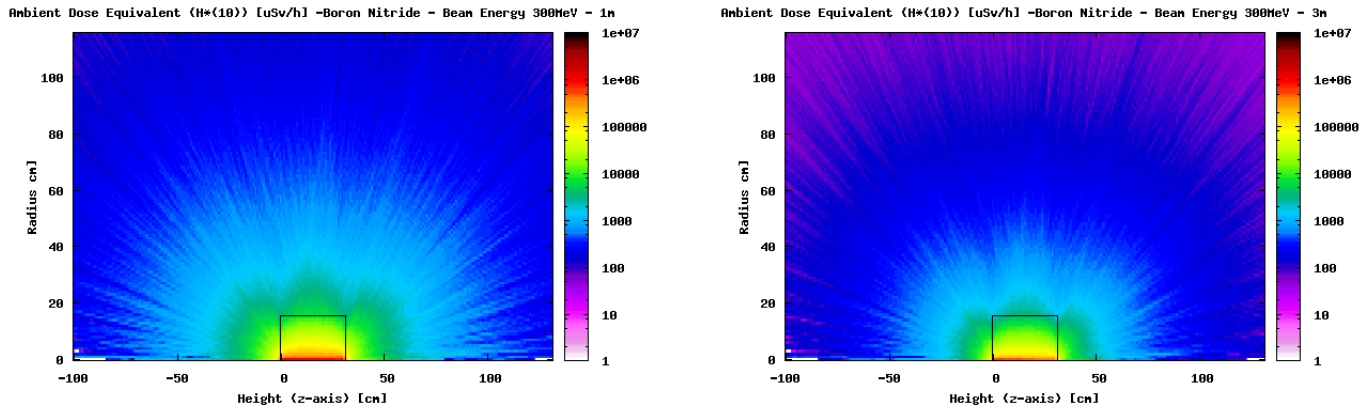


Figure 12.23: cooling times: 1m and 3m

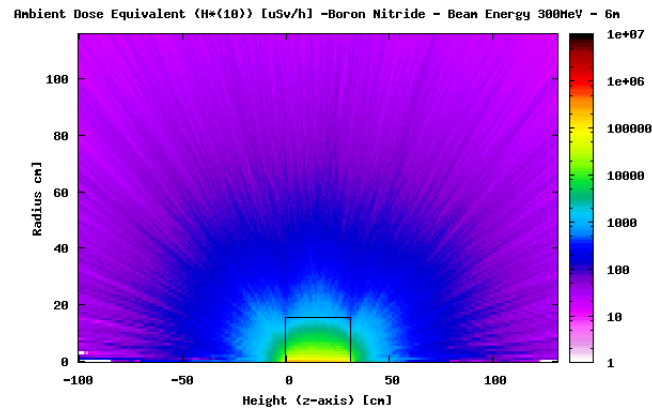


Figure 12.24: cooling time: 6m

12.1.7 Boron Nitride - 350MeV

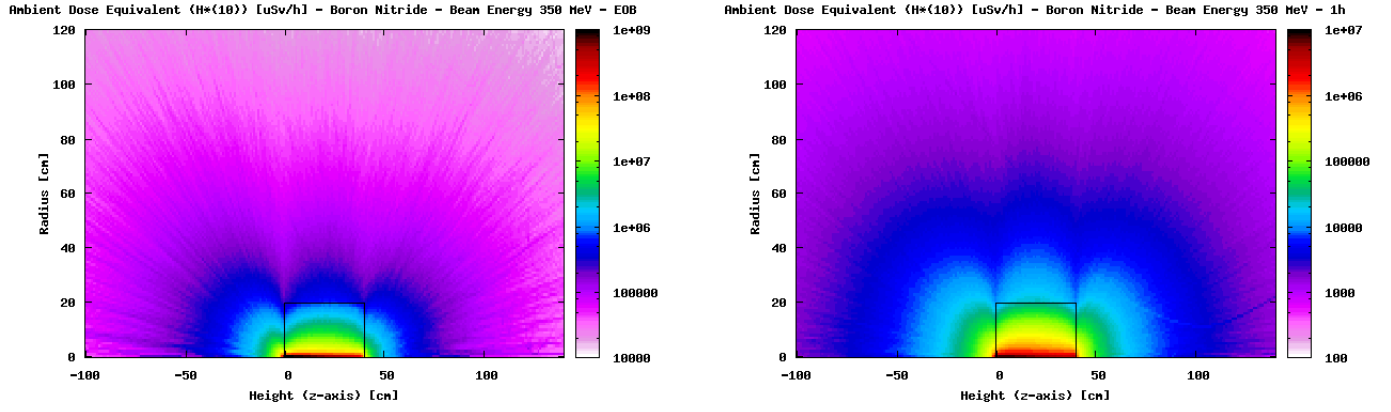


Figure 12.25: cooling times: EOB and 1h

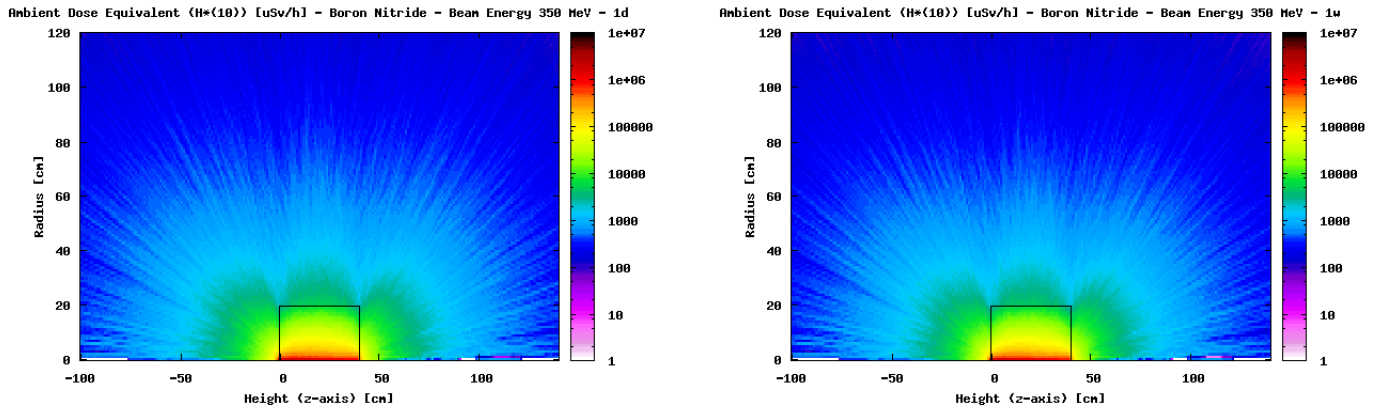


Figure 12.26: cooling times: 1d and 1w

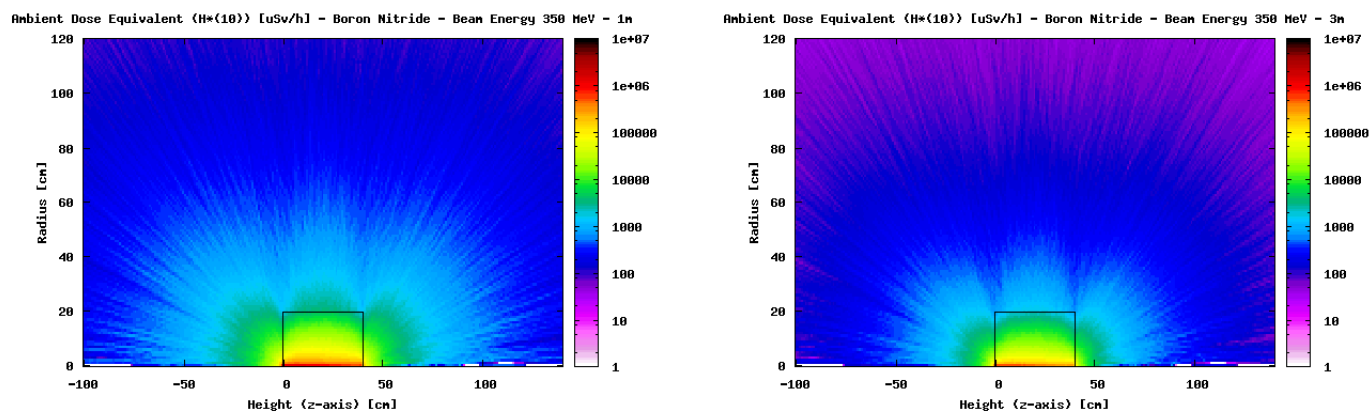


Figure 12.27: cooling times: 1m and 3m

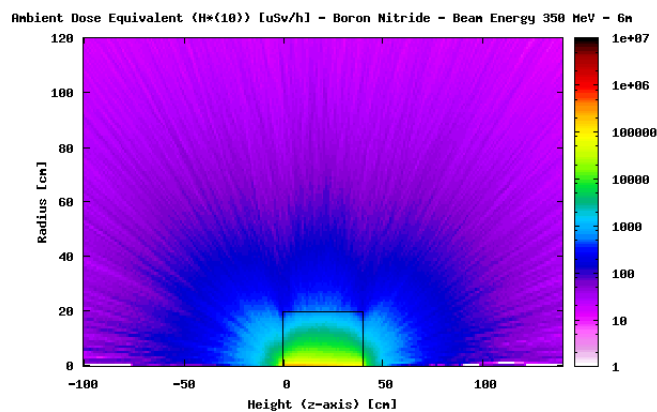


Figure 12.28: cooling time: 6m

12.1.8 Boron Nitride - 400MeV

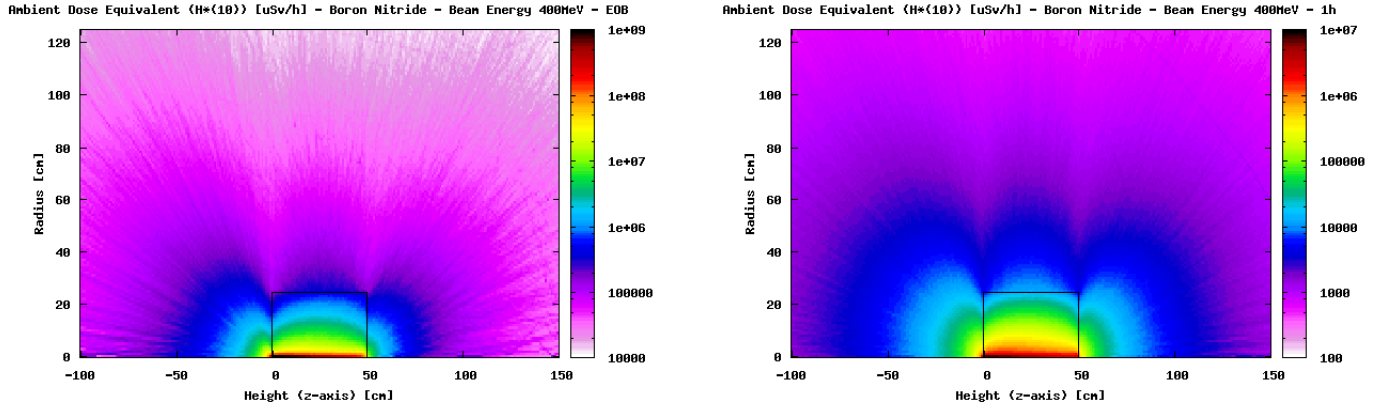


Figure 12.29: cooling times: EOB and 1h

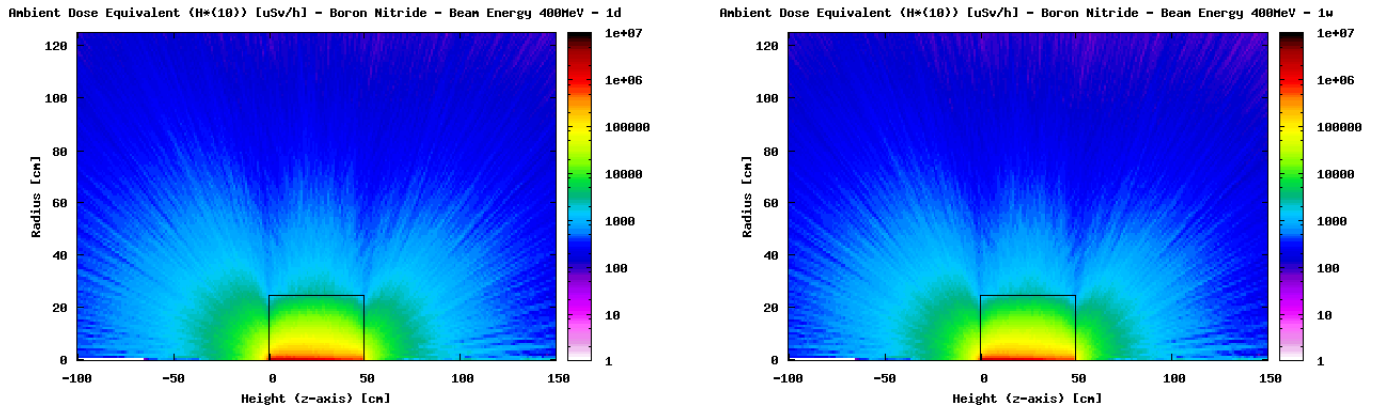


Figure 12.30: cooling times: 1d and 1w

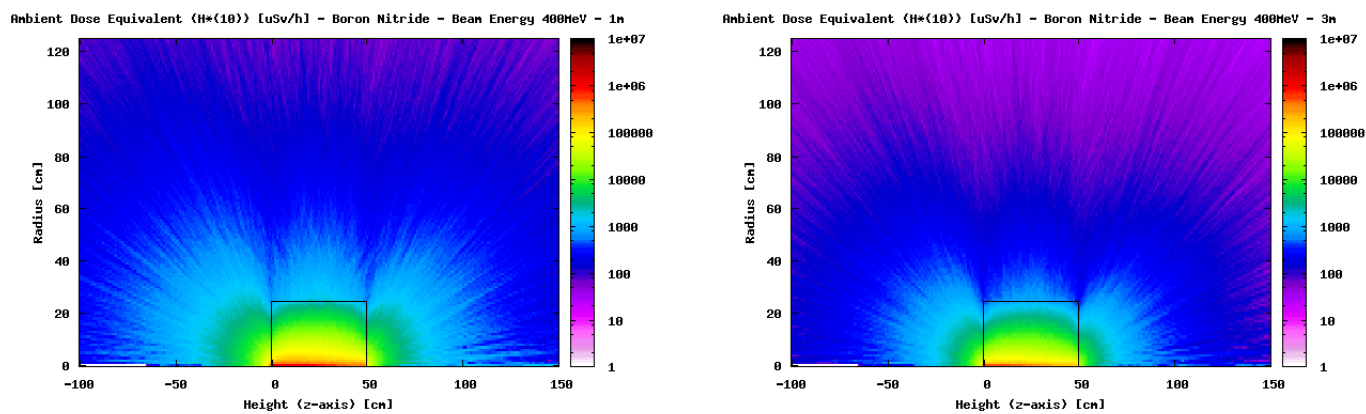


Figure 12.31: cooling times: 1m and 3m

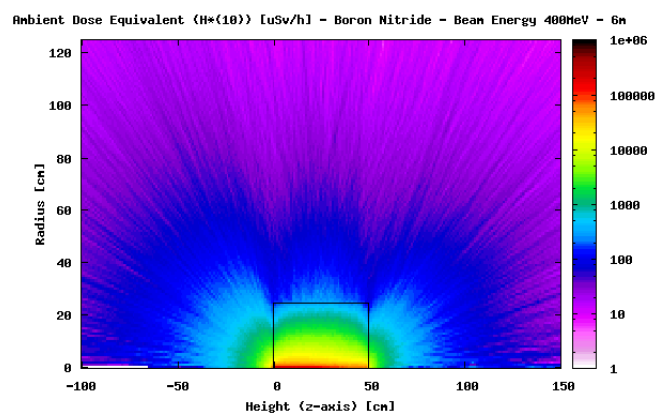


Figure 12.32: cooling time: 6m

12.1.9 Carbon(Graphite) - 50MeV

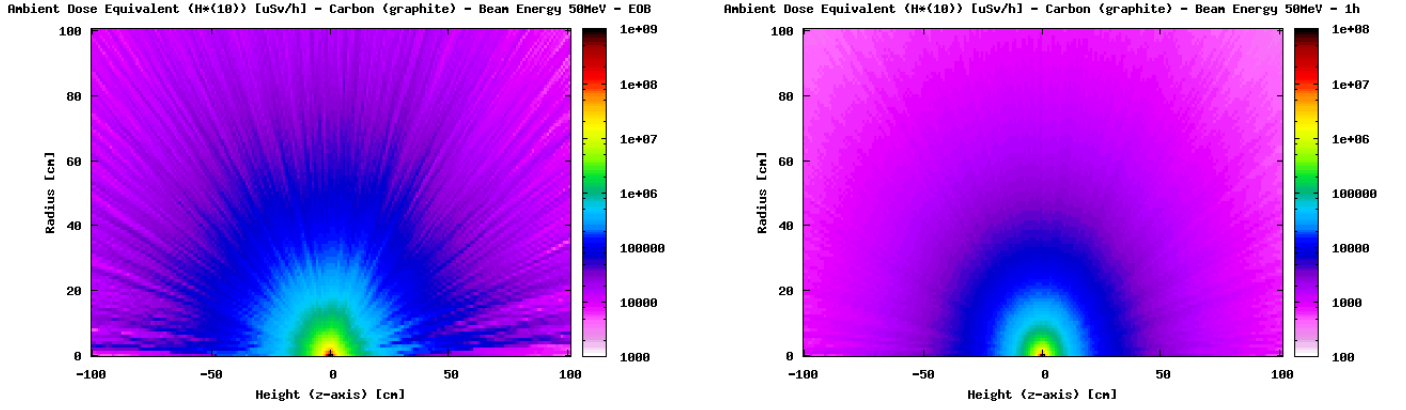


Figure 12.33: cooling times: EOB and 1h

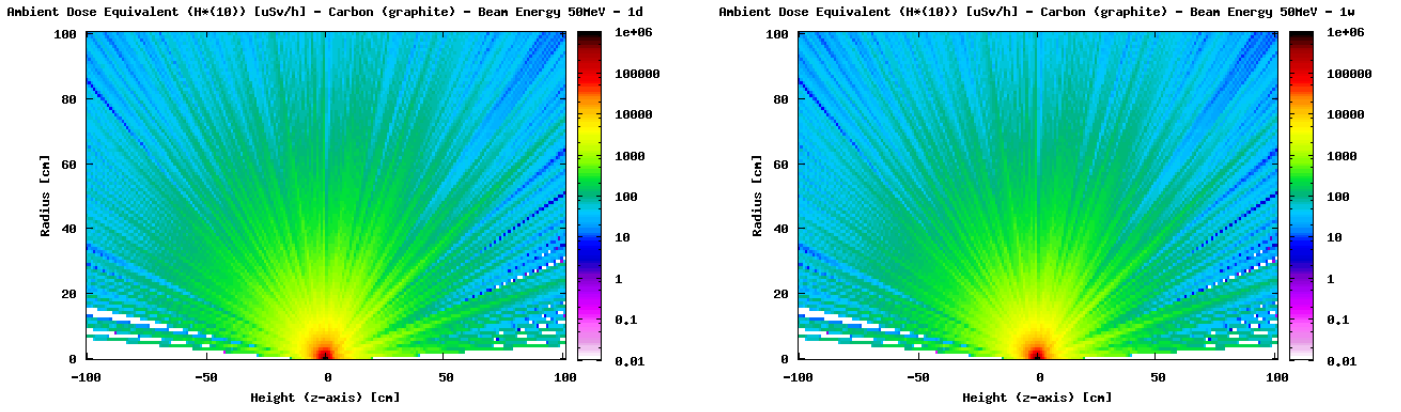


Figure 12.34: cooling times: 1d and 1w

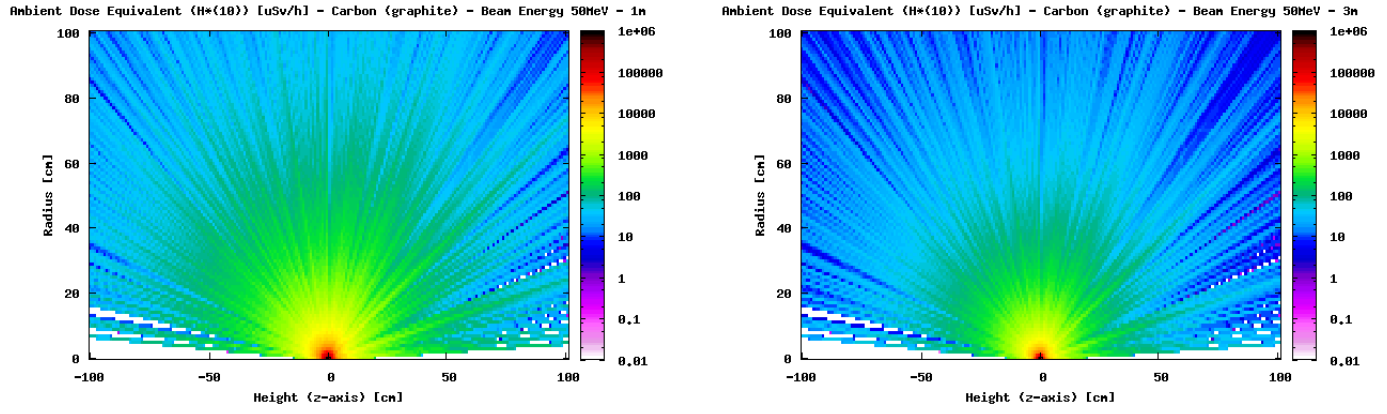


Figure 12.35: cooling times: 1m and 3m

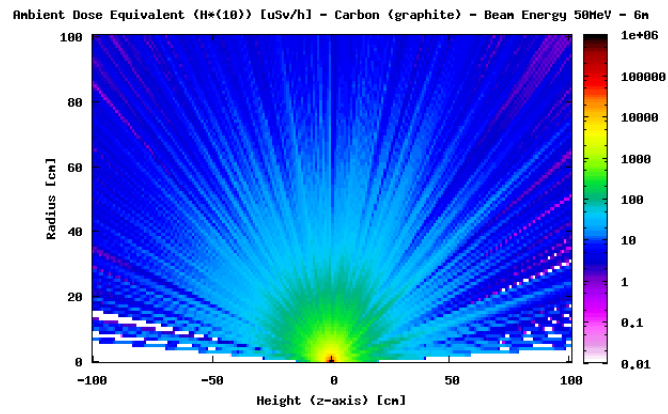


Figure 12.36: cooling time: 6m

12.1.10 Carbon(Graphite) - 100MeV

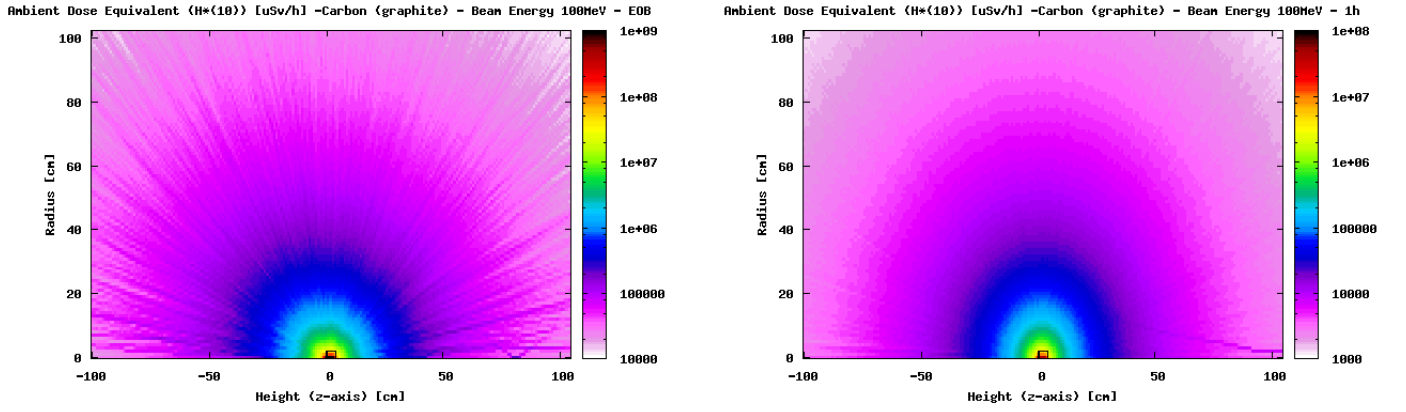


Figure 12.37: cooling times: EOB and 1h

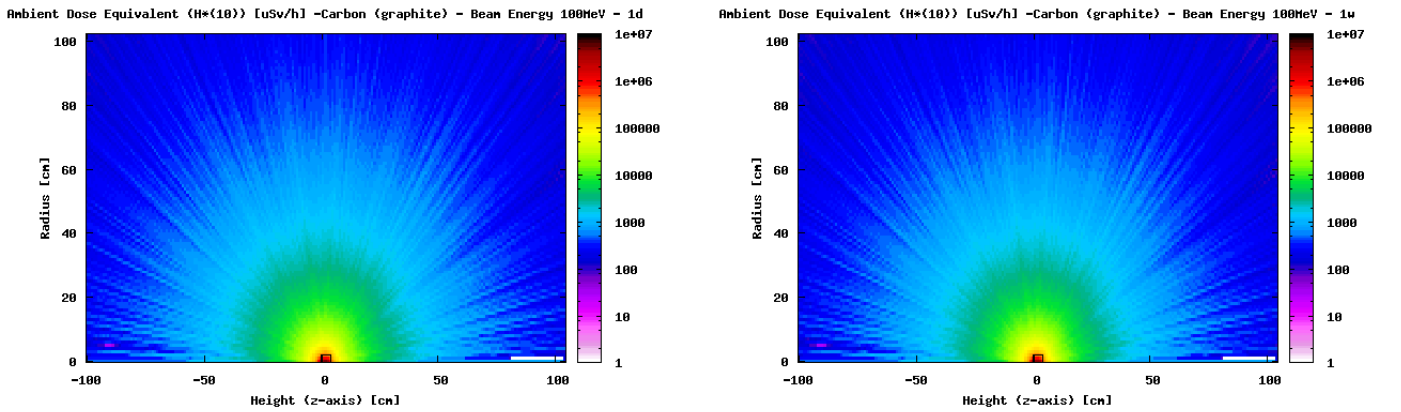


Figure 12.38: cooling times: 1d and 1w

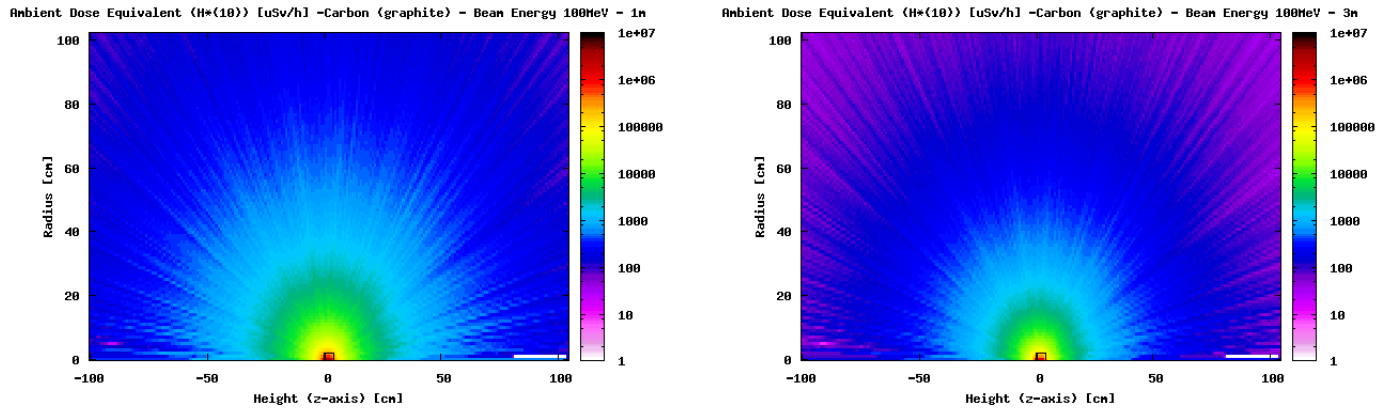


Figure 12.39: cooling times: 1m and 3m

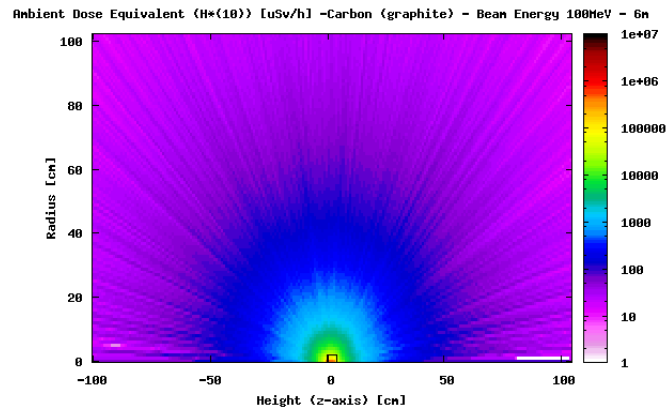


Figure 12.40: cooling time: 6m

12.1.11 Carbon(Graphite) - 150MeV

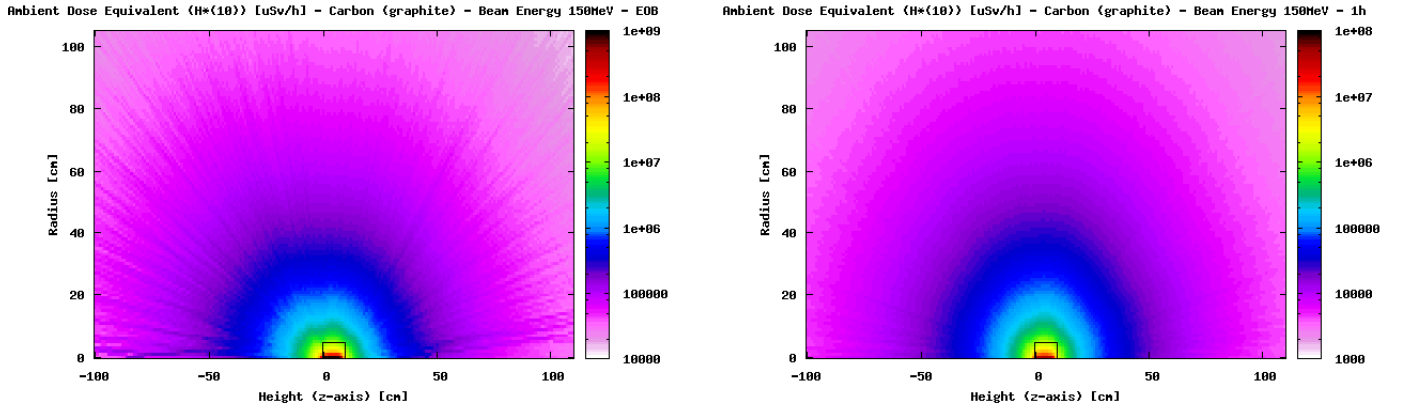


Figure 12.41: cooling times: EOB and 1h

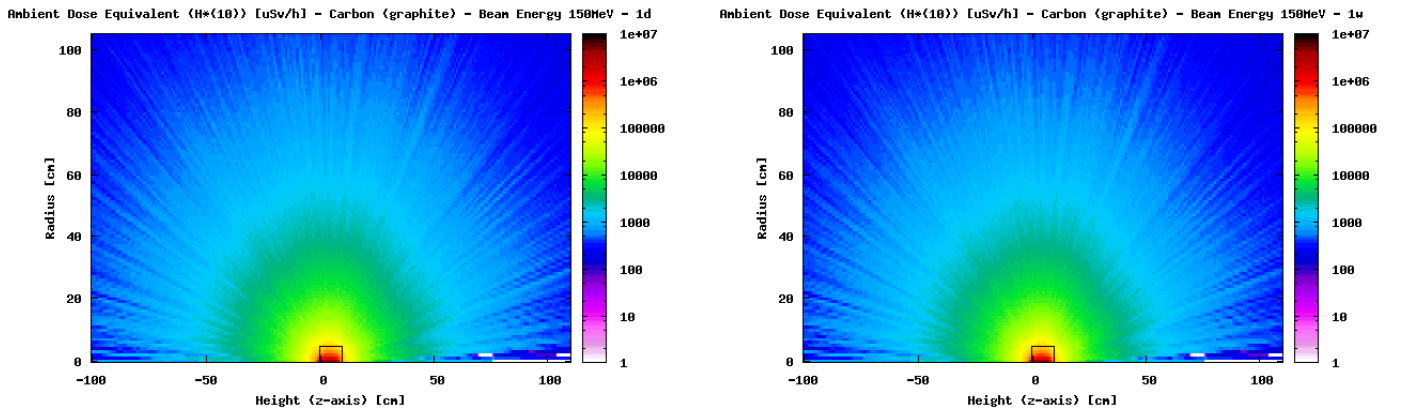


Figure 12.42: cooling times: 1d and 1w

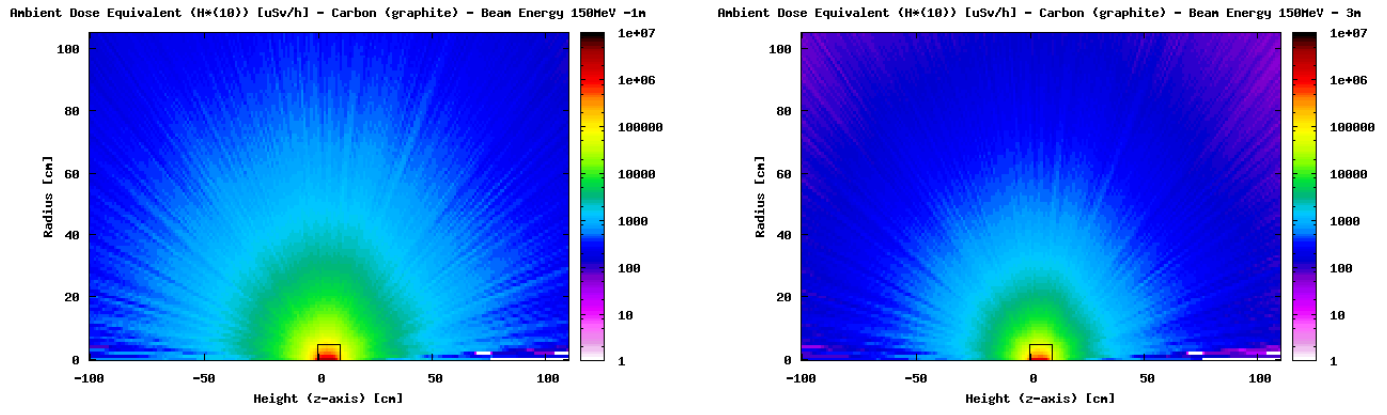


Figure 12.43: cooling times: 1m and 3m

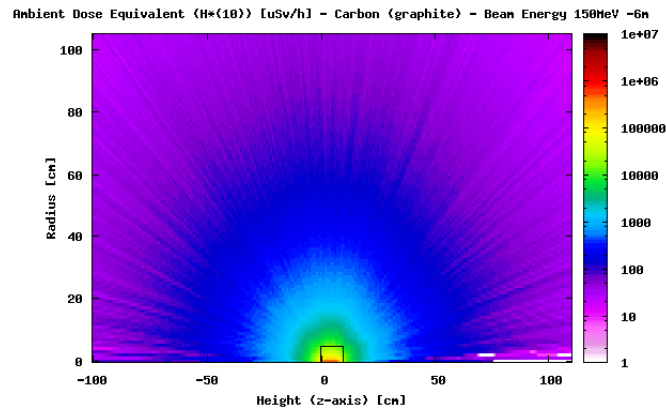


Figure 12.44: cooling time: 6m

12.1.12 Carbon(Graphite) - 200MeV

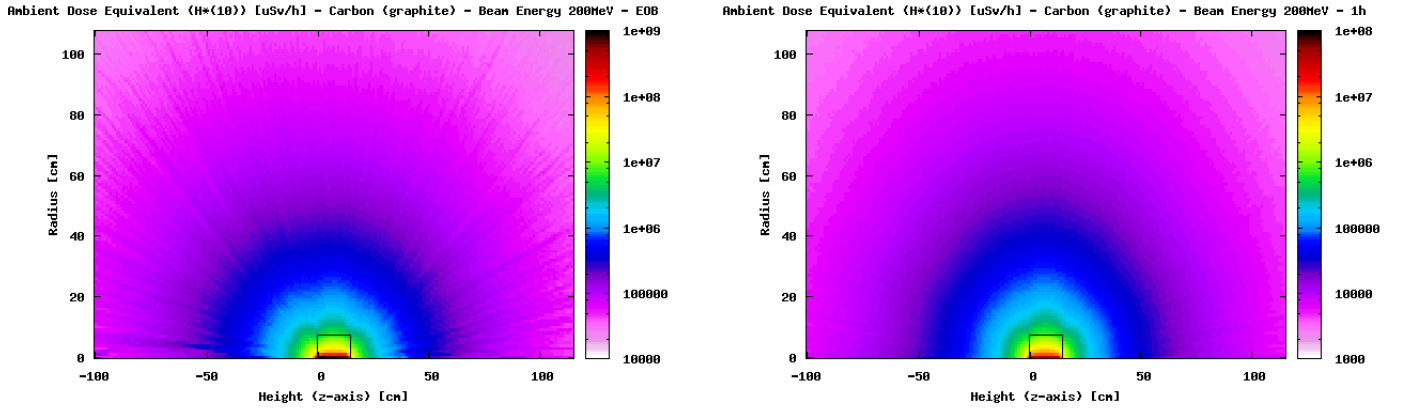


Figure 12.45: cooling times: EOB and 1h

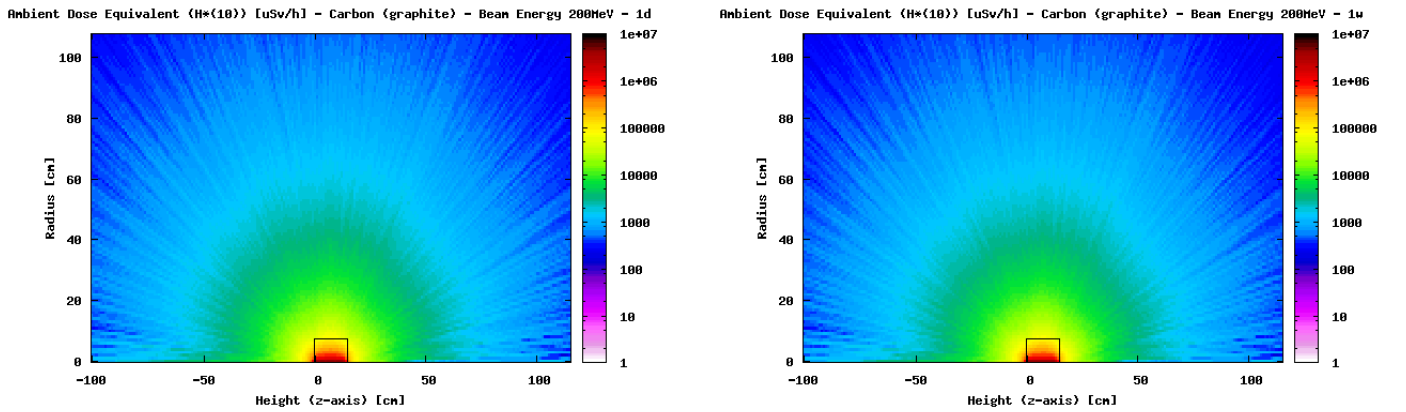


Figure 12.46: cooling times: 1d and 1w

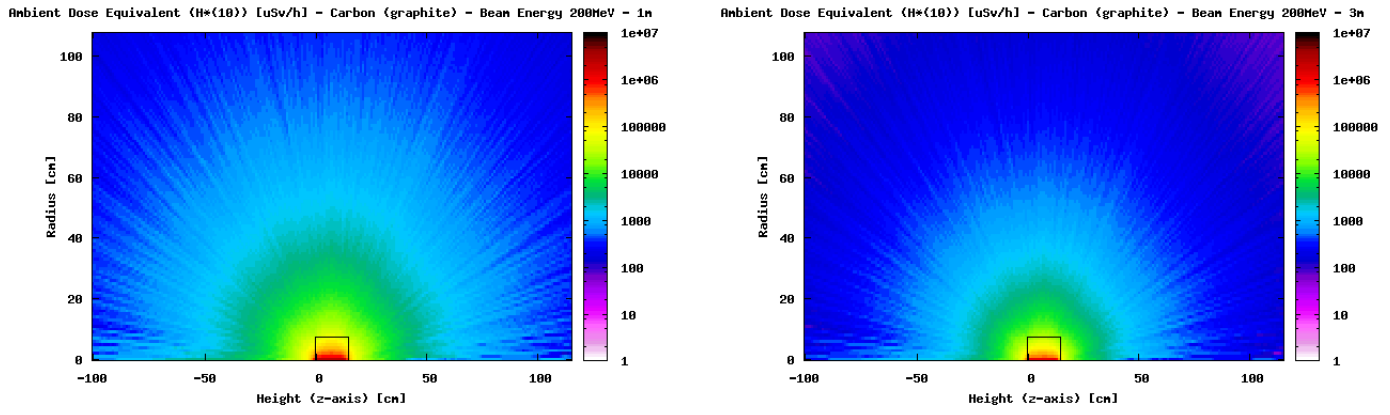


Figure 12.47: cooling times: 1m and 3m

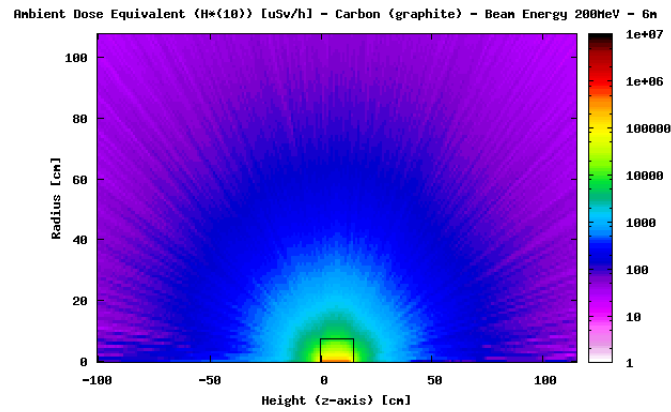


Figure 12.48: cooling time: 6m

12.1.13 Carbon(Graphite) - 250MeV

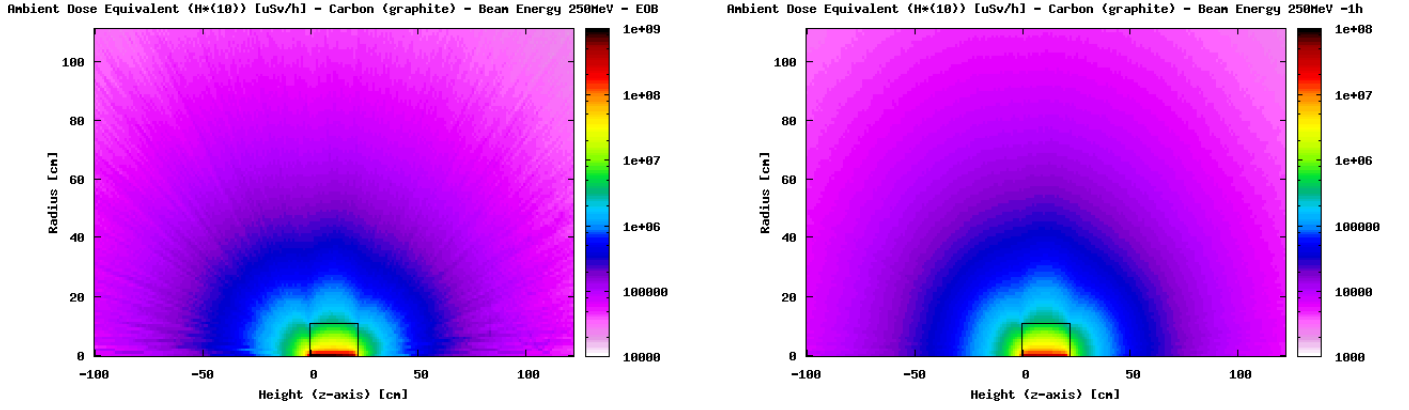


Figure 12.49: cooling times: EOB and 1h

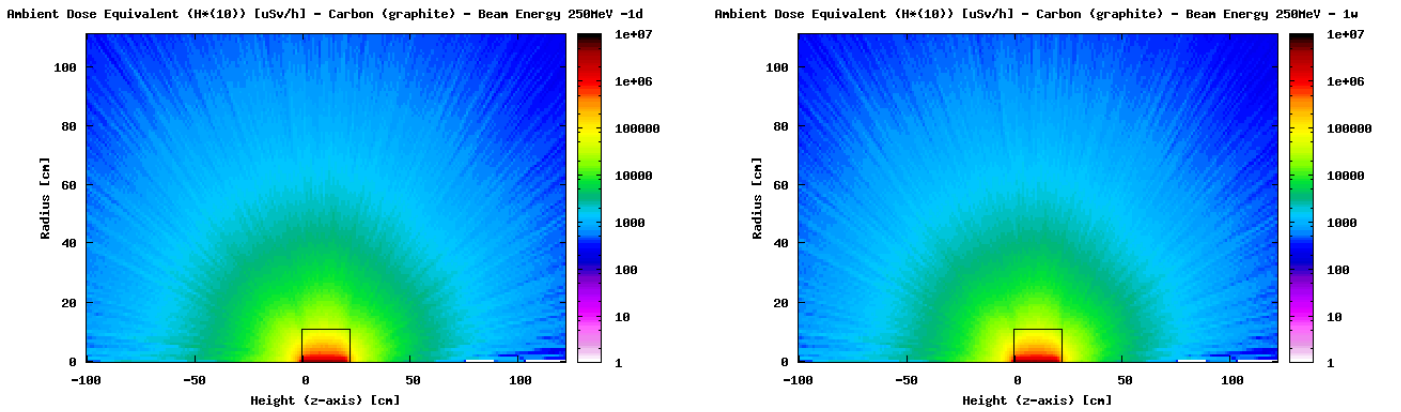


Figure 12.50: cooling times: 1d and 1w

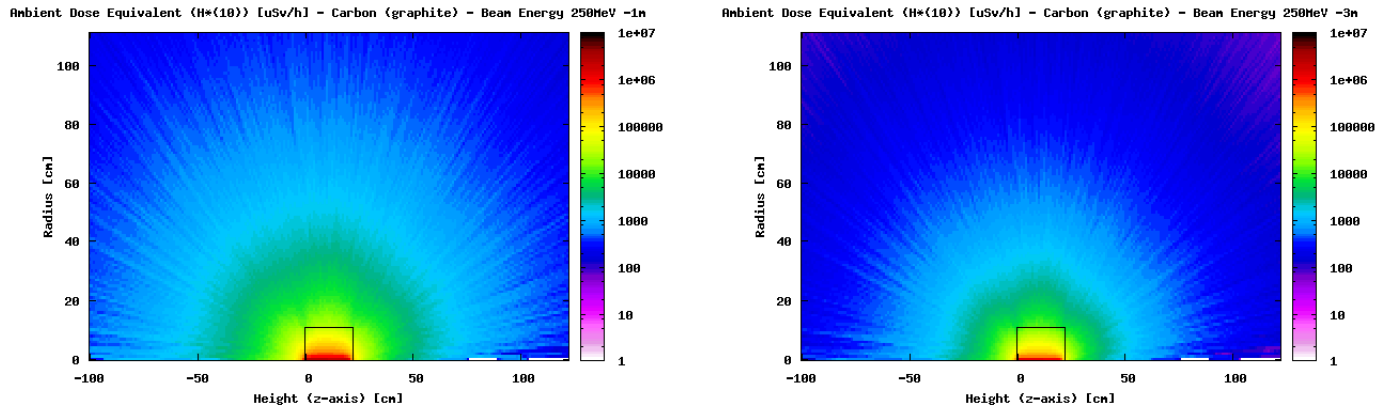


Figure 12.51: cooling times: 1m and 3m

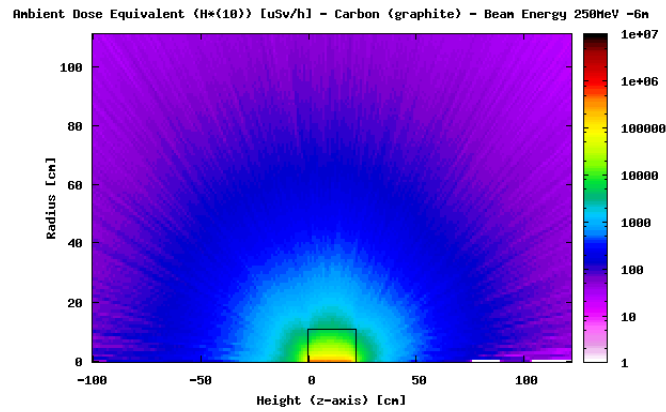


Figure 12.52: cooling time: 6m

12.1.14 Carbon(Graphite) - 300MeV

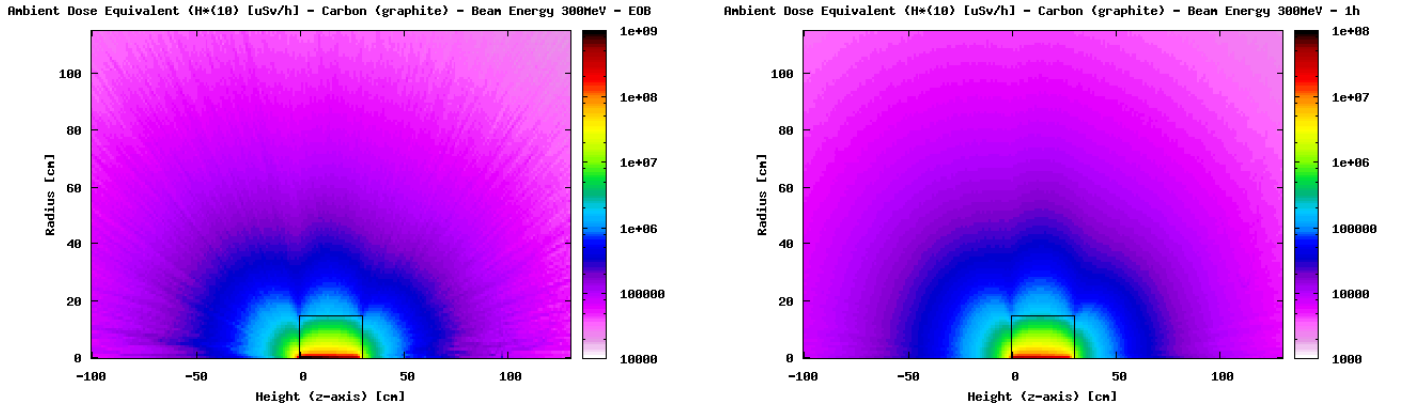


Figure 12.53: cooling times: EOB and 1h

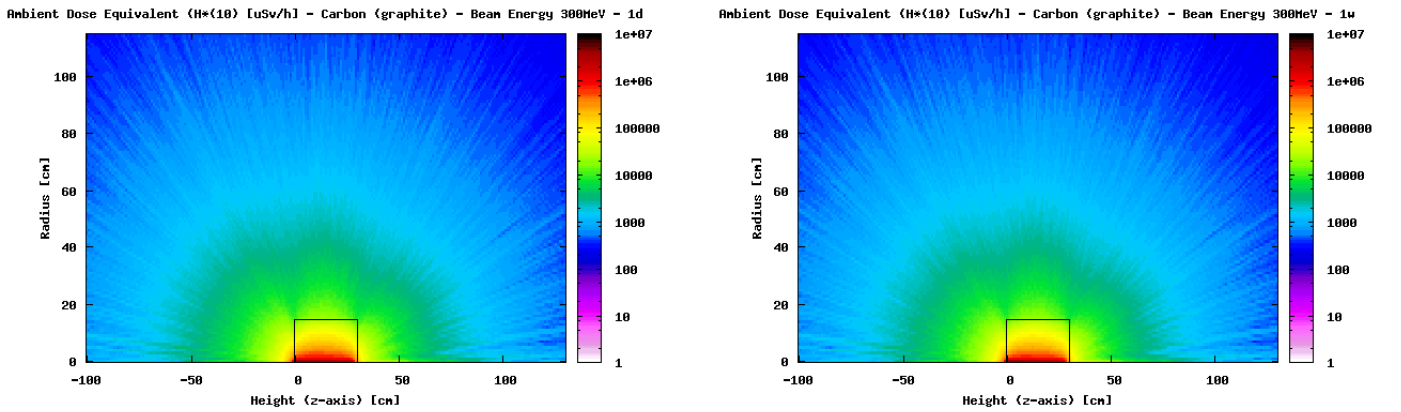


Figure 12.54: cooling times: 1d and 1w

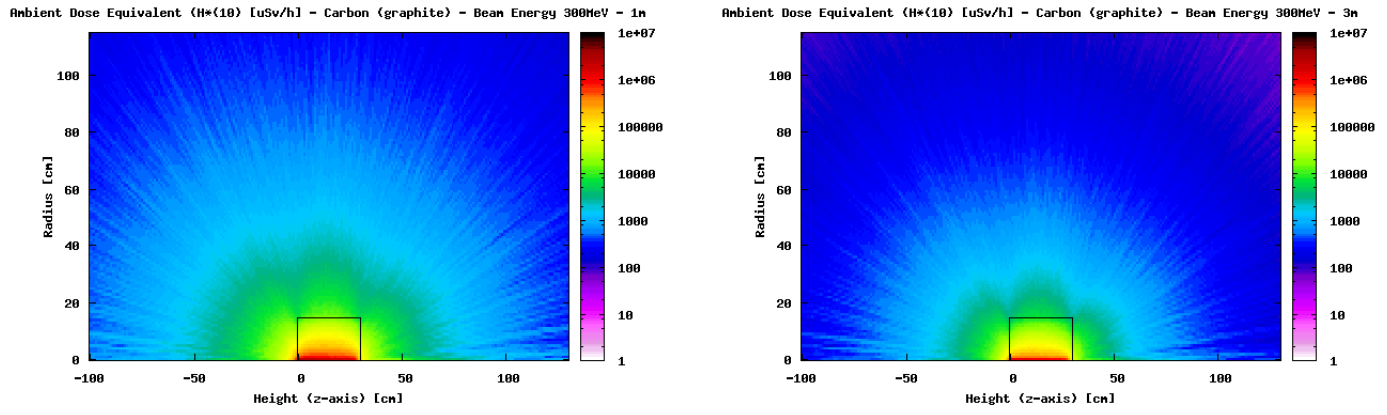


Figure 12.55: cooling times: 1m and 3m

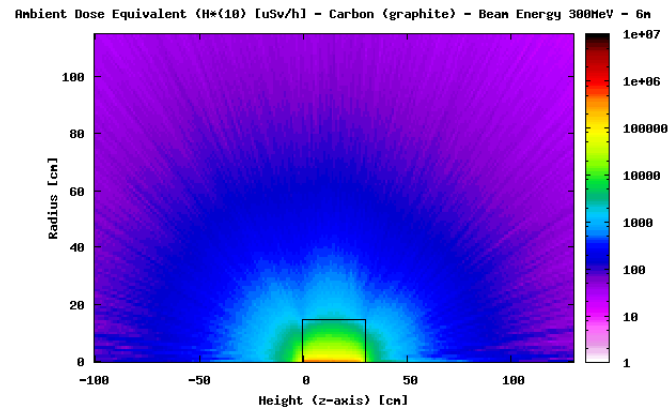


Figure 12.56: cooling time: 6m

12.1.15 Carbon(Graphite) - 350MeV

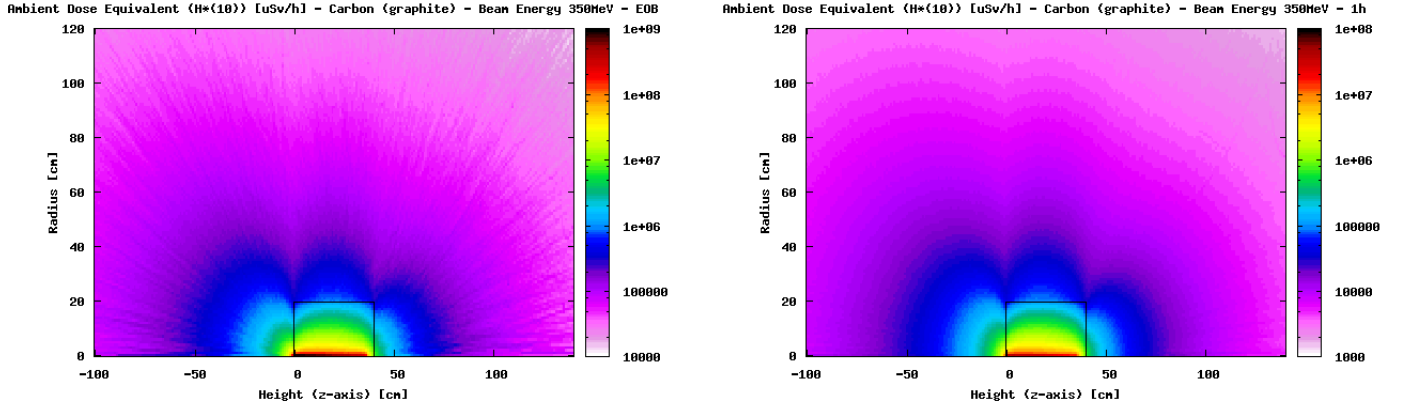


Figure 12.57: cooling times: EOB and 1h

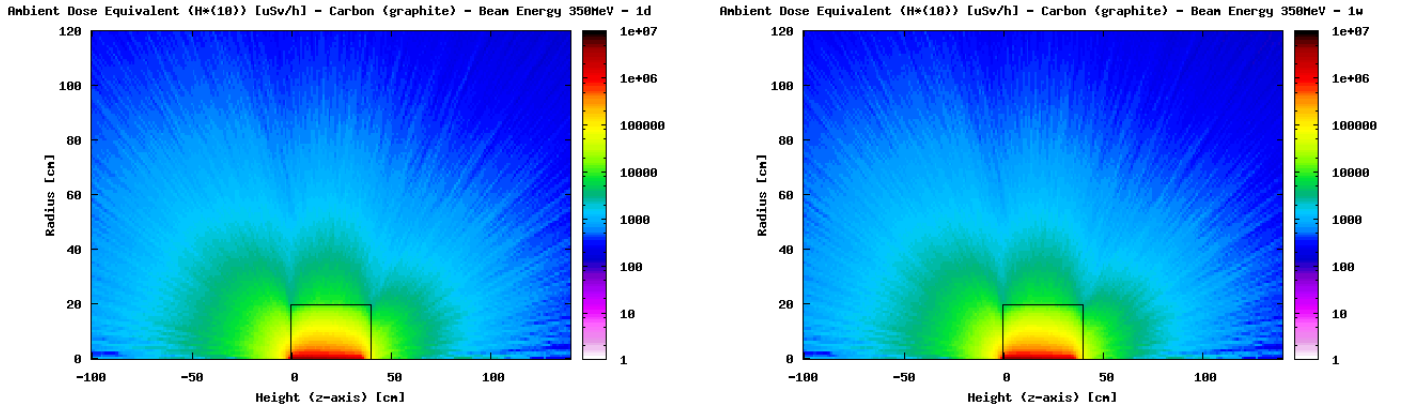


Figure 12.58: cooling times: 1d and 1w

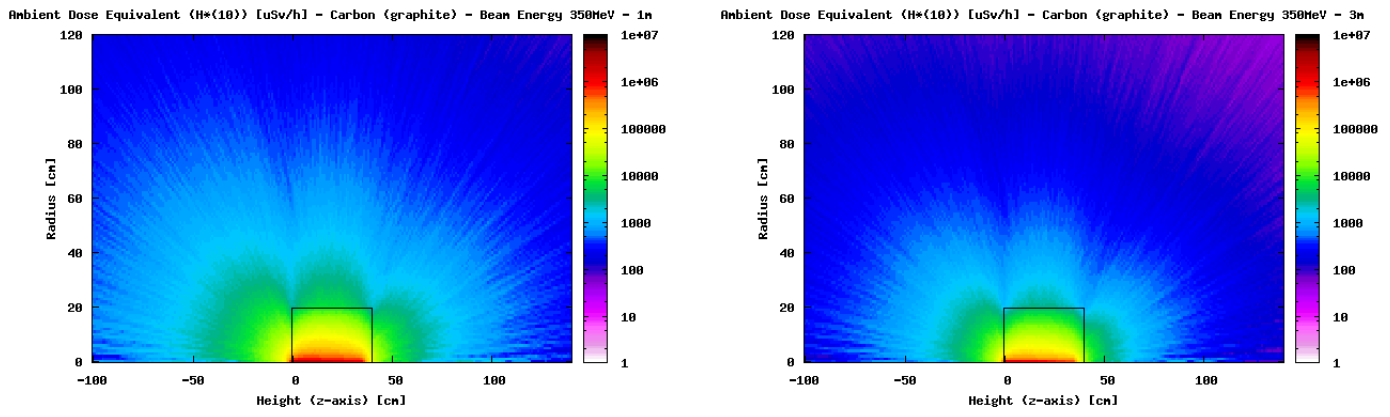


Figure 12.59: cooling times: 1m and 3m

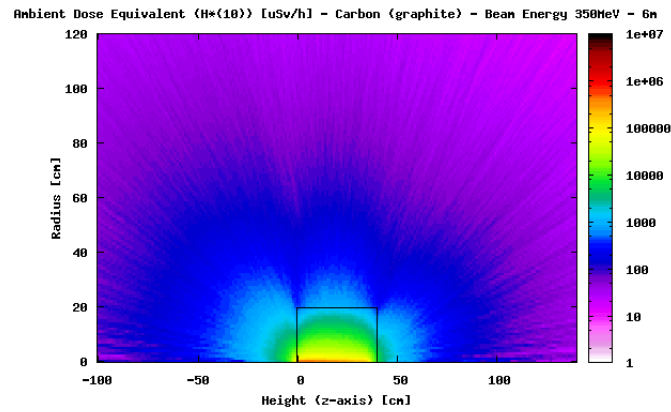


Figure 12.60: cooling time: 6m

12.1.16 Carbon(Graphite) - 400MeV

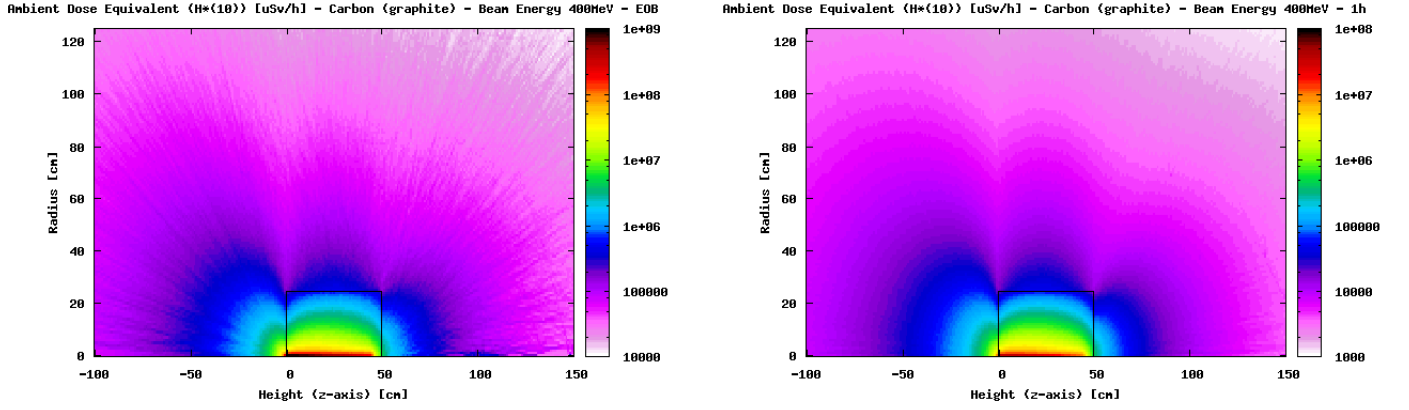


Figure 12.61: cooling times: EOB and 1h

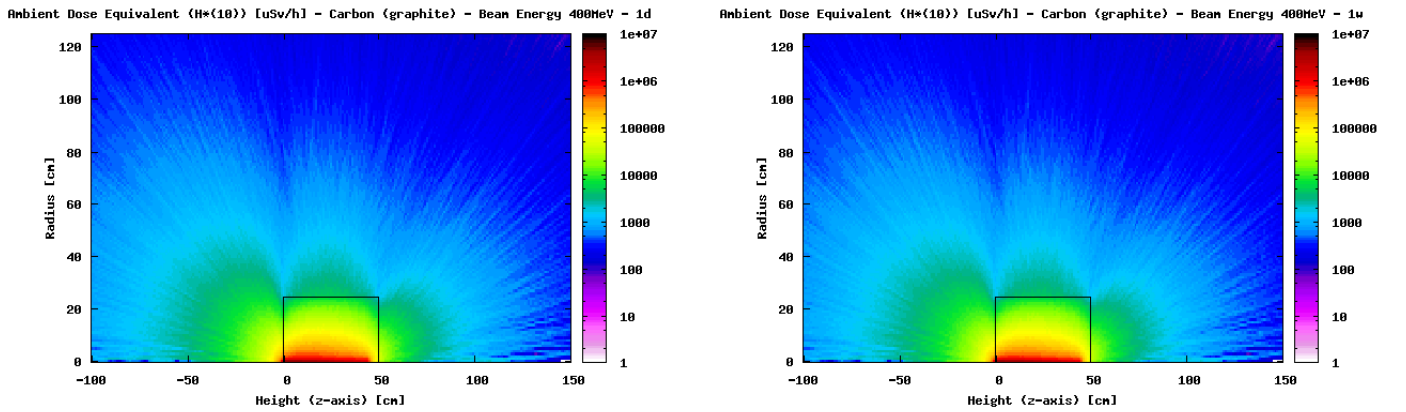


Figure 12.62: cooling times: 1d and 1w

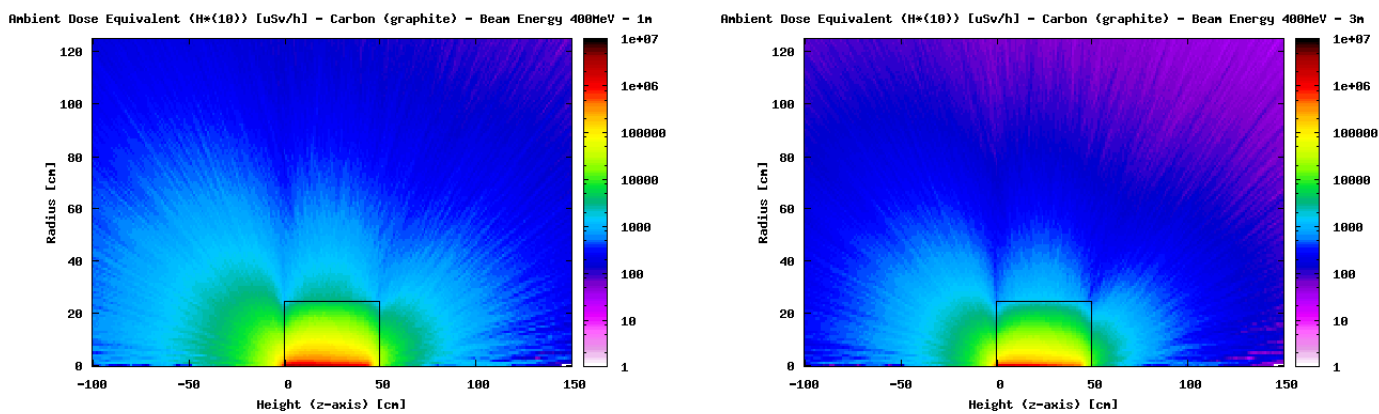


Figure 12.63: cooling times: 1m and 3m

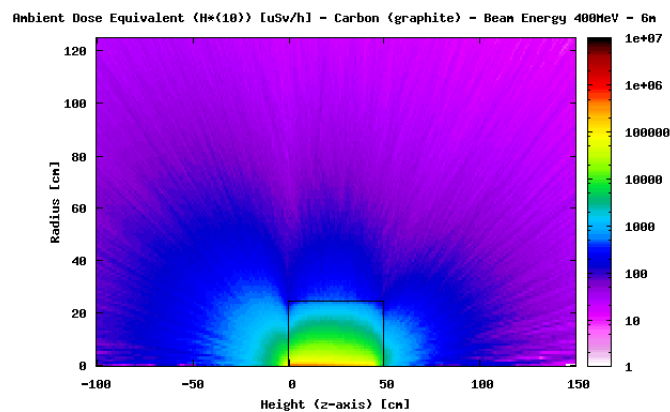


Figure 12.64: cooling time: 6m

12.1.17 Copper - 50MeV

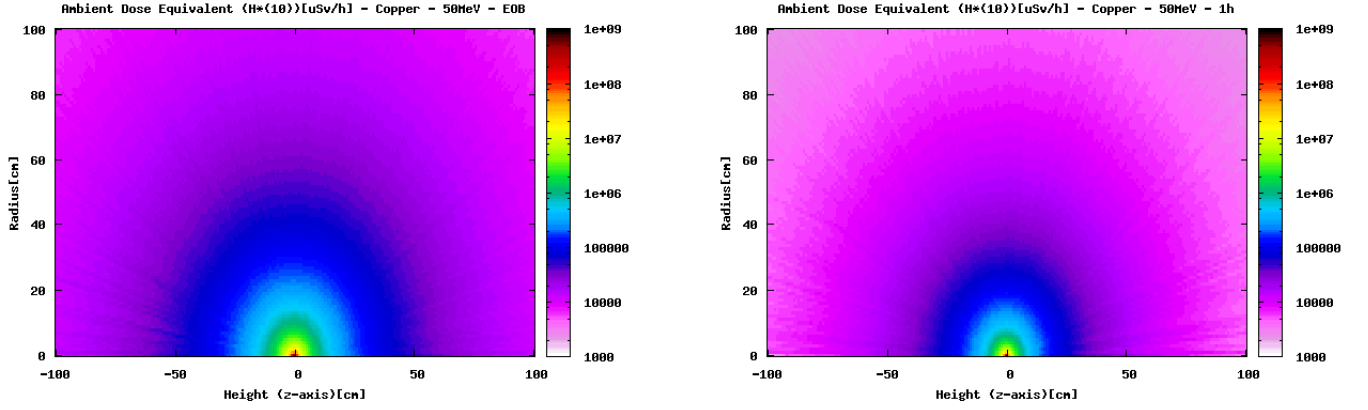


Figure 12.65: cooling times: EOB and 1h

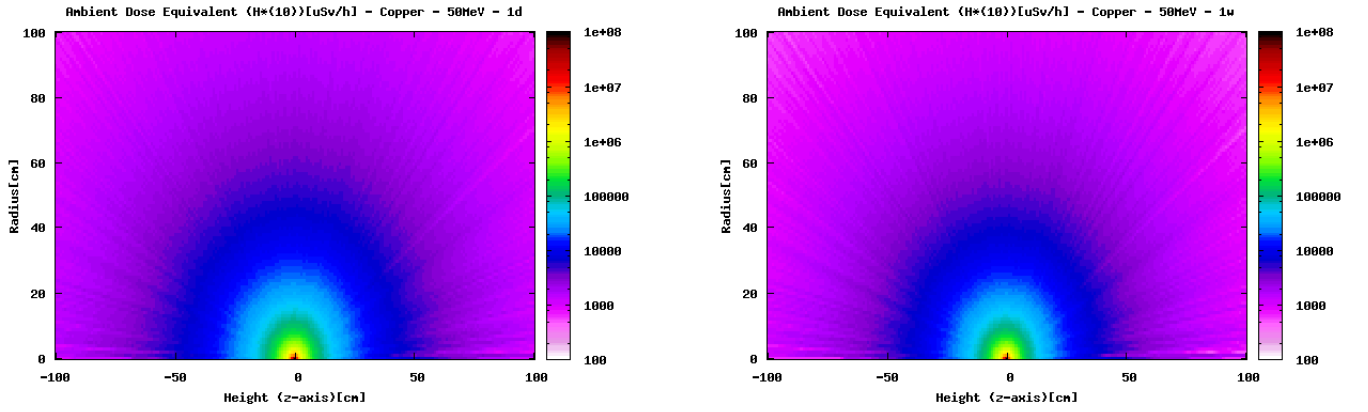


Figure 12.66: cooling times: 1d and 1w

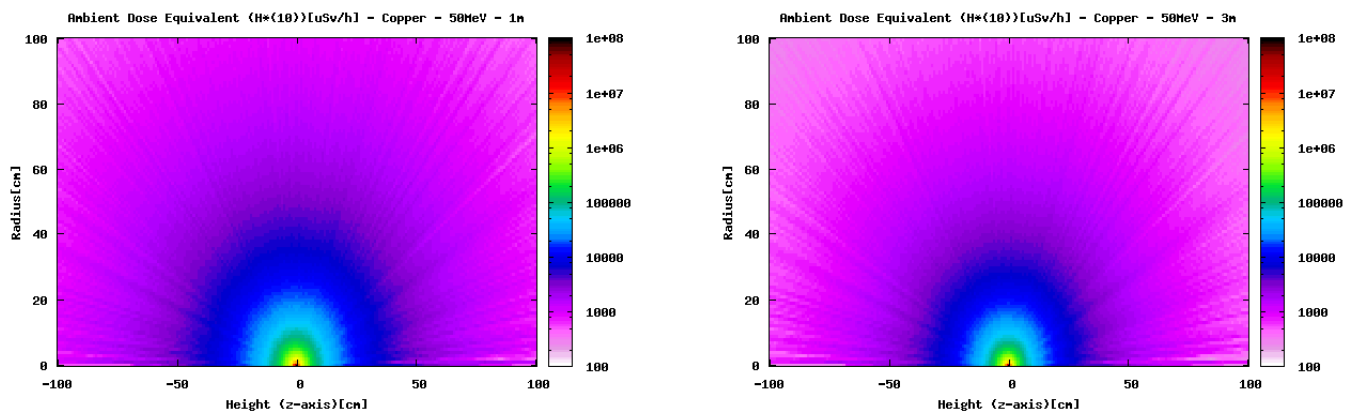


Figure 12.67: cooling times: 1m and 3m

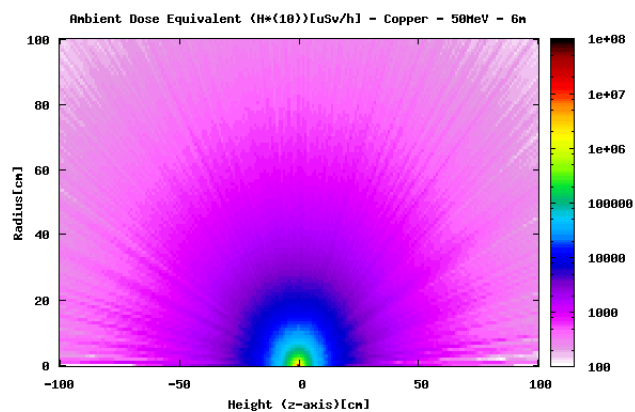


Figure 12.68: cooling time: 6m

12.1.18 Copper - 100MeV

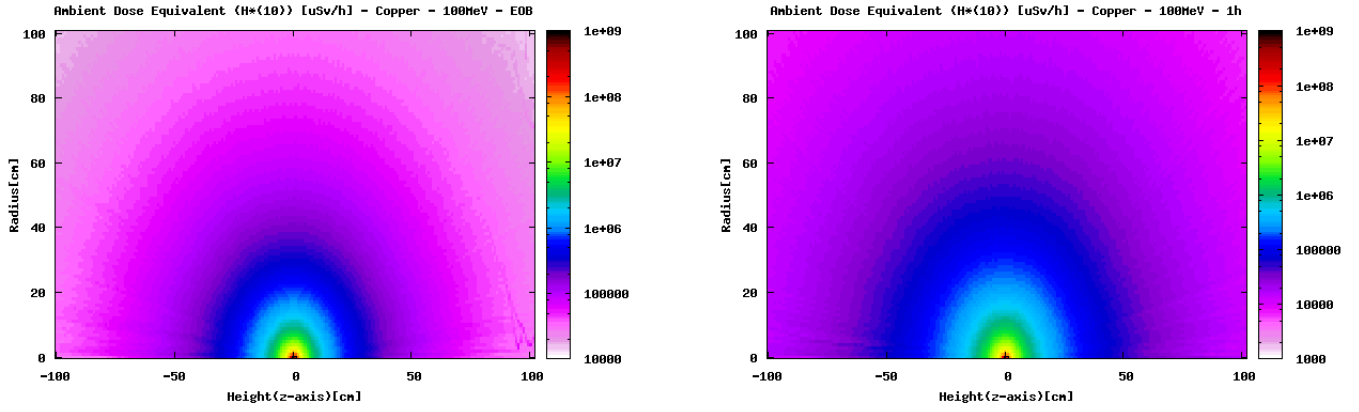


Figure 12.69: cooling times: EOB and 1h

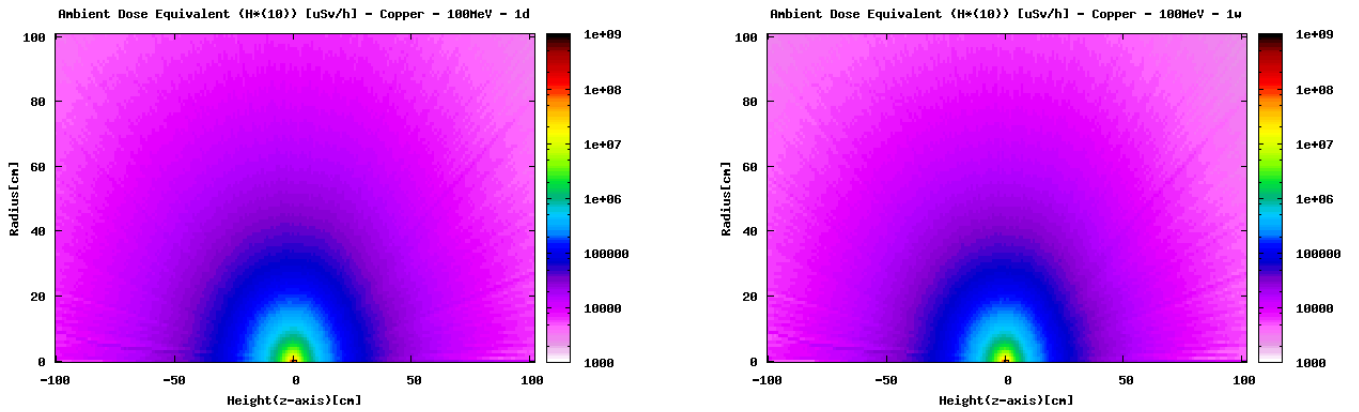


Figure 12.70: cooling times: 1d and 1w

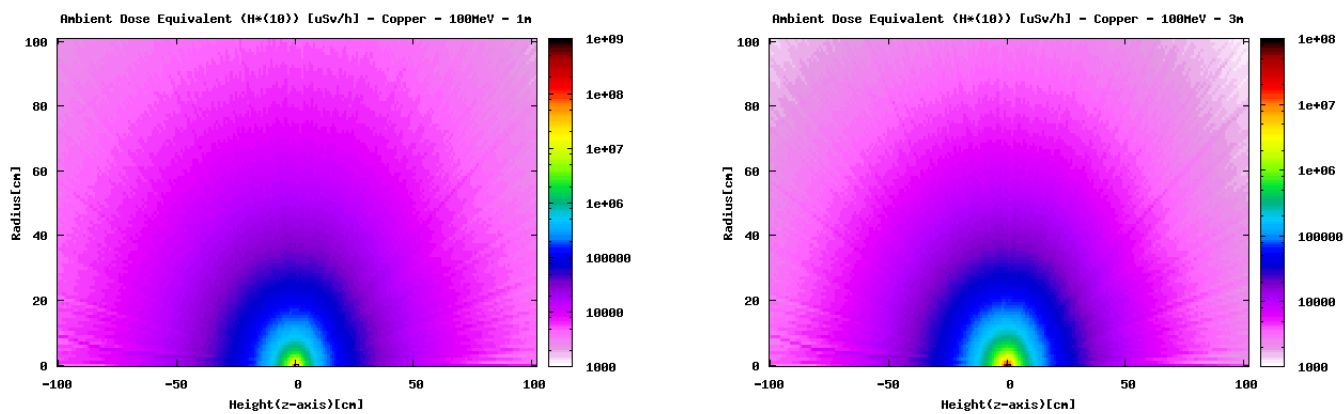


Figure 12.71: cooling times: 1m and 3m

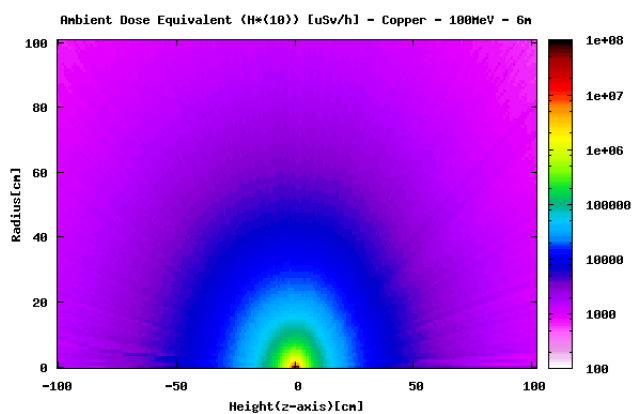


Figure 12.72: cooling time: 6m

12.1.19 Copper - 150MeV

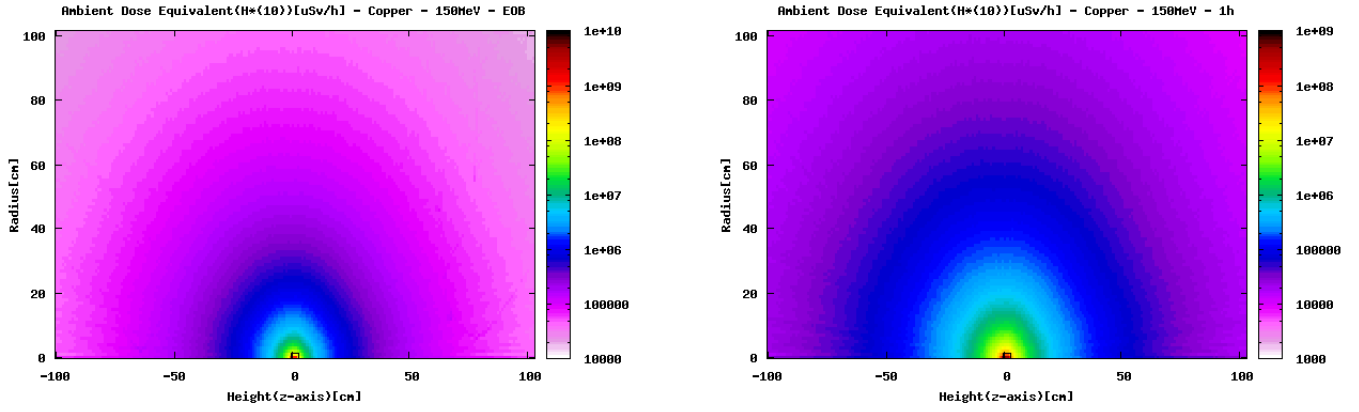


Figure 12.73: cooling times: EOB and 1h

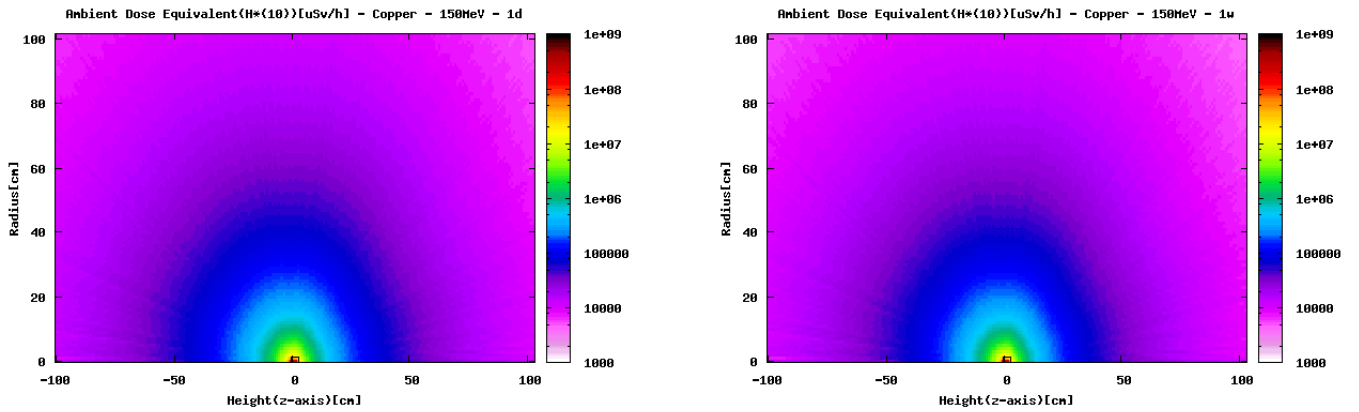


Figure 12.74: cooling times: 1d and 1w

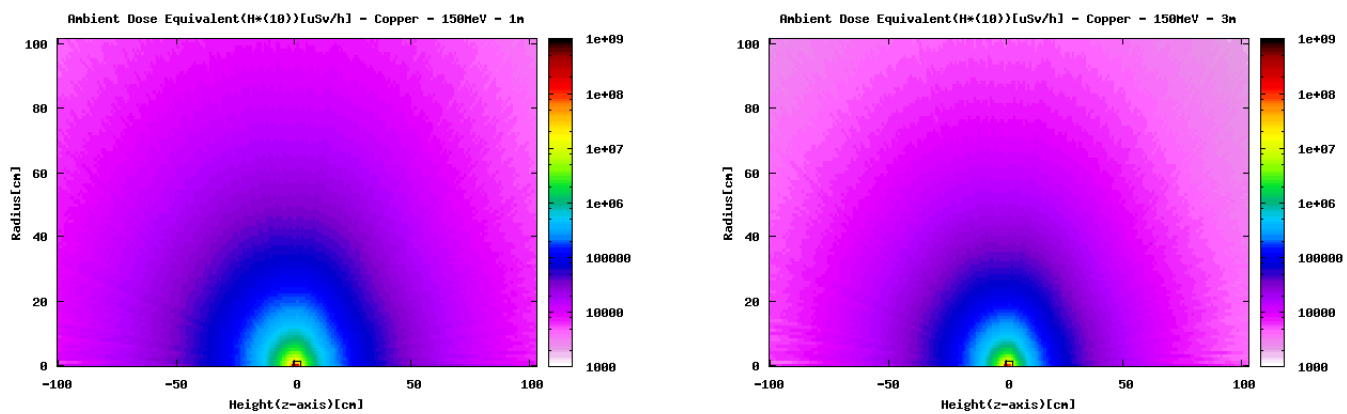


Figure 12.75: cooling times: 1m and 3m

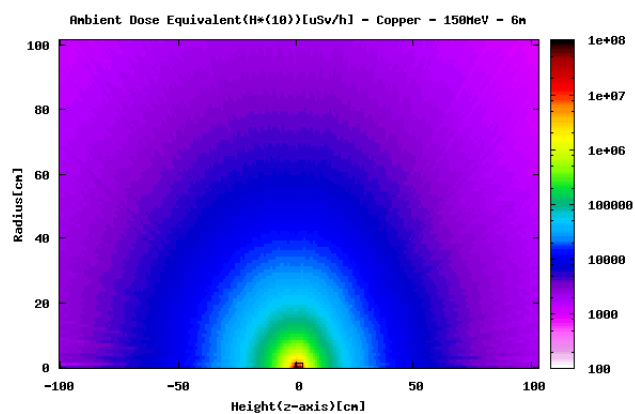


Figure 12.76: cooling time: 6m

12.1.20 Copper - 200MeV

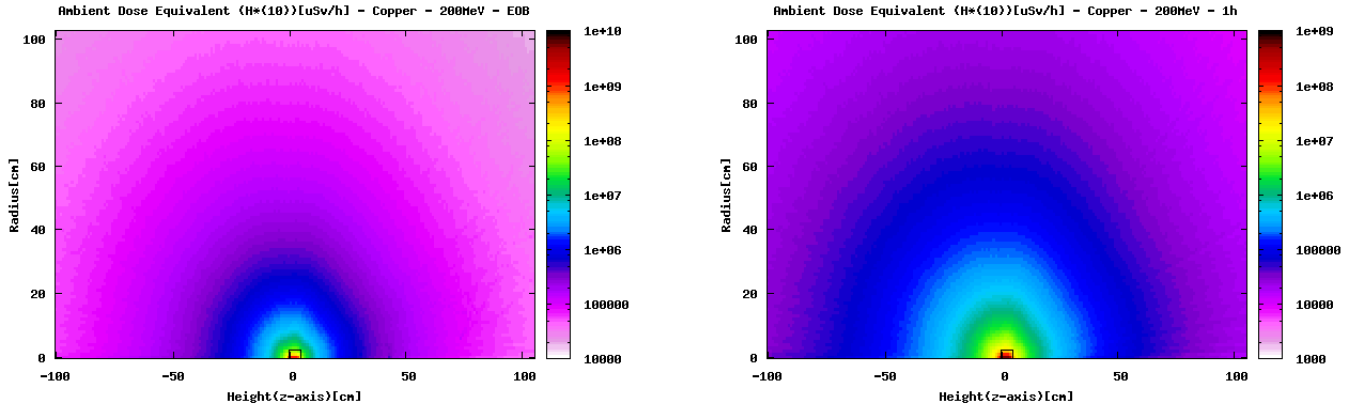


Figure 12.77: cooling times: EOB and 1h

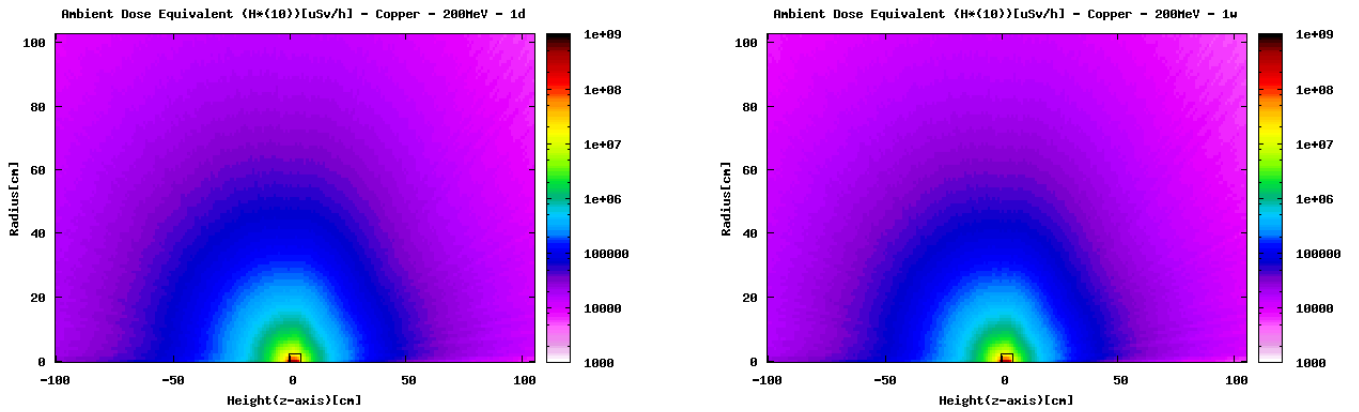


Figure 12.78: cooling times: 1d and 1w

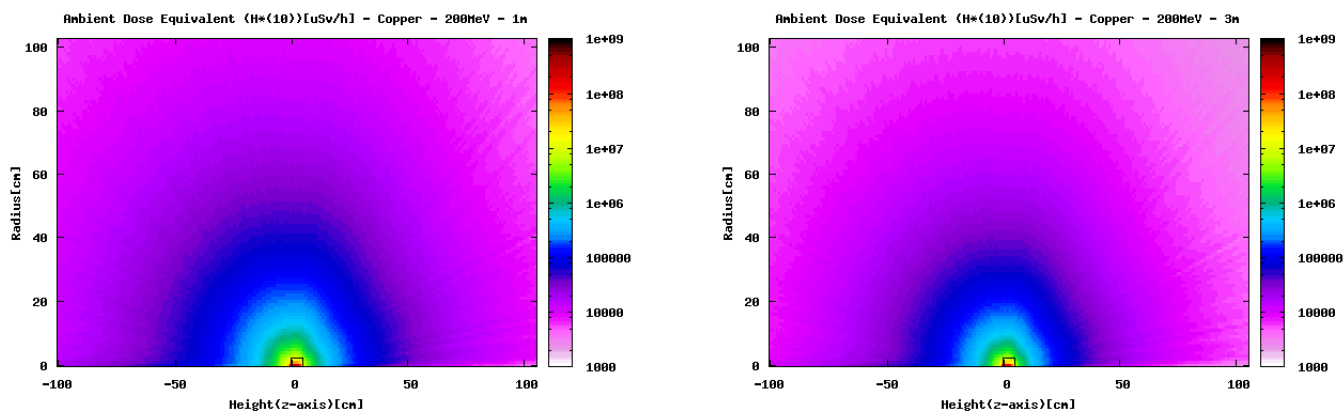


Figure 12.79: cooling times: 1m and 3m

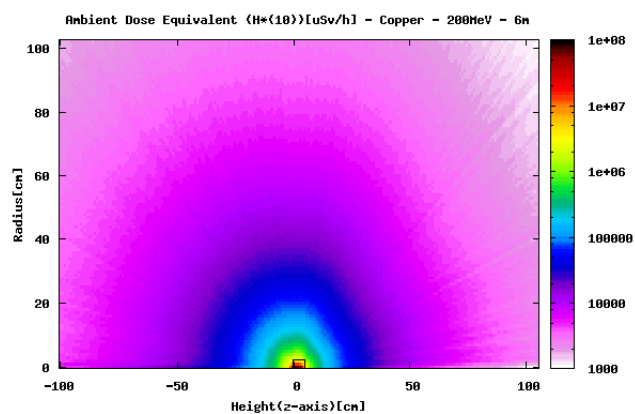


Figure 12.80: cooling time: 6m

12.1.21 Copper - 250MeV

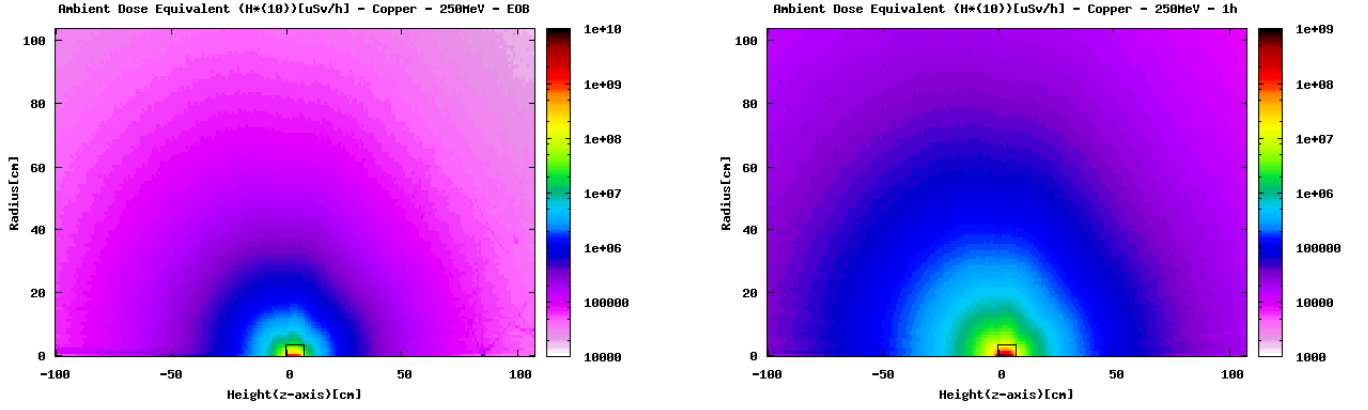


Figure 12.81: cooling times: EOB and 1h

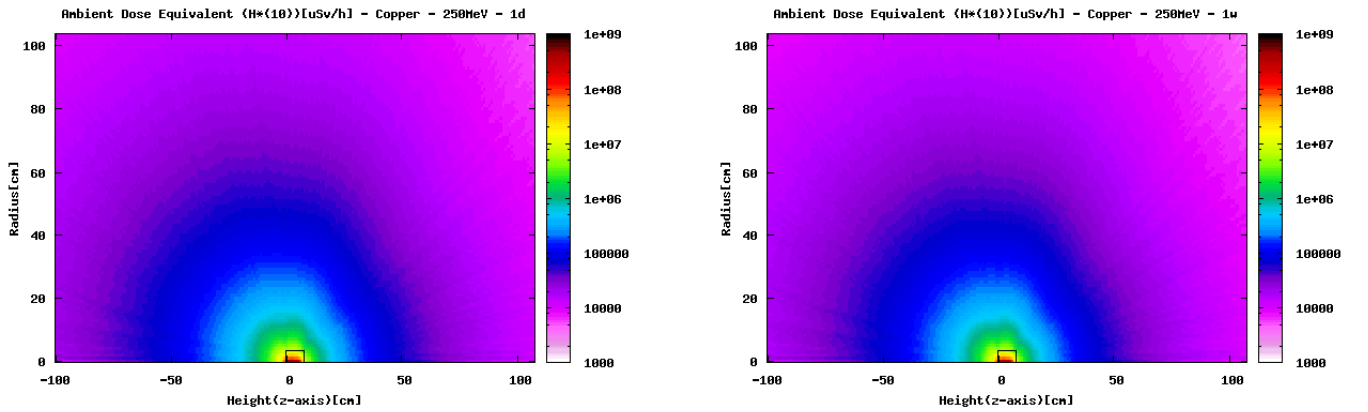


Figure 12.82: cooling times: 1d and 1w

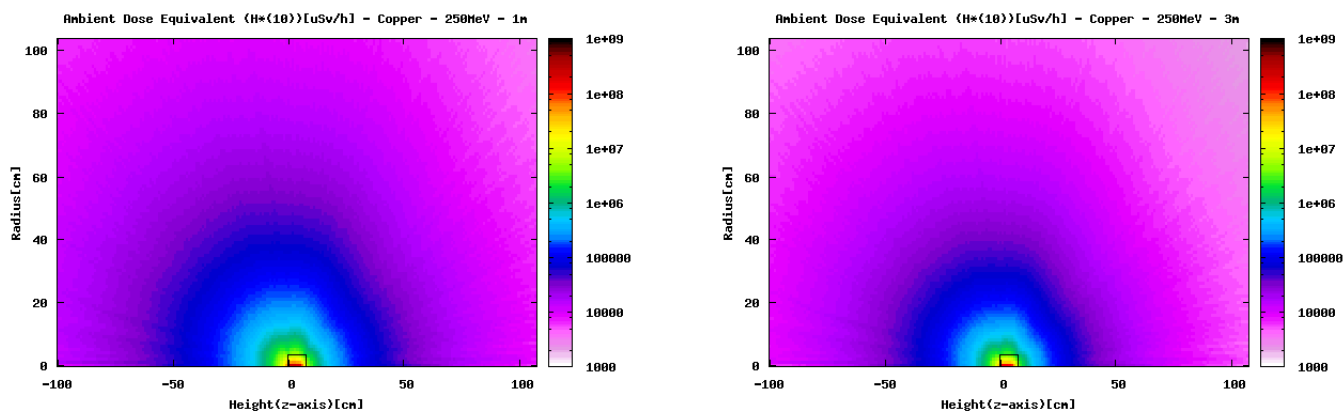


Figure 12.83: cooling times: 1m and 3m

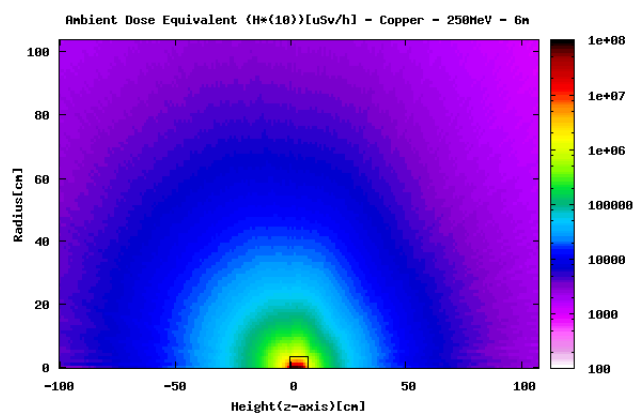


Figure 12.84: cooling time: 6m

12.1.22 Copper - 300MeV

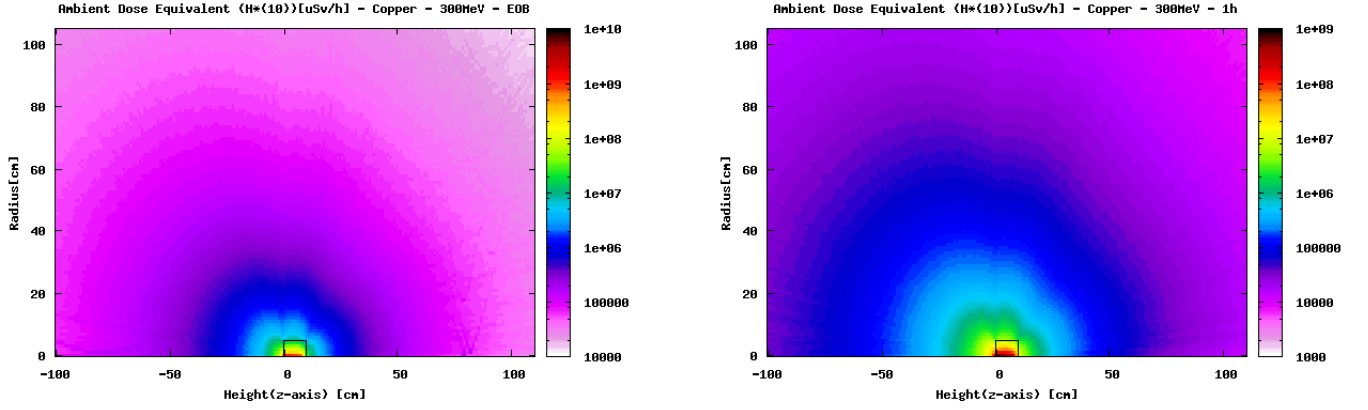


Figure 12.85: cooling times: EOB and 1h

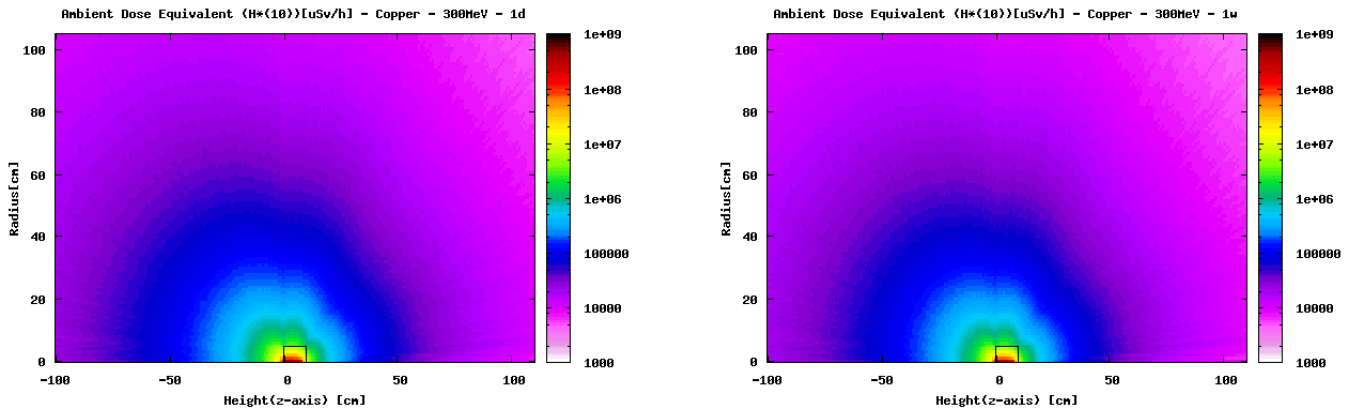


Figure 12.86: cooling times: 1d and 1w

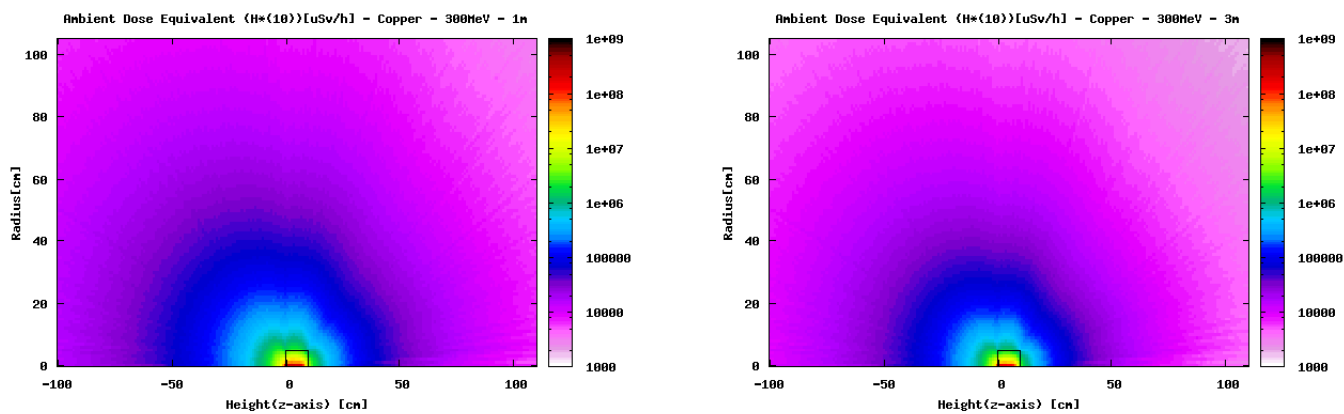


Figure 12.87: cooling times: 1m and 3m

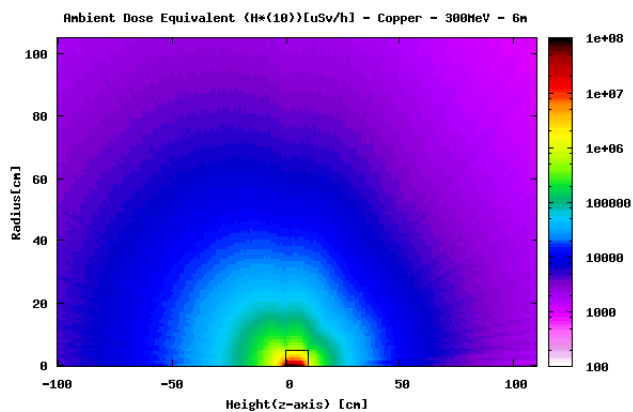


Figure 12.88: cooling time: 6m

12.1.23 Copper - 350MeV

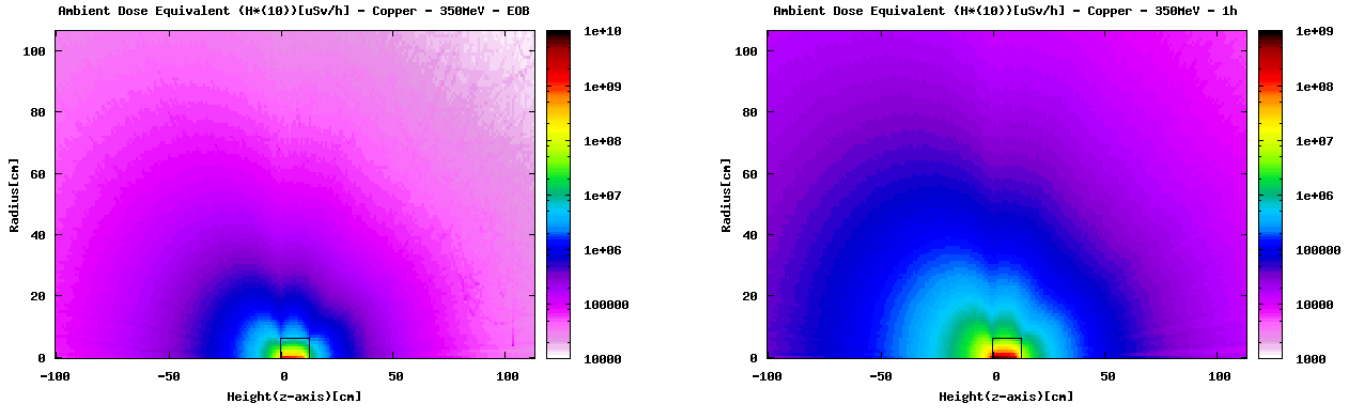


Figure 12.89: cooling times: EOB and 1h

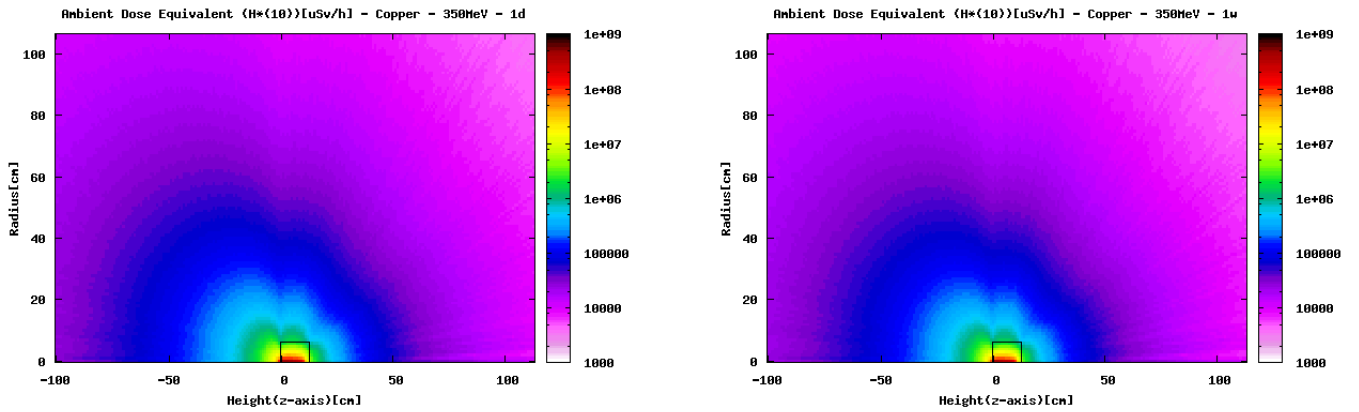


Figure 12.90: cooling times: 1d and 1w

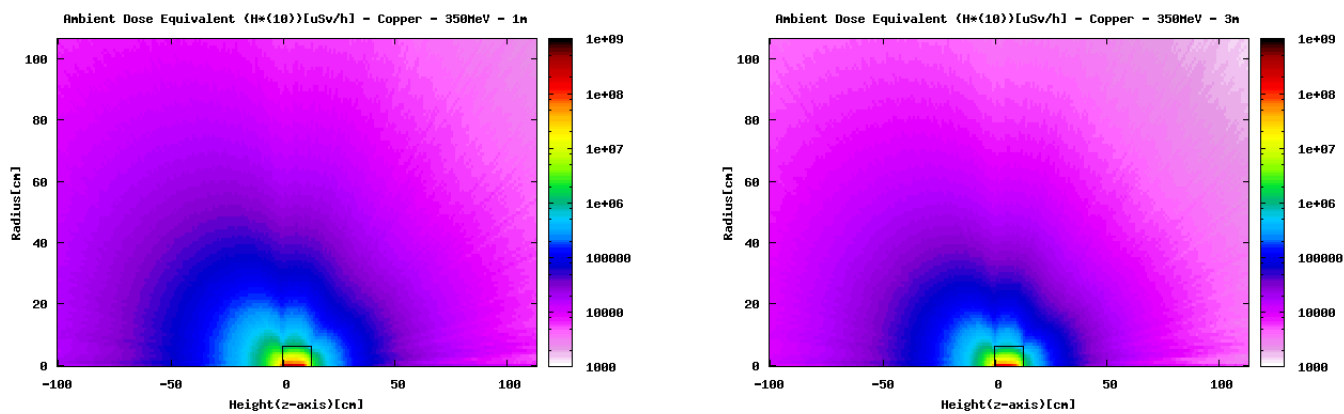


Figure 12.91: cooling times: 1m and 3m

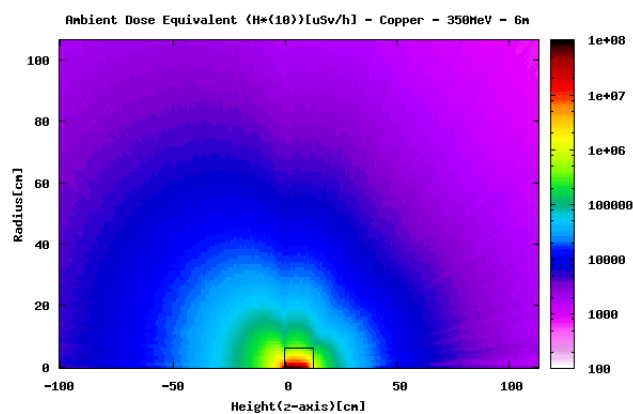


Figure 12.92: cooling time: 6m

12.1.24 Copper - 400MeV

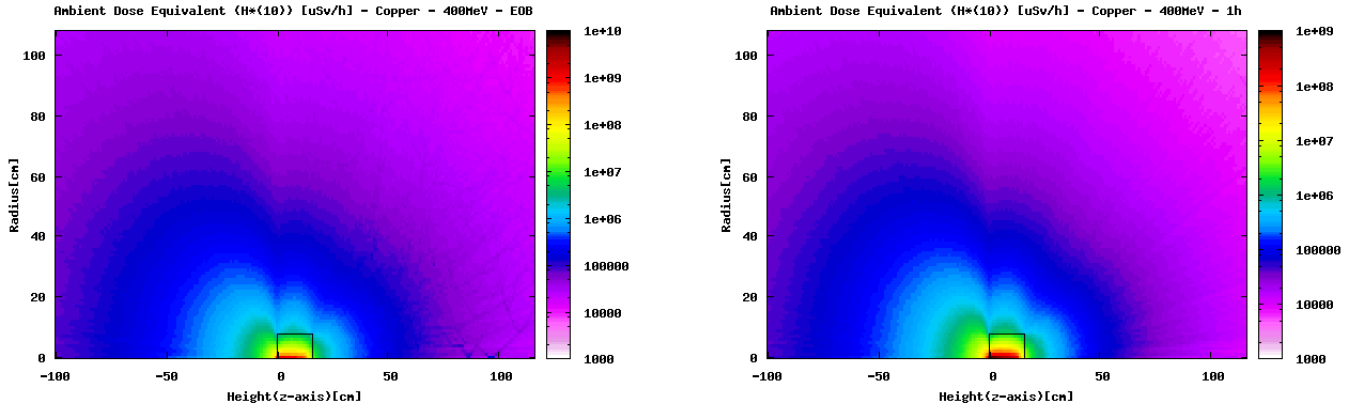


Figure 12.93: cooling times: EOB and 1h

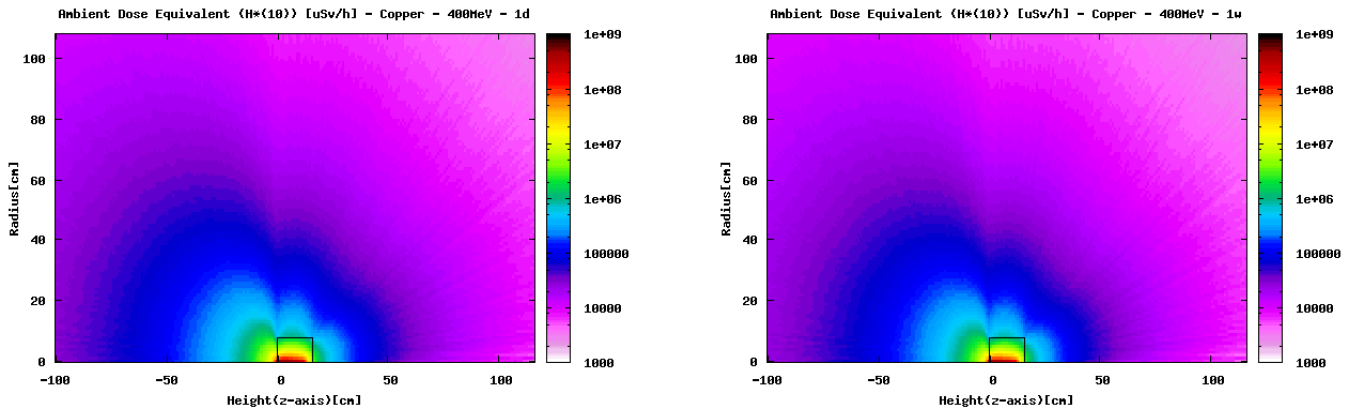


Figure 12.94: cooling times: 1d and 1w

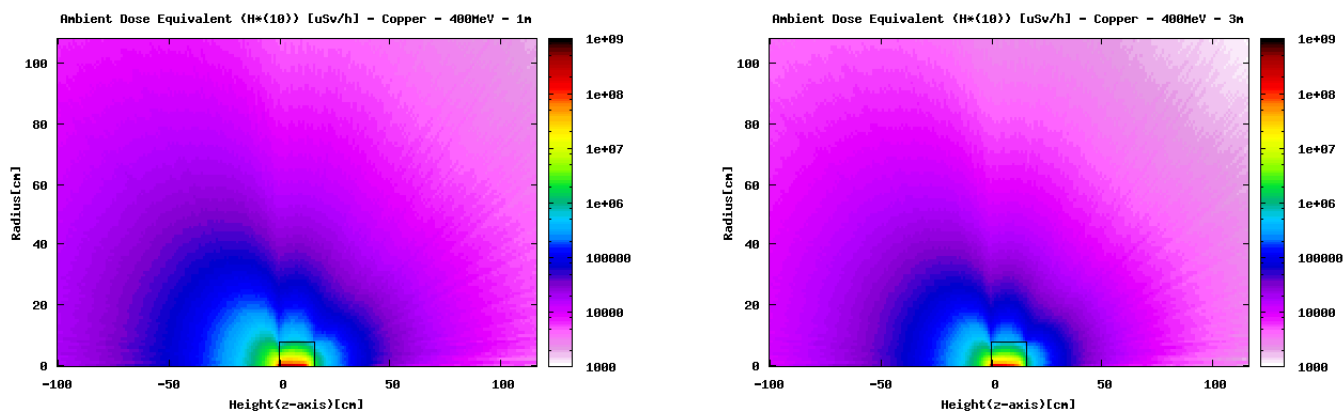


Figure 12.95: cooling times: 1m and 3m

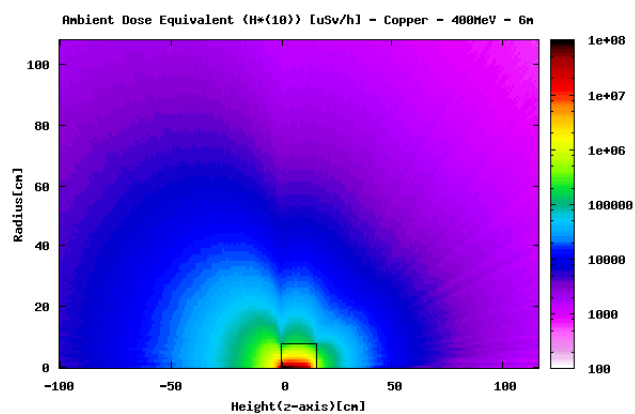


Figure 12.96: cooling time: 6m

12.1.25 Iron - 50MeV

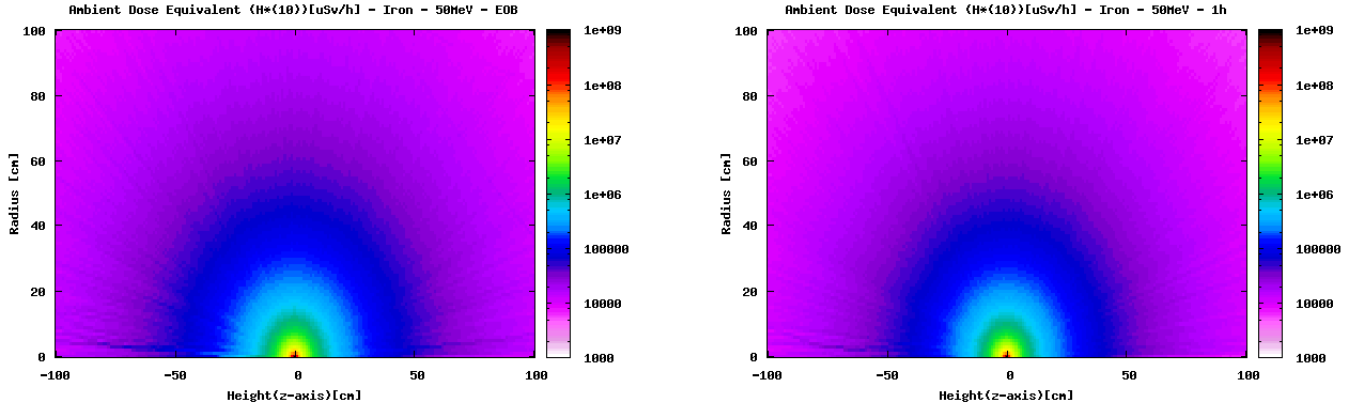


Figure 12.97: cooling times: EOB and 1h

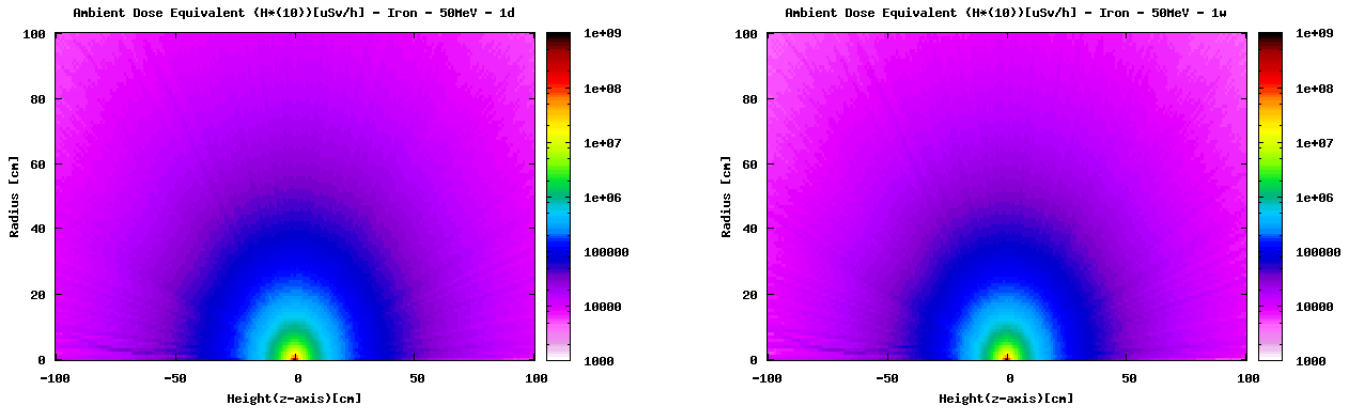


Figure 12.98: cooling times: 1d and 1w

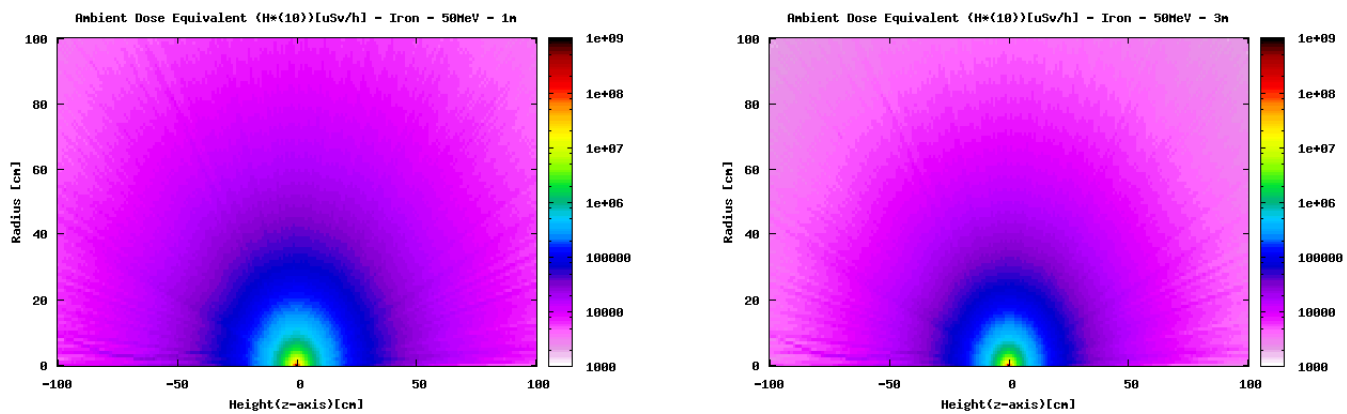


Figure 12.99: cooling times: 1m and 3m

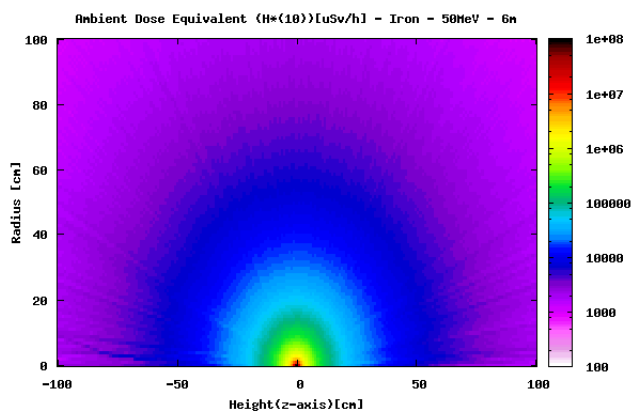


Figure 12.100: cooling time: 6m

12.1.26 Iron - 100MeV

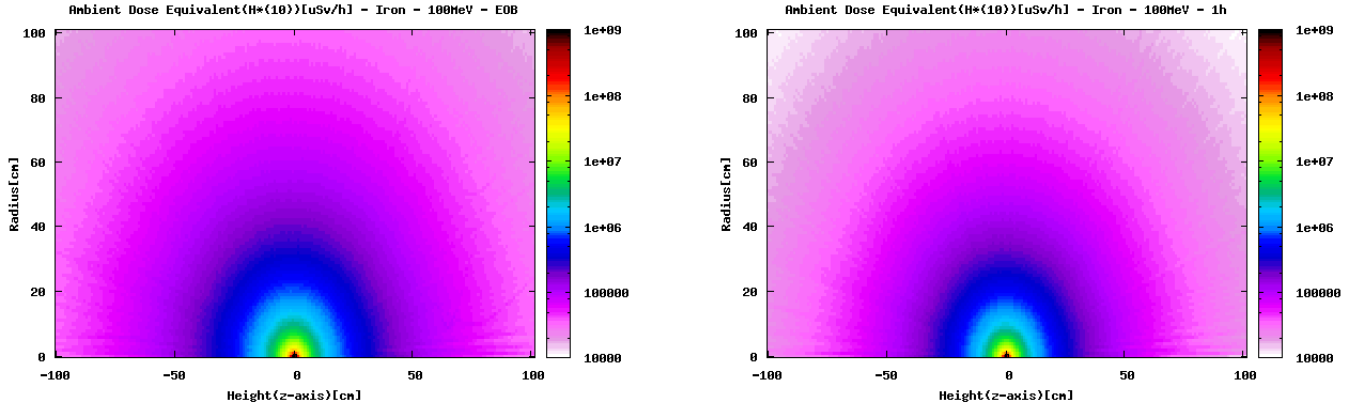


Figure 12.101: cooling times: EOB and 1h

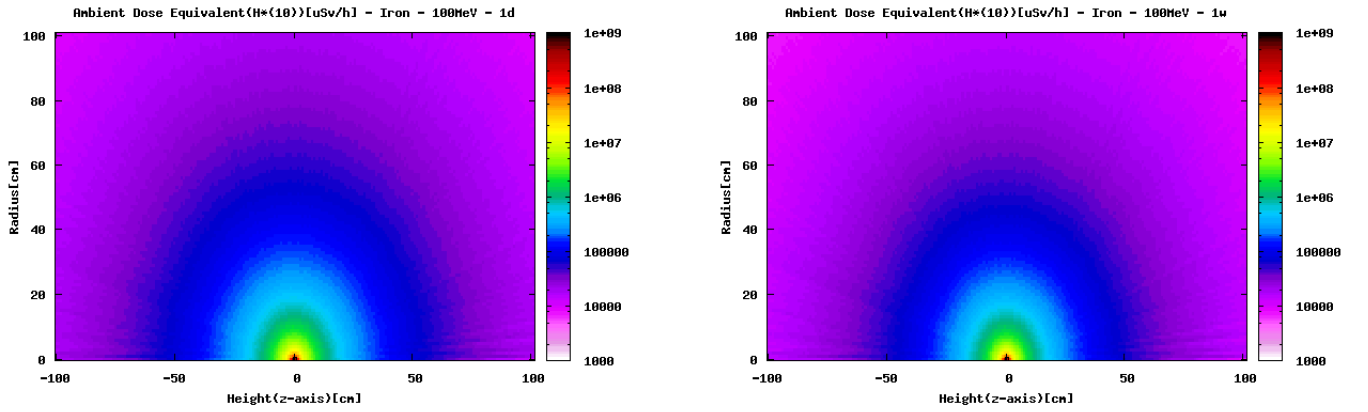


Figure 12.102: cooling times: 1d and 1w

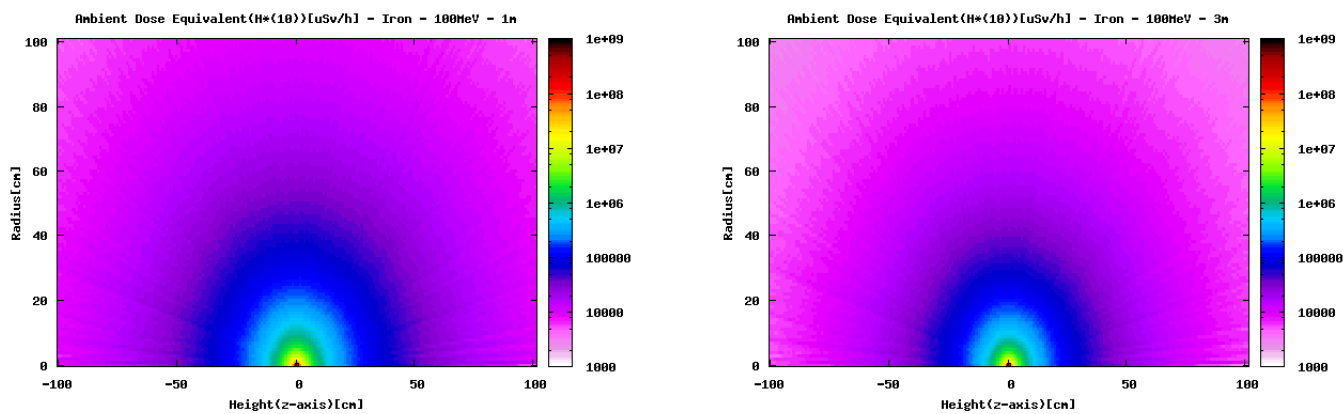


Figure 12.103: cooling times: 1m and 3m

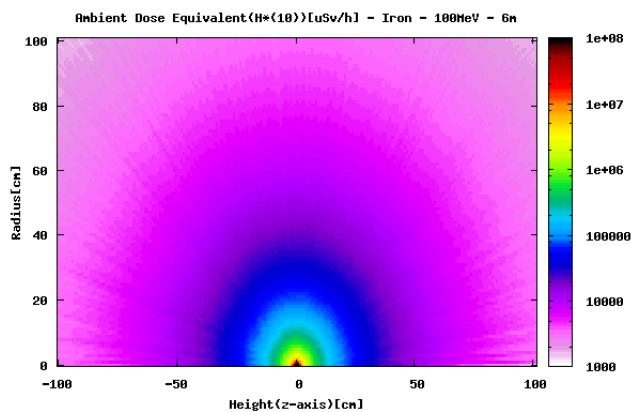


Figure 12.104: cooling time: 6m

12.1.27 Iron - 150MeV

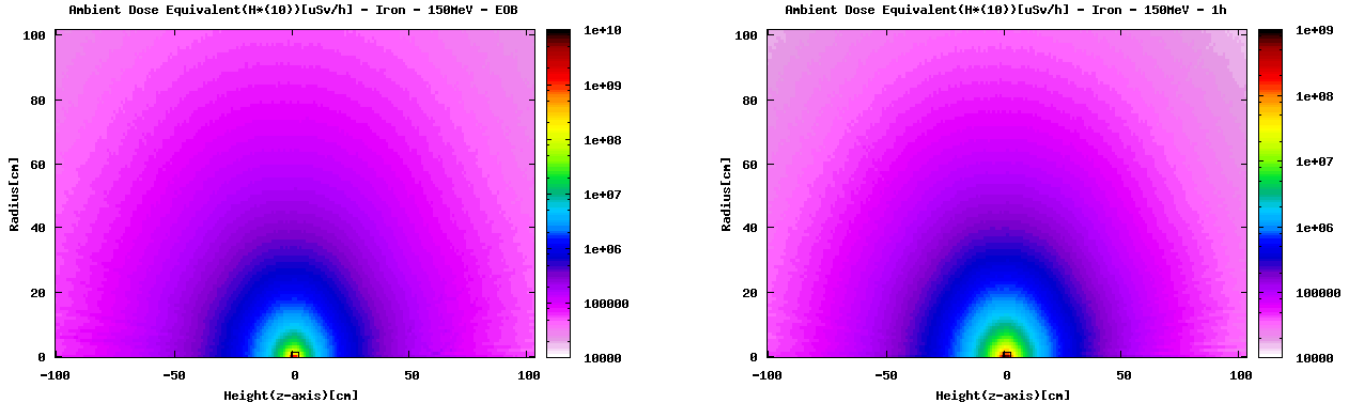


Figure 12.105: cooling times: EOB and 1h

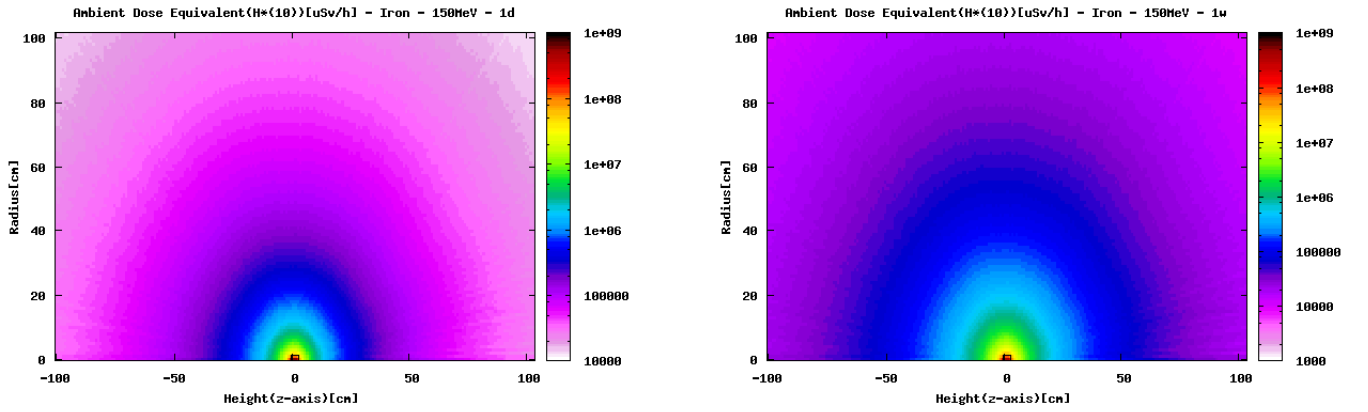


Figure 12.106: cooling times: 1d and 1w

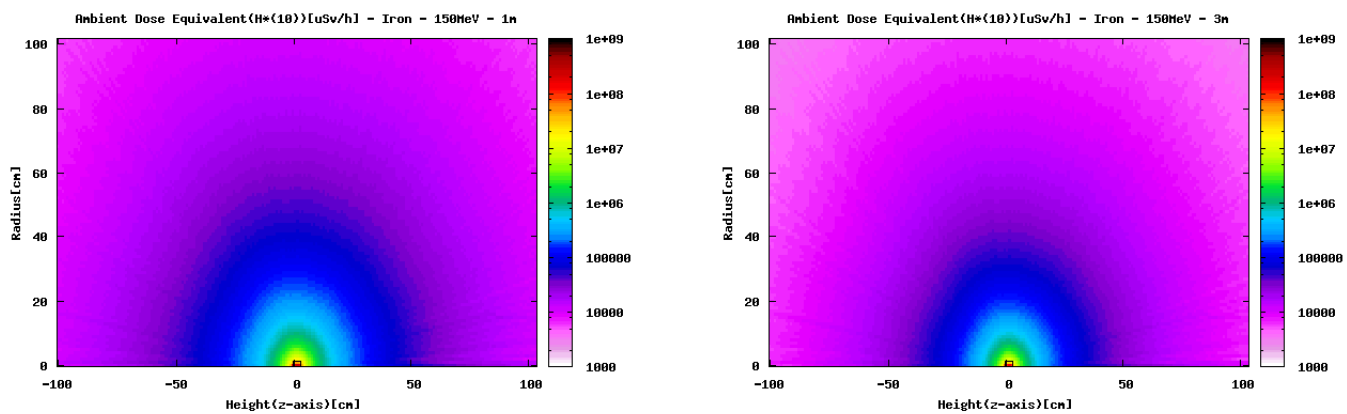


Figure 12.107: cooling times: 1m and 3m

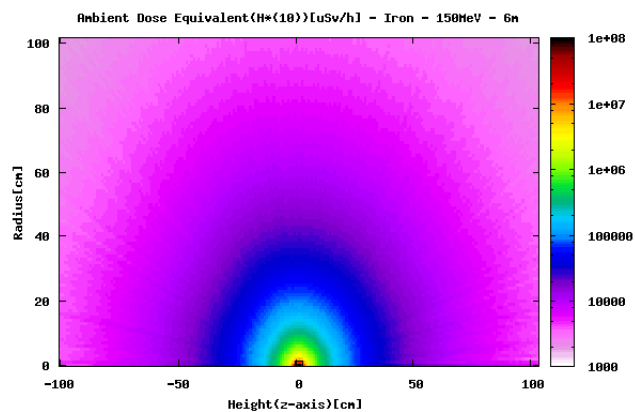


Figure 12.108: cooling time: 6m

12.1.28 Iron - 200MeV

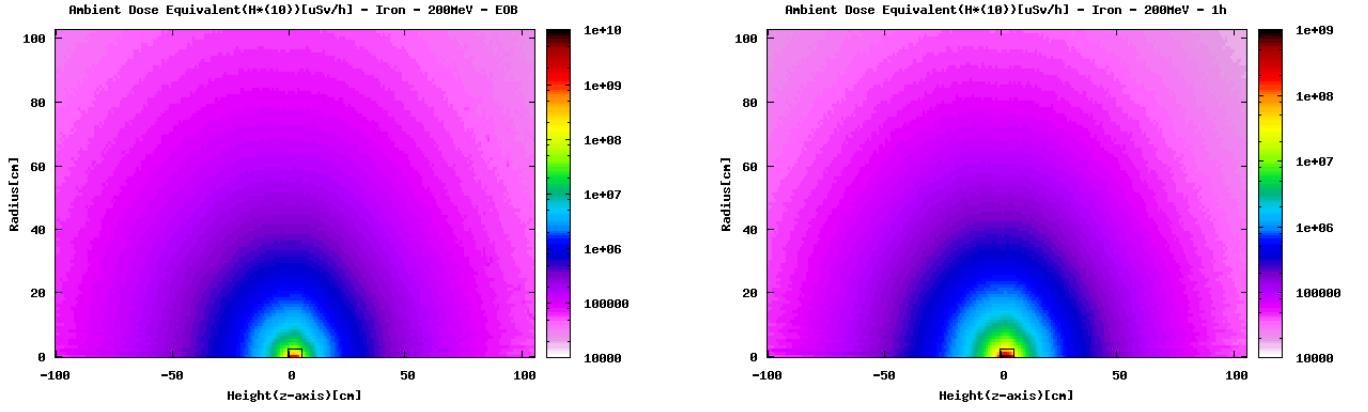


Figure 12.109: cooling times: EOB and 1h

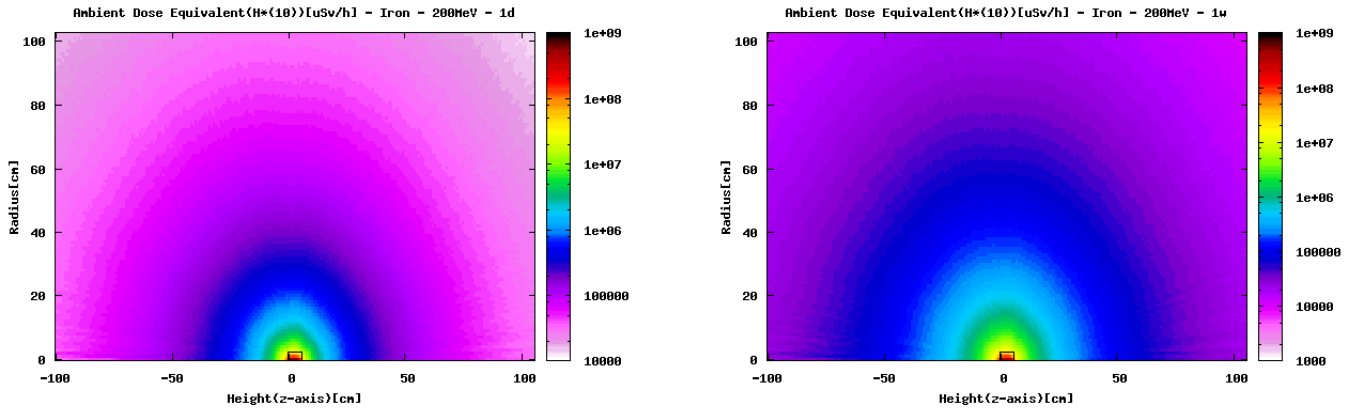


Figure 12.110: cooling times: 1d and 1w

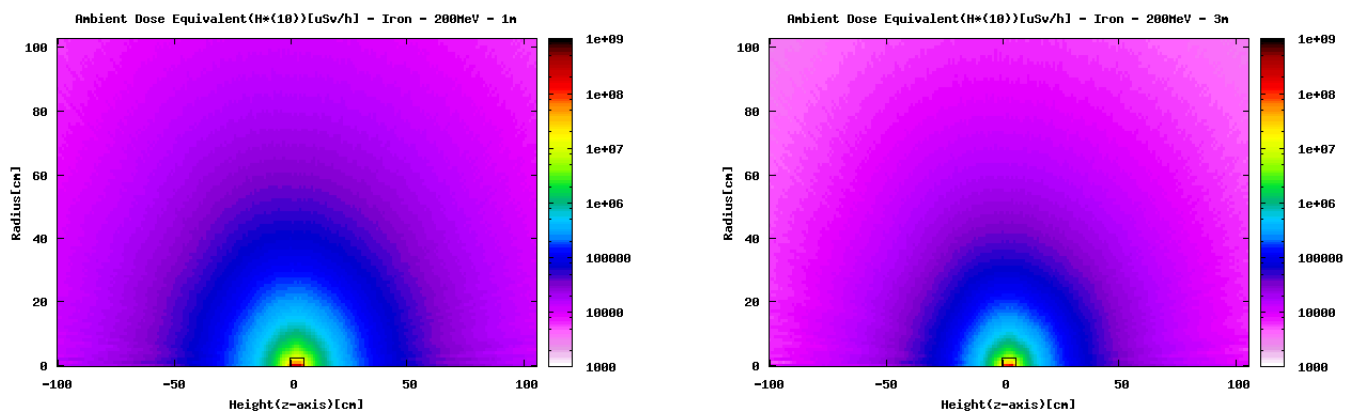


Figure 12.111: cooling times: 1m and 3m

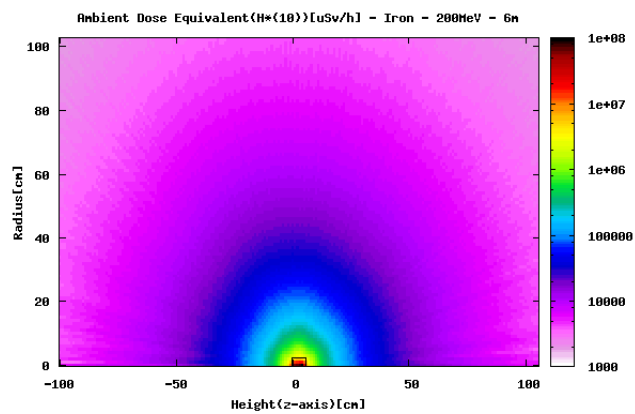


Figure 12.112: cooling time: 6m

12.1.29 Iron - 250MeV

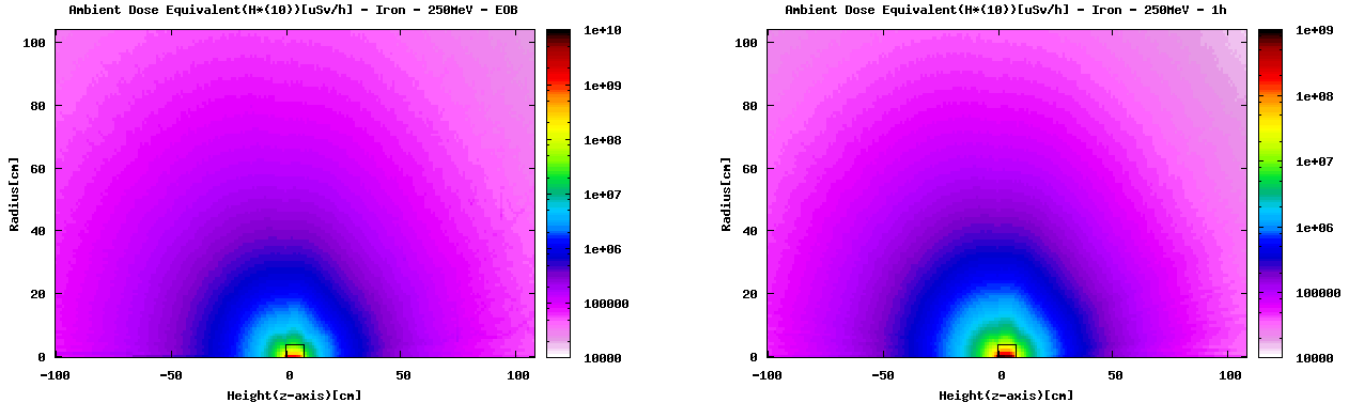


Figure 12.113: cooling times: EOB and 1h

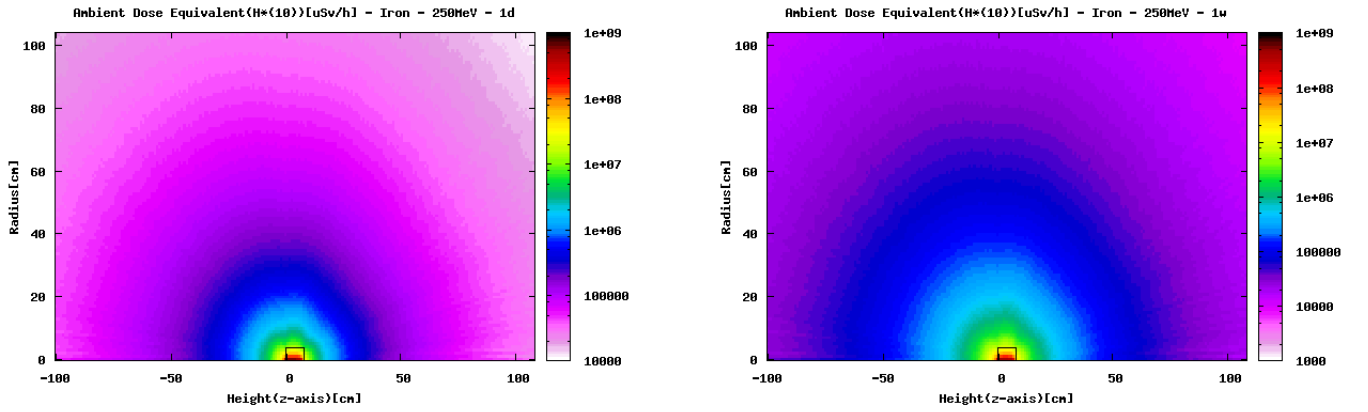


Figure 12.114: cooling times: 1d and 1w

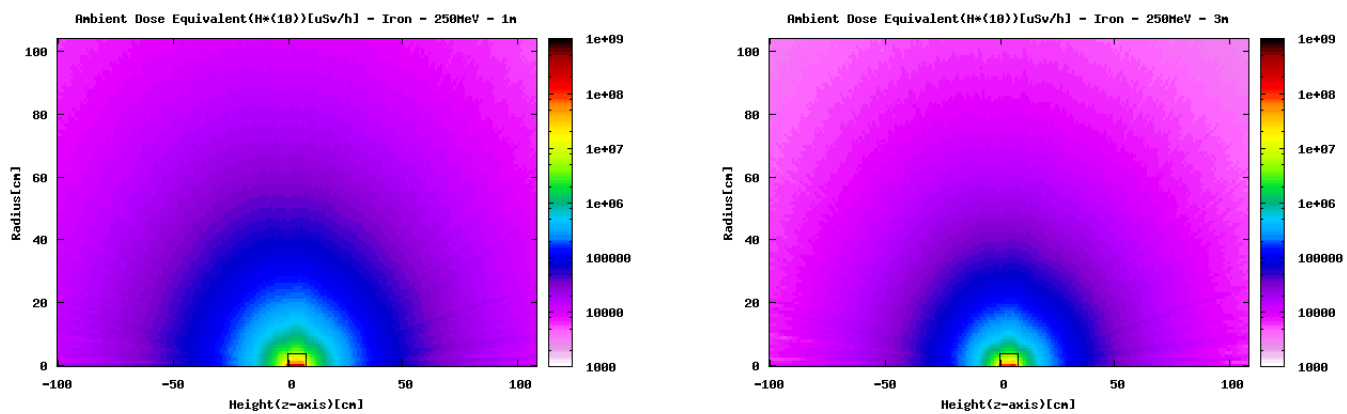


Figure 12.115: cooling times: 1m and 3m

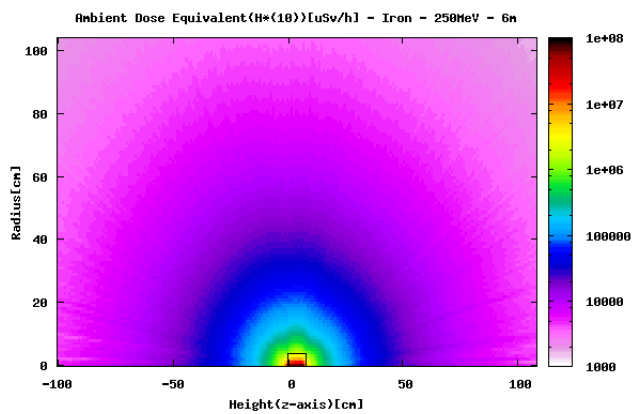


Figure 12.116: cooling time: 6m

12.1.30 Iron - 300MeV

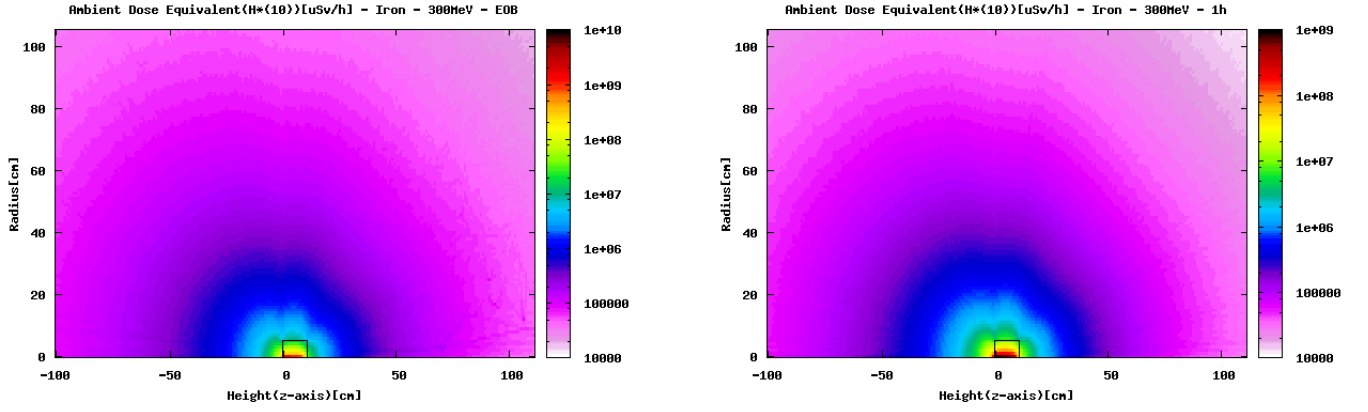


Figure 12.117: cooling times: EOB and 1h

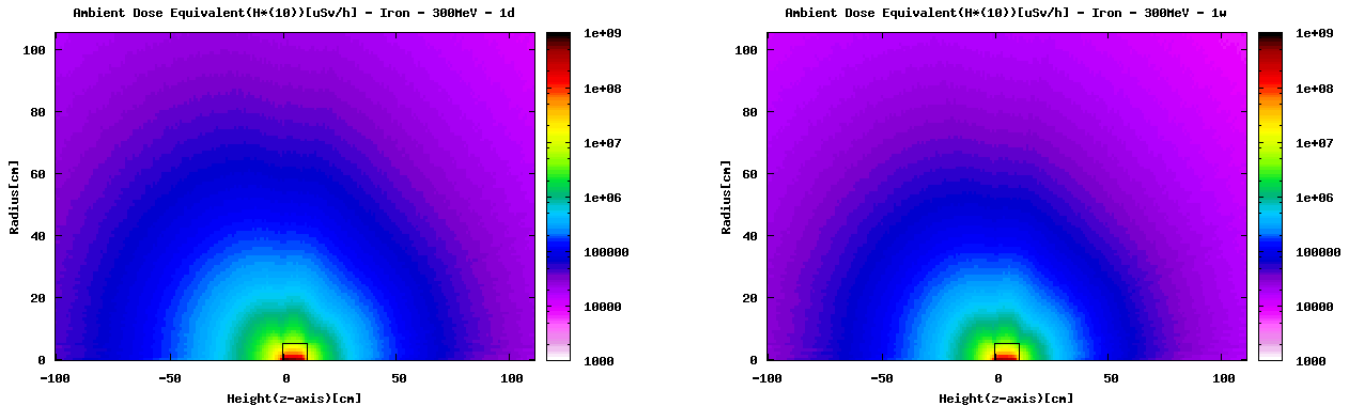


Figure 12.118: cooling times: 1d and 1w

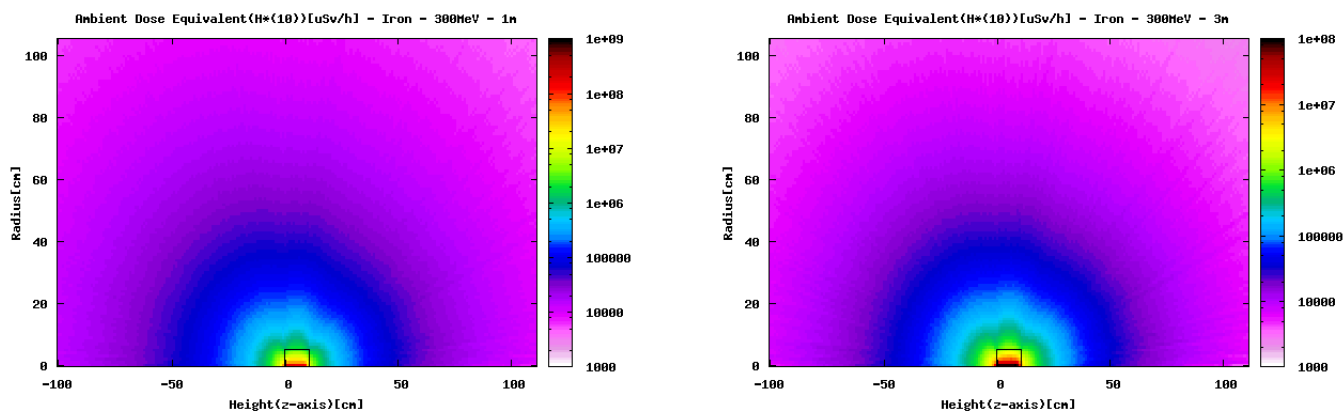


Figure 12.119: cooling times: 1m and 3m

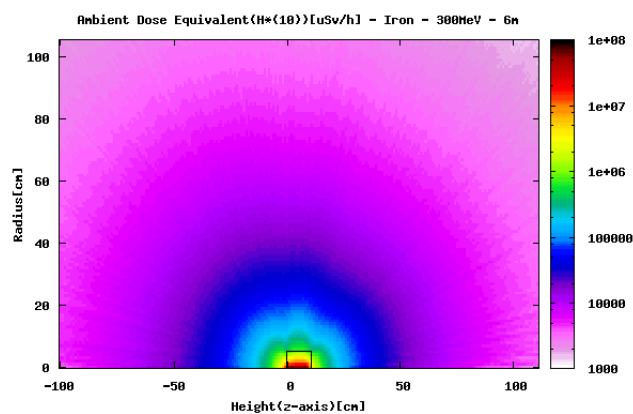


Figure 12.120: cooling time: 6m

12.1.31 Iron - 350MeV

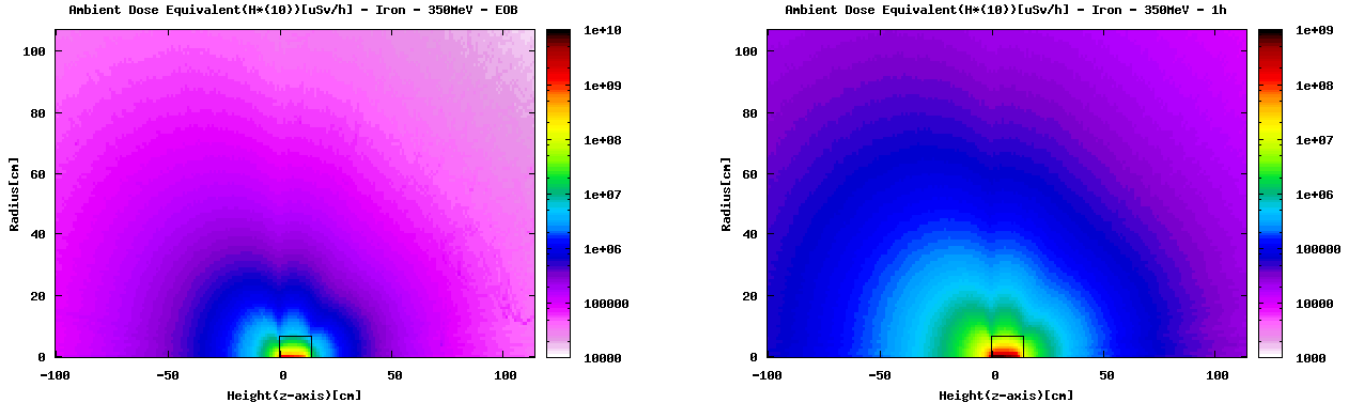


Figure 12.121: cooling times: EOB and 1h

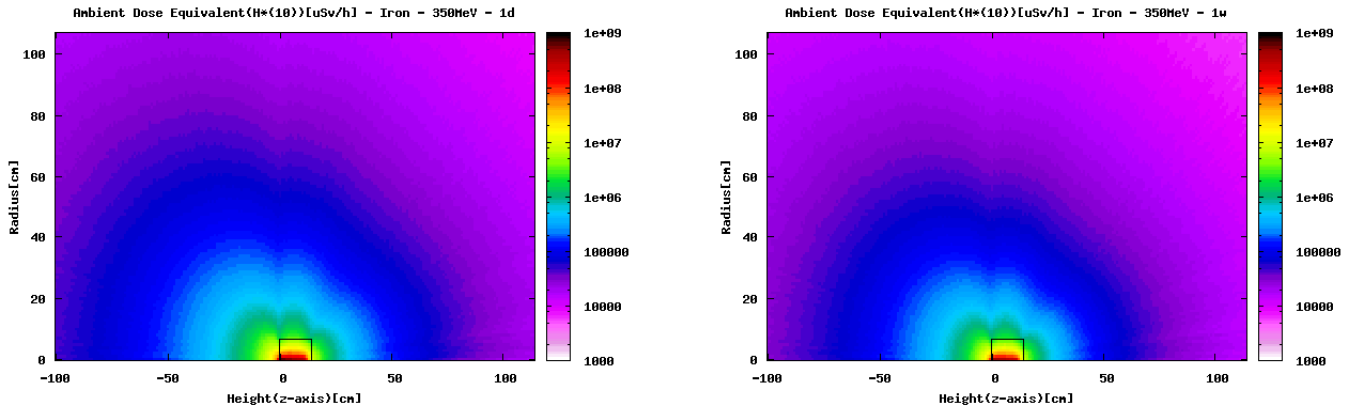


Figure 12.122: cooling times: 1d and 1w

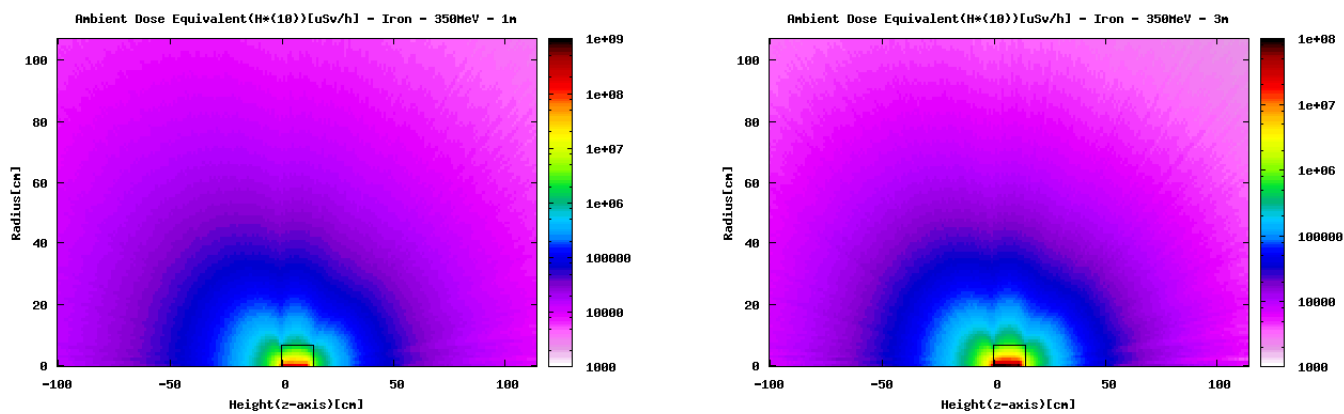


Figure 12.123: cooling times: 1m and 3m

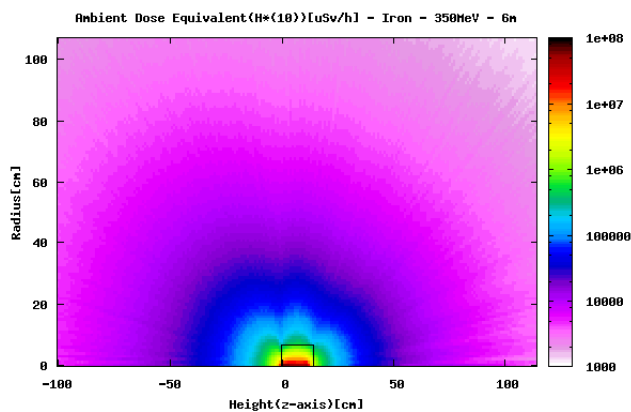


Figure 12.124: cooling time: 6m

12.1.32 Iron - 400MeV

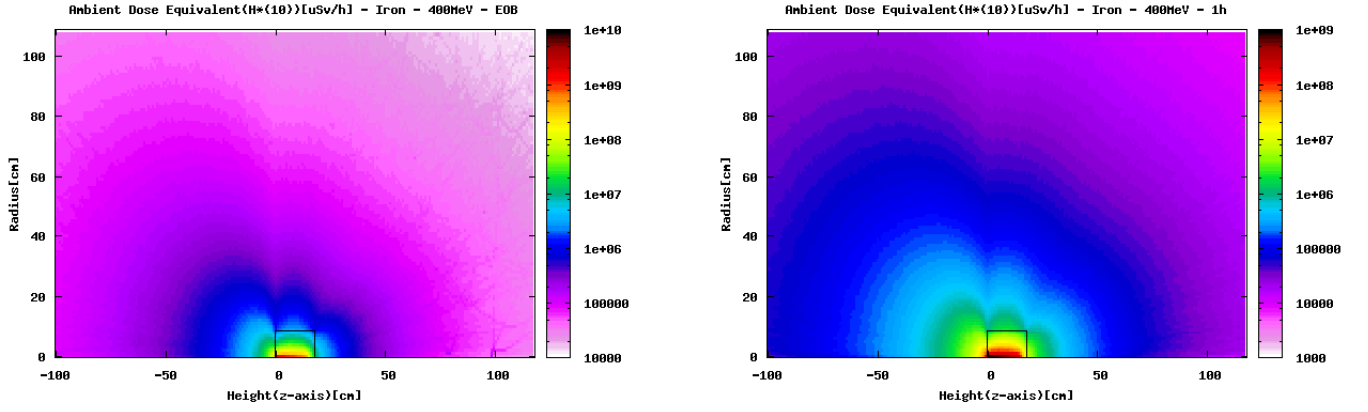


Figure 12.125: cooling times: EOB and 1h

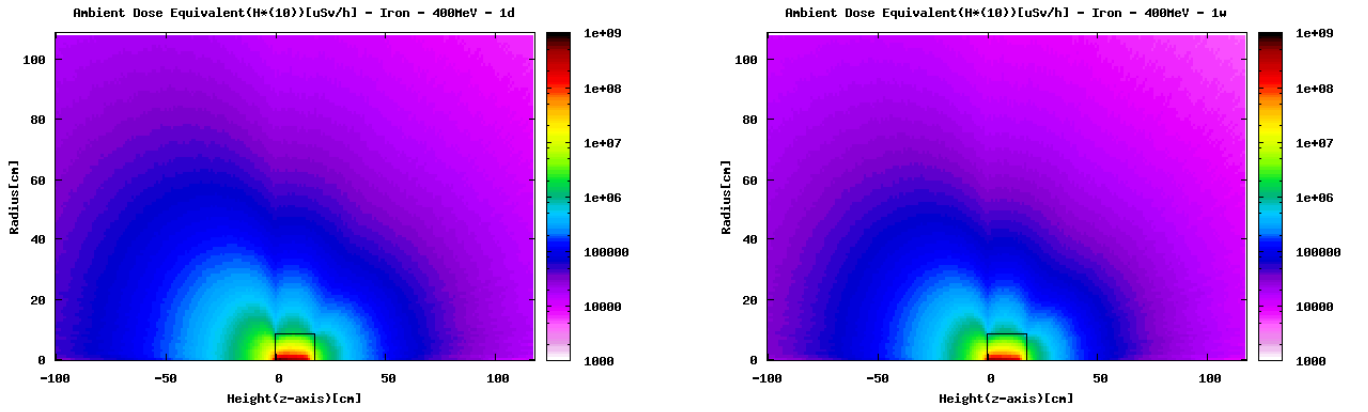


Figure 12.126: cooling times: 1d and 1w

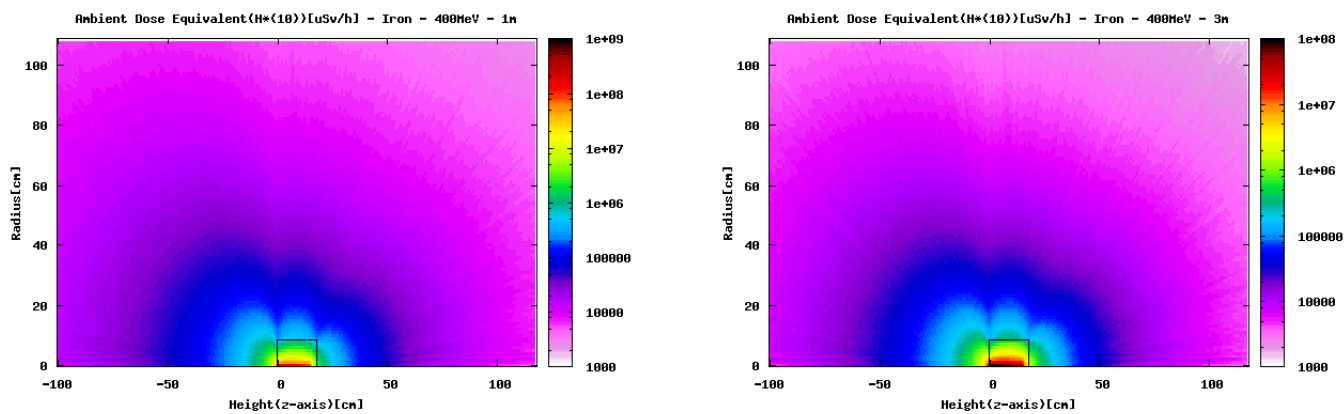


Figure 12.127: cooling times: 1m and 3m

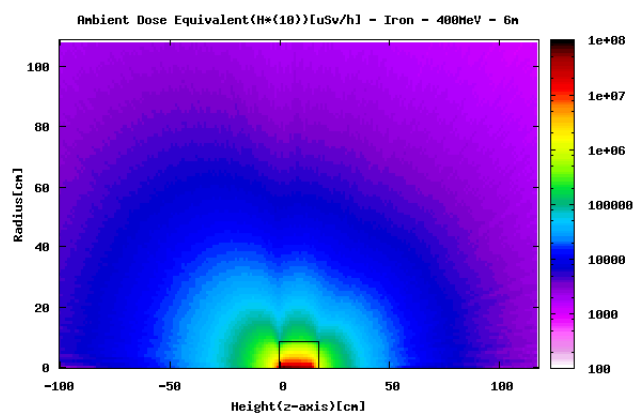


Figure 12.128: cooling time: 6m

12.1.33 Stainless Steel - 50MeV

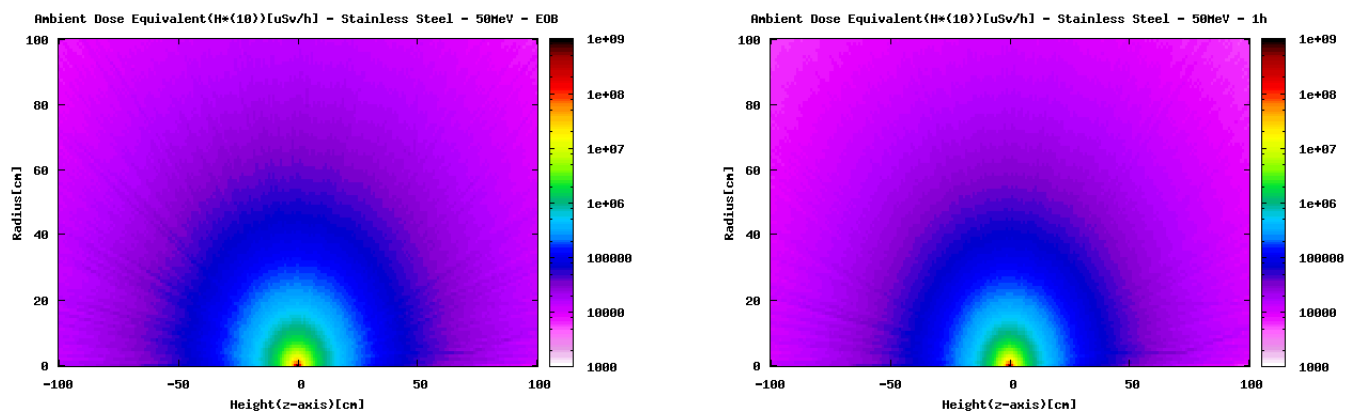


Figure 12.129: cooling times: EOB and 1h

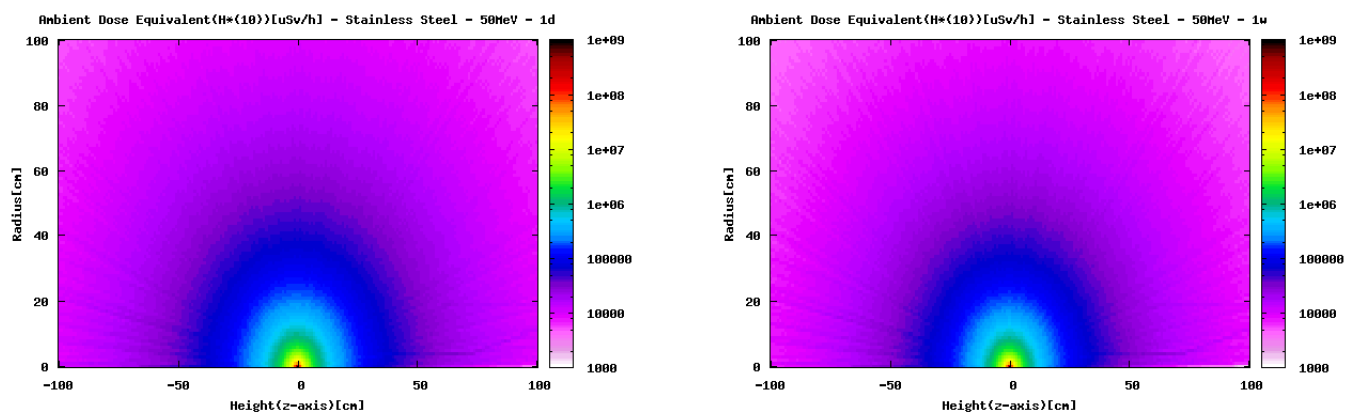


Figure 12.130: cooling times: 1d and 1w

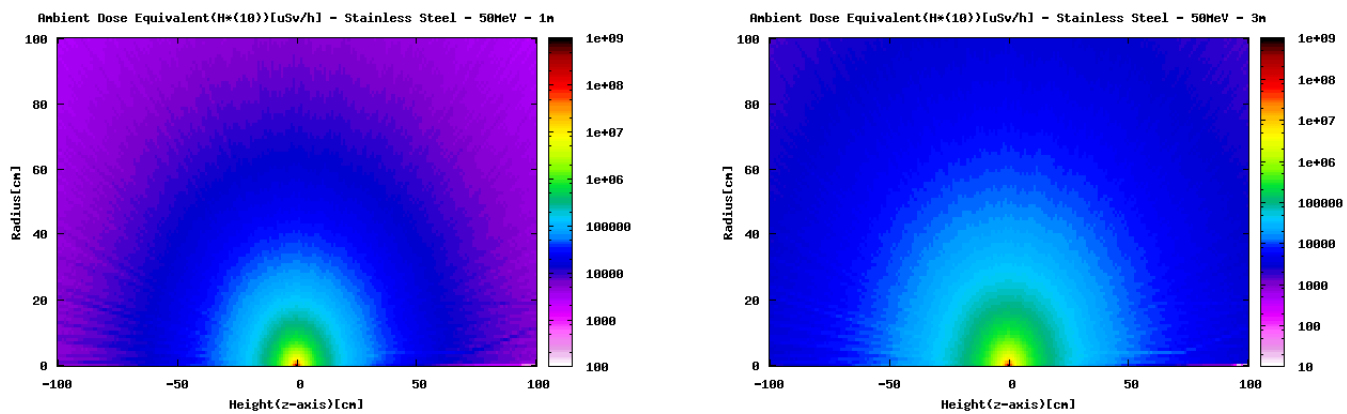


Figure 12.134: cooling times: 1m and 3m

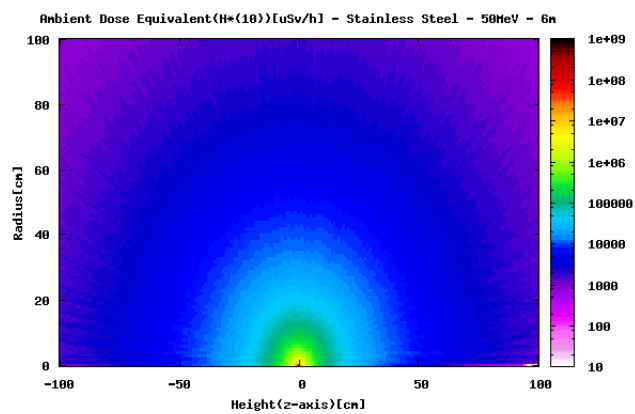


Figure 12.132: cooling time: 6m

12.1.34 Stainless Steel - 100MeV

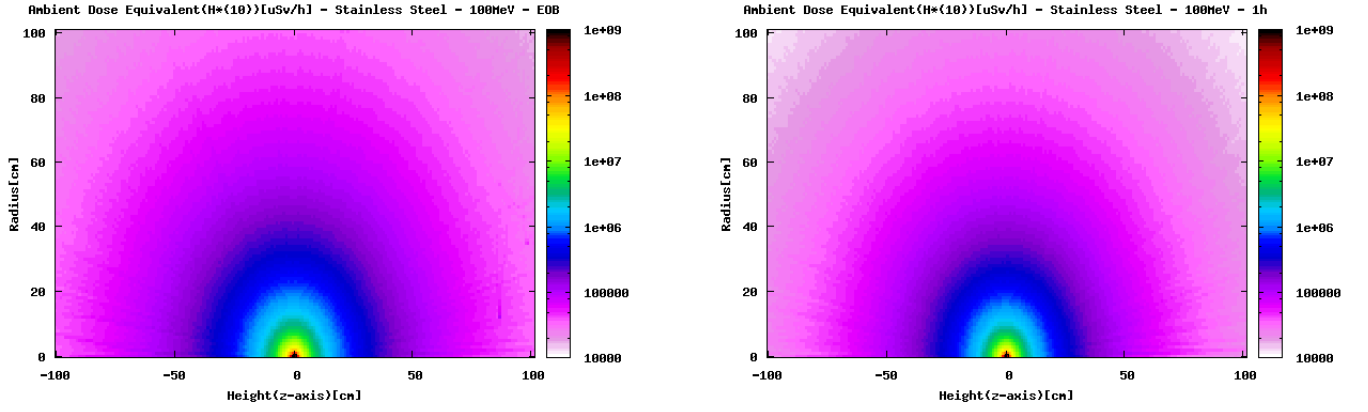


Figure 12.133: cooling times: EOB and 1h

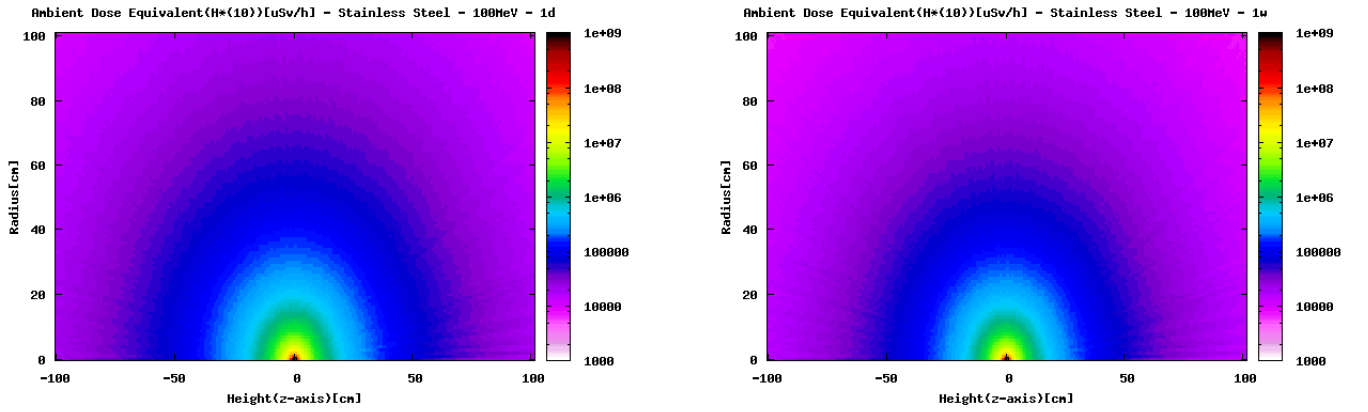


Figure 12.134: cooling times: 1d and 1w

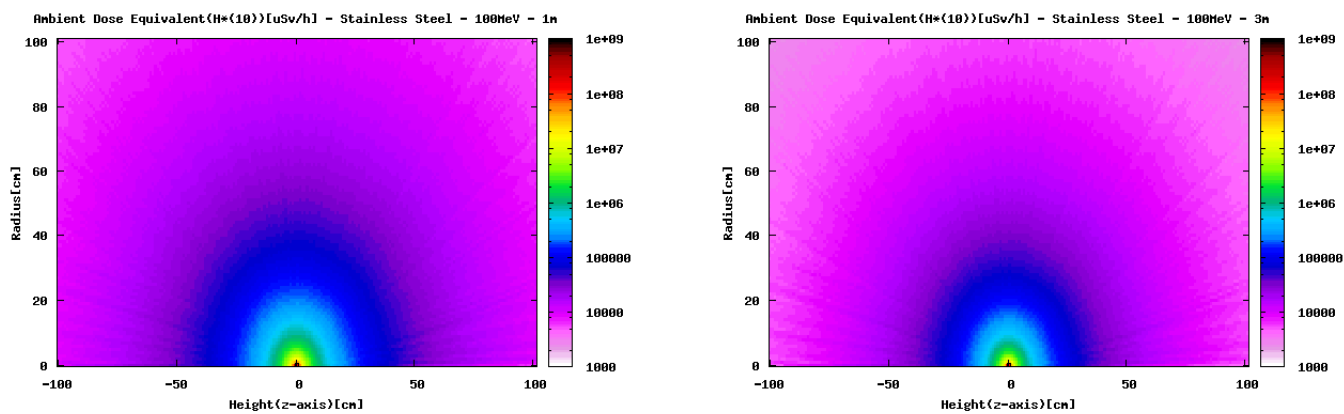


Figure 12.135: cooling times: 1m and 3m

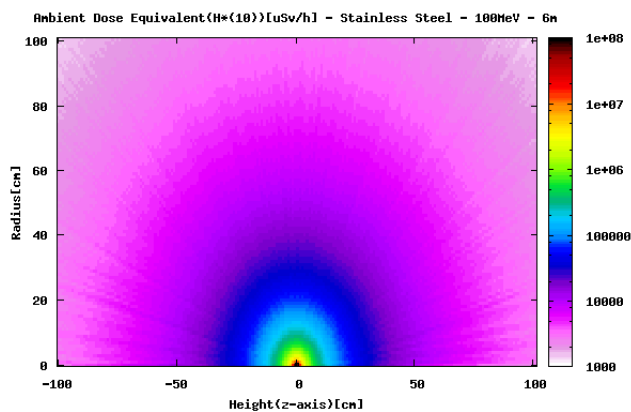


Figure 12.136: cooling time: 6m

12.1.35 Stainless Steel - 150MeV

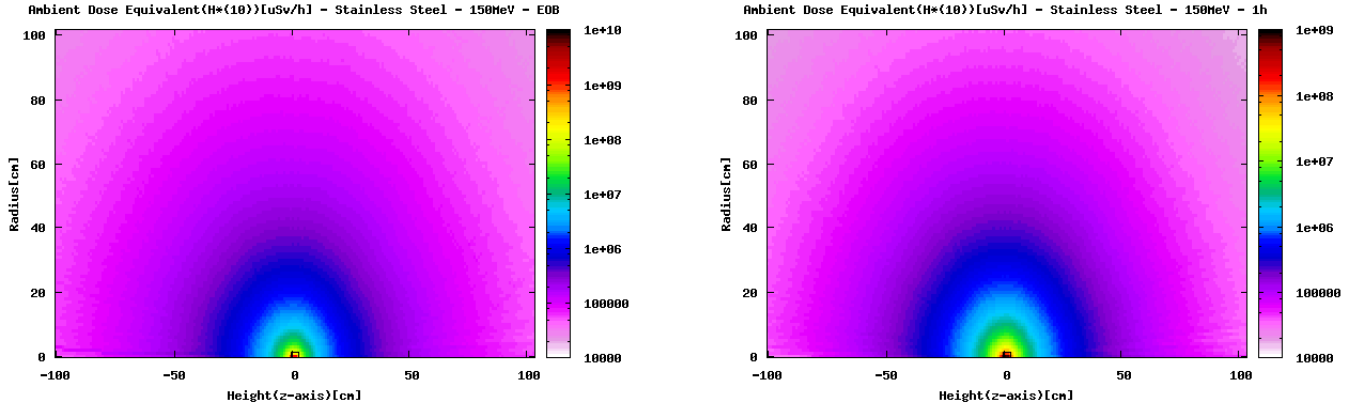


Figure 12.137: cooling times: EOB and 1h

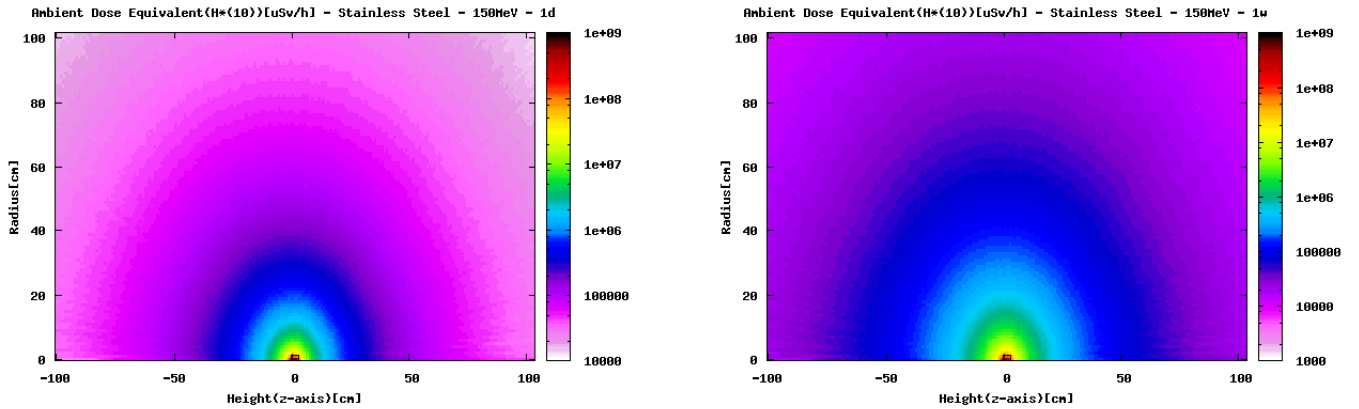


Figure 12.138: cooling times: 1d and 1w

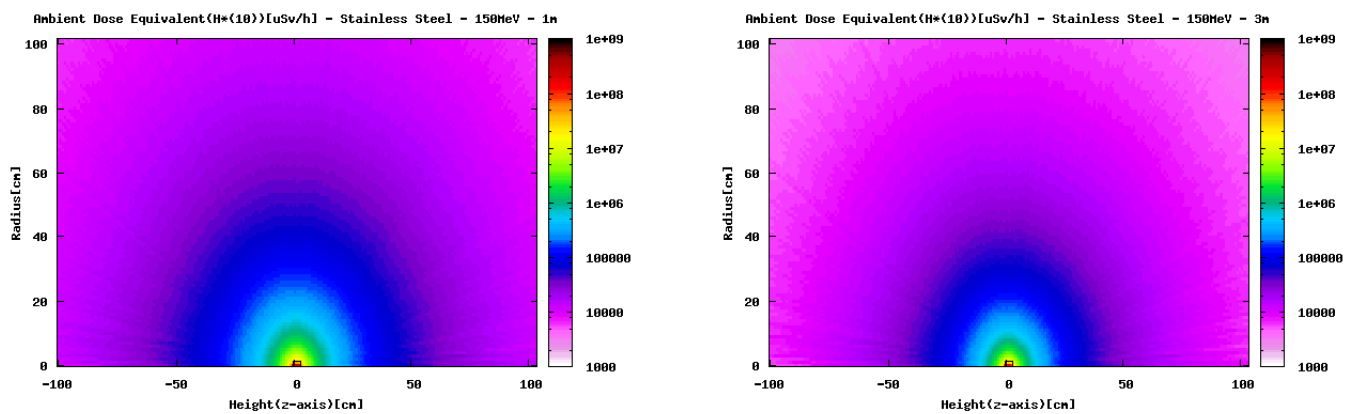


Figure 12.139: cooling times: 1m and 3m

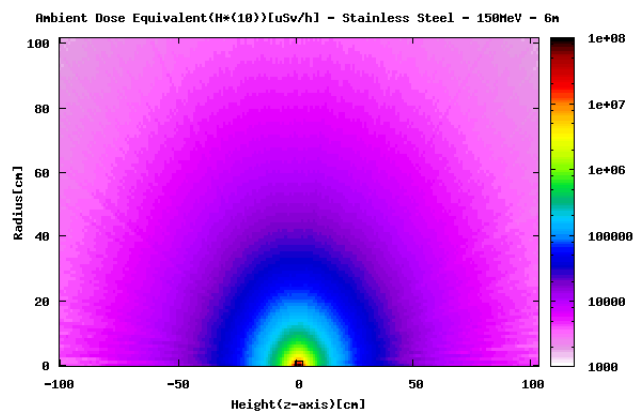


Figure 12.140: cooling time: 6m

12.1.36 Stainless Steel - 200MeV

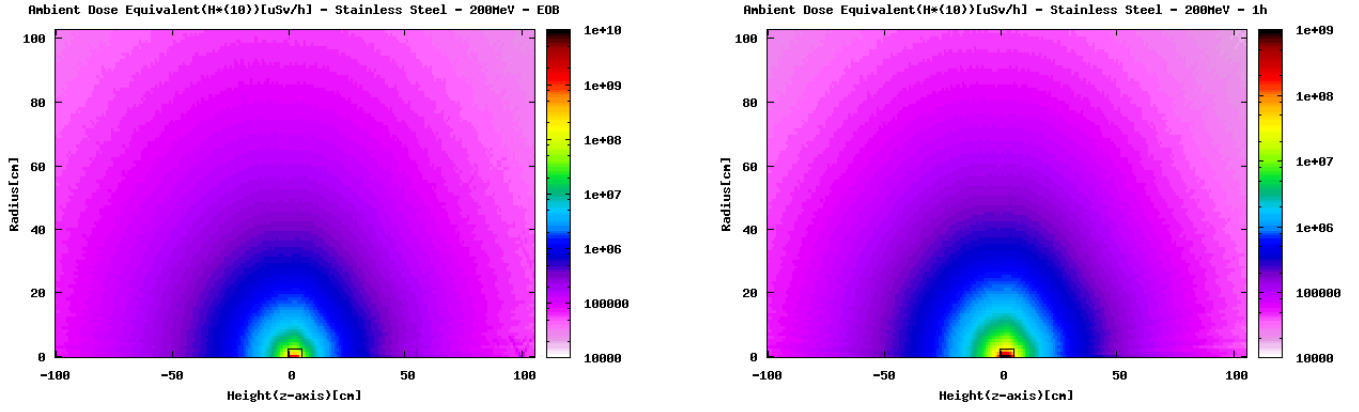


Figure 12.141: cooling times: EOB and 1h

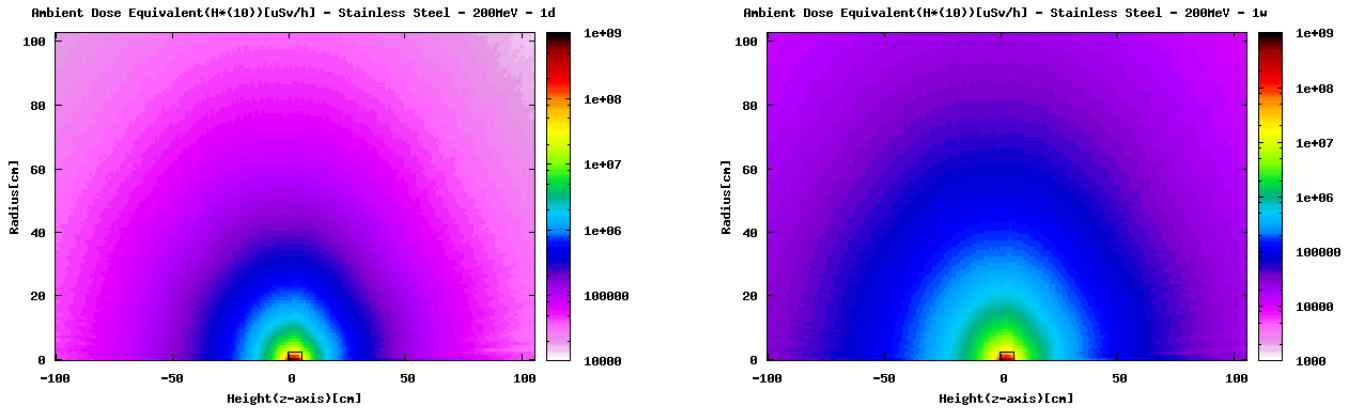


Figure 12.142: cooling times: 1d and 1w

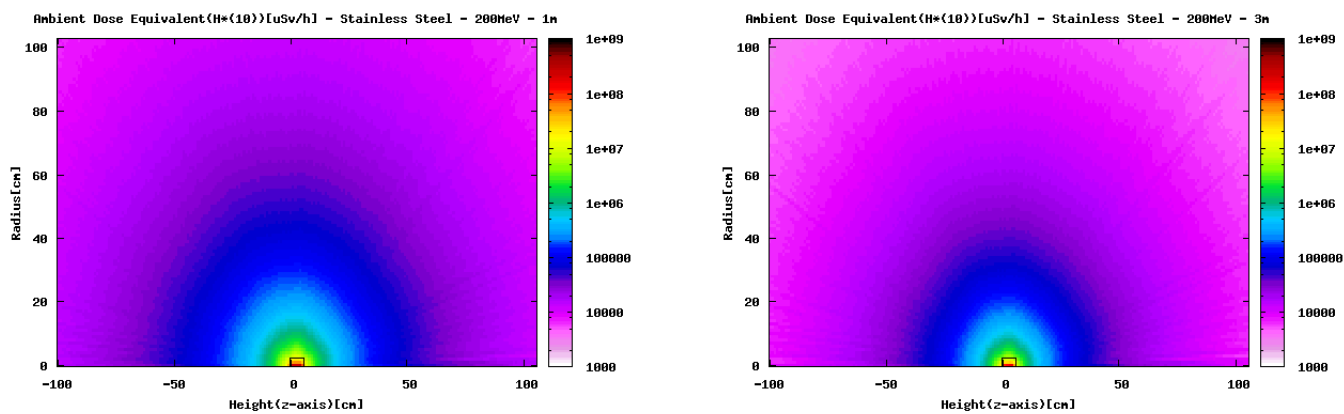


Figure 12.143: cooling times: 1m and 3m

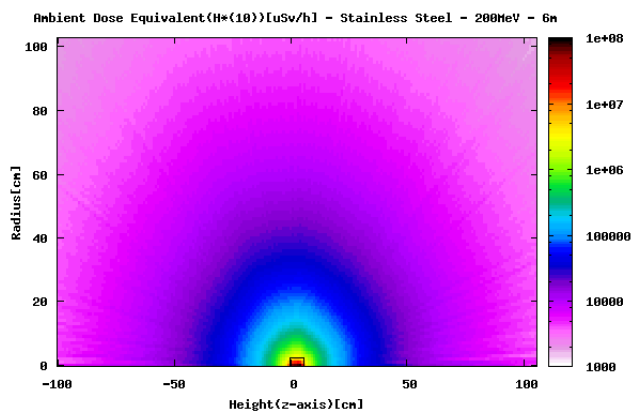


Figure 12.144: cooling time: 6m

12.1.37 Stainless Steel - 250MeV

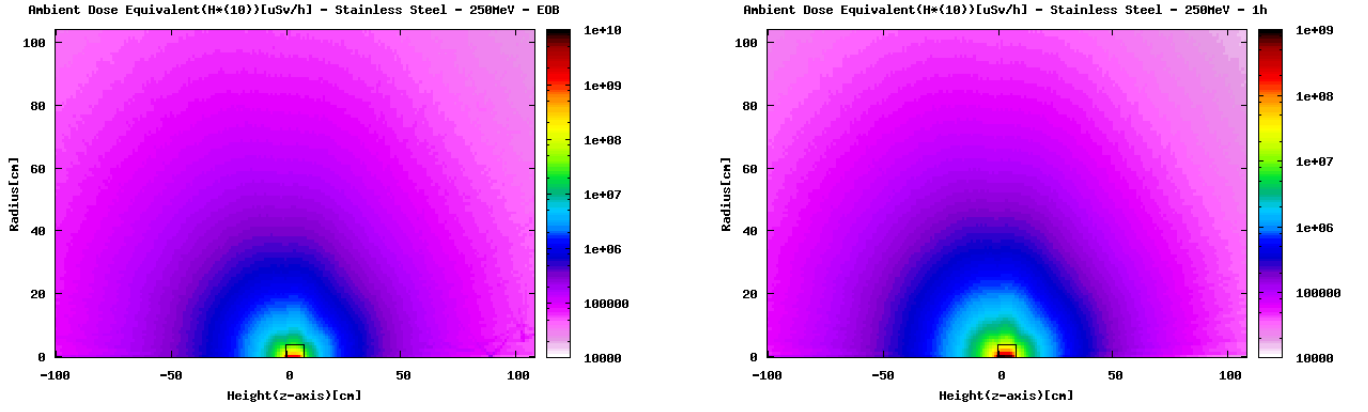


Figure 12.145: cooling times: EOB and 1h

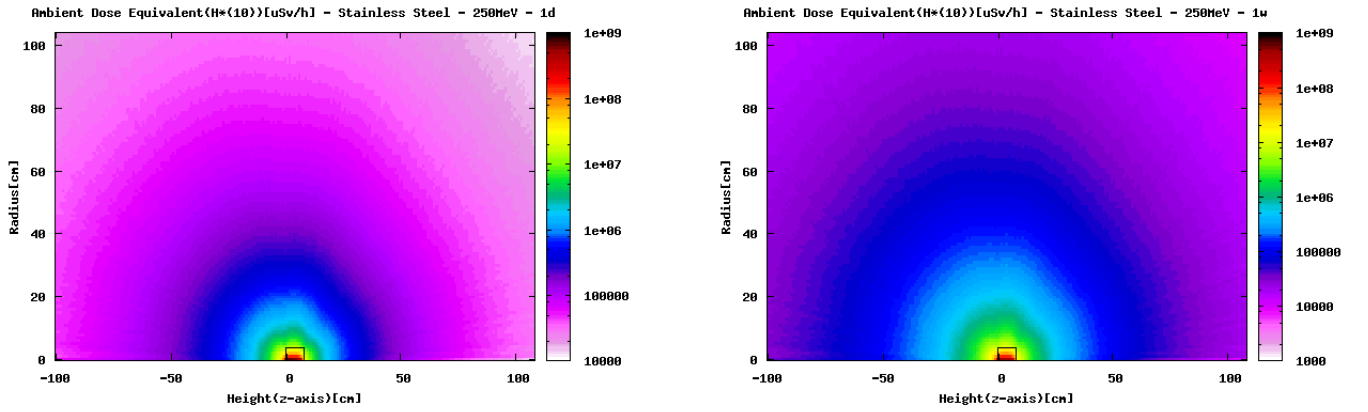


Figure 12.146: cooling times: 1d and 1w

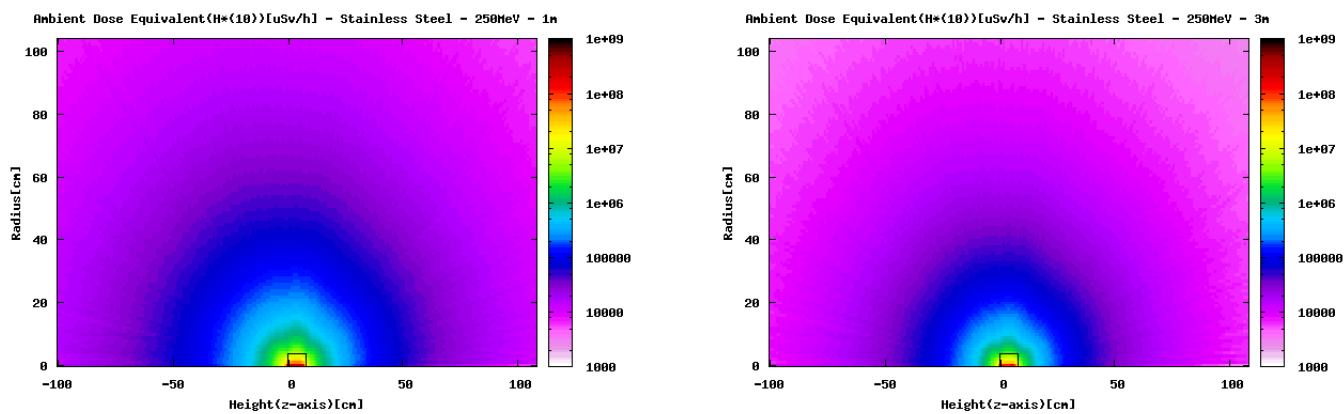


Figure 12.147: cooling times: 1m and 3m

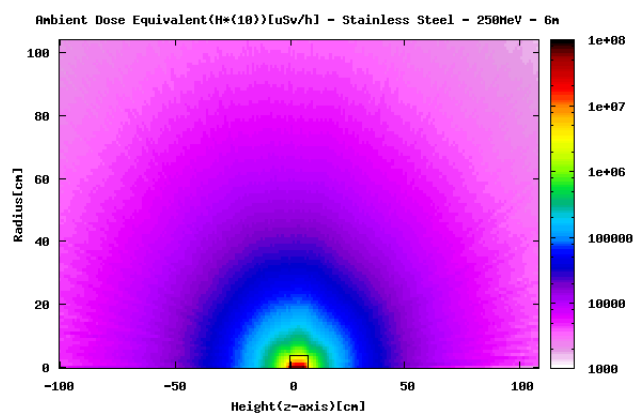


Figure 12.148: cooling time: 6m

12.1.38 Stainless Steel - 300MeV

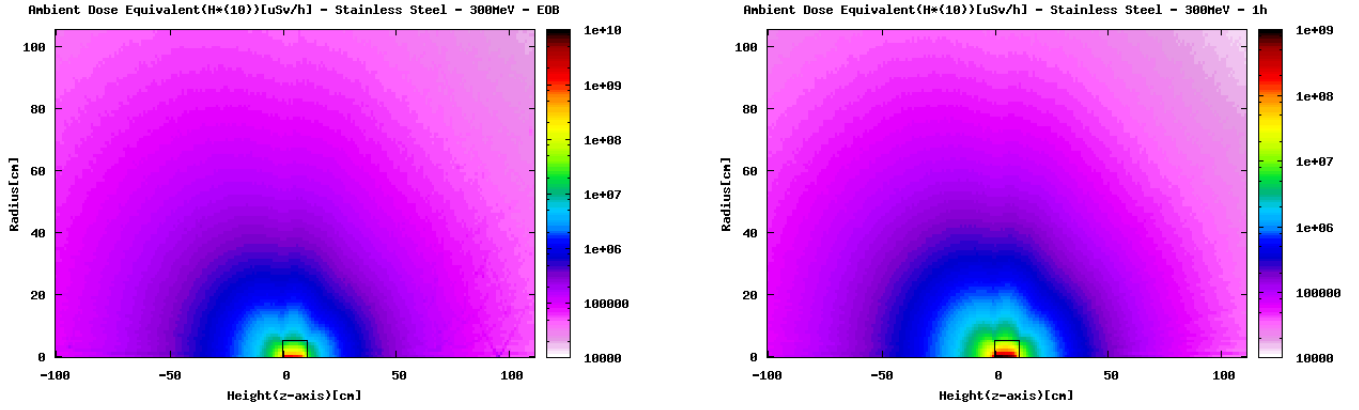


Figure 12.149: cooling times: EOB and 1h

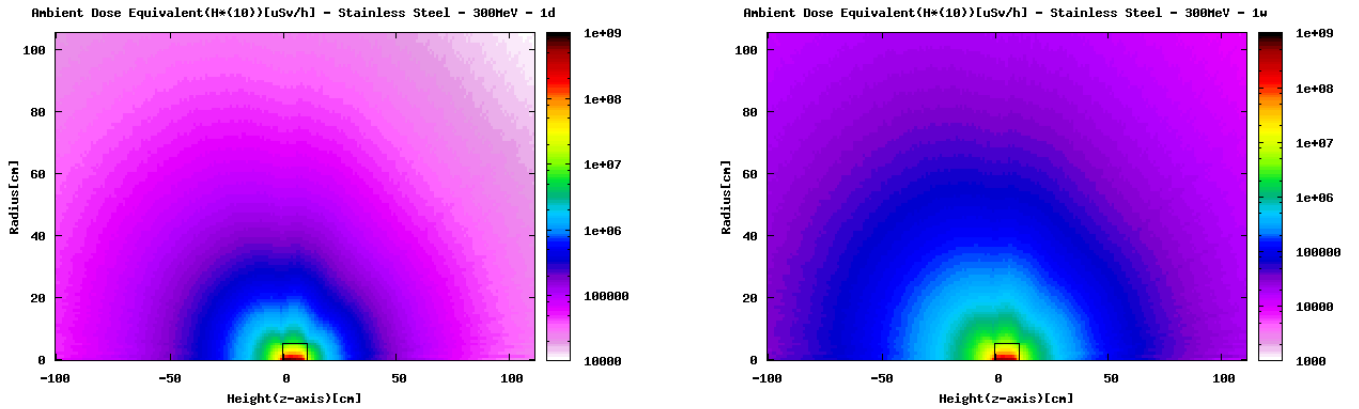


Figure 12.150: cooling times: 1d and 1w

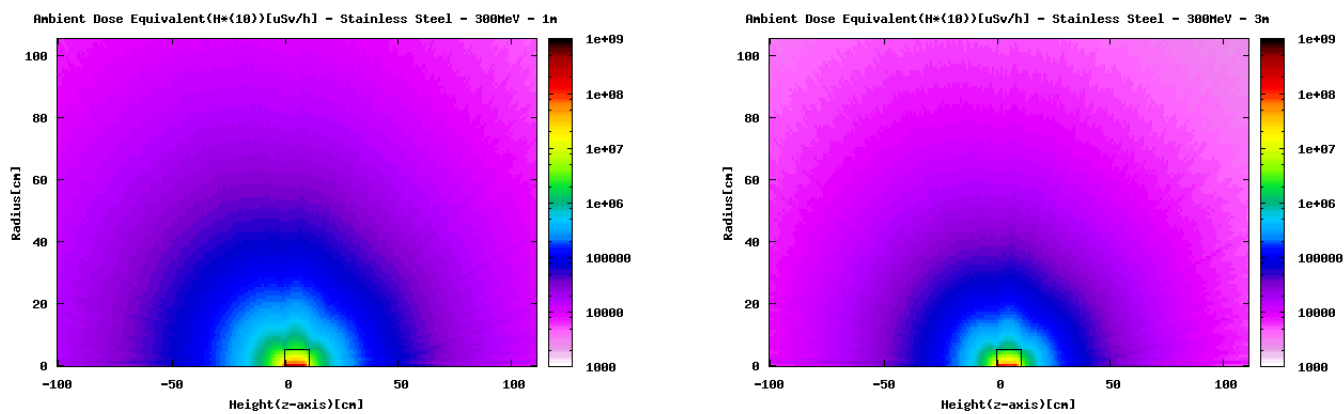


Figure 12.151: cooling times: 1m and 3m

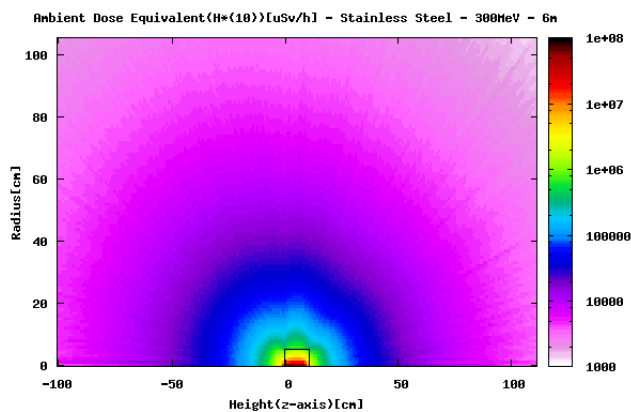


Figure 12.152: cooling time: 6m

12.1.39 Stainless Steel - 350MeV

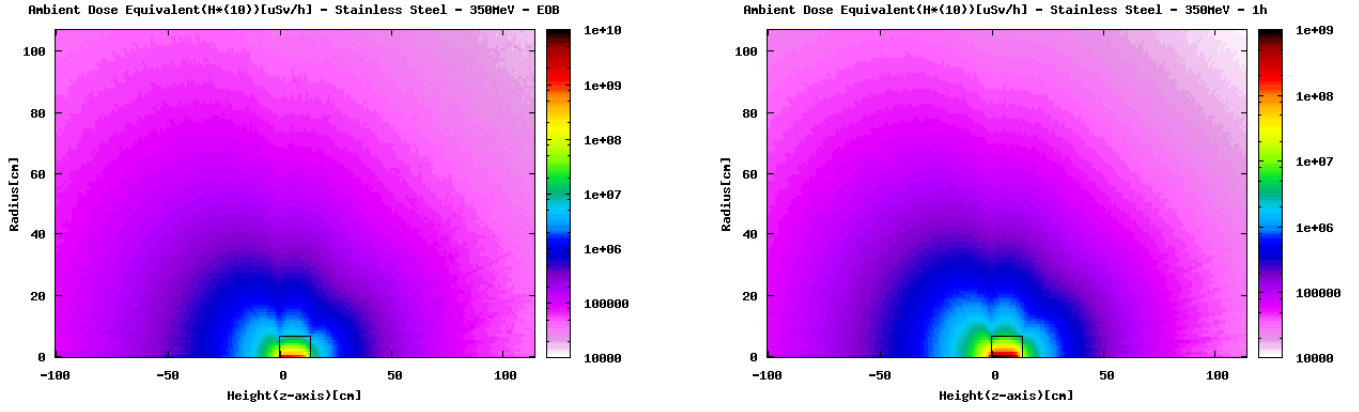


Figure 12.153: cooling times: EOB and 1h

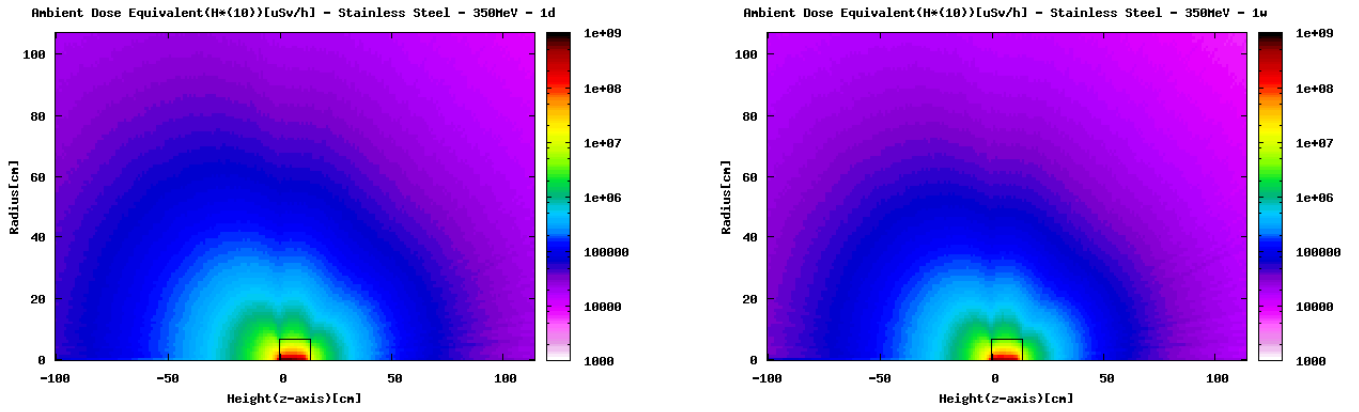


Figure 12.154: cooling times: 1d and 1w

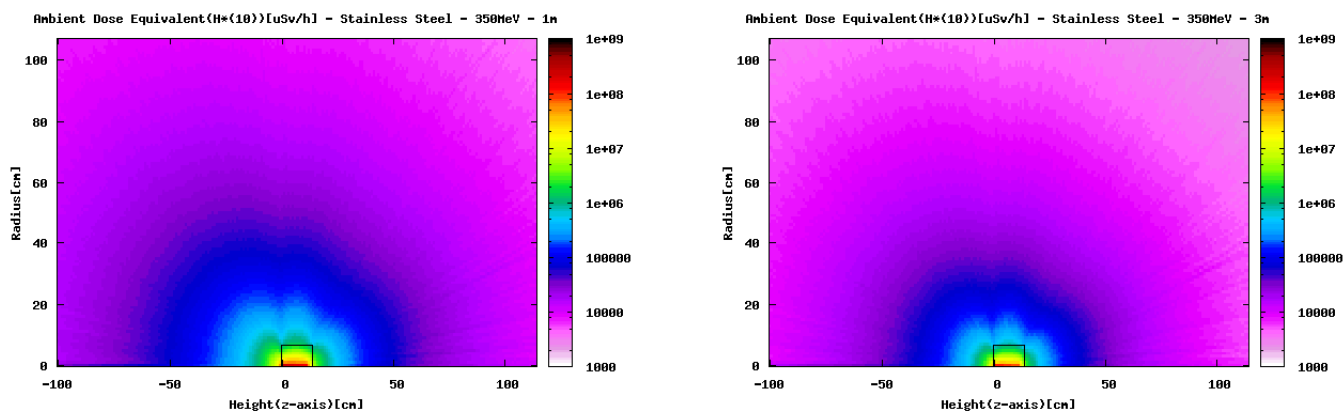


Figure 12.155: cooling times: 1m and 3m

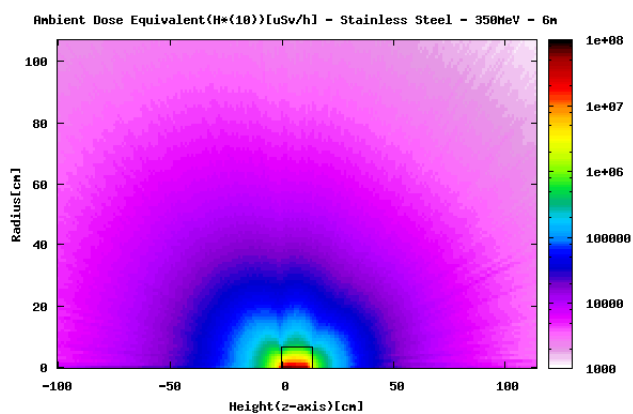


Figure 12.156: cooling time: 6m

12.1.40 Stainless Steel - 400MeV

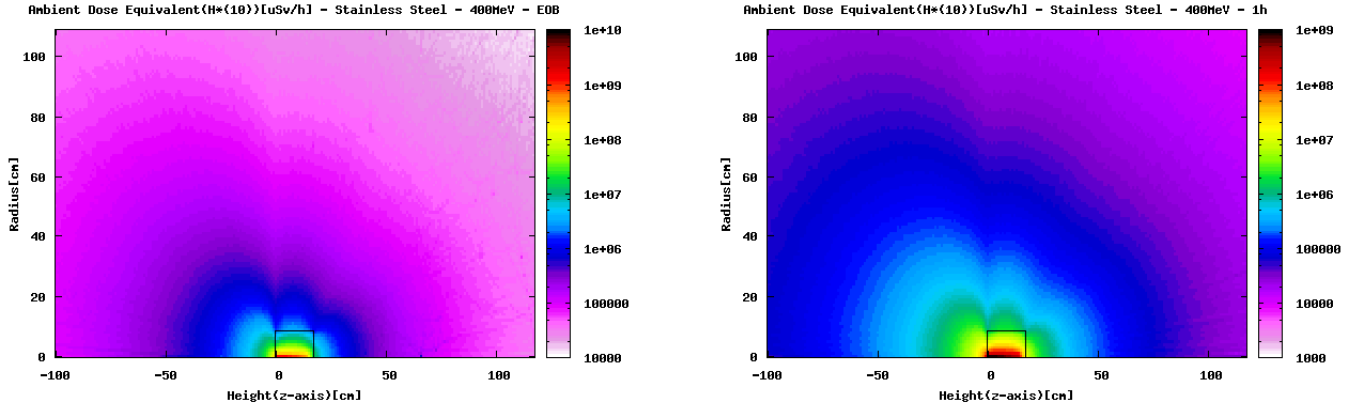


Figure 12.157: cooling times: EOB and 1h

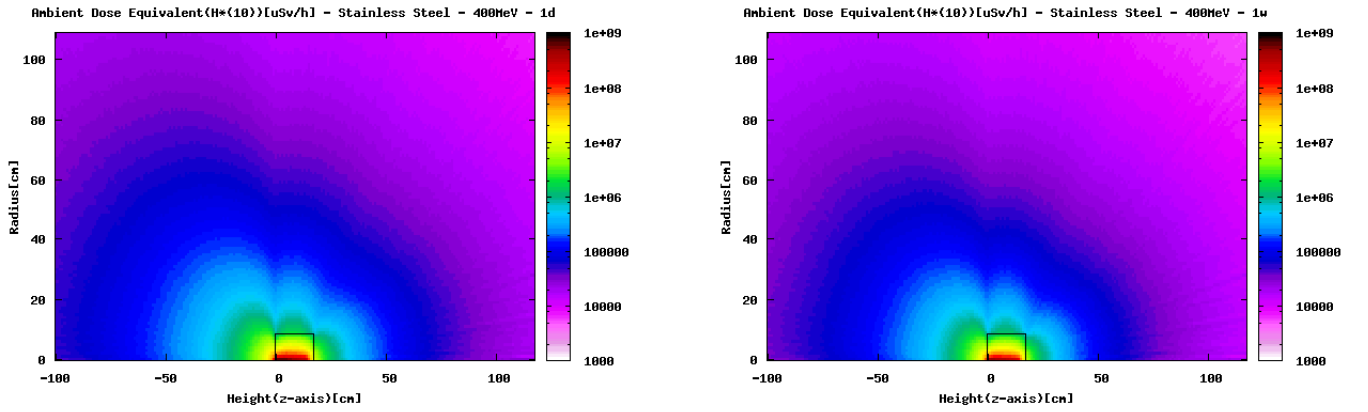


Figure 12.158: cooling times: 1d and 1w

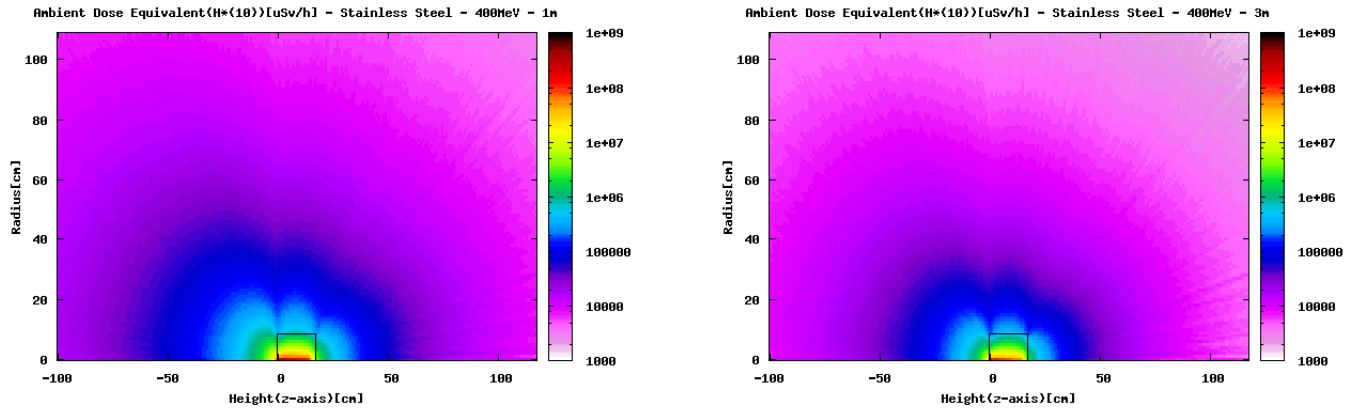


Figure 12.159: cooling times: 1m and 3m

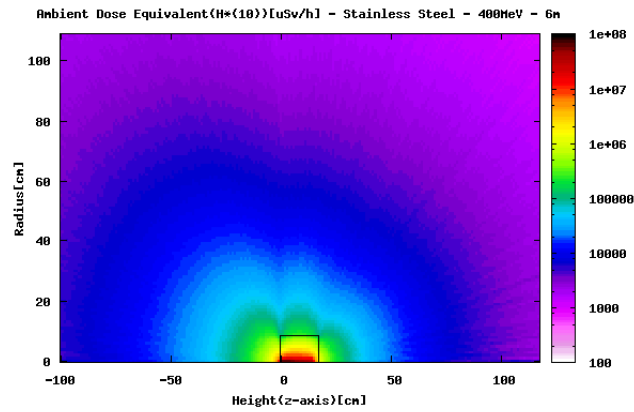


Figure 12.160: cooling time: 6m

12.2 Ambient Dose Equivalent Plots (cooling times)

The following plots are presenting the evolution of the ambient dose equivalent as a function of the several cooling times. The dose equivalent is obtained at a distance of 50cm from the lateral surface of the cylinder each time. The cooling times are expressed in hours, while the EOB has been assigned at the time of 36 seconds for visualisation purposes. The scale of both axes is logarithmic, and the unit of the ambient dose equivalent is $\mu\text{Sv/h}$.

12.2.1 Boron Nitride

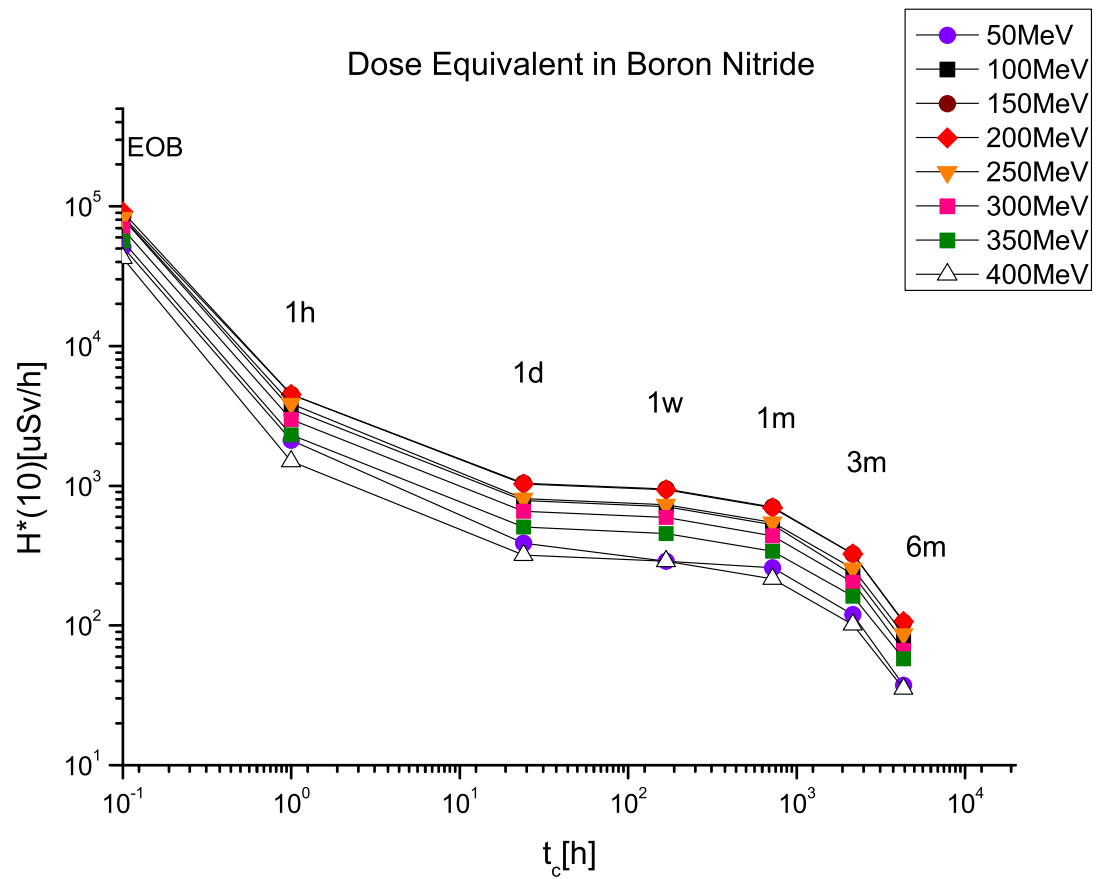


Figure 12.161: Boron Nitride Dose Equivalent as a function of cooling times

12.2.2 Carbon(Graphite)

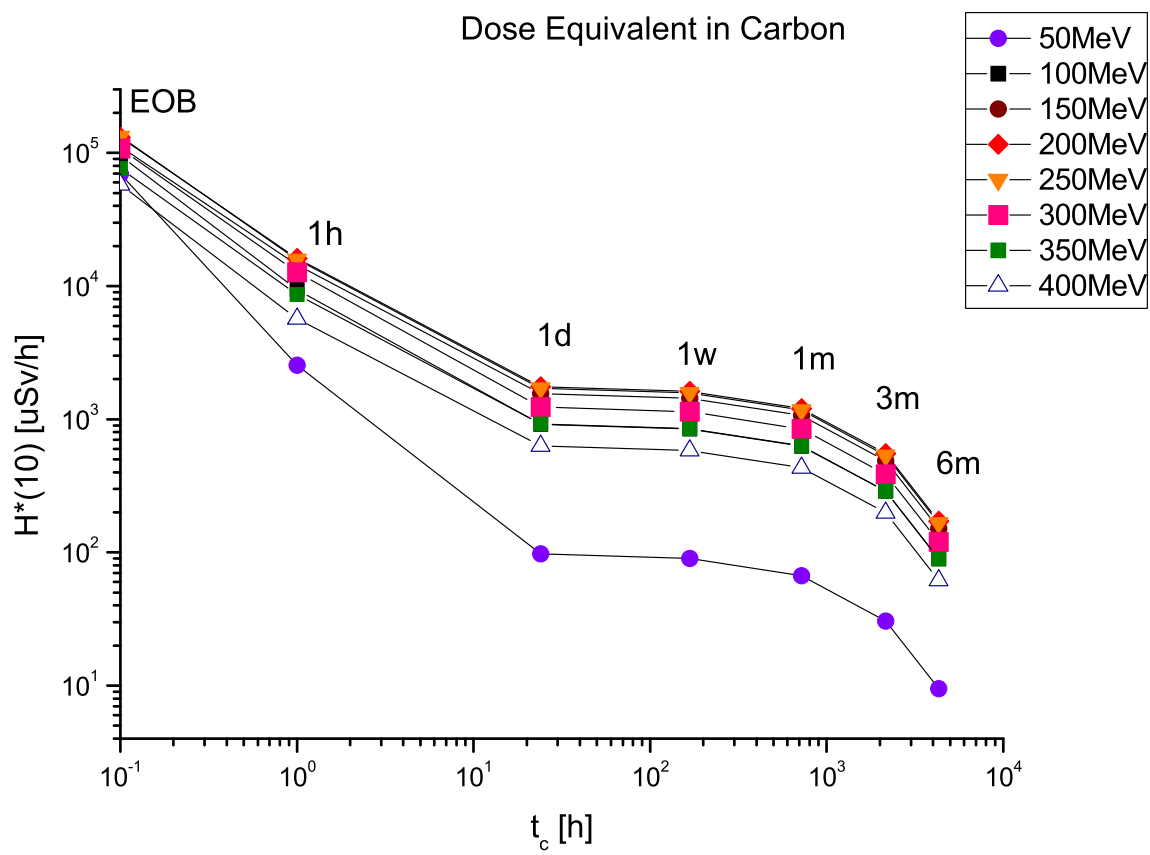


Figure 12.162: Carbon(Graphite) Dose Equivalent as a function of cooling times

12.2.3 Copper

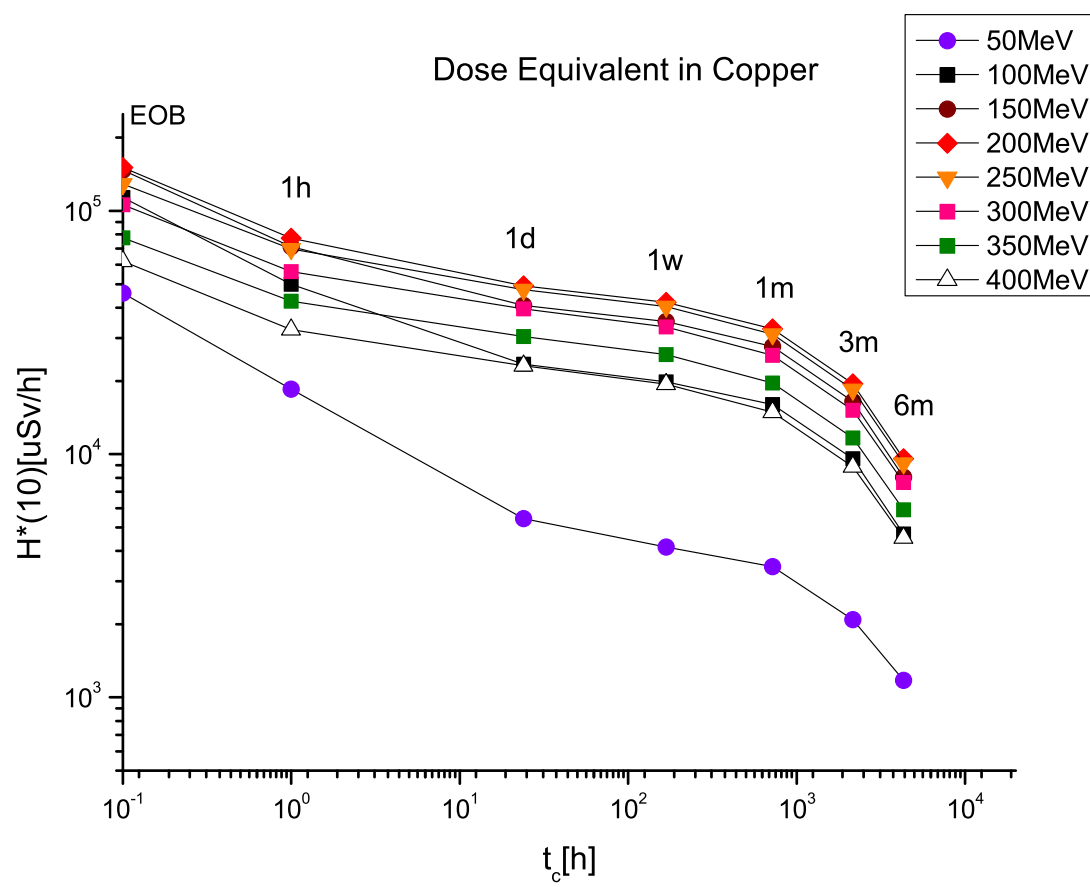


Figure 12.163: Copper Dose Equivalent as a function of cooling times

12.2.4 Iron

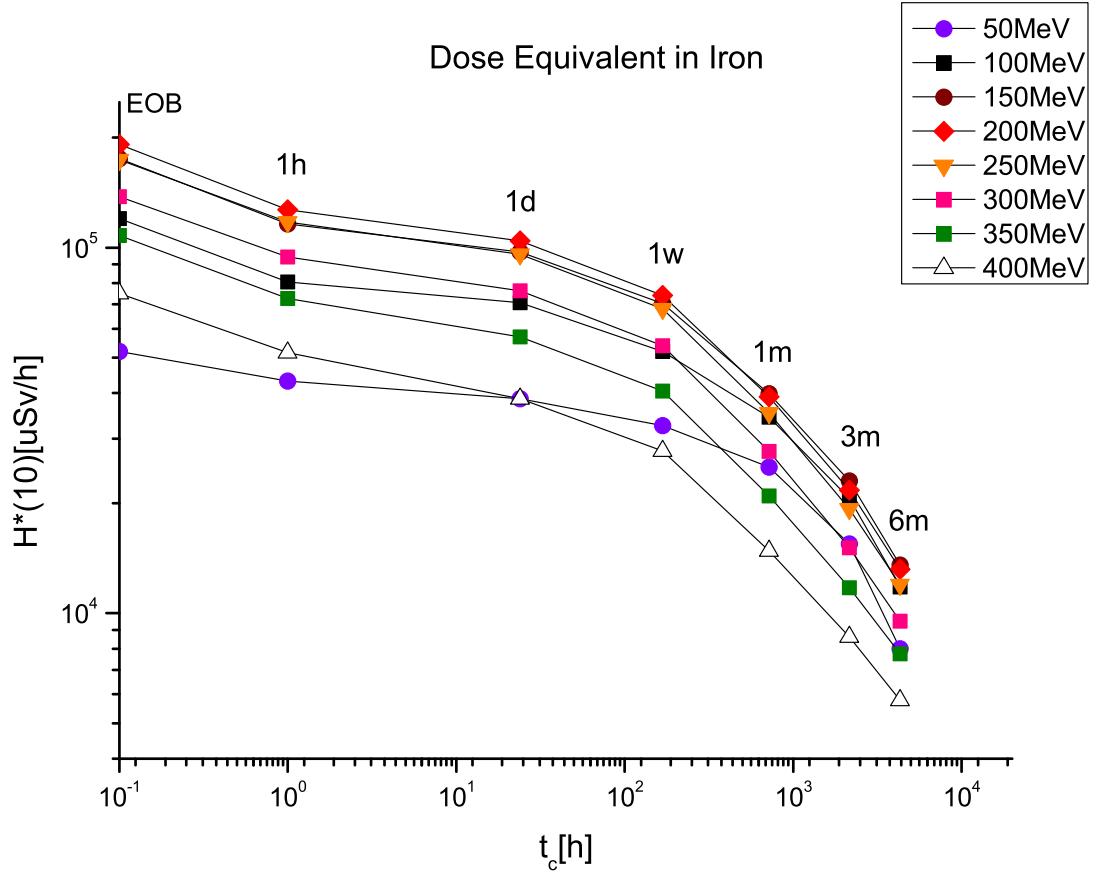


Figure 12.164: Iron Dose Equivalent as a function of cooling times

In the plot (12.164), one can see that the derivative of the curves is increasing as the corresponding beam energy is increasing, and that causes that “strange” effect of the “inter-crossing” that the curve corresponding to the beam energy of 50MeV’s presents in the above plot. In the framework of this study, an investigation was done to explain this behavior.

Self Shielding

Firstly, we investigated the role of selfshielding effect, that is, whether the shape of the curve is changing due to the selfshielding effect, since the shape and the radius of the cylinders are increasing as the energy is increasing. For this scope, a test-simulation was done, preserving the same height on the cylinder, but changing the radius. The results are being presented in the plot (12.165).

From the plot (12.165) it is profound that the selfshielding is playing a significant role in the overall order of magnitude of the dose equivalent, although, the derivative of the curve does not explicitly depend on the dimensions of the cylinder.

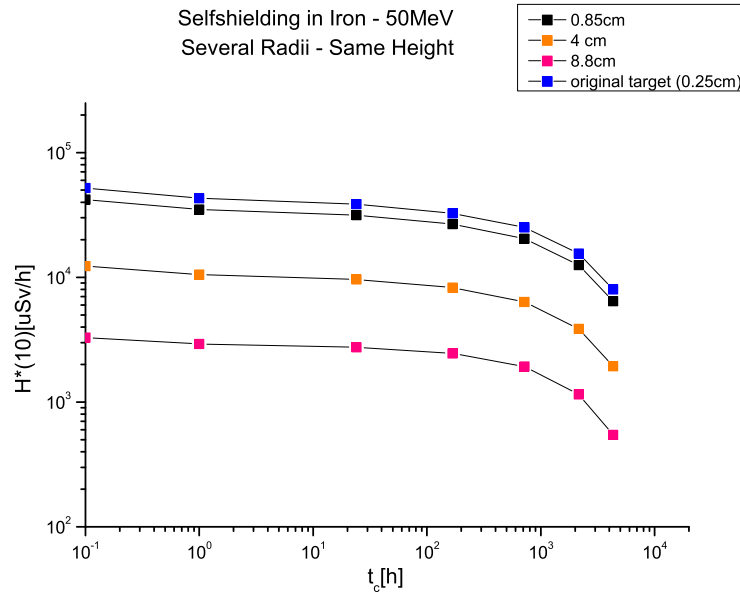


Figure 12.165: Ambient Dose Equivalent in several cooling times, for different radii

Residual Nuclei

The residual nuclei inventory was analyzed for the two cases of the most “intercrossing” curves appearing in the plot (12.164), that one of the 50MeV’s and the one of the 400MeV’s, as well as the half-lives of each were found in the literature. The following conclusions were extracted:

- 50MeV’s - EOB cooling time. 48 different radionuclides are being produced, both short-living and long-living ones. The most contributing to the dose one’s are: Co-55 (γ of 931keV), Mn-52(γ of 1.4MeV), Mn-52m (γ of 1.4MeV), Fe-53m (γ of 1.3MeV and 1.1MeV), Co-54m (γ of 1.4MeV), V-48(γ of 1.3MeV), Sc-44(γ of 1.1MeV), Al-29 (γ of 1.2MeV), were the referred γ rays are only the most abundand ones, found in the literature.
- 50MeV’s - 1 month cooling time. In the case of 50MeV’s, and at the cooling time of 1 month, we have in the inventory 16 nuclei, from which the most contributing to the dose ones are: Mn-52,V-48 and Sc-44.
- 400MeV’s - EOB cooling time. In that case, a sum of 185 different radionuclides are being produced. A large majority of them has a half-live of under 1 hour. Among them, a large number are highly contributing to the dose by producing high energy gamma rays, for example Mn-52(γ of 1.4MeV), Mn-52m (γ of 1.4MeV), Sc-44 (γ of 1.1MeV), Co-54m (γ of 1.4MeV), Sc-42m (γ of 1.2MeV), Al-29 (γ of 1.2MeV), Na-24 (γ of 2.4MeV), C-15(γ of 5MeV), Al-30(γ of 2.5MeV), Be-11 (γ of 2MeV), Ca-47 (γ of 1.3MeV), Cl-40 (γ of 1.5MeV) and, between others the highly contributing to the dose B-14(γ of 6MeV).
- 400MeV’s - 1 month cooling time. After one month decay time, only 37 nuclei have survived, from which only 8 are highly contributing to the dose equivalent.

From the above, as far as the end of bombardment time is concerned (EOB), the many more nuclides that are being produced due to the different energy, are explaining why at the end of bombardment the ambient dose equivalent for the 400MeV's is several order of magnitudes higher than the corresponding to the 50MeV's one, as one can see in the plot (12.164). As for the overall order of magnitude of ambient dose equivalent for the case of 400MeV's, one should take into account the very significant role of selfshielding, which, for the case of 400MeV's is being illustrated in figure (12.166).

As for the curve derivatives, in the case of 400MeV's much more short-living isotopes are being produced, which are dominating the derivative of the curve, in the sense that the dose equivalent is rapidly reduced, because all the short-lived isotopes are dying fastly. Of course, that is not the case at the 50MeV's, where the amount of relatively short-living isotopes is smaller.

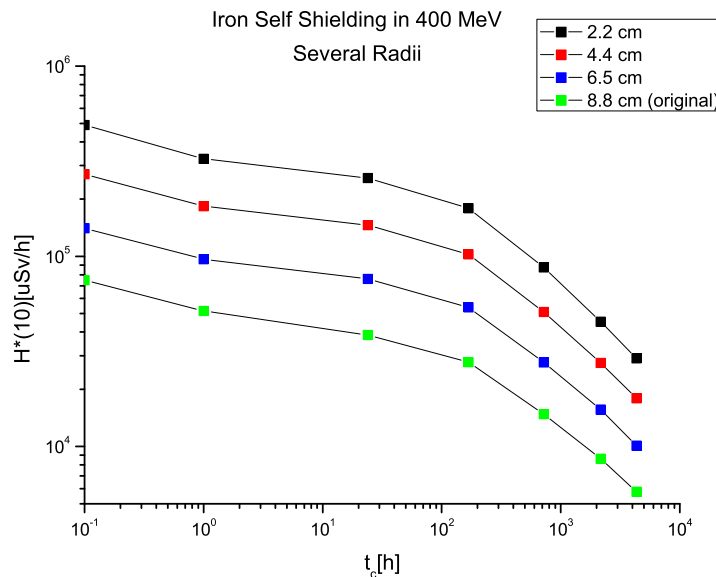


Figure 12.166: Ambient Dose Equivalent in several cooling times, for different radii

12.2.5 Stainless Steel

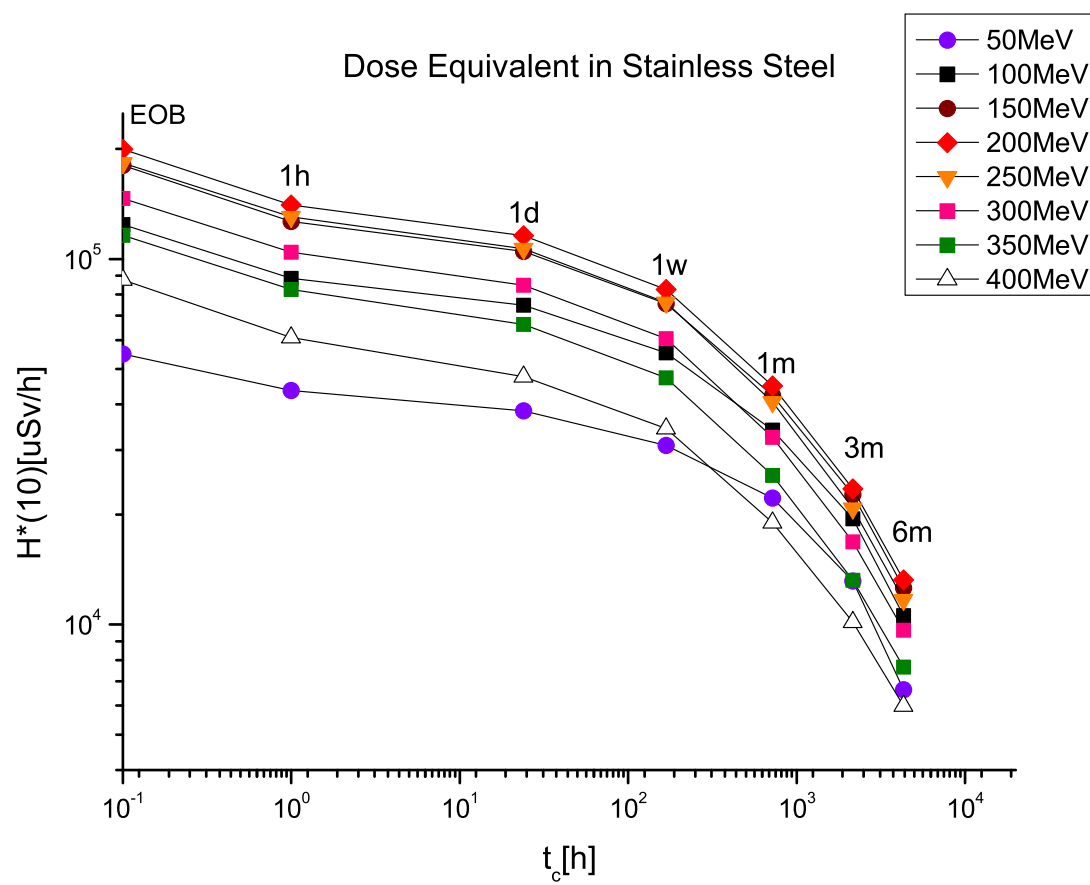


Figure 12.167: Stainless Steel Dose Equivalent as a function of cooling times

12.3 Neutron Spectra

In the following plots, the neutron spectra of the prompt escaping neutrons from the target to the air is being presented. The x-axis of the plots is the corresponding neutron energy, with unit [GeV], while the y-axis is the double differential neutron yield, in respect to the polar angle (θ) from the beam direction, and in respect to the neutron energy, multiplied by the energy, i.e $E \cdot \frac{d^2N}{dE d\theta}$. In each plot, the angle θ was fixed, in order to display the angular distribution of the escaping neutrons. Therefore, the unit of the y-axis of the plot is [sr^{-1} per primary proton], since all the results in fluka are normalized to one primary.

12.3.1 Boron Nitride

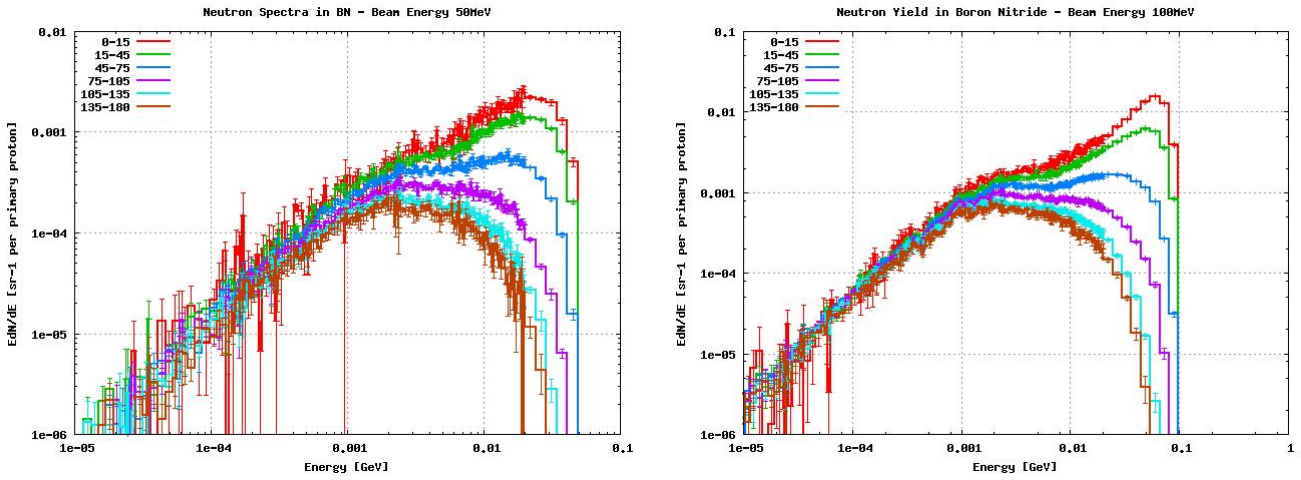


Figure 12.168: Beam Energies: 50 and 100 MeV's

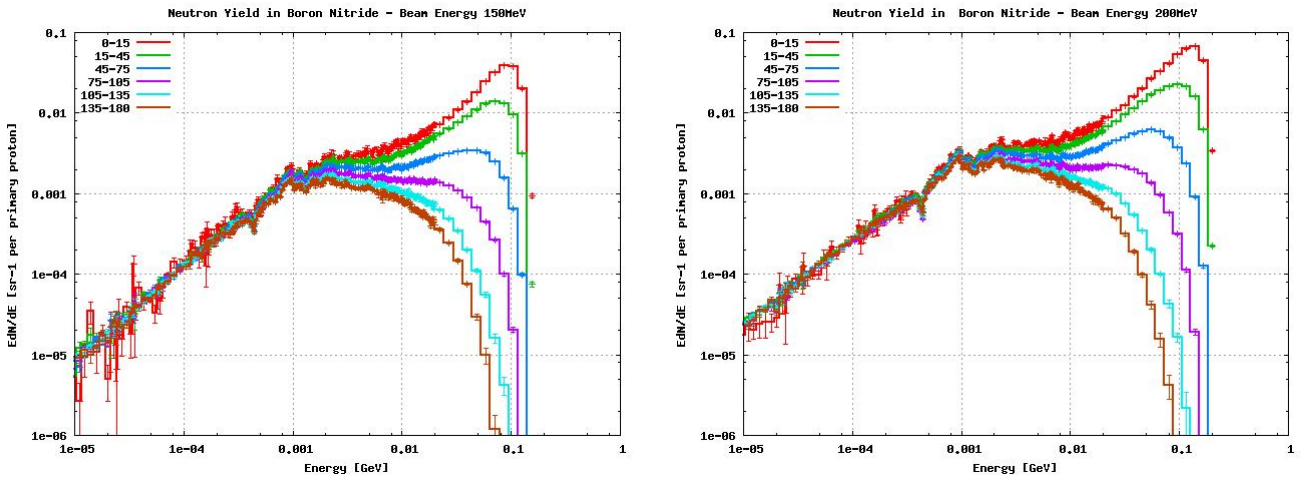


Figure 12.169: Beam Energies: 150 and 200 MeV's

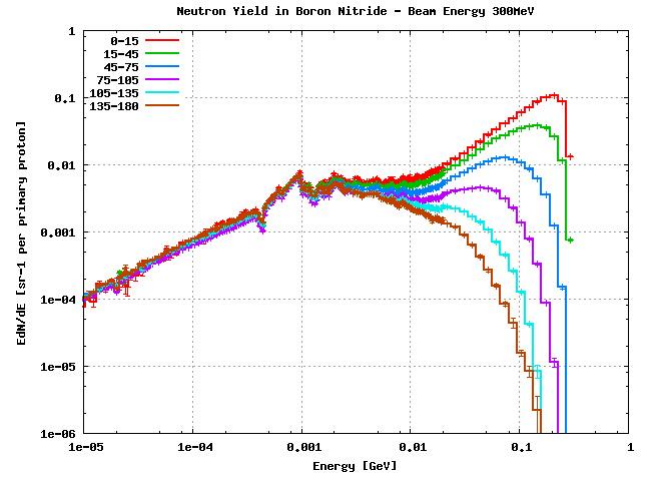
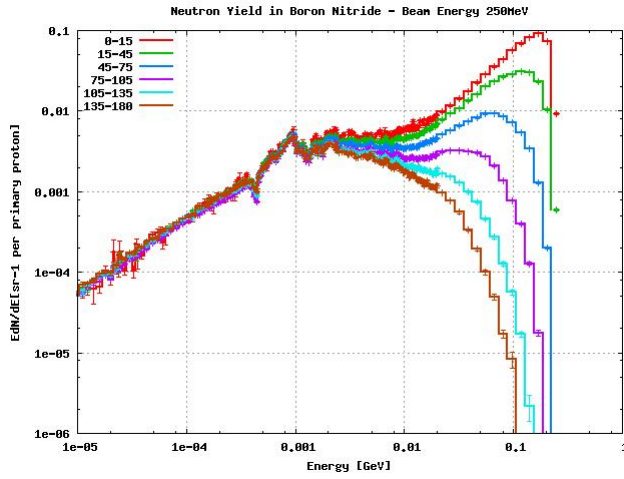


Figure 12.170: Beam Energies: 250 and 300 MeV's

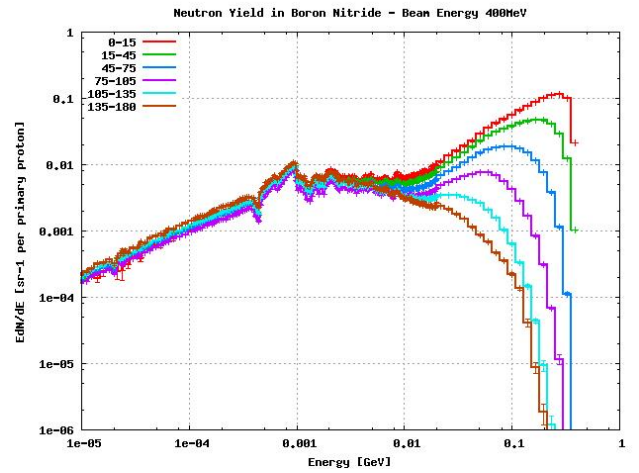
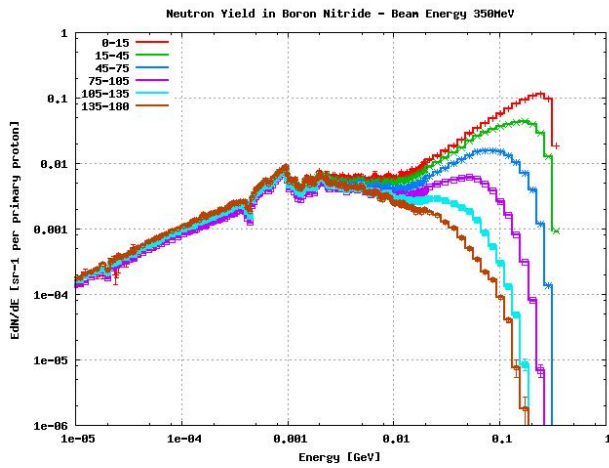


Figure 12.171: Beam Energies: 350 and 400 MeV's

12.3.2 Carbon (Graphite)

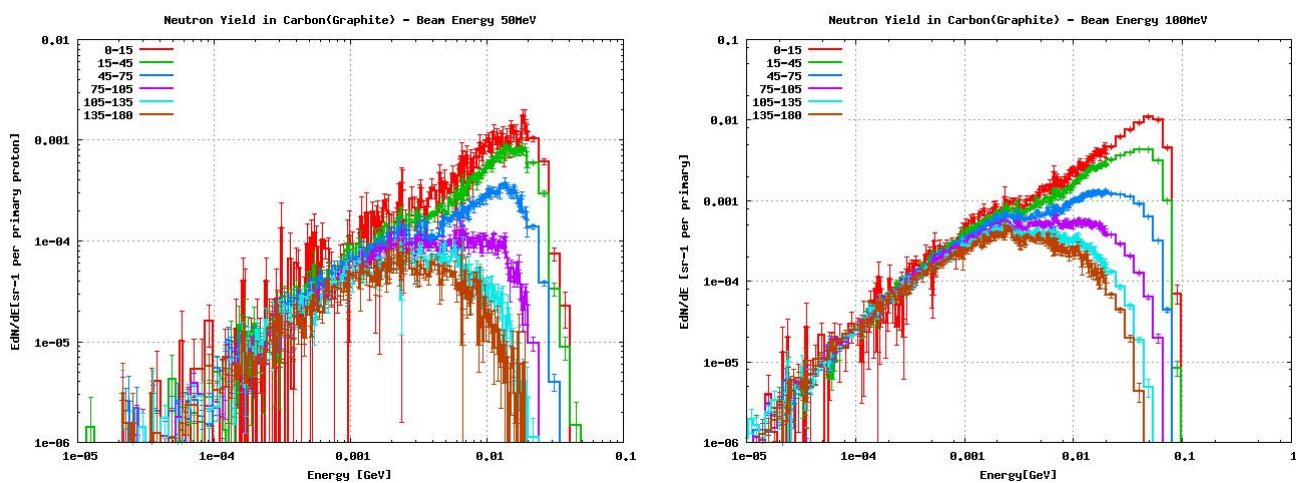


Figure 12.172: Beam Energies: 50 and 100 MeV's

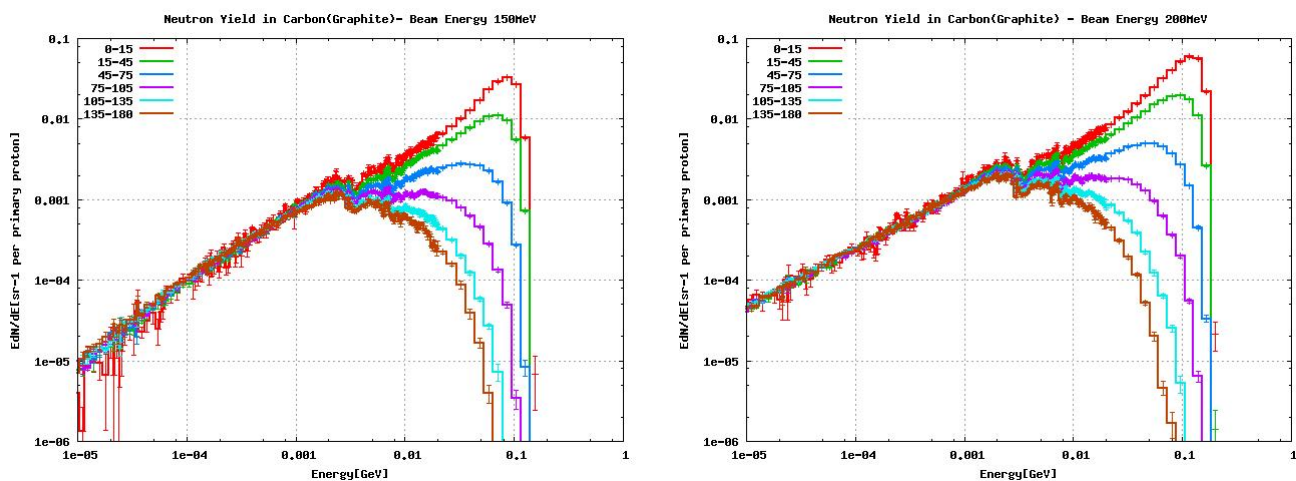


Figure 12.173: Beam Energies: 150 and 200 MeV's

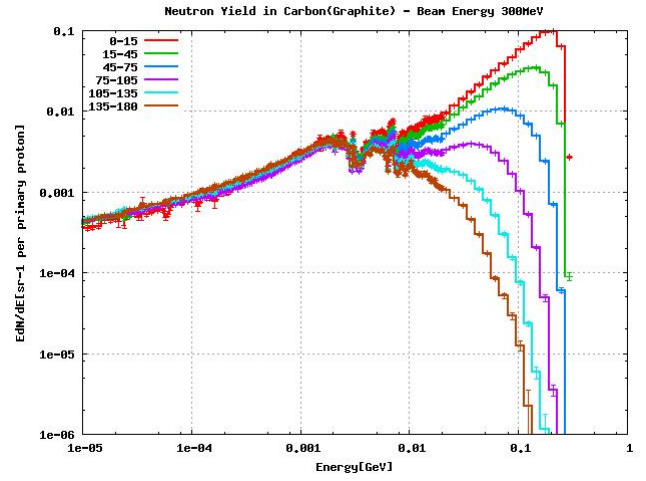
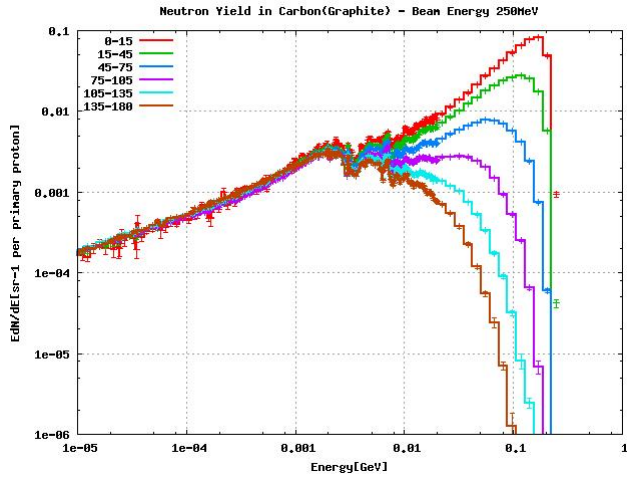


Figure 12.174: Beam Energies: 250 and 300 MeV's

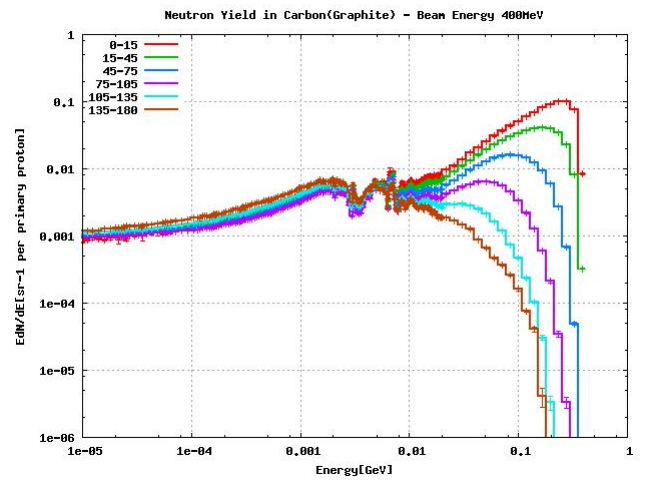
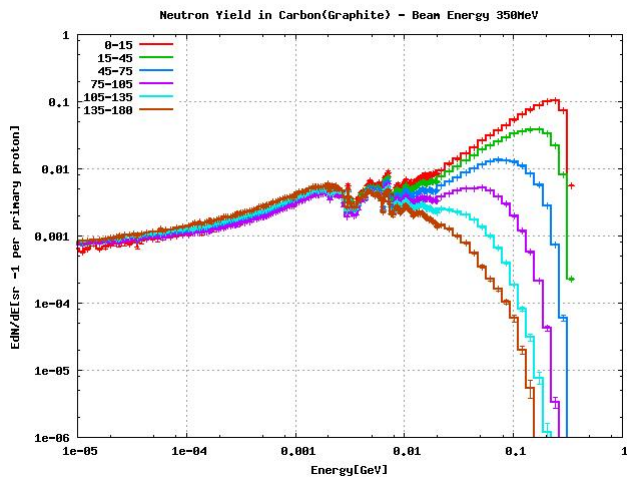


Figure 12.175: Beam Energies: 350 and 400 MeV's

12.3.3 Copper

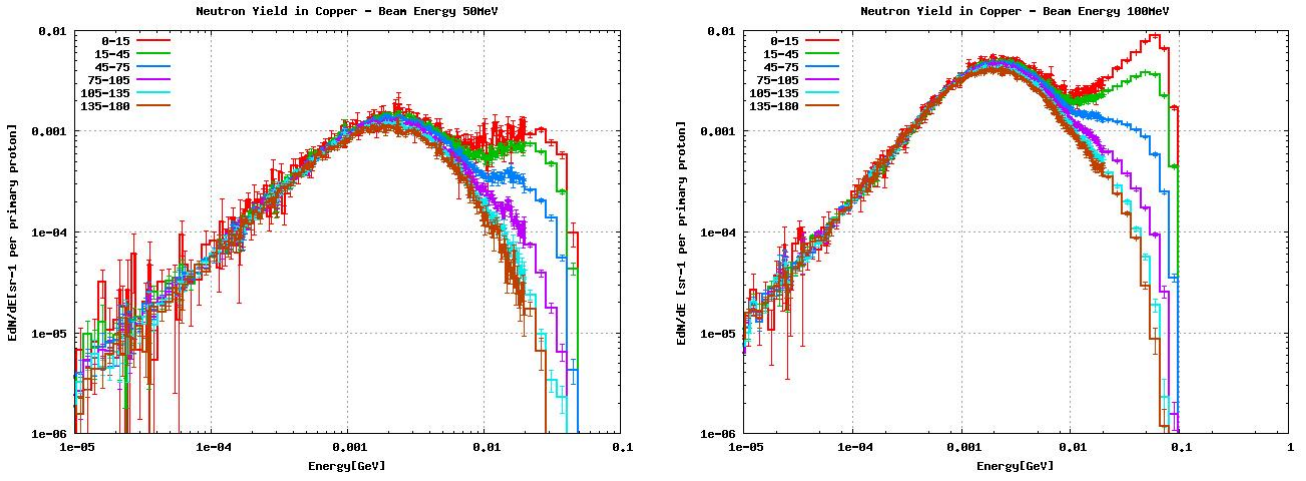


Figure 12.176: Beam Energies: 50 and 100 MeV's

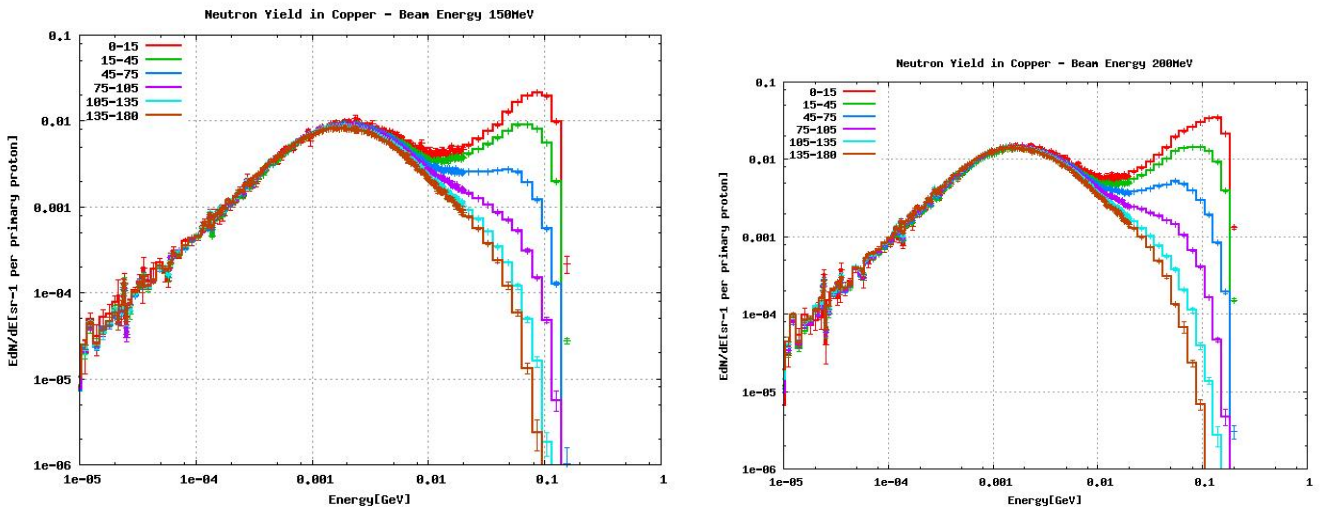


Figure 12.177: Beam Energies: 150 and 200 MeV's

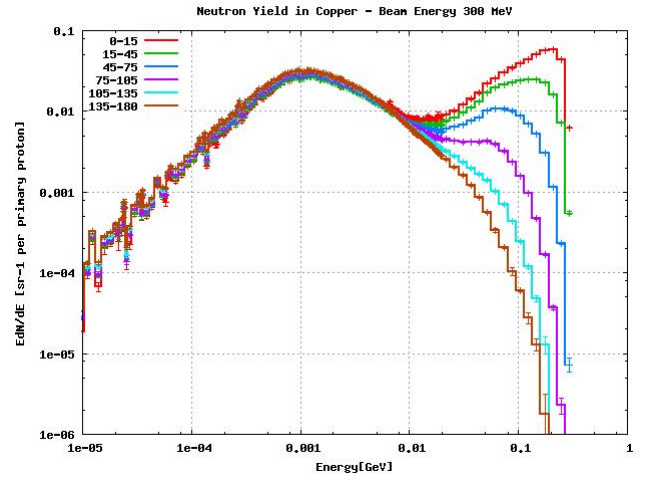
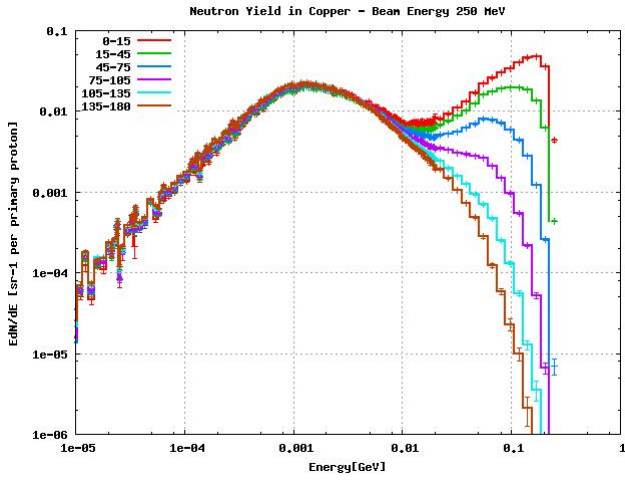


Figure 12.178: Beam Energies: 250 and 300 MeV's

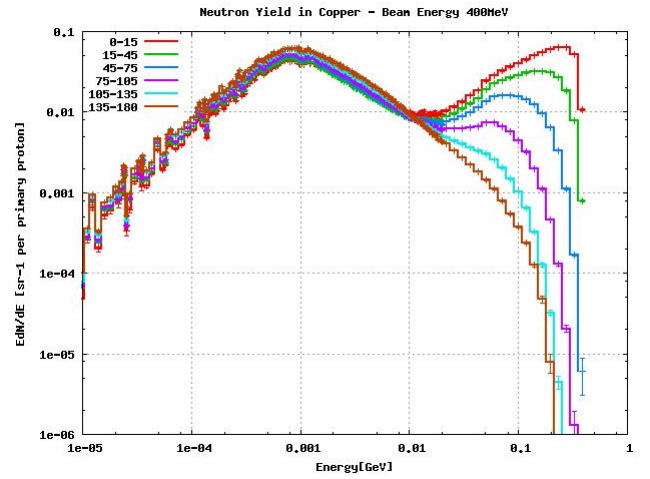
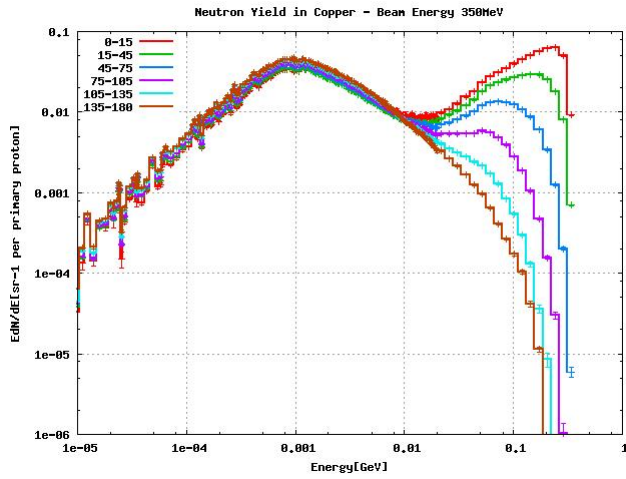


Figure 12.179: Beam Energies: 350 and 400 MeV's

12.3.4 Iron

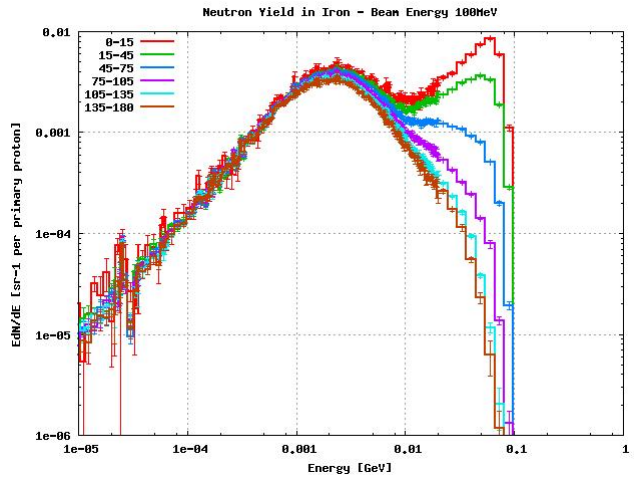
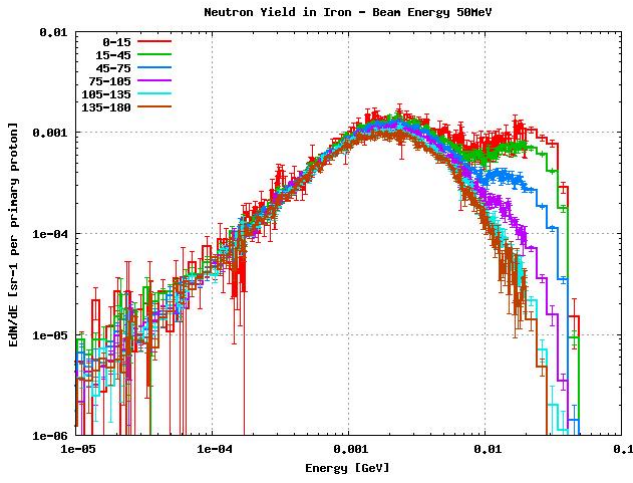


Figure 12.180: Beam Energies: 50 and 100 MeV's

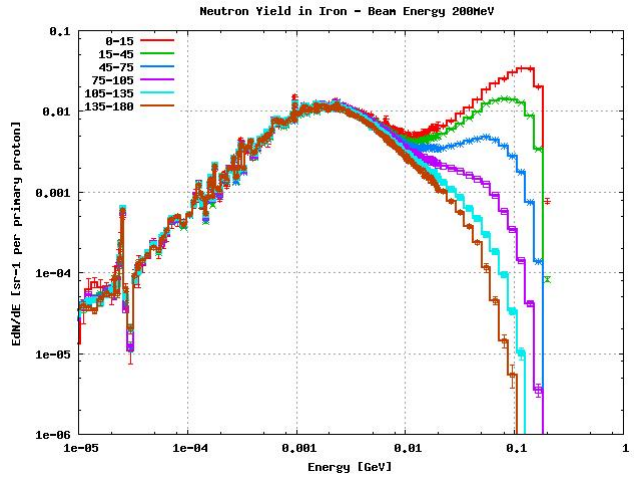
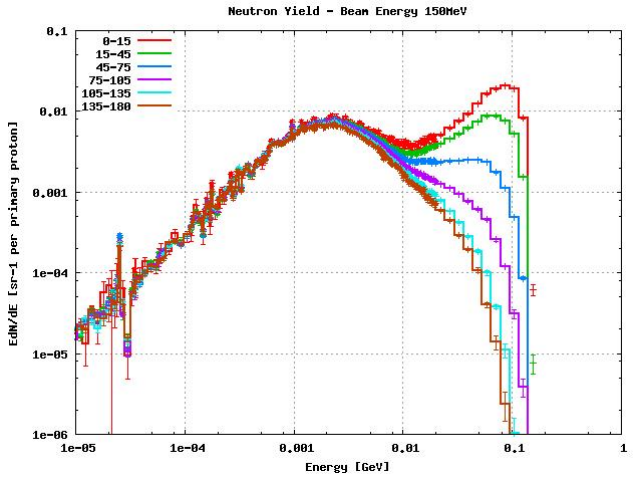


Figure 12.181: Beam Energies: 150 and 200 MeV's

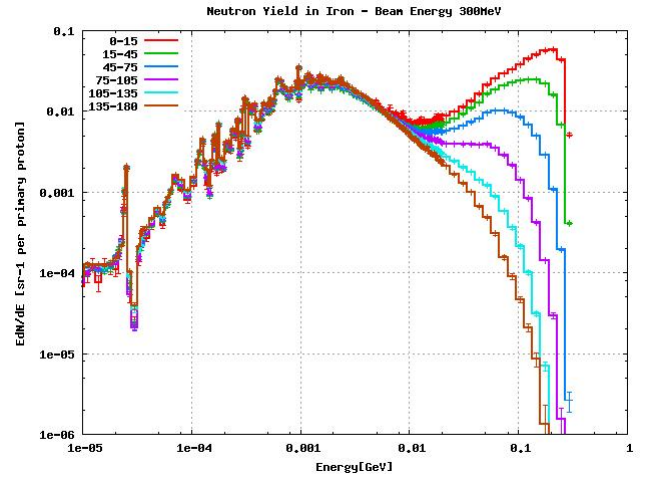
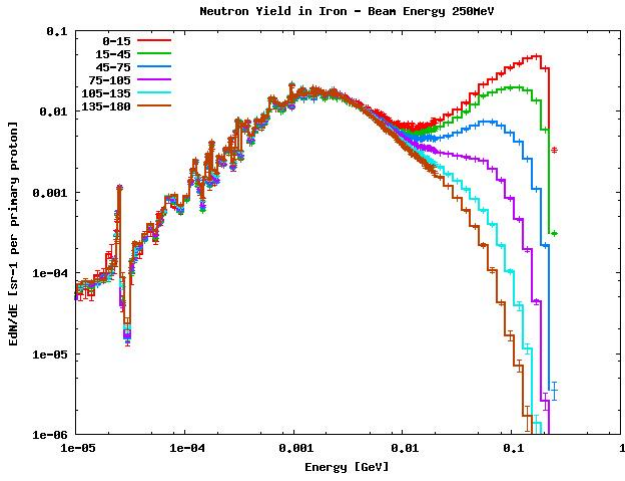


Figure 12.182: Beam Energies: 250 and 300 MeV's

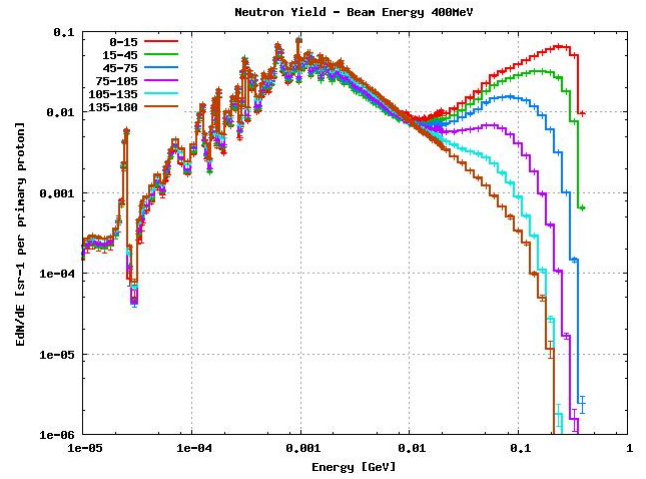
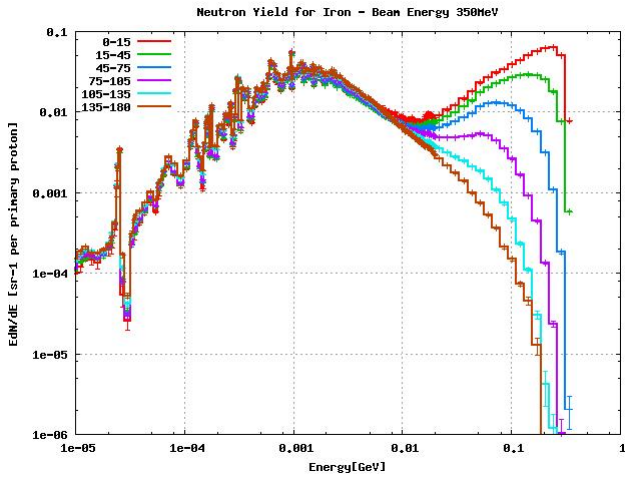


Figure 12.183: Beam Energies: 350 and 400 MeV's

12.3.5 Stainless Steel

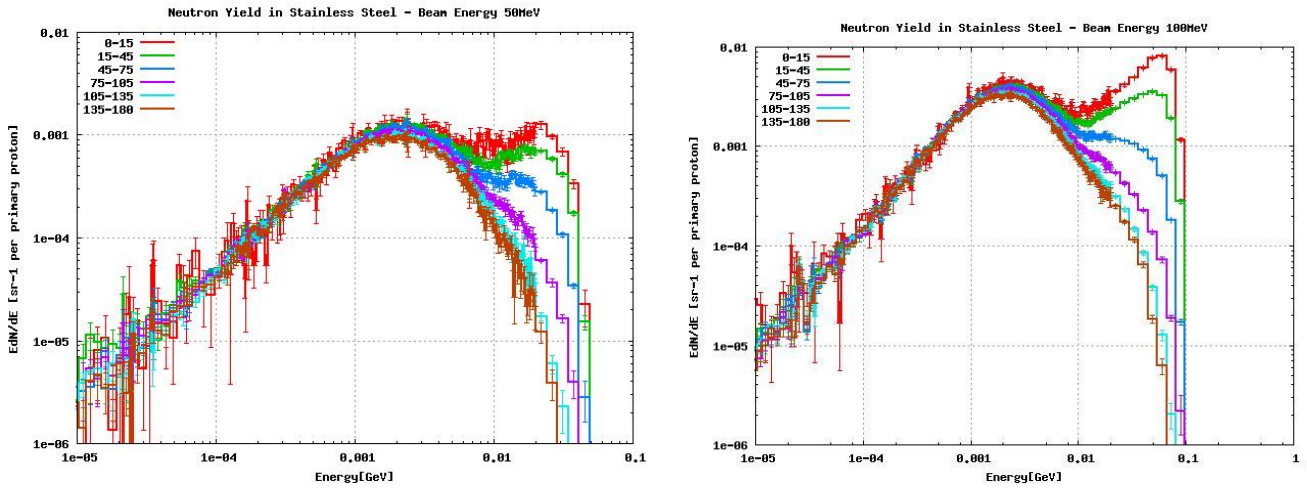


Figure 12.184: Beam Energies: 50 and 100 MeV's

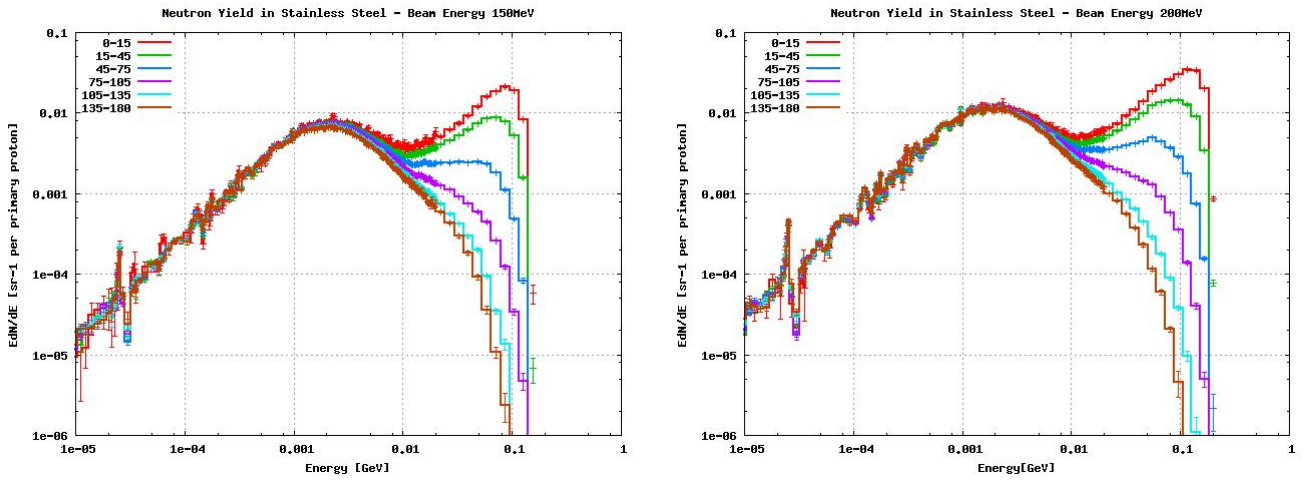


Figure 12.185: Beam Energies: 150 and 200 MeV's

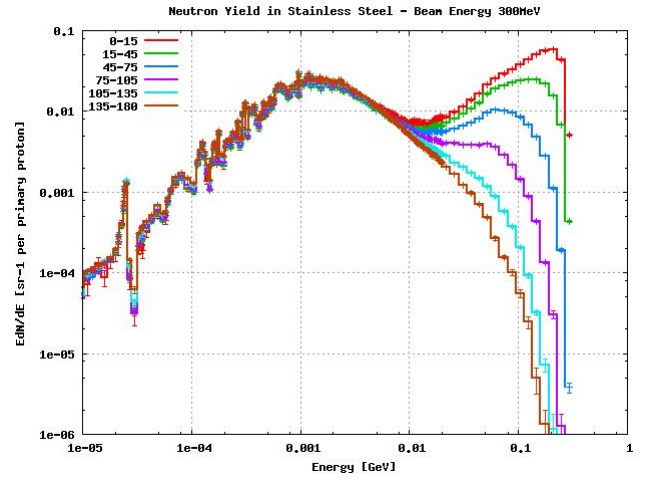
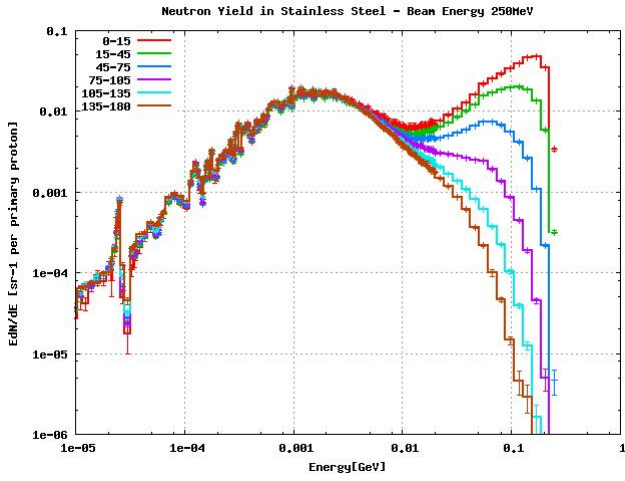


Figure 12.186: Beam Energies: 250 and 300 MeV's

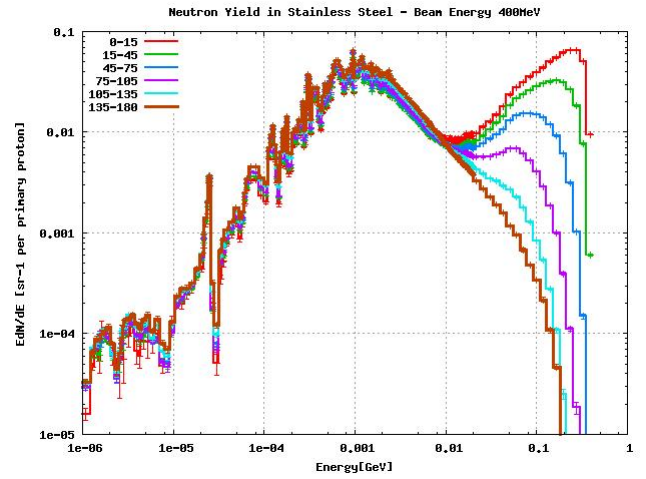
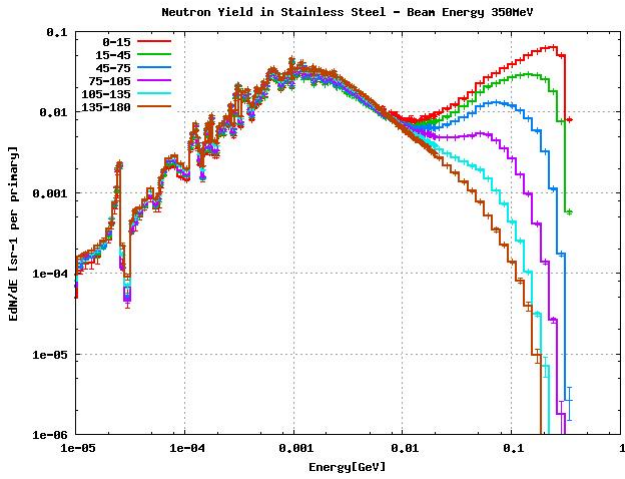


Figure 12.187: Beam Energies: 350 and 400 MeV's

Chapter 13

Tunnel Effect

In the framework of the present thesis, a special case was examined: investigation of the effect of a concrete shielding around the target, simulating a tunnel into which are usually the accelerators located. The ambient dose equivalent as well as the neutron spectra were scored inside the tunnel. In order to achieve that goal, a special set of simulations was prepared and performed, and the results are being presented and compared with the corresponding case without the tunnel.

13.1 Tunnel

The tunnel was modeled in the simulations as a sphere around the target, in a distance of 2m away from the target, while the height of the tunnel was 1m. The space between the target and the concrete sphere was filled with air, while the space outside the tunnel was also filled with air. The Ambient Dose Equivalent was scored at the distances of 50cm and 1m from the lateral surface of the cylinder, for the same cooling times, and the results are being presented in the following plots.

13.2 Material Composition

The tunnel composition appears in the Table (13.1). The specific composition is a mixture of the LHC tunnel concrete.

13.3 Ambient Dose Equivalent Plots

In the following plots, the Ambient Dose Equivalent for two beam energies, 100MeV and 400MeV impinging on the iron target are being presented. The Ambient Dose Equivalent was scored inside the tunnel, in both the distances of 50cm and 1m for each case.

Table 13.1: Concrete Composition [Mass % composition] ($\rho = 2.35g/cm^3$)

element	percentage
O	49.2852
Si	18.867
Ca	20.091
Al	2.063
Na	0.453
Fe	1.118
H	0.6
C	5.62
Mg	0.663
K	0.656
P	0.048
S	0.012
Ti	0.347
Mn	0.0387
Zn	0.0241
Sr	0.0423
Zr	7.4E-3
Ba	0.0179
Pb	0.0464

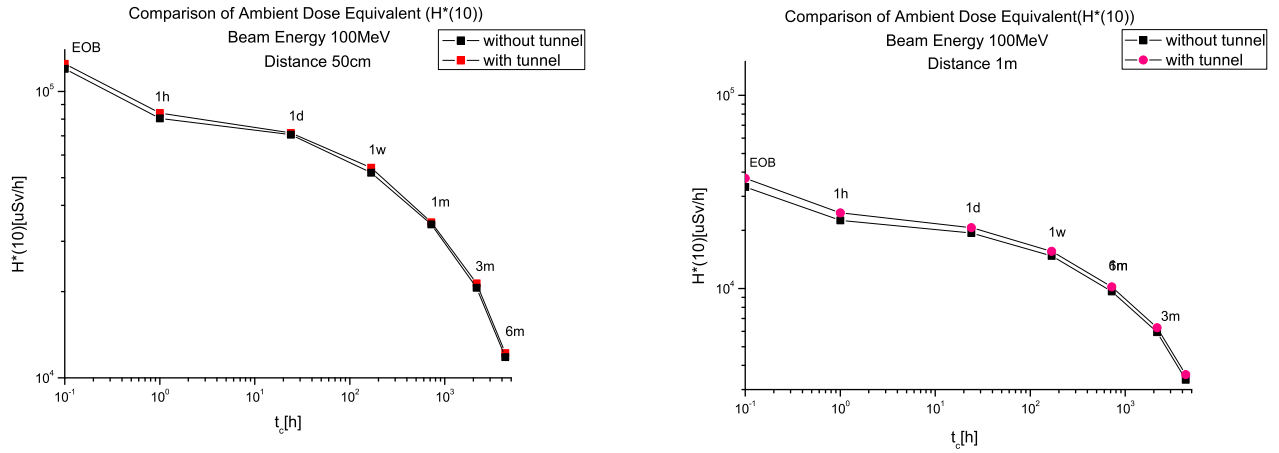


Figure 13.1: Beam Energy 100MeV, distance: 50cm and 1m from the target

From the Plots (13.1) and (13.2) one can see that the Ambient Dose Equivalent is increased when the tunnel is present. The effect is more clear in close distance from the concrete wall. The cause of this effect is mainly the thermal neutrons occurring from the thermalizing of fast neutrons impinging on the concrete, and reflected back.

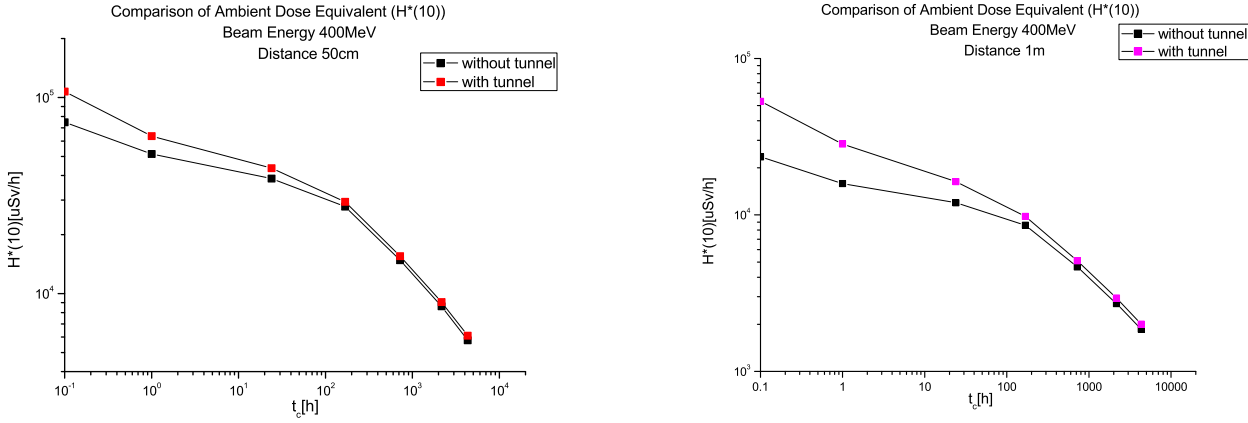


Figure 13.2: Beam Energy 400MeV, distance: 50cm and 1m from the target

13.4 Neutron Spectra

Two neutron detectors were implemented in that set of simulations, which were performed only for the energy of the impinging beam of 400MeV's on iron, because the effect is more clear in that energy, than any other lower. The first detector, was scoring the one way escaping neutrons from the target to the surrounding air in several angular beams, exactly as in the previous cases without the tunnel. The second one, was scoring the neutron fluence in respect to the neutron energy in the whole region of the surrounding air. This type of scoring was ideal in order to investigate wheather the number of thermal neutrons is being affectuated from the presence of the concrete tunnel, in comparison with the case without the tunnel.

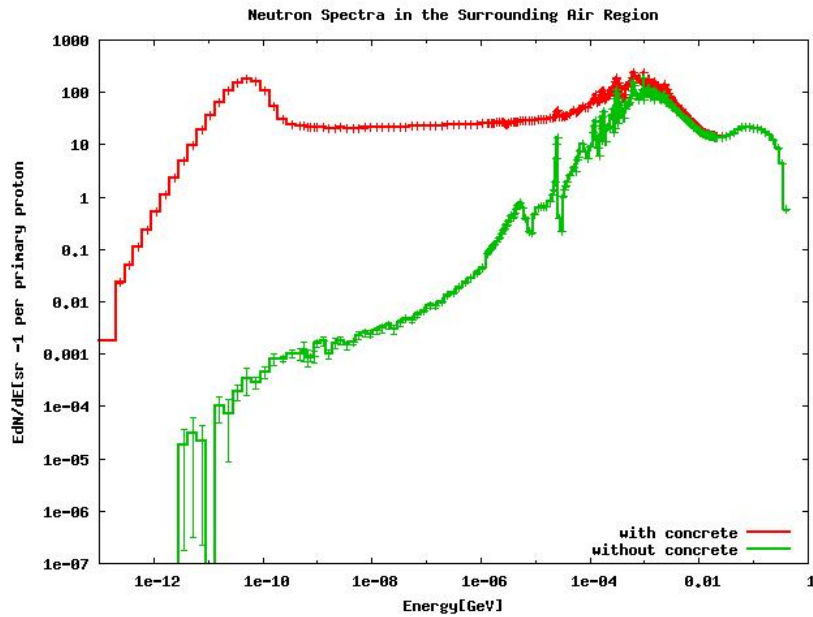


Figure 13.3: Neutron Spectra in the surrounding air with and without the concrete tunnel

In figure (13.3) the neutron spectra in the surrounding air region is plotted, with, and without the concrete shielding. The target is iron and the impinging beam energy is 400MeV. From the plot, one can see the thermal neutron peak in the spectra, at around 10^{-3} eV, which of course is not present in the case without the concrete. The fast neutrons escaping from the target, are impinging on the concrete wall and being scattered, losing a large part of their energy. A significant number of them is reflected back to the air as thermal neutrons.

At the second case, the prompt escaping neutron spectra, in respect to their energy in several angular bins is being plotted, for the case with the concrete tunnel surrounding the target, and without. The plots can be found at 13.4.

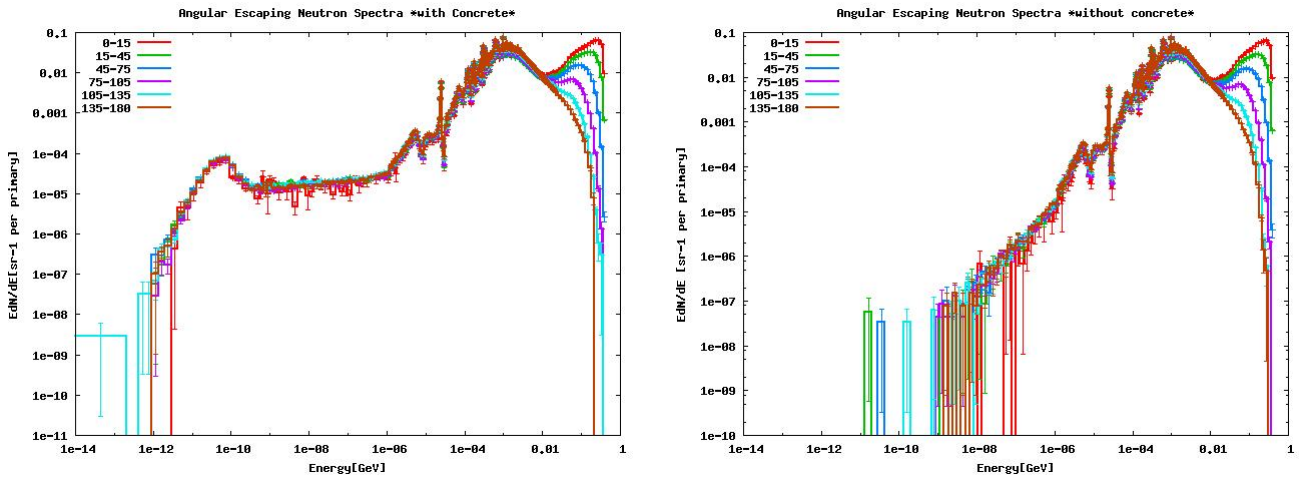


Figure 13.4: Escaping neutron spectra, in several angular bins, with and without the concrete tunnel

From the figures (13.4) one can see that the tunnel has an effect also in the escaping neutron spectra. Although the scoring was done one way, in the sense that only the escaping neutrons (direction target to air) were counted in both cases, in the case with the concrete there are a lot of “circulating” neutrons, that escaping the target for first time and being reflected in the concrete. These neutrons are returning in the target without being scored by the detectors, and after more interaction with the target material, they are exiting the target, after having lost a huge amount of their initial energy. The “thermal peak” appearing in the figure (13.4) around 10^{-2} eV is caused exactly from the “circulating” neutrons. However, the number of these escaping thermal neutrons is significantly lower than the thermal neutrons travelling in the air region.

Chapter 14

Residual Nuclei Tables

In the following sections, all the residual nuclei in the target, after all the cooling times are being presented. The activity (in Bq) as well as the specific activity (Bq/g) of each nuclei also appears in the tables. For visualisation reasons, in these tables only the most abundant in terms of activity nuclei appear. The whole inventory is available, in electronic form.

14.1 Boron Nitride

14.1.1 50MeV

Table 14.1: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
C-11	6.34E+09	2.23E+10	Be-7	3.98E+09	1.40E+10
Be-7	3.98E+09	1.40E+10	C-11	8.27E+08	2.91E+09
N-13	3.01E+09	1.06E+10	H-3	1.32E+08	4.65E+08
O-14	1.17E+09	4.12E+09	N-13	4.63E+07	1.63E+08
C-10	8.69E+08	3.06E+09	Ar-37	3.44E+07	1.21E+08
O-15	3.92E+08	1.38E+09	Sc-46	1.09E+06	3.84E+06
Be-8	2.35E+08	8.26E+08	Sc-47	9.66E+05	3.40E+06
H-3	1.32E+08	4.65E+08	Sc-48	9.57E+05	3.37E+06
B-8	1.30E+08	4.59E+08	Sc-44	8.89E+05	3.13E+06
Li-8	9.46E+07	3.33E+08	Sc-43	8.15E+05	2.87E+06
He-6	8.61E+07	3.03E+08	F-18	6.68E+05	2.35E+06
Ca-39	8.01E+07	2.82E+08	Cl-34m	6.31E+05	2.22E+06
N-12	4.57E+07	1.61E+08	Sc-44m	4.80E+05	1.69E+06
Ar-37	3.44E+07	1.21E+08			
K-38	2.93E+07	1.03E+08			
K-38m	2.93E+07	1.03E+08			
B-12	1.14E+07	4.03E+07			
B-9	9.49E+06	3.34E+07			
C-9	9.49E+06	3.34E+07			
O-13	8.52E+06	3.00E+07			
Sc-41	5.37E+06	1.89E+07			
Ar-35	4.37E+06	1.54E+07			
Sc-40	3.41E+06	1.20E+07			
Cl-34	3.35E+06	1.18E+07			
Si-27	3.15E+06	1.11E+07			

Table 14.2: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	3.95E+09	1.39E+10	Be-7	3.64E+09	1.28E+10
H-3	1.32E+08	4.65E+08	H-3	1.32E+08	4.65E+08
Ar-37	3.38E+07	1.19E+08	Ar-37	3.01E+07	1.06E+08
Sc-46	1.08E+06	3.81E+06	Sc-46	1.03E+06	3.63E+06
Sc-47	7.93E+05	2.79E+06	Sc-47	2.28E+05	8.04E+05
Sc-48	6.65E+05	2.34E+06	Sc-44	7.07E+04	2.49E+05
Sc-44	3.95E+05	1.39E+06	Sc-48	6.76E+04	2.38E+05
Sc-44m	3.66E+05	1.29E+06	Sc-44m	6.68E+04	2.35E+05

Table 14.3: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	2.70E+09	9.50E+09	Be-7	1.24E+09	4.35E+09
H-3	1.32E+08	4.63E+08	H-3	1.30E+08	4.59E+08
Ar-37	1.90E+07	6.69E+07	Ar-37	5.80E+06	2.04E+07
Sc-46	8.52E+05	3.00E+06	Sc-46	5.20E+05	1.83E+06

Table 14.4: Cooling times of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	<i>3.84E+08</i>	1.35E+09
H-3	<i>1.29E+08</i>	4.53E+08
Ar-37	<i>9.77E+05</i>	3.44E+06
Sc-46	<i>2.46E+05</i>	8.67E+05

14.1.2 100MeV

Table 14.5: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
C-11	<i>2.54E+08</i>	3.73E+10	Be-7	<i>2.08E+08</i>	3.06E+10
N-13	<i>2.21E+08</i>	3.24E+10	C-11	<i>3.31E+07</i>	4.86E+09
Be-7	<i>2.08E+08</i>	3.06E+10	H-3	<i>1.19E+07</i>	1.74E+09
O-14	<i>5.14E+07</i>	7.55E+09	Ar-37	<i>7.77E+06</i>	1.14E+09
C-10	<i>4.61E+07</i>	6.76E+09	N-13	<i>3.40E+06</i>	4.99E+08
O-15	<i>3.90E+07</i>	5.73E+09	Cl-34m	<i>3.40E+05</i>	4.99E+07
Be-8	<i>3.67E+07</i>	5.39E+09	P-32	<i>2.97E+05</i>	4.36E+07
B-8	<i>1.85E+07</i>	2.71E+09	Cl-34	<i>1.52E+05</i>	2.23E+07
Li-8	<i>1.55E+07</i>	2.28E+09	P-33	<i>1.28E+05</i>	1.88E+07
He-6	<i>1.29E+07</i>	1.90E+09	Sc-44	<i>7.97E+04</i>	1.17E+07
H-3	<i>1.19E+07</i>	1.74E+09	Sc-47	<i>6.95E+04</i>	1.02E+07
Ar-37	<i>7.77E+06</i>	1.14E+09	S-35	<i>6.72E+04</i>	9.87E+06
Ca-39	<i>7.02E+06</i>	1.03E+09	K-42	<i>6.07E+04</i>	8.91E+06
N-12	<i>4.26E+06</i>	6.26E+08	Sc-44m	<i>4.33E+04</i>	6.35E+06
B-12	<i>4.10E+06</i>	6.02E+08	K-43	<i>3.97E+04</i>	5.82E+06
K-38	<i>3.28E+06</i>	4.82E+08	Sc-43	<i>3.91E+04</i>	5.74E+06
K-38m	<i>3.15E+06</i>	4.62E+08	Ca-47	<i>2.90E+04</i>	4.26E+06
B-9	<i>2.23E+06</i>	3.27E+08	F-18	<i>2.40E+04</i>	3.52E+06
C-9	<i>2.23E+06</i>	3.27E+08	Na-22	<i>2.33E+04</i>	3.42E+06
Cl-34	<i>1.81E+06</i>	2.65E+08	Sc-46	<i>1.57E+04</i>	2.30E+06
Cl-34m	<i>1.25E+06</i>	1.83E+08	K-38	<i>1.42E+04</i>	2.08E+06
Li-9	<i>1.04E+06</i>	1.53E+08	Ca-45	<i>1.21E+04</i>	1.77E+06
O-13	<i>7.49E+05</i>	1.10E+08	Na-24	<i>1.12E+04</i>	1.64E+06

Table 14.6: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>2.06E+08</i>	3.02E+10	Be-7	<i>1.91E+08</i>	2.80E+10
H-3	<i>1.19E+07</i>	1.74E+09	H-3	<i>1.19E+07</i>	1.74E+09
Ar-37	<i>7.63E+06</i>	1.12E+09	Ar-37	<i>6.79E+06</i>	9.96E+08
P-32	<i>2.83E+05</i>	4.16E+07	P-32	<i>2.12E+05</i>	3.11E+07
P-33	<i>1.25E+05</i>	1.83E+07	P-33	<i>1.06E+05</i>	1.56E+07
S-35	<i>6.68E+04</i>	9.80E+06	S-35	<i>6.36E+04</i>	9.34E+06
Sc-47	<i>6.20E+04</i>	9.10E+06	Sc-47	<i>2.85E+04</i>	4.19E+06
Sc-44	<i>3.55E+04</i>	5.21E+06	Na-22	<i>2.32E+04</i>	3.40E+06
Sc-44m	<i>3.30E+04</i>	4.84E+06	Sc-46	<i>1.49E+04</i>	2.18E+06
Ca-47	<i>2.51E+04</i>	3.68E+06	Ca-45	<i>1.17E+04</i>	1.71E+06
Na-22	<i>2.33E+04</i>	3.42E+06	Ca-47	<i>1.00E+04</i>	1.47E+06
K-43	<i>1.94E+04</i>	2.85E+06			
K-42	<i>1.67E+04</i>	2.45E+06			
Sc-46	<i>1.56E+04</i>	2.29E+06			
Ca-45	<i>1.20E+04</i>	1.76E+06			

Table 14.7: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>1.41E+08</i>	2.07E+10	Be-7	<i>6.47E+07</i>	9.50E+09
H-3	<i>1.18E+07</i>	1.73E+09	H-3	<i>1.17E+07</i>	1.72E+09
Ar-37	<i>4.31E+06</i>	6.32E+08	Ar-37	<i>1.31E+06</i>	1.93E+08
P-32	<i>6.95E+04</i>	1.02E+07	S-35	<i>3.30E+04</i>	4.84E+06
P-33	<i>5.65E+04</i>	8.30E+06	Na-22	<i>2.18E+04</i>	3.20E+06
S-35	<i>5.31E+04</i>	7.79E+06	P-33	<i>1.10E+04</i>	1.61E+06
Na-22	<i>2.28E+04</i>	3.35E+06	Ca-45	<i>8.24E+03</i>	1.21E+06
Sc-46	<i>1.23E+04</i>	1.80E+06	Sc-46	<i>7.49E+03</i>	1.10E+06
Ca-45	<i>1.06E+04</i>	1.56E+06			

Table 14.8: Cooling times of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	<i>2.01E+07</i>	2.95E+09
H-3	<i>1.15E+07</i>	1.69E+09
Ar-37	<i>2.21E+05</i>	3.25E+07
Na-22	<i>2.04E+04</i>	3.00E+06
S-35	<i>1.61E+04</i>	2.37E+06

14.1.3 150MeV

Table 14.9: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
N-13	<i>5.01E+07</i>	6.68E+10	Be-7	<i>3.74E+07</i>	4.99E+10
C-11	<i>4.27E+07</i>	5.70E+10	C-11	<i>5.56E+06</i>	7.42E+09
Be-7	<i>3.74E+07</i>	4.99E+10	H-3	<i>2.69E+06</i>	3.59E+09
Be-8	<i>9.37E+06</i>	1.25E+10	Ar-37	<i>1.60E+06</i>	2.14E+09
O-15	<i>8.54E+06</i>	1.14E+10	N-13	<i>7.72E+05</i>	1.03E+09
O-14	<i>7.80E+06</i>	1.04E+10	P-32	<i>1.07E+05</i>	1.43E+08
C-10	<i>7.80E+06</i>	1.04E+10	Cl-34m	<i>8.47E+04</i>	1.13E+08
Li-8	<i>4.42E+06</i>	5.90E+09	Cl-34	<i>3.79E+04</i>	5.05E+07
B-8	<i>4.18E+06</i>	5.58E+09	P-33	<i>3.01E+04</i>	4.02E+07
He-6	<i>3.22E+06</i>	4.30E+09	S-35	<i>2.33E+04</i>	3.11E+07
H-3	<i>2.69E+06</i>	3.59E+09	K-43	<i>1.62E+04</i>	2.16E+07
Ar-37	<i>1.60E+06</i>	2.14E+09	K-42	<i>1.27E+04</i>	1.70E+07
Ca-39	<i>1.56E+06</i>	2.08E+09	Sc-47	<i>1.21E+04</i>	1.62E+07
B-12	<i>1.18E+06</i>	1.57E+09	Sc-44	<i>1.06E+04</i>	1.41E+07
N-12	<i>8.84E+05</i>	1.18E+09	F-18	<i>9.67E+03</i>	1.29E+07
K-38	<i>6.91E+05</i>	9.22E+08	Ca-47	<i>6.39E+03</i>	8.52E+06
K-38m	<i>6.64E+05</i>	8.86E+08	Na-22	<i>6.30E+03</i>	8.40E+06
B-9	<i>5.61E+05</i>	7.48E+08	Sc-43	<i>5.91E+03</i>	7.89E+06
C-9	<i>5.61E+05</i>	7.48E+08	Sc-44m	<i>5.71E+03</i>	7.62E+06
Cl-34	<i>4.52E+05</i>	6.03E+08	Si-31	<i>5.43E+03</i>	7.24E+06
Li-9	<i>4.00E+05</i>	5.33E+08	Na-24	<i>4.29E+03</i>	5.73E+06
Cl-34m	<i>3.11E+05</i>	4.15E+08	Ca-45	<i>3.53E+03</i>	4.71E+06
P-30	<i>1.91E+05</i>	2.55E+08	K-38	<i>2.98E+03</i>	3.98E+06
O-13	<i>1.50E+05</i>	2.00E+08	Sc-46	<i>2.30E+03</i>	3.07E+06
Ar-35	<i>1.20E+05</i>	1.60E+08	Cl-38	<i>1.05E+03</i>	1.40E+06
Be-11	<i>1.11E+05</i>	1.48E+08			
P-32	<i>1.07E+05</i>	1.43E+08			
K-37	<i>7.95E+04</i>	1.06E+08			

Table 14.10: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	3.69E+07	4.92E+10	Be-7	3.41E+07	4.55E+10
H-3	2.69E+06	3.59E+09	H-3	2.69E+06	3.59E+09
Ar-37	1.57E+06	2.10E+09	Ar-37	1.39E+06	1.86E+09
P-32	1.02E+05	1.36E+08	P-32	7.65E+04	1.02E+08
P-33	2.94E+04	3.92E+07	P-33	2.49E+04	3.32E+07
S-35	2.32E+04	3.09E+07	S-35	2.21E+04	2.95E+07
Sc-47	1.10E+04	1.47E+07	Na-22	6.27E+03	8.36E+06
K-43	7.95E+03	1.06E+07	Sc-47	5.52E+03	7.37E+06
Na-22	6.29E+03	8.39E+06	Ca-45	3.43E+03	4.57E+06
Ca-47	5.52E+03	7.36E+06	Ca-47	2.20E+03	2.94E+06
Sc-44	4.68E+03	6.25E+06	Sc-46	2.17E+03	2.90E+06
Sc-44m	4.35E+03	5.81E+06	Sc-44	8.39E+02	1.12E+06
Ca-45	3.52E+03	4.69E+06	Sc-44m	7.95E+02	1.06E+06
K-42	3.52E+03	4.69E+06			
Sc-46	2.29E+03	3.05E+06			
Na-24	1.48E+03	1.97E+06			

Table 14.11: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	2.53E+07	3.38E+10	Be-7	1.16E+07	1.55E+10
H-3	2.68E+06	3.58E+09	H-3	2.65E+06	3.54E+09
Ar-37	8.84E+05	1.18E+09	Ar-37	2.71E+05	3.61E+08
P-32	2.50E+04	3.33E+07	S-35	1.15E+04	1.53E+07
S-35	1.84E+04	2.46E+07	Na-22	5.89E+03	7.86E+06
P-33	1.33E+04	1.77E+07	P-33	2.57E+03	3.43E+06
Na-22	6.16E+03	8.22E+06	Ca-45	2.41E+03	3.22E+06
Ca-45	3.11E+03	4.15E+06	P-32	1.36E+03	1.81E+06
Sc-46	1.80E+03	2.40E+06	Sc-46	1.09E+03	1.46E+06

Table 14.12: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	3.60E+06	4.80E+09
H-3	2.62E+06	3.50E+09
Ar-37	4.56E+04	6.08E+07
S-35	5.61E+03	7.48E+06
Na-22	5.52E+03	7.36E+06
Ca-45	1.65E+03	2.20E+06

14.1.4 200MeV

Table 14.13: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
N-13	1.91E+07	1.10E+11	Be-7	1.23E+07	7.06E+10
C-11	1.33E+07	7.64E+10	C-11	1.73E+06	9.94E+09
Be-7	1.23E+07	7.07E+10	H-3	1.05E+06	6.06E+09
Be-8	3.80E+06	2.19E+10	Ar-37	6.44E+05	3.71E+09
O-15	3.11E+06	1.79E+10	N-13	2.93E+05	1.69E+09
C-10	2.38E+06	1.37E+10	P-32	5.19E+04	2.99E+08
O-14	2.22E+06	1.28E+10	Cl-34m	2.92E+04	1.68E+08
Li-8	1.96E+06	1.13E+10	P-33	1.31E+04	7.53E+07
B-8	1.54E+06	8.88E+09	Cl-34	1.30E+04	7.49E+07
He-6	1.35E+06	7.79E+09	S-35	1.29E+04	7.44E+07
H-3	1.05E+06	6.06E+09	K-42	5.90E+03	3.40E+07
Ar-37	6.44E+05	3.71E+09	K-43	4.62E+03	2.66E+07
Ca-39	5.90E+05	3.40E+09	F-18	4.37E+03	2.52E+07
B-12	5.28E+05	3.04E+09	Na-24	3.40E+03	1.96E+07
N-12	3.11E+05	1.79E+09	Sc-44	3.12E+03	1.80E+07
K-38	2.41E+05	1.39E+09	Na-22	2.86E+03	1.65E+07
K-38m	2.24E+05	1.29E+09	Sc-47	2.81E+03	1.62E+07
Li-9	2.13E+05	1.23E+09	Ca-47	1.93E+03	1.11E+07
B-9	2.03E+05	1.17E+09			
C-9	2.03E+05	1.17E+09			

Table 14.14: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	1.21E+07	6.98E+10	Be-7	1.12E+07	6.45E+10
H-3	1.05E+06	6.06E+09	H-3	1.05E+06	6.05E+09
Ar-37	6.32E+05	3.64E+09	Ar-37	5.61E+05	3.23E+09
P-32	4.95E+04	2.85E+08	P-32	3.70E+04	2.13E+08
S-35	1.28E+04	7.38E+07	S-35	1.22E+04	7.04E+07
P-33	1.27E+04	7.34E+07	P-33	1.08E+04	6.22E+07
Na-22	2.86E+03	1.65E+07	Na-22	2.85E+03	1.64E+07
Sc-47	2.64E+03	1.52E+07	Sc-47	1.46E+03	8.43E+06
K-43	2.26E+03	1.30E+07	Ca-45	1.39E+03	8.00E+06
Ca-47	1.66E+03	9.56E+06	Ca-47	6.63E+02	3.82E+06
K-42	1.63E+03	9.38E+06	C-14	2.76E+02	1.59E+06
Ca-45	1.42E+03	8.21E+06	Sc-44	2.48E+02	1.43E+06
Sc-44	1.39E+03	7.99E+06	Sc-44m	2.34E+02	1.35E+06
Sc-44m	1.29E+03	7.42E+06			
Na-24	1.17E+03	6.76E+06			
C-14	2.76E+02	1.59E+06			

Table 14.15: Cooling times of **1 month** and **3 months**

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>8.30E+06</i>	4.78E+10	Be-7	<i>3.80E+06</i>	2.19E+10
H-3	<i>1.05E+06</i>	6.03E+09	H-3	<i>1.04E+06</i>	5.97E+09
Ar-37	<i>3.56E+05</i>	2.05E+09	Ar-37	<i>1.09E+05</i>	6.26E+08
P-32	<i>1.21E+04</i>	6.96E+07	S-35	<i>6.34E+03</i>	3.65E+07
S-35	<i>1.02E+04</i>	5.87E+07	Na-22	<i>2.67E+03</i>	1.54E+07
P-33	<i>5.76E+03</i>	3.32E+07	P-33	<i>1.12E+03</i>	6.43E+06
Na-22	<i>2.79E+03</i>	1.61E+07	Ca-45	<i>9.77E+02</i>	5.63E+06
Ca-45	<i>1.26E+03</i>	7.26E+06	P-32	<i>6.56E+02</i>	3.78E+06
C-14	<i>2.76E+02</i>	1.59E+06	C-14	<i>2.76E+02</i>	1.59E+06

Table 14.16: Cooling time of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	<i>1.18E+06</i>	6.80E+09
H-3	<i>1.02E+06</i>	5.89E+09
Ar-37	<i>1.84E+04</i>	1.06E+08
S-35	<i>3.11E+03</i>	1.79E+07
Na-22	<i>2.52E+03</i>	1.45E+07
Ca-45	<i>6.68E+02</i>	3.85E+06
C-14	<i>2.76E+02</i>	1.59E+06

14.1.5 250MeV

Table 14.17: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
N-13	8.67E+06	1.59E+11	Be-7	5.00E+06	9.18E+10
C-11	5.35E+06	9.82E+10	C-11	6.98E+05	1.28E+10
Be-7	5.00E+06	9.18E+10	H-3	4.97E+05	9.11E+09
Be-8	1.86E+06	3.41E+10	Ar-37	2.94E+05	5.40E+09
O-15	1.37E+06	2.51E+10	N-13	1.34E+05	2.45E+09
Li-8	1.04E+06	1.91E+10	P-32	2.52E+04	4.63E+08
C-10	9.21E+05	1.69E+10	Cl-34m	1.32E+04	2.42E+08
O-14	8.34E+05	1.53E+10	S-35	7.30E+03	1.34E+08
He-6	6.87E+05	1.26E+10	P-33	6.43E+03	1.18E+08
B-8	6.59E+05	1.21E+10	Cl-34	5.89E+03	1.08E+08
H-3	4.97E+05	9.11E+09	K-43	3.35E+03	6.15E+07
Ar-37	2.94E+05	5.40E+09	K-42	2.92E+03	5.35E+07
B-12	2.71E+05	4.97E+09	F-18	2.11E+03	3.87E+07
Ca-39	2.51E+05	4.61E+09	Na-24	1.87E+03	3.44E+07
Li-9	1.38E+05	2.54E+09	Si-31	1.58E+03	2.90E+07
N-12	1.32E+05	2.42E+09	Sc-47	1.44E+03	2.65E+07
K-38	1.08E+05	1.98E+09	Na-22	1.25E+03	2.30E+07
K-38m	9.92E+04	1.82E+09	Ca-47	1.16E+03	2.13E+07
B-9	8.88E+04	1.63E+09	Sc-44	1.11E+03	2.03E+07
C-9	8.88E+04	1.63E+09	Sc-43	6.27E+02	1.15E+07
Cl-34	7.03E+04	1.29E+09	Sc-44m	6.00E+02	1.10E+07

Table 14.18: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	4.94E+06	9.06E+10	Be-7	4.57E+06	8.38E+10
H-3	4.97E+05	9.11E+09	H-3	4.96E+05	9.10E+09
Ar-37	2.89E+05	5.30E+09	Ar-37	2.56E+05	4.70E+09
P-32	2.41E+04	4.42E+08	P-32	1.80E+04	3.30E+08
S-35	7.25E+03	1.33E+08	S-35	6.87E+03	1.26E+08
P-33	6.27E+03	1.15E+08	P-33	5.32E+03	9.76E+07
K-43	1.64E+03	3.01E+07	Na-22	1.25E+03	2.29E+07
Sc-47	1.38E+03	2.53E+07	Sc-47	8.23E+02	1.51E+07
Na-22	1.25E+03	2.30E+07	Ca-47	4.01E+02	7.35E+06
Ca-47	1.00E+03	1.84E+07	Ca-45	3.74E+02	6.86E+06
K-42	8.01E+02	1.47E+07	C-14	1.89E+02	3.46E+06
Na-24	6.43E+02	1.18E+07	Sc-46	1.58E+02	2.90E+06
Sc-44	4.92E+02	9.03E+06	Sc-44	8.83E+01	1.62E+06
Sc-44m	4.57E+02	8.39E+06	Sc-44m	8.34E+01	1.53E+06
Ca-45	3.83E+02	7.03E+06			
C-14	1.89E+02	3.46E+06			
Sc-46	1.66E+02	3.05E+06			
Sc-48	6.38E+01	1.17E+06			

Table 14.19: Cooling times of **1 month** and **3 months**

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>3.38E+06</i>	6.21E+10	Be-7	<i>1.55E+06</i>	2.85E+10
H-3	<i>4.94E+05</i>	9.07E+09	H-3	<i>4.90E+05</i>	8.99E+09
Ar-37	<i>1.62E+05</i>	2.98E+09	Ar-37	<i>4.97E+04</i>	9.11E+08
P-32	<i>5.89E+03</i>	1.08E+08	S-35	<i>3.57E+03</i>	6.55E+07
S-35	<i>5.72E+03</i>	1.05E+08	Na-22	<i>1.18E+03</i>	2.16E+07
P-33	<i>2.83E+03</i>	5.20E+07	P-33	<i>5.50E+02</i>	1.01E+07
Na-22	<i>1.23E+03</i>	2.25E+07	P-32	<i>3.19E+02</i>	5.85E+06
Ca-45	<i>3.39E+02</i>	6.22E+06	Ca-45	<i>2.63E+02</i>	4.83E+06
C-14	<i>1.89E+02</i>	3.46E+06	C-14	<i>1.89E+02</i>	3.46E+06
Sc-46	<i>1.31E+02</i>	2.40E+06	Sc-46	<i>7.96E+01</i>	1.46E+06

Table 14.20: Cooling time of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
H-3	<i>4.83E+05</i>	8.87E+09
Be-7	<i>4.81E+05</i>	8.83E+09
Ar-37	<i>8.39E+03</i>	1.54E+08
S-35	<i>1.75E+03</i>	3.21E+07
Na-22	<i>1.10E+03</i>	2.02E+07
C-14	<i>1.89E+02</i>	3.46E+06
Ca-45	<i>1.80E+02</i>	3.30E+06

14.1.6 300MeV

Table 14.21: Cooling times of EOB and 1 hour

N-13	<i>4.68E+06</i>	2.15E+11	Be-7	<i>2.50E+06</i>	1.15E+11
C-11	<i>2.63E+06</i>	1.21E+11	C-11	<i>3.44E+05</i>	1.58E+10
Be-7	<i>2.50E+06</i>	1.15E+11	H-3	<i>2.83E+05</i>	1.30E+10
Be-8	<i>1.07E+06</i>	4.90E+10	Ar-37	<i>1.63E+05</i>	7.50E+09
O-15	<i>7.12E+05</i>	3.27E+10	N-13	<i>7.20E+04</i>	3.31E+09
Li-8	<i>6.36E+05</i>	2.92E+10	P-32	<i>1.50E+04</i>	6.90E+08
C-10	<i>4.35E+05</i>	2.00E+10	Cl-34m	<i>6.94E+03</i>	3.19E+08
He-6	<i>4.14E+05</i>	1.90E+10	S-35	<i>4.51E+03</i>	2.07E+08
O-14	<i>3.83E+05</i>	1.76E+10	P-33	<i>3.83E+03</i>	1.76E+08
B-8	<i>3.37E+05</i>	1.55E+10	Cl-34	<i>3.09E+03</i>	1.42E+08
H-3	<i>2.83E+05</i>	1.30E+10	K-42	<i>1.78E+03</i>	8.19E+07
B-12	<i>1.71E+05</i>	7.87E+09	K-43	<i>1.52E+03</i>	6.98E+07
Ar-37	<i>1.63E+05</i>	7.51E+09	F-18	<i>1.29E+03</i>	5.93E+07
Ca-39	<i>1.35E+05</i>	6.19E+09	Na-24	<i>1.23E+03</i>	5.65E+07
Li-9	<i>9.16E+04</i>	4.21E+09	Si-31	<i>8.88E+02</i>	4.08E+07
N-12	<i>6.38E+04</i>	2.93E+09	Sc-47	<i>8.21E+02</i>	3.77E+07
K-38	<i>5.92E+04</i>	2.72E+09	Na-22	<i>8.05E+02</i>	3.70E+07
K-38m	<i>5.40E+04</i>	2.48E+09	Ca-47	<i>6.86E+02</i>	3.15E+07
B-9	<i>4.72E+04</i>	2.17E+09	Sc-44	<i>3.57E+02</i>	1.64E+07
C-9	<i>4.72E+04</i>	2.17E+09	Ca-45	<i>3.20E+02</i>	1.47E+07
Cl-34	<i>3.70E+04</i>	1.70E+09	K-38	<i>2.55E+02</i>	1.17E+07
Be-11	<i>3.09E+04</i>	1.42E+09	Sc-43	<i>2.18E+02</i>	1.00E+07
Cl-34m	<i>2.55E+04</i>	1.17E+09	Sc-44m	<i>1.93E+02</i>	8.89E+06
P-30	<i>2.22E+04</i>	1.02E+09	C-14	<i>1.43E+02</i>	6.55E+06
P-32	<i>1.51E+04</i>	6.92E+08	Sc-46	<i>1.34E+02</i>	6.15E+06
B-13	<i>1.46E+04</i>	6.72E+08	Ar-41	<i>1.15E+02</i>	5.27E+06
N-16	<i>1.01E+04</i>	4.64E+08	Cl-38	<i>7.33E+01</i>	3.37E+06
Ar-35	<i>9.90E+03</i>	4.55E+08	Al-28	<i>5.42E+01</i>	2.49E+06
O-13	<i>8.38E+03</i>	3.85E+08	Mg-28	<i>5.42E+01</i>	2.49E+06
K-37	<i>7.20E+03</i>	3.31E+08	Cl-39	<i>4.42E+01</i>	2.03E+06
Al-26m	<i>6.99E+03</i>	3.21E+08	Sc-48	<i>3.68E+01</i>	1.69E+06
Si-27	<i>6.29E+03</i>	2.89E+08	K-44	<i>3.13E+01</i>	1.44E+06
Al-28	<i>5.38E+03</i>	2.47E+08			
Ca-38	<i>5.22E+03</i>	2.40E+08			
S-35	<i>4.51E+03</i>	2.07E+08			
He-8	<i>4.46E+03</i>	2.05E+08			
P-33	<i>3.83E+03</i>	1.76E+08			

Table 14.22: Cooling time of 1 day and 1 week

1 day (86400 s)			1 week (604800s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	2.48E+06	1.14E+11	Be-7	2.29E+06	1.05E+11
H-3	2.83E+05	1.30E+10	H-3	2.83E+05	1.30E+10
Ar-37	1.60E+05	7.36E+09	Ar-37	1.42E+05	6.54E+09
P-32	1.43E+04	6.59E+08	P-32	1.07E+04	4.92E+08
S-35	4.46E+03	2.05E+08	S-35	4.24E+03	1.95E+08
P-33	3.74E+03	1.72E+08	P-33	3.18E+03	1.46E+08
Na-22	8.05E+02	3.70E+07	Na-22	8.01E+02	3.68E+07
Sc-47	7.88E+02	3.62E+07	Sc-47	4.79E+02	2.20E+07
K-43	7.44E+02	3.42E+07	Ca-45	3.11E+02	1.43E+07
Ca-47	5.92E+02	2.72E+07	Ca-47	2.37E+02	1.09E+07
K-42	4.92E+02	2.26E+07	C-14	1.43E+02	6.55E+06
Na-24	4.22E+02	1.94E+07	Sc-46	1.26E+02	5.80E+06
Ca-45	3.20E+02	1.47E+07	Sc-44	2.85E+01	1.31E+06
Sc-44	1.59E+02	7.30E+06	Sc-44m	2.68E+01	1.23E+06
Sc-44m	1.48E+02	6.78E+06			
C-14	1.43E+02	6.55E+06			
Sc-46	1.33E+02	6.10E+06			
Sc-48	2.55E+01	1.17E+06			
Al-28	2.52E+01	1.16E+06			

Table 14.23: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	1.70E+06	7.79E+10	Be-7	7.77E+05	3.57E+10
H-3	2.83E+05	1.30E+10	H-3	2.79E+05	1.28E+10
Ar-37	9.03E+04	4.15E+09	Ar-37	2.76E+04	1.27E+09
S-35	3.55E+03	1.63E+08	S-35	2.20E+03	1.01E+08
P-32	3.50E+03	1.61E+08	Na-22	7.55E+02	3.47E+07
P-33	1.69E+03	7.77E+07	P-33	3.26E+02	1.50E+07
Na-22	7.88E+02	3.62E+07	Ca-45	2.20E+02	1.01E+07
Ca-45	2.83E+02	1.30E+07	P-32	1.90E+02	8.74E+06
C-14	1.43E+02	6.55E+06	C-14	1.43E+02	6.55E+06
Sc-46	1.04E+02	4.80E+06	Sc-46	6.36E+01	2.92E+06
Sc-47	2.33E+01	1.07E+06			

Table 14.24: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
H-3	2.76E+05	1.27E+10
Be-7	2.42E+05	1.11E+10
Ar-37	4.64E+03	2.13E+08
S-35	1.08E+03	4.97E+07
Na-22	7.07E+02	3.25E+07
Ca-45	1.50E+02	6.87E+06
C-14	1.43E+02	6.55E+06
Sc-46	3.03E+01	1.39E+06
P-33	2.79E+01	1.28E+06

14.1.7 350MeV

Table 14.25: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
N-13	2.78E+06	2.73E+11	Be-7	1.42E+06	1.39E+11
C-11	1.49E+06	1.46E+11	C-11	1.92E+05	1.89E+10
Be-7	1.42E+06	1.39E+11	H-3	1.80E+05	1.77E+10
Be-8	6.78E+05	6.66E+10	Ar-37	1.02E+05	1.00E+10
Li-8	4.28E+05	4.20E+10	N-13	4.29E+04	4.21E+09
O-15	4.23E+05	4.15E+10	P-32	8.64E+03	8.49E+08
He-6	2.73E+05	2.68E+10	Cl-34m	4.14E+03	4.07E+08
C-10	2.34E+05	2.30E+10	S-35	2.94E+03	2.89E+08
O-14	2.00E+05	1.96E+10	P-33	2.31E+03	2.27E+08
B-8	1.93E+05	1.90E+10	Cl-34	1.85E+03	1.82E+08
H-3	1.80E+05	1.77E+10	K-43	1.38E+03	1.36E+08
B-12	1.18E+05	1.16E+10	K-42	1.21E+03	1.19E+08
Ar-37	1.03E+05	1.01E+10	F-18	9.27E+02	9.10E+07
Ca-39	7.99E+04	7.85E+09	Na-24	7.41E+02	7.28E+07
Li-9	6.36E+04	6.25E+09	Na-22	6.08E+02	5.97E+07
N-12	3.72E+04	3.65E+09	Si-31	5.63E+02	5.53E+07
K-38	3.46E+04	3.40E+09	Sc-47	4.80E+02	4.71E+07
K-38m	3.14E+04	3.08E+09	Ca-47	4.34E+02	4.26E+07
B-9	2.57E+04	2.52E+09	Sc-44	1.75E+02	1.72E+07
C-9	2.57E+04	2.52E+09	Ca-45	1.68E+02	1.65E+07
Be-11	2.29E+04	2.25E+09	K-38	1.50E+02	1.47E+07
Cl-34	2.21E+04	2.17E+09	Sc-43	1.24E+02	1.22E+07
Cl-34m	1.52E+04	1.49E+09	C-14	1.12E+02	1.10E+07
P-30	1.37E+04	1.35E+09	Ar-41	1.08E+02	1.06E+07
B-13	1.07E+04	1.05E+09	Sc-44m	9.49E+01	9.32E+06
P-32	8.66E+03	8.50E+08	Sc-46	8.60E+01	8.45E+06
N-16	7.77E+03	7.63E+08	Cl-38	8.23E+01	8.08E+06
Ar-35	5.88E+03	5.77E+08	Al-28	4.23E+01	4.15E+06
K-37	4.61E+03	4.53E+08	Mg-28	4.23E+01	4.15E+06
Al-26m	4.59E+03	4.51E+08	Cl-39	4.13E+01	4.06E+06
Al-28	4.14E+03	4.07E+08	K-44	2.00E+01	1.96E+06
O-13	4.12E+03	4.05E+08	Ar-39	9.22E+00	9.05E+05
Si-27	3.80E+03	3.73E+08	S-38	6.83E+00	6.71E+05
He-8	3.40E+03	3.34E+08	K-45	3.94E+00	3.87E+05
Ca-38	3.28E+03	3.22E+08	Mg-27	2.79E+00	2.74E+05
S-35	2.94E+03	2.89E+08			
P-33	2.31E+03	2.27E+08			
K-43	1.44E+03	1.41E+08			
F-18	1.35E+03	1.33E+08			
S-31	1.31E+03	1.29E+08			
K-42	1.28E+03	1.26E+08			
Cl-33	1.10E+03	1.08E+08			

Table 14.26: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	1.39E+06	1.37E+11	Be-7	1.29E+06	1.27E+11
H-3	1.80E+05	1.77E+10	H-3	1.79E+05	1.76E+10
Ar-37	1.00E+05	9.86E+09	Ar-37	8.92E+04	8.76E+09
P-32	8.25E+03	8.10E+08	P-32	6.16E+03	6.05E+08
S-35	2.91E+03	2.86E+08	S-35	2.78E+03	2.73E+08
P-33	2.25E+03	2.21E+08	P-33	1.90E+03	1.87E+08
K-43	6.79E+02	6.67E+07	Na-22	6.05E+02	5.94E+07
Na-22	6.08E+02	5.97E+07	Sc-47	2.93E+02	2.88E+07
Sc-47	4.65E+02	4.57E+07	Ca-45	1.63E+02	1.60E+07
Ca-47	3.75E+02	3.68E+07	Ca-47	1.50E+02	1.47E+07
K-42	3.35E+02	3.29E+07	C-14	1.12E+02	1.10E+07
Na-24	2.56E+02	2.51E+07	Sc-46	8.13E+01	7.98E+06
Ca-45	1.67E+02	1.64E+07	Sc-44	1.39E+01	1.37E+06
C-14	1.12E+02	1.10E+07	Sc-44m	1.31E+01	1.29E+06
Sc-46	8.53E+01	8.38E+06			
Sc-44	7.78E+01	7.64E+06			
Sc-44m	7.23E+01	7.10E+06			
Al-28	1.98E+01	1.94E+06			
Mg-28	1.97E+01	1.93E+06			

Table 14.27: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	9.56E+05	9.39E+10	Be-7	4.38E+05	4.30E+10
H-3	1.79E+05	1.76E+10	H-3	1.77E+05	1.74E+10
Ar-37	5.66E+04	5.56E+09	Ar-37	1.73E+04	1.70E+09
S-35	2.32E+03	2.28E+08	S-35	1.44E+03	1.41E+08
P-32	2.02E+03	1.98E+08	Na-22	5.69E+02	5.59E+07
P-33	1.02E+03	9.99E+07	P-33	1.98E+02	1.94E+07
Na-22	5.95E+02	5.84E+07	Ca-45	1.15E+02	1.13E+07
Ca-45	1.48E+02	1.45E+07	C-14	1.12E+02	1.10E+07
C-14	1.12E+02	1.10E+07	P-32	1.09E+02	1.07E+07
Sc-46	6.72E+01	6.60E+06			
Sc-47	1.47E+01	1.44E+06			

Table 14.28: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
H-3	1.75E+05	1.72E+10
Be-7	1.36E+05	1.34E+10
Ar-37	2.91E+03	2.86E+08
S-35	7.07E+02	6.94E+07
Na-22	5.34E+02	5.24E+07
C-14	1.12E+02	1.10E+07
Ca-45	7.84E+01	7.70E+06
Sc-46	1.94E+01	1.91E+06
P-33	1.68E+01	1.65E+06

14.1.8 400MeV

Table 14.29: Cooling time of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
N-13	<i>1.78E+06</i>	3.36E+11	Be-7	<i>8.70E+05</i>	1.64E+11
C-11	<i>9.02E+05</i>	1.70E+11	H-3	<i>1.24E+05</i>	2.34E+10
Be-7	<i>8.70E+05</i>	1.64E+11	C-11	<i>1.17E+05</i>	2.21E+10
Be-8	<i>4.64E+05</i>	8.75E+10	Ar-37	<i>6.90E+04</i>	1.30E+10
Li-8	<i>3.05E+05</i>	5.74E+10	N-13	<i>2.75E+04</i>	5.18E+09
O-15	<i>2.63E+05</i>	4.96E+10	P-32	<i>5.84E+03</i>	1.10E+09
He-6	<i>1.95E+05</i>	3.68E+10	Cl-34m	<i>2.62E+03</i>	4.94E+08
C-10	<i>1.35E+05</i>	2.55E+10	S-35	<i>1.92E+03</i>	3.62E+08
H-3	<i>1.24E+05</i>	2.34E+10	P-33	<i>1.59E+03</i>	2.99E+08
B-8	<i>1.20E+05</i>	2.26E+10	Cl-34	<i>1.17E+03</i>	2.20E+08
O-14	<i>1.14E+05</i>	2.15E+10	K-43	<i>9.55E+02</i>	1.80E+08
B-12	<i>8.22E+04</i>	1.55E+10	K-42	<i>7.16E+02</i>	1.35E+08
Ar-37	<i>6.90E+04</i>	1.30E+10	F-18	<i>6.68E+02</i>	1.26E+08
Ca-39	<i>5.06E+04</i>	9.53E+09	Na-24	<i>5.78E+02</i>	1.09E+08
Li-9	<i>4.79E+04</i>	9.03E+09	Si-31	<i>4.33E+02</i>	8.16E+07
K-38	<i>2.21E+04</i>	4.16E+09	Na-22	<i>3.66E+02</i>	6.90E+07
N-12	<i>2.20E+04</i>	4.14E+09	Sc-47	<i>3.45E+02</i>	6.51E+07
K-38m	<i>1.97E+04</i>	3.72E+09	Ca-47	<i>2.94E+02</i>	5.54E+07
Be-11	<i>1.73E+04</i>	3.27E+09	Ca-45	<i>1.37E+02</i>	2.59E+07
B-9	<i>1.63E+04</i>	3.08E+09	K-38	<i>9.55E+01</i>	1.80E+07
C-9	<i>1.63E+04</i>	3.08E+09	C-14	<i>8.97E+01</i>	1.69E+07
Cl-34	<i>1.40E+04</i>	2.63E+09	Sc-44	<i>7.90E+01</i>	1.49E+07
Cl-34m	<i>9.60E+03</i>	1.81E+09	Sc-43	<i>7.22E+01</i>	1.36E+07
P-30	<i>9.18E+03</i>	1.73E+09	Cl-38	<i>5.52E+01</i>	1.04E+07
B-13	<i>8.38E+03</i>	1.58E+09			
N-16	<i>6.10E+03</i>	1.15E+09			
P-32	<i>5.84E+03</i>	1.10E+09			

Table 14.30: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	$8.59E+05$	$1.62E+11$	Be-7	$7.96E+05$	$1.50E+11$
H-3	$1.24E+05$	$2.34E+10$	H-3	$1.24E+05$	$2.34E+10$
Ar-37	$6.74E+04$	$1.27E+10$	Ar-37	$5.99E+04$	$1.13E+10$
P-32	$5.57E+03$	$1.05E+09$	P-32	$4.14E+03$	$7.81E+08$
S-35	$1.90E+03$	$3.59E+08$	S-35	$1.82E+03$	$3.43E+08$
P-33	$1.55E+03$	$2.92E+08$	P-33	$1.32E+03$	$2.48E+08$
K-43	$4.68E+02$	$8.82E+07$	Na-22	$3.64E+02$	$6.87E+07$
Na-22	$3.66E+02$	$6.90E+07$	Sc-47	$2.03E+02$	$3.83E+07$
Sc-47	$3.32E+02$	$6.26E+07$	Ca-45	$1.33E+02$	$2.51E+07$
Ca-47	$2.54E+02$	$4.78E+07$	Ca-47	$1.01E+02$	$1.91E+07$
Na-24	$1.99E+02$	$3.75E+07$	C-14	$8.97E+01$	$1.69E+07$
K-42	$1.98E+02$	$3.74E+07$	Sc-46	$2.70E+01$	$5.08E+06$
Ca-45	$1.37E+02$	$2.58E+07$	Ar-39	$7.32E+00$	$1.38E+06$
C-14	$8.97E+01$	$1.69E+07$	Sc-44	$6.26E+00$	$1.18E+06$
Sc-44	$3.50E+01$	$6.60E+06$	Sc-44m	$5.94E+00$	$1.12E+06$
Sc-44m	$3.25E+01$	$6.13E+06$	K-43	$5.31E+00$	$1.00E+06$
Sc-46	$2.83E+01$	$5.34E+06$			
Ar-39	$7.32E+00$	$1.38E+06$			

Table 14.31: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	$5.89E+05$	$1.11E+11$	Be-7	$2.70E+05$	$5.08E+10$
H-3	$1.24E+05$	$2.33E+10$	H-3	$1.23E+05$	$2.31E+10$
Ar-37	$3.81E+04$	$7.18E+09$	Ar-37	$1.16E+04$	$2.19E+09$
S-35	$1.52E+03$	$2.86E+08$	S-35	$9.44E+02$	$1.78E+08$
P-32	$1.35E+03$	$2.55E+08$	Na-22	$3.43E+02$	$6.47E+07$
P-33	$7.00E+02$	$1.32E+08$	P-33	$1.36E+02$	$2.56E+07$
Na-22	$3.59E+02$	$6.76E+07$	Ca-45	$9.39E+01$	$1.77E+07$
Ca-45	$1.21E+02$	$2.28E+07$	C-14	$8.97E+01$	$1.69E+07$
C-14	$8.97E+01$	$1.69E+07$	P-32	$7.37E+01$	$1.39E+07$
Sc-46	$2.23E+01$	$4.20E+06$	Sc-46	$1.36E+01$	$2.56E+06$
Sc-47	$9.92E+00$	$1.87E+06$	Ar-39	$7.32E+00$	$1.38E+06$
Ar-39	$7.32E+00$	$1.38E+06$	K-42	$6.42E-01$	$1.21E+05$

Table 14.32: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
H-3	$1.20E+05$	$2.27E+10$
Be-7	$8.38E+04$	$1.58E+10$
Ar-37	$1.96E+03$	$3.70E+08$
S-35	$4.62E+02$	$8.71E+07$
Na-22	$3.21E+02$	$6.05E+07$
C-14	$8.97E+01$	$1.69E+07$
Ca-45	$6.42E+01$	$1.21E+07$
P-33	$1.16E+01$	$2.18E+06$
Ar-39	$7.27E+00$	$1.37E+06$
Sc-46	$6.42E+00$	$1.21E+06$

14.2 Carbon(graphite)

14.2.1 50MeV

Table 14.33: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
C-11	<i>9.53E+09</i>	3.29E+10	Be-7	<i>1.90E+09</i>	6.57E+09
Be-7	<i>1.90E+09</i>	6.57E+09	C-11	<i>1.24E+09</i>	4.28E+09
Be-8	<i>3.22E+08</i>	1.11E+09	H-3	<i>2.27E+07</i>	7.83E+07
B-8	<i>3.19E+08</i>	1.10E+09			
N-12	<i>1.50E+08</i>	5.17E+08			
C-10	<i>1.09E+08</i>	3.75E+08			
N-13	<i>2.73E+07</i>	9.43E+07			
H-3	<i>2.27E+07</i>	7.83E+07			
B-12	<i>1.64E+07</i>	5.66E+07			

Table 14.34: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>1.88E+09</i>	6.49E+09	Be-7	<i>1.74E+09</i>	6.00E+09
H-3	<i>2.27E+07</i>	7.82E+07	H-3	<i>2.27E+07</i>	7.82E+07

Table 14.35: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>1.29E+09</i>	4.45E+09	Be-7	<i>5.91E+08</i>	2.04E+09
H-3	<i>2.26E+07</i>	7.79E+07	H-3	<i>2.24E+07</i>	7.72E+07

Table 14.36: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	<i>1.83E+08</i>	6.32E+08
H-3	<i>2.21E+07</i>	7.61E+07

14.2.2 100MeV

Table 14.37: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
C-11	$9.08E+08$	1.30E+11	Be-7	$2.72E+08$	3.90E+10
Be-7	$2.72E+08$	3.90E+10	C-11	$1.18E+08$	1.69E+10
Be-8	$3.44E+07$	4.92E+09	H-3	$6.89E+06$	9.86E+08
B-8	$2.58E+07$	3.70E+09			
C-10	$2.13E+07$	3.05E+09			
N-12	$8.24E+06$	1.18E+09			
Li-8	$7.41E+06$	1.06E+09			
H-3	$6.89E+06$	9.86E+08			
He-6	$4.17E+06$	5.97E+08			
B-12	$3.78E+06$	5.41E+08			
B-9	$1.12E+06$	1.60E+08			
C-9	$1.12E+06$	1.60E+08			
N-13	$7.13E+05$	1.02E+08			

Table 14.38: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	$2.69E+08$	3.85E+10	Be-7	$2.49E+08$	3.56E+10
H-3	$6.89E+06$	9.86E+08	H-3	$6.88E+06$	9.85E+08

Table 14.39: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	$1.84E+08$	2.64E+10	Be-7	$8.45E+07$	1.21E+10
H-3	$6.85E+06$	9.81E+08	H-3	$6.79E+06$	9.72E+08

Table 14.40: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	$2.62E+07$	3.75E+09
H-3	$6.70E+06$	9.59E+08

14.2.3 150MeV

Table 14.41: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
C-11	1.59E+08	2.50E+11	Be-7	4.92E+07	7.73E+10
Be-7	4.93E+07	7.74E+10	C-11	2.07E+07	3.25E+10
Be-8	6.62E+06	1.04E+10	H-3	1.61E+06	2.53E+09
C-10	4.88E+06	7.66E+09	N-13	1.26E+03	1.98E+06
B-8	4.23E+06	6.65E+09			
Li-8	2.01E+06	3.15E+09			
H-3	1.61E+06	2.53E+09			
B-12	1.31E+06	2.05E+09			
He-6	1.25E+06	1.96E+09			
N-12	1.20E+06	1.88E+09			
B-9	3.30E+05	5.18E+08			
C-9	3.30E+05	5.18E+08			
N-13	8.21E+04	1.29E+08			
Li-9	7.32E+04	1.15E+08			

Table 14.42: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	4.86E+07	7.64E+10	Be-7	4.49E+07	7.06E+10
H-3	1.61E+06	2.53E+09	H-3	1.61E+06	2.53E+09

Table 14.43: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	3.34E+07	5.24E+10	Be-7	1.53E+07	2.40E+10
H-3	1.60E+06	2.52E+09	H-3	1.59E+06	2.50E+09

Table 14.44: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	4.74E+06	7.44E+09
H-3	1.57E+06	2.46E+09

14.2.4 200MeV

Table 14.45: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
C-11	7.26E+07	3.85E+11	Be-7	2.24E+07	1.19E+11
Be-7	2.24E+07	1.19E+11	C-11	9.43E+06	5.00E+10
Be-8	3.28E+06	1.74E+10	H-3	8.58E+05	4.55E+09
C-10	2.62E+06	1.39E+10			
B-8	1.87E+06	9.91E+09			
Li-8	1.19E+06	6.32E+09			
H-3	8.58E+05	4.55E+09			
B-12	8.38E+05	4.44E+09			
He-6	7.96E+05	4.22E+09			
N-12	5.04E+05	2.67E+09			
B-9	1.87E+05	9.89E+08			
C-9	1.87E+05	9.89E+08			
Li-9	6.39E+04	3.39E+08			
N-13	2.92E+04	1.55E+08			

Table 14.46: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	2.21E+07	1.17E+11	Be-7	2.04E+07	1.08E+11
H-3	8.58E+05	4.55E+09	H-3	8.56E+05	4.54E+09

Table 14.47: Cooling times of 1 months and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	1.52E+07	8.04E+10	Be-7	6.96E+06	3.69E+10
H-3	8.54E+05	4.53E+09	H-3	8.45E+05	4.48E+09

Table 14.48: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	2.15E+06	1.14E+10
H-3	8.34E+05	4.42E+09

14.2.5 250MeV

Table 14.49: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
C-11	3.21E+07	5.37E+11	Be-7	9.86E+06	1.65E+11
Be-7	9.86E+06	1.65E+11	C-11	4.18E+06	6.99E+10
Be-8	1.52E+06	2.55E+10	H-3	4.23E+05	7.08E+09
C-10	1.27E+06	2.12E+10			
B-8	7.89E+05	1.32E+10			
Li-8	6.28E+05	1.05E+10			
B-12	5.12E+05	8.56E+09			
H-3	4.23E+05	7.08E+09			
He-6	4.15E+05	6.94E+09			
N-12	2.03E+05	3.40E+09			
B-9	8.67E+04	1.45E+09			
C-9	8.67E+04	1.45E+09			
Li-9	4.14E+04	6.93E+08			
Be-11	1.16E+04	1.94E+08			
N-13	8.13E+03	1.36E+08			
B-13	4.87E+03	8.14E+07			

Table 14.50: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	9.75E+06	1.63E+11	Be-7	9.03E+06	1.51E+11
H-3	4.23E+05	7.08E+09	H-3	4.23E+05	7.07E+09

Table 14.51: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	6.70E+06	1.12E+11	Be-7	3.06E+06	5.12E+10
H-3	4.22E+05	7.05E+09	H-3	4.17E+05	6.98E+09

Table 14.52: Cooling times of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	9.51E+05	1.59E+10
H-3	4.12E+05	6.89E+09

14.2.6 300MeV

Table 14.53: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
C-11	<i>1.66E+07</i>	7.03E+11	Be-7	<i>5.07E+06</i>	2.15E+11
Be-7	<i>5.07E+06</i>	2.15E+11	C-11	<i>2.16E+06</i>	9.14E+10
Be-8	<i>8.32E+05</i>	3.53E+10	H-3	<i>2.41E+05</i>	1.02E+10
C-10	<i>6.93E+05</i>	2.94E+10			
Li-8	<i>3.89E+05</i>	1.65E+10			
B-8	<i>3.87E+05</i>	1.64E+10			
B-12	<i>3.37E+05</i>	1.43E+10			
He-6	<i>2.48E+05</i>	1.05E+10			
H-3	<i>2.41E+05</i>	1.02E+10			
N-12	<i>9.38E+04</i>	3.98E+09			
B-9	<i>4.50E+04</i>	1.91E+09			
C-9	<i>4.50E+04</i>	1.91E+09			
Li-9	<i>2.78E+04</i>	1.18E+09			
Be-11	<i>7.88E+03</i>	3.34E+08			
N-13	<i>4.17E+03</i>	1.77E+08			
B-13	<i>3.73E+03</i>	1.58E+08			

Table 14.54: Cooling times of 1 day and 1 week

1 day (86400s)			1 week (604800s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>5.00E+06</i>	2.12E+11	Be-7	<i>4.62E+06</i>	1.96E+11
H-3	<i>2.41E+05</i>	1.02E+10	H-3	<i>2.41E+05</i>	1.02E+10

Table 14.55: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>3.44E+06</i>	1.46E+11	Be-7	<i>1.57E+06</i>	6.67E+10
H-3	<i>2.41E+05</i>	1.02E+10	H-3	<i>2.38E+05</i>	1.01E+10

Table 14.56: Cooling times of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	<i>4.88E+05</i>	2.07E+10
H-3	<i>2.34E+05</i>	9.92E+09

14.2.7 350MeV

Table 14.57: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
C-11	8.75E+06	8.80E+11	Be-7	2.68E+06	2.69E+11
Be-7	2.68E+06	2.69E+11	C-11	1.14E+06	1.15E+11
Be-8	4.68E+05	4.70E+10	H-3	1.40E+05	1.41E+10
C-10	3.81E+05	3.83E+10			
Li-8	2.39E+05	2.40E+10			
B-12	2.35E+05	2.36E+10			
B-8	1.96E+05	1.97E+10			
He-6	1.51E+05	1.52E+10			
H-3	1.40E+05	1.41E+10			
N-12	4.39E+04	4.41E+09			
B-9	2.36E+04	2.37E+09			
C-9	2.36E+04	2.37E+09			
Li-9	1.93E+04	1.94E+09			
Be-11	5.55E+03	5.58E+08			
B-13	2.44E+03	2.45E+08			
N-13	2.05E+03	2.06E+08			
He-8	1.15E+03	1.16E+08			

Table 14.58: Cooling time of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	2.64E+06	2.65E+11	Be-7	2.44E+06	2.45E+11
H-3	1.40E+05	1.41E+10	H-3	1.40E+05	1.41E+10

Table 14.59: Cooling time of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	1.81E+06	1.82E+11	Be-7	8.30E+05	8.34E+10
H-3	1.40E+05	1.41E+10	H-3	1.39E+05	1.40E+10

Table 14.60: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	2.58E+05	2.59E+10
H-3	1.37E+05	1.38E+10

14.2.8 400MeV

Table 14.61: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
C-11	<i>5.40E+06</i>	1.06E+12	Be-7	<i>1.65E+06</i>	3.24E+11
Be-7	<i>1.65E+06</i>	3.24E+11	C-11	<i>7.03E+05</i>	1.38E+11
Be-8	<i>3.12E+05</i>	6.12E+10	H-3	<i>9.47E+04</i>	1.86E+10
C-10	<i>2.40E+05</i>	4.72E+10			
B-12	<i>1.73E+05</i>	3.40E+10			
Li-8	<i>1.72E+05</i>	3.37E+10			
B-8	<i>1.18E+05</i>	2.31E+10			
He-6	<i>1.06E+05</i>	2.09E+10			
H-3	<i>9.47E+04</i>	1.86E+10			
N-12	<i>2.38E+04</i>	4.68E+09			
B-9	<i>1.51E+04</i>	2.96E+09			
C-9	<i>1.51E+04</i>	2.96E+09			
Li-9	<i>1.48E+04</i>	2.90E+09			

Table 14.62: Cooling times of 1 day and 1 week

1 day (86400s)			1 week (604800s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>1.63E+06</i>	3.20E+11	Be-7	<i>1.51E+06</i>	2.96E+11
H-3	<i>9.47E+04</i>	1.86E+10	H-3	<i>9.47E+04</i>	1.86E+10

Table 14.63: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Be-7	<i>1.12E+06</i>	2.19E+11	Be-7	<i>5.14E+05</i>	1.01E+11
H-3	<i>9.42E+04</i>	1.85E+10	H-3	<i>9.37E+04</i>	1.84E+10

Table 14.64: Cooling times of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Be-7	<i>1.59E+05</i>	3.12E+10
H-3	<i>9.22E+04</i>	1.81E+10

14.3 Copper

14.3.1 50MeV

Table 14.65: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cu-62	<i>5.56E+10</i>	3.82E+10	Cu-61	<i>1.94E+10</i>	1.33E+10
Cu-61	<i>2.37E+10</i>	1.63E+10	Cu-64	<i>1.40E+10</i>	9.59E+09
Zn-63	<i>1.53E+10</i>	1.05E+10	Co-58	<i>9.08E+09</i>	6.23E+09
Cu-64	<i>1.47E+10</i>	1.01E+10	Cu-62	<i>6.92E+09</i>	4.75E+09
Co-58	<i>9.08E+09</i>	6.23E+09	Zn-62	<i>6.12E+09</i>	4.20E+09
Zn-62	<i>6.60E+09</i>	4.53E+09	Zn-63	<i>5.19E+09</i>	3.56E+09
Co-58m	<i>4.88E+09</i>	3.35E+09	Co-58m	<i>4.52E+09</i>	3.10E+09
Zn-65	<i>3.16E+09</i>	2.17E+09	Zn-65	<i>3.16E+09</i>	2.17E+09
Co-57	<i>2.07E+09</i>	1.42E+09	Co-57	<i>2.07E+09</i>	1.42E+09
Cu-60	<i>1.38E+09</i>	9.44E+08	Cu-60	<i>2.37E+08</i>	1.63E+08
Co-60m	<i>4.38E+08</i>	3.01E+08	Fe-55	<i>1.84E+08</i>	1.26E+08
Zn-61	<i>4.18E+08</i>	2.87E+08	Co-61	<i>1.45E+08</i>	9.97E+07
Co-61	<i>2.21E+08</i>	1.52E+08	Ni-57	<i>8.81E+07</i>	6.05E+07
Fe-55	<i>1.84E+08</i>	1.26E+08	Co-60	<i>8.24E+07</i>	5.66E+07
Ni-57	<i>8.99E+07</i>	6.17E+07	Mn-54	<i>5.93E+07</i>	4.07E+07
Co-60	<i>8.24E+07</i>	5.66E+07	Cr-51	<i>2.74E+07</i>	1.88E+07
Mn-54	<i>5.93E+07</i>	4.07E+07	H-3	<i>1.49E+07</i>	1.02E+07
Cr-51	<i>2.74E+07</i>	1.88E+07			
Cu-66	<i>1.75E+07</i>	1.20E+07			
H-3	<i>1.49E+07</i>	1.02E+07			

Table 14.66: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	9.02E+09	6.19E+09	Co-58	8.51E+09	5.84E+09
Cu-64	3.98E+09	2.73E+09	Zn-65	3.10E+09	2.13E+09
Zn-65	3.15E+09	2.16E+09	Co-57	2.04E+09	1.40E+09
Co-57	2.07E+09	1.42E+09	Fe-55	1.84E+08	1.26E+08
Cu-62	1.10E+09	7.54E+08	Co-60	8.23E+07	5.65E+07
Zn-62	1.08E+09	7.41E+08	Mn-54	5.83E+07	4.00E+07
Co-58m	7.91E+08	5.43E+08	Cr-51	2.30E+07	1.58E+07
Fe-55	1.84E+08	1.26E+08	H-3	1.49E+07	1.02E+07
Cu-61	1.62E+08	1.11E+08	Co-56	1.07E+07	7.36E+06
Co-60	8.24E+07	5.66E+07	Ni-63	4.73E+06	3.25E+06
Mn-54	5.91E+07	4.06E+07	Be-7	4.43E+06	3.04E+06
Ni-57	5.64E+07	3.87E+07	Ni-57	3.41E+06	2.34E+06
Cr-51	2.68E+07	1.84E+07	Fe-59	3.31E+06	2.27E+06
H-3	1.49E+07	1.02E+07	Ag-105	2.20E+06	1.51E+06
Co-56	1.13E+07	7.77E+06	Tc-95m	1.65E+06	1.13E+06
Be-7	4.79E+06	3.29E+06	Cu-64	1.54E+06	1.06E+06
Ni-63	4.73E+06	3.25E+06			
Fe-59	3.64E+06	2.50E+06			
Ag-105	2.43E+06	1.67E+06			
Tc-96	2.11E+06	1.45E+06			
Tc-95m	1.76E+06	1.21E+06			

Table 14.67: Cooling time of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	6.79E+09	4.66E+09	Co-58	3.77E+09	2.59E+09
Zn-65	2.90E+09	1.99E+09	Zn-65	2.45E+09	1.68E+09
Co-57	1.92E+09	1.32E+09	Co-57	1.65E+09	1.13E+09
Fe-55	1.81E+08	1.24E+08	Fe-55	1.72E+08	1.18E+08
Co-60	8.16E+07	5.60E+07	Co-60	7.98E+07	5.48E+07
Mn-54	5.54E+07	3.80E+07	Mn-54	4.85E+07	3.33E+07
H-3	1.49E+07	1.02E+07	H-3	1.47E+07	1.01E+07
Cr-51	1.29E+07	8.89E+06	Co-56	5.10E+06	3.50E+06
Co-56	8.73E+06	5.99E+06	Ni-63	4.72E+06	3.24E+06
Ni-63	4.73E+06	3.25E+06	Cr-51	2.88E+06	1.98E+06
Be-7	3.29E+06	2.26E+06	Be-7	1.50E+06	1.03E+06
Fe-59	2.32E+06	1.59E+06			
Ag-105	1.50E+06	1.03E+06			

Table 14.68: Cooling time of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Zn-65	<i>1.89E+09</i>	1.30E+09
Co-58	<i>1.56E+09</i>	1.07E+09
Co-57	<i>1.31E+09</i>	8.98E+08
Fe-55	<i>1.62E+08</i>	1.11E+08
Co-60	<i>7.73E+07</i>	5.31E+07
Mn-54	<i>3.98E+07</i>	2.73E+07
H-3	<i>1.45E+07</i>	9.97E+06
Ni-63	<i>4.72E+06</i>	3.24E+06
Co-56	<i>2.27E+06</i>	1.56E+06

14.3.2 100MeV

Table 14.69: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cu-62	<i>3.30E+09</i>	8.90E+10	Cu-61	<i>1.35E+09</i>	3.63E+10
Cu-61	<i>1.66E+09</i>	4.46E+10	Cu-64	<i>9.39E+08</i>	2.53E+10
Cu-64	<i>9.91E+08</i>	2.67E+10	Co-58	<i>8.72E+08</i>	2.35E+10
Co-58	<i>8.72E+08</i>	2.35E+10	Co-57	<i>4.49E+08</i>	1.21E+10
Zn-63	<i>5.90E+08</i>	1.59E+10	Co-58m	<i>4.34E+08</i>	1.17E+10
Co-58m	<i>4.68E+08</i>	1.26E+10	Cu-62	<i>3.08E+08</i>	8.30E+09
Co-57	<i>4.49E+08</i>	1.21E+10	Zn-62	<i>2.61E+08</i>	7.04E+09
Cu-60	<i>3.10E+08</i>	8.36E+09	Co-56	<i>2.12E+08</i>	5.72E+09
Zn-62	<i>2.82E+08</i>	7.59E+09	Zn-63	<i>2.00E+08</i>	5.40E+09
Co-56	<i>2.13E+08</i>	5.73E+09	Zn-65	<i>1.11E+08</i>	2.98E+09
Zn-65	<i>1.11E+08</i>	2.98E+09	Fe-55	<i>5.46E+07</i>	1.47E+09
Co-60m	<i>6.83E+07</i>	1.84E+09	Cu-60	<i>5.38E+07</i>	1.45E+09
Fe-55	<i>5.46E+07</i>	1.47E+09	Mn-54	<i>4.30E+07</i>	1.16E+09
Mn-54	<i>4.30E+07</i>	1.16E+09	Ni-57	<i>3.24E+07</i>	8.72E+08
Co-61	<i>3.33E+07</i>	8.98E+08	Co-61	<i>2.19E+07</i>	5.90E+08
Ni-57	<i>3.30E+07</i>	8.89E+08	Cr-51	<i>2.01E+07</i>	5.41E+08
Zn-61	<i>2.60E+07</i>	7.01E+08	Co-55	<i>1.73E+07</i>	4.65E+08
Cu-59	<i>2.45E+07</i>	6.61E+08	Co-60	<i>1.28E+07</i>	3.46E+08
Cr-51	<i>2.01E+07</i>	5.41E+08	Mn-56	<i>1.17E+07</i>	3.14E+08
Co-55	<i>1.79E+07</i>	4.83E+08	Mn-52	<i>1.12E+07</i>	3.02E+08
Mn-56	<i>1.53E+07</i>	4.11E+08	H-3	<i>6.68E+06</i>	1.80E+08
Co-60	<i>1.28E+07</i>	3.46E+08	Fe-59	<i>4.53E+06</i>	1.22E+08
Mn-52	<i>1.12E+07</i>	3.03E+08			
Mn-52m	<i>1.05E+07</i>	2.83E+08			
Fe-53	<i>9.24E+06</i>	2.49E+08			
H-3	<i>6.68E+06</i>	1.80E+08			
Fe-53m	<i>4.60E+06</i>	1.24E+08			
Fe-59	<i>4.53E+06</i>	1.22E+08			
Mn-57	<i>4.53E+06</i>	1.22E+08			
Cu-66	<i>4.27E+06</i>	1.15E+08			
Ni-56	<i>3.71E+06</i>	1.00E+08			

Table 14.70: Cooling time of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	$8.68E+08$	$2.34E+10$	Co-58	$8.16E+08$	$2.20E+10$
Co-57	$4.49E+08$	$1.21E+10$	Co-57	$4.42E+08$	$1.19E+10$
Cu-64	$2.68E+08$	$7.22E+09$	Co-56	$2.00E+08$	$5.38E+09$
Co-56	$2.11E+08$	$5.68E+09$	Zn-65	$1.08E+08$	$2.92E+09$
Zn-65	$1.10E+08$	$2.97E+09$	Fe-55	$5.46E+07$	$1.47E+09$
Co-58m	$7.61E+07$	$2.05E+09$	Mn-54	$4.23E+07$	$1.14E+09$
Fe-55	$5.46E+07$	$1.47E+09$	Cr-51	$1.68E+07$	$4.54E+08$
Cu-62	$4.68E+07$	$1.26E+09$	Co-60	$1.28E+07$	$3.46E+08$
Zn-62	$4.60E+07$	$1.24E+09$	H-3	$6.64E+06$	$1.79E+08$
Mn-54	$4.27E+07$	$1.15E+09$	Mn-52	$4.75E+06$	$1.28E+08$
Ni-57	$2.07E+07$	$5.57E+08$	Fe-59	$4.04E+06$	$1.09E+08$
Cr-51	$1.96E+07$	$5.28E+08$	V-49	$2.97E+06$	$8.00E+07$
Co-60	$1.28E+07$	$3.46E+08$	Be-7	$2.91E+06$	$7.83E+07$
Cu-61	$1.12E+07$	$3.03E+08$	V-48	$2.04E+06$	$5.50E+07$
Mn-52	$9.95E+06$	$2.68E+08$	Ni-56	$1.64E+06$	$4.41E+07$
Co-55	$6.94E+06$	$1.87E+08$	Ni-57	$1.25E+06$	$3.37E+07$
H-3	$6.68E+06$	$1.80E+08$	Ni-63	$8.50E+05$	$2.29E+07$
Fe-59	$4.45E+06$	$1.20E+08$	Sc-46	$4.30E+05$	$1.16E+07$
Ni-56	$3.31E+06$	$8.92E+07$			
Be-7	$3.14E+06$	$8.47E+07$			
V-49	$3.01E+06$	$8.10E+07$			
V-48	$2.65E+06$	$7.14E+07$			
Ni-63	$8.50E+05$	$2.29E+07$			
Sc-46	$4.53E+05$	$1.22E+07$			

Table 14.71: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	<i>6.53E+08</i>	1.76E+10	Co-58	<i>3.63E+08</i>	9.78E+09
Co-57	<i>4.16E+08</i>	1.12E+10	Co-57	<i>3.58E+08</i>	9.65E+09
Co-56	<i>1.63E+08</i>	4.38E+09	Co-56	<i>9.50E+07</i>	2.56E+09
Zn-65	<i>1.02E+08</i>	2.74E+09	Zn-65	<i>8.57E+07</i>	2.31E+09
Fe-55	<i>5.34E+07</i>	1.44E+09	Fe-55	<i>5.12E+07</i>	1.38E+09
Mn-54	<i>4.01E+07</i>	1.08E+09	Mn-54	<i>3.51E+07</i>	9.46E+08
Co-60	<i>1.27E+07</i>	3.43E+08	Co-60	<i>1.24E+07</i>	3.35E+08
Cr-51	<i>9.46E+06</i>	2.55E+08	H-3	<i>6.57E+06</i>	1.77E+08
H-3	<i>6.64E+06</i>	1.79E+08	V-49	<i>2.50E+06</i>	6.75E+07
V-49	<i>2.83E+06</i>	7.63E+07	Cr-51	<i>2.11E+06</i>	5.69E+07
Fe-59	<i>2.83E+06</i>	7.63E+07	Fe-59	<i>1.11E+06</i>	3.00E+07
Be-7	<i>2.16E+06</i>	5.81E+07	Be-7	<i>9.87E+05</i>	2.66E+07
Ni-63	<i>8.50E+05</i>	2.29E+07	Ni-63	<i>8.50E+05</i>	2.29E+07
V-48	<i>7.53E+05</i>	2.03E+07	Sc-46	<i>2.17E+05</i>	5.84E+06
Sc-46	<i>3.56E+05</i>	9.59E+06	V-48	<i>5.57E+04</i>	1.50E+06
Mn-52	<i>2.73E+05</i>	7.37E+06	Ag-105	<i>5.57E+04</i>	1.50E+06
Ag-105	<i>1.52E+05</i>	4.10E+06	Na-22	<i>3.79E+04</i>	1.02E+06
Ni-56	<i>1.10E+05</i>	2.96E+06			
Rh-103m	<i>6.57E+04</i>	1.77E+06			
Pd-103	<i>6.57E+04</i>	1.77E+06			
Tc-97m	<i>5.57E+04</i>	1.50E+06			
Nb-91m	<i>4.30E+04</i>	1.16E+06			
Na-22	<i>3.93E+04</i>	1.06E+06			

Table 14.72: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Co-57	<i>2.85E+08</i>	7.67E+09
Co-58	<i>1.50E+08</i>	4.05E+09
Zn-65	<i>6.64E+07</i>	1.79E+09
Fe-55	<i>4.82E+07</i>	1.30E+09
Co-56	<i>4.23E+07</i>	1.14E+09
Mn-54	<i>2.88E+07</i>	7.75E+08
Co-60	<i>1.21E+07</i>	3.25E+08
H-3	<i>6.49E+06</i>	1.75E+08
V-49	<i>2.08E+06</i>	5.61E+07
Ni-63	<i>8.46E+05</i>	2.28E+07
Be-7	<i>3.06E+05</i>	8.25E+06
Fe-59	<i>2.73E+05</i>	7.37E+06
Cr-51	<i>2.22E+05</i>	5.99E+06
Sc-46	<i>1.03E+05</i>	2.77E+06

14.3.3 150MeV

Table 14.73: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cu-62	<i>7.37E+08</i>	1.45E+11	Cu-61	<i>2.95E+08</i>	5.80E+10
Cu-61	<i>3.63E+08</i>	7.14E+10	Cu-64	<i>2.35E+08</i>	4.62E+10
Cu-64	<i>2.48E+08</i>	4.88E+10	Co-58	<i>2.34E+08</i>	4.61E+10
Co-58	<i>2.34E+08</i>	4.61E+10	Co-57	<i>1.35E+08</i>	2.66E+10
Co-57	<i>1.35E+08</i>	2.66E+10	Co-58m	<i>1.17E+08</i>	2.30E+10
Co-58m	<i>1.26E+08</i>	2.48E+10	Co-56	<i>7.32E+07</i>	1.44E+10
Zn-63	<i>1.01E+08</i>	1.99E+10	Cu-62	<i>5.74E+07</i>	1.13E+10
Cu-60	<i>7.37E+07</i>	1.45E+10	Zn-62	<i>4.73E+07</i>	9.30E+09
Co-56	<i>7.32E+07</i>	1.44E+10	Zn-63	<i>3.43E+07</i>	6.74E+09
Zn-62	<i>5.08E+07</i>	1.00E+10	Fe-55	<i>2.24E+07</i>	4.41E+09
Fe-55	<i>2.24E+07</i>	4.41E+09	Mn-54	<i>2.24E+07</i>	4.40E+09
Mn-54	<i>2.24E+07</i>	4.40E+09	Cr-51	<i>1.94E+07</i>	3.81E+09
Co-60m	<i>2.18E+07</i>	4.28E+09	Zn-65	<i>1.78E+07</i>	3.50E+09
Cr-51	<i>1.94E+07</i>	3.81E+09	Cu-60	<i>1.28E+07</i>	2.52E+09
Zn-65	<i>1.78E+07</i>	3.50E+09	Ni-57	<i>1.13E+07</i>	2.22E+09
Ni-57	<i>1.15E+07</i>	2.26E+09	Mn-52	<i>7.62E+06</i>	1.50E+09
Co-61	<i>1.14E+07</i>	2.25E+09	Co-61	<i>7.52E+06</i>	1.48E+09
Cu-59	<i>7.67E+06</i>	1.51E+09	Co-55	<i>7.17E+06</i>	1.41E+09
Mn-52	<i>7.67E+06</i>	1.51E+09	Mn-56	<i>5.13E+06</i>	1.01E+09
Co-55	<i>7.47E+06</i>	1.47E+09			
Mn-52m	<i>6.96E+06</i>	1.37E+09			
Mn-56	<i>6.76E+06</i>	1.33E+09			
Fe-53	<i>6.20E+06</i>	1.22E+09			
Zn-61	<i>5.29E+06</i>	1.04E+09			

Table 14.74: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	2.33E+08	4.58E+10	Co-58	2.20E+08	4.32E+10
Co-57	1.35E+08	2.66E+10	Co-57	1.33E+08	2.62E+10
Co-56	7.27E+07	1.43E+10	Co-56	6.91E+07	1.36E+10
Cu-64	6.71E+07	1.32E+10	Fe-55	2.23E+07	4.39E+09
Fe-55	2.24E+07	4.41E+09	Mn-54	2.21E+07	4.34E+09
Mn-54	2.23E+07	4.39E+09	Zn-65	1.74E+07	3.43E+09
Co-58m	2.04E+07	4.02E+09	Cr-51	1.63E+07	3.20E+09
Cr-51	1.89E+07	3.72E+09	Co-60	4.08E+06	8.02E+08
Zn-65	1.77E+07	3.49E+09	V-49	3.39E+06	6.67E+08
Cu-62	8.49E+06	1.67E+09	Mn-52	3.23E+06	6.36E+08
Zn-62	8.33E+06	1.64E+09	H-3	3.08E+06	6.07E+08
Ni-57	7.22E+06	1.42E+09	V-48	2.70E+06	5.32E+08
Mn-52	6.81E+06	1.34E+09	Fe-59	1.97E+06	3.87E+08
Co-60	4.09E+06	8.04E+08	Be-7	1.37E+06	2.69E+08
V-48	3.50E+06	6.89E+08	Ni-56	6.20E+05	1.22E+08
V-49	3.43E+06	6.75E+08	Sc-46	4.83E+05	9.50E+07
H-3	3.09E+06	6.08E+08	Ni-57	4.36E+05	8.58E+07
Co-55	2.89E+06	5.69E+08	Ni-63	3.25E+05	6.39E+07
Cu-61	2.46E+06	4.85E+08	Ca-45	8.13E+04	1.60E+07
Fe-59	2.16E+06	4.25E+08	Sc-47	7.83E+04	1.54E+07
Be-7	1.48E+06	2.91E+08			
Ni-56	1.26E+06	2.47E+08			

Table 14.75: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	1.75E+08	3.45E+10	Co-57	1.08E+08	2.12E+10
Co-57	1.26E+08	2.47E+10	Co-58	9.76E+07	1.92E+10
Co-56	5.59E+07	1.10E+10	Co-56	3.27E+07	6.44E+09
Fe-55	2.20E+07	4.32E+09	Fe-55	2.10E+07	4.14E+09
Mn-54	2.09E+07	4.12E+09	Mn-54	1.83E+07	3.61E+09
Zn-65	1.63E+07	3.21E+09	Zn-65	1.38E+07	2.71E+09
Cr-51	9.15E+06	1.80E+09	Co-60	3.96E+06	7.79E+08
Co-60	4.05E+06	7.96E+08	H-3	3.05E+06	6.00E+08
V-49	3.23E+06	6.36E+08	V-49	2.86E+06	5.62E+08
H-3	3.07E+06	6.05E+08	Cr-51	2.04E+06	4.01E+08
Fe-59	1.38E+06	2.71E+08	Fe-59	5.39E+05	1.06E+08
Be-7	1.02E+06	2.00E+08	Be-7	4.65E+05	9.15E+07
V-48	9.96E+05	1.96E+08	Ni-63	3.24E+05	6.38E+07
Sc-46	3.99E+05	7.86E+07	Sc-46	2.43E+05	4.78E+07
Ni-63	3.25E+05	6.39E+07	V-48	7.37E+04	1.45E+07
Mn-52	1.87E+05	3.67E+07	Ca-45	5.74E+04	1.13E+07
Ca-45	7.37E+04	1.45E+07			

Table 14.76: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Co-57	<i>8.54E+07</i>	1.68E+10
Co-58	<i>4.04E+07</i>	7.95E+09
Fe-55	<i>1.98E+07</i>	3.89E+09
Mn-54	<i>1.50E+07</i>	2.95E+09
Co-56	<i>1.46E+07</i>	2.87E+09
Zn-65	<i>1.07E+07</i>	2.10E+09
Co-60	<i>3.83E+06</i>	7.54E+08
H-3	<i>3.00E+06</i>	5.91E+08
V-49	<i>2.38E+06</i>	4.68E+08
Ni-63	<i>3.24E+05</i>	6.37E+07
Cr-51	<i>2.14E+05</i>	4.22E+07
Be-7	<i>1.44E+05</i>	2.84E+07
Fe-59	<i>1.33E+05</i>	2.62E+07
Sc-46	<i>1.15E+05</i>	2.27E+07

14.3.4 200MeV

Table 14.77: Cooling time of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cu-62	<i>2.36E+08</i>	2.12E+11	Cu-61	<i>8.97E+07</i>	8.07E+10
Cu-61	<i>1.11E+08</i>	9.94E+10	Cu-64	<i>8.50E+07</i>	7.64E+10
Cu-64	<i>8.97E+07</i>	8.07E+10	Co-58	<i>8.16E+07</i>	7.34E+10
Co-58	<i>8.16E+07</i>	7.34E+10	Co-57	<i>4.75E+07</i>	4.27E+10
Co-57	<i>4.75E+07</i>	4.27E+10	Co-58m	<i>4.06E+07</i>	3.65E+10
Co-58m	<i>4.38E+07</i>	3.94E+10	Co-56	<i>2.79E+07</i>	2.51E+10
Co-56	<i>2.79E+07</i>	2.51E+10	Cu-62	<i>1.56E+07</i>	1.40E+10
Zn-63	<i>2.57E+07</i>	2.31E+10	Zn-62	<i>1.22E+07</i>	1.10E+10
Cu-60	<i>2.27E+07</i>	2.04E+10	Cr-51	<i>1.13E+07</i>	1.02E+10
Zn-62	<i>1.32E+07</i>	1.19E+10	Mn-54	<i>9.99E+06</i>	8.98E+09
Cr-51	<i>1.13E+07</i>	1.02E+10	Fe-55	<i>9.15E+06</i>	8.23E+09
Mn-54	<i>1.00E+07</i>	8.99E+09	Zn-63	<i>8.72E+06</i>	7.84E+09
Fe-55	<i>9.15E+06</i>	8.23E+09	Zn-65	<i>4.56E+06</i>	4.10E+09
Co-60m	<i>8.48E+06</i>	7.63E+09	Mn-52	<i>4.20E+06</i>	3.78E+09
Co-61	<i>4.85E+06</i>	4.36E+09	Ni-57	<i>3.99E+06</i>	3.59E+09
Zn-65	<i>4.57E+06</i>	4.11E+09	Cu-60	<i>3.93E+06</i>	3.53E+09
Mn-52	<i>4.23E+06</i>	3.80E+09	Co-61	<i>3.18E+06</i>	2.86E+09
Ni-57	<i>4.07E+06</i>	3.66E+09	Co-55	<i>2.97E+06</i>	2.67E+09
Mn-52m	<i>3.84E+06</i>	3.45E+09	V-48	<i>2.70E+06</i>	2.43E+09
Mn-56	<i>3.20E+06</i>	2.88E+09	Mn-56	<i>2.45E+06</i>	2.20E+09
Fe-53	<i>3.10E+06</i>	2.79E+09	V-49	<i>2.32E+06</i>	2.09E+09
Co-55	<i>3.09E+06</i>	2.78E+09	Co-60	<i>1.59E+06</i>	1.43E+09
V-48	<i>2.70E+06</i>	2.43E+09	H-3	<i>1.41E+06</i>	1.27E+09
Cu-59	<i>2.41E+06</i>	2.17E+09			
V-49	<i>2.32E+06</i>	2.09E+09			
Cu-66	<i>1.97E+06</i>	1.77E+09			
Co-60	<i>1.59E+06</i>	1.43E+09			
Fe-53m	<i>1.55E+06</i>	1.39E+09			
Zn-61	<i>1.47E+06</i>	1.32E+09			
Mn-51	<i>1.45E+06</i>	1.30E+09			
H-3	<i>1.41E+06</i>	1.27E+09			
Cr-49	<i>1.21E+06</i>	1.09E+09			

Table 14.78: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	$8.11E+07$	$7.29E+10$	Co-58	$7.65E+07$	$6.88E+10$
Co-57	$4.74E+07$	$4.26E+10$	Co-57	$4.67E+07$	$4.20E+10$
Co-56	$2.77E+07$	$2.49E+10$	Co-56	$2.62E+07$	$2.36E+10$
Cu-64	$2.42E+07$	$2.18E+10$	Mn-54	$9.84E+06$	$8.85E+09$
Cr-51	$1.11E+07$	$9.97E+09$	Cr-51	$9.54E+06$	$8.58E+09$
Mn-54	$9.98E+06$	$8.97E+09$	Fe-55	$9.11E+06$	$8.19E+09$
Fe-55	$9.14E+06$	$8.22E+09$	Zn-65	$4.47E+06$	$4.02E+09$
Co-58m	$7.12E+06$	$6.40E+09$	V-49	$2.29E+06$	$2.06E+09$
Zn-65	$4.55E+06$	$4.09E+09$	V-48	$2.00E+06$	$1.80E+09$
Mn-52	$3.75E+06$	$3.37E+09$	Mn-52	$1.78E+06$	$1.60E+09$
V-48	$2.59E+06$	$2.33E+09$	Co-60	$1.59E+06$	$1.43E+09$
Ni-57	$2.55E+06$	$2.29E+09$	H-3	$1.41E+06$	$1.27E+09$
V-49	$2.31E+06$	$2.08E+09$	Fe-59	$8.59E+05$	$7.72E+08$
Cu-62	$2.19E+06$	$1.97E+09$	Be-7	$6.97E+05$	$6.27E+08$
Zn-62	$2.16E+06$	$1.94E+09$	Sc-46	$4.14E+05$	$3.72E+08$
Co-60	$1.59E+06$	$1.43E+09$	Ni-56	$2.36E+05$	$2.12E+08$
H-3	$1.41E+06$	$1.27E+09$	Ni-63	$1.55E+05$	$1.39E+08$
Co-55	$1.20E+06$	$1.08E+09$	Ni-57	$1.55E+05$	$1.39E+08$
Fe-59	$9.43E+05$	$8.48E+08$	Sc-47	$5.36E+04$	$4.82E+07$
Be-7	$7.53E+05$	$6.77E+08$	Ca-45	$4.96E+04$	$4.46E+07$
Cu-61	$7.52E+05$	$6.76E+08$	Ar-37	$4.79E+04$	$4.31E+07$
Ni-56	$4.77E+05$	$4.29E+08$	Sc-44	$4.18E+04$	$3.76E+07$
Sc-46	$4.35E+05$	$3.91E+08$	Sc-44m	$3.84E+04$	$3.45E+07$
Sc-44	$2.28E+05$	$2.05E+08$	Ag-105	$2.10E+04$	$1.89E+07$
Sc-44m	$2.10E+05$	$1.89E+08$	S-35	$1.68E+04$	$1.51E+07$
Sc-47	$1.86E+05$	$1.67E+08$	P-32	$1.49E+04$	$1.34E+07$
Ni-63	$1.55E+05$	$1.39E+08$			

Table 14.79: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	6.11E+07	5.49E+10	Co-57	3.78E+07	3.40E+10
Co-57	4.40E+07	3.96E+10	Co-58	3.39E+07	3.05E+10
Co-56	2.14E+07	1.92E+10	Co-56	1.25E+07	1.12E+10
Mn-54	9.35E+06	8.41E+09	Fe-55	8.60E+06	7.73E+09
Fe-55	8.96E+06	8.06E+09	Mn-54	8.18E+06	7.36E+09
Cr-51	5.37E+06	4.83E+09	Zn-65	3.54E+06	3.18E+09
Zn-65	4.19E+06	3.77E+09	V-49	1.93E+06	1.74E+09
V-49	2.18E+06	1.96E+09	Co-60	1.55E+06	1.39E+09
Co-60	1.58E+06	1.42E+09	H-3	1.39E+06	1.25E+09
H-3	1.40E+06	1.26E+09	Cr-51	1.20E+06	1.08E+09
V-48	7.37E+05	6.63E+08	Be-7	2.37E+05	2.13E+08
Fe-59	6.01E+05	5.40E+08	Fe-59	2.36E+05	2.12E+08
Be-7	5.17E+05	4.65E+08	Sc-46	2.08E+05	1.87E+08
Sc-46	3.43E+05	3.08E+08	Ni-63	1.55E+05	1.39E+08
Ni-63	1.55E+05	1.39E+08	V-48	5.46E+04	4.91E+07
Mn-52	1.03E+05	9.24E+07	Ca-45	3.49E+04	3.14E+07
Ca-45	4.49E+04	4.04E+07			
Ar-37	3.04E+04	2.73E+07			
Ni-56	1.58E+04	1.42E+07			
Ag-105	1.42E+04	1.28E+07			
S-35	1.40E+04	1.26E+07			

Table 14.80: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Co-57	3.00E+07	2.70E+10
Co-58	1.40E+07	1.26E+10
Fe-55	8.07E+06	7.26E+09
Mn-54	6.69E+06	6.02E+09
Co-56	5.56E+06	5.00E+09
Zn-65	2.74E+06	2.46E+09
V-49	1.60E+06	1.44E+09
Co-60	1.49E+06	1.34E+09
H-3	1.37E+06	1.23E+09
Ni-63	1.55E+05	1.39E+08
Cr-51	1.26E+05	1.13E+08
Sc-46	9.89E+04	8.89E+07
Be-7	7.34E+04	6.60E+07
Fe-59	5.80E+04	5.22E+07
Ca-45	2.38E+04	2.14E+07

14.3.5 250MeV

Table 14.81: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cu-62	<i>1.01E+08</i>	2.94E+11	Cu-64	<i>4.14E+07</i>	1.20E+11
Cu-61	<i>4.52E+07</i>	1.31E+11	Cu-61	<i>3.66E+07</i>	1.06E+11
Cu-64	<i>4.38E+07</i>	1.27E+11	Co-58	<i>3.59E+07</i>	1.04E+11
Co-58	<i>3.59E+07</i>	1.04E+11	Co-57	<i>2.10E+07</i>	6.09E+10
Co-57	<i>2.10E+07</i>	6.09E+10	Co-58m	<i>1.78E+07</i>	5.17E+10
Co-58m	<i>1.93E+07</i>	5.58E+10	Co-56	<i>1.26E+07</i>	3.64E+10
Co-56	<i>1.26E+07</i>	3.64E+10	Cr-51	<i>6.56E+06</i>	1.90E+10
Zn-63	<i>9.15E+06</i>	2.65E+10	Cu-62	<i>5.83E+06</i>	1.69E+10
Cu-60	<i>9.08E+06</i>	2.63E+10	Mn-54	<i>5.11E+06</i>	1.48E+10
Cr-51	<i>6.59E+06</i>	1.91E+10	Fe-55	<i>4.42E+06</i>	1.28E+10
Mn-54	<i>5.11E+06</i>	1.48E+10	Zn-62	<i>4.38E+06</i>	1.27E+10
Zn-62	<i>4.73E+06</i>	1.37E+10	Zn-63	<i>3.10E+06</i>	8.98E+09
Fe-55	<i>4.42E+06</i>	1.28E+10	Mn-52	<i>2.31E+06</i>	6.70E+09
Co-60m	<i>4.25E+06</i>	1.23E+10	Ni-57	<i>1.80E+06</i>	5.22E+09
Co-61	<i>2.54E+06</i>	7.37E+09	V-48	<i>1.75E+06</i>	5.06E+09
Mn-52	<i>2.32E+06</i>	6.73E+09	Co-61	<i>1.67E+06</i>	4.84E+09
Mn-52m	<i>2.10E+06</i>	6.07E+09	Zn-65	<i>1.59E+06</i>	4.60E+09
Ni-57	<i>1.84E+06</i>	5.33E+09	Cu-60	<i>1.57E+06</i>	4.56E+09
V-48	<i>1.75E+06</i>	5.07E+09	V-49	<i>1.45E+06</i>	4.21E+09
Fe-53	<i>1.67E+06</i>	4.83E+09	Co-55	<i>1.44E+06</i>	4.17E+09
Mn-56	<i>1.66E+06</i>	4.82E+09	Mn-56	<i>1.27E+06</i>	3.69E+09
Zn-65	<i>1.59E+06</i>	4.60E+09	Co-60	<i>7.94E+05</i>	2.30E+09
Cu-66	<i>1.56E+06</i>	4.52E+09	H-3	<i>7.22E+05</i>	2.09E+09
Co-55	<i>1.50E+06</i>	4.34E+09	Fe-59	<i>5.25E+05</i>	1.52E+09
V-49	<i>1.45E+06</i>	4.21E+09	Ni-65	<i>5.01E+05</i>	1.45E+09
Cu-59	<i>9.98E+05</i>	2.89E+09	Be-7	<i>4.38E+05</i>	1.27E+09
Mn-51	<i>8.70E+05</i>	2.52E+09	Sc-44	<i>4.18E+05</i>	1.21E+09
Fe-53m	<i>8.35E+05</i>	2.42E+09	Mn-51	<i>3.52E+05</i>	1.02E+09
Co-60	<i>7.94E+05</i>	2.30E+09	Sc-46	<i>3.49E+05</i>	1.01E+09
Cr-49	<i>7.87E+05</i>	2.28E+09			
H-3	<i>7.22E+05</i>	2.09E+09			
Ni-65	<i>6.59E+05</i>	1.91E+09			
Zn-61	<i>5.52E+05</i>	1.60E+09			
Fe-59	<i>5.25E+05</i>	1.52E+09			
Sc-44	<i>4.52E+05</i>	1.31E+09			
Be-7	<i>4.38E+05</i>	1.27E+09			
Mn-57	<i>4.35E+05</i>	1.26E+09			
Sc-46	<i>3.49E+05</i>	1.01E+09			

Table 14.82: Cooling times of **1 day** and **1 week**

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	<i>3.56E+07</i>	1.03E+11	Co-58	<i>3.36E+07</i>	9.73E+10
Co-57	<i>2.10E+07</i>	6.07E+10	Co-57	<i>2.06E+07</i>	5.98E+10
Co-56	<i>1.24E+07</i>	3.60E+10	Co-56	<i>1.18E+07</i>	3.42E+10
Cu-64	<i>1.18E+07</i>	3.43E+10	Cr-51	<i>5.52E+06</i>	1.60E+10
Cr-51	<i>6.42E+06</i>	1.86E+10	Mn-54	<i>5.01E+06</i>	1.45E+10
Mn-54	<i>5.07E+06</i>	1.47E+10	Fe-55	<i>4.38E+06</i>	1.27E+10
Fe-55	<i>4.42E+06</i>	1.28E+10	Zn-65	<i>1.56E+06</i>	4.51E+09
Co-58m	<i>3.13E+06</i>	9.06E+09	V-49	<i>1.43E+06</i>	4.15E+09
Mn-52	<i>2.06E+06</i>	5.96E+09	V-48	<i>1.29E+06</i>	3.75E+09
V-48	<i>1.68E+06</i>	4.86E+09	Mn-52	<i>9.77E+05</i>	2.83E+09
Zn-65	<i>1.58E+06</i>	4.58E+09	Co-60	<i>7.94E+05</i>	2.30E+09
V-49	<i>1.45E+06</i>	4.20E+09	H-3	<i>7.22E+05</i>	2.09E+09
Ni-57	<i>1.15E+06</i>	3.34E+09	Fe-59	<i>4.70E+05</i>	1.36E+09
Co-60	<i>7.94E+05</i>	2.30E+09	Be-7	<i>4.00E+05</i>	1.16E+09
Cu-62	<i>7.87E+05</i>	2.28E+09	Sc-46	<i>3.28E+05</i>	9.49E+08
Zn-62	<i>7.73E+05</i>	2.24E+09	Ni-56	<i>1.07E+05</i>	3.11E+08
H-3	<i>7.22E+05</i>	2.09E+09	Ni-63	<i>9.01E+04</i>	2.61E+08
Co-55	<i>5.80E+05</i>	1.68E+09	Ni-57	<i>6.97E+04</i>	2.02E+08
Fe-59	<i>5.14E+05</i>	1.49E+09	Ar-37	<i>4.97E+04</i>	1.44E+08
Be-7	<i>4.32E+05</i>	1.25E+09	Sc-47	<i>4.45E+04</i>	1.29E+08
Sc-46	<i>3.45E+05</i>	9.98E+08	Ca-45	<i>4.11E+04</i>	1.19E+08
Cu-61	<i>3.07E+05</i>	8.90E+08			
Ni-56	<i>2.17E+05</i>	6.29E+08			
Sc-44	<i>1.85E+05</i>	5.37E+08			
Sc-44m	<i>1.71E+05</i>	4.96E+08			
Sc-47	<i>1.53E+05</i>	4.42E+08			
Ni-63	<i>9.01E+04</i>	2.61E+08			
Ar-37	<i>5.59E+04</i>	1.62E+08			
Ca-45	<i>4.21E+04</i>	1.22E+08			
Sc-48	<i>3.59E+04</i>	1.04E+08			

Table 14.83: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	2.68E+07	7.77E+10	Co-57	1.67E+07	4.84E+10
Co-57	1.95E+07	5.64E+10	Co-58	1.49E+07	4.32E+10
Co-56	9.60E+06	2.78E+10	Co-56	5.59E+06	1.62E+10
Mn-54	4.76E+06	1.38E+10	Mn-54	4.18E+06	1.21E+10
Fe-55	4.32E+06	1.25E+10	Fe-55	4.14E+06	1.20E+10
Cr-51	3.11E+06	9.00E+09	Zn-65	1.23E+06	3.56E+09
Zn-65	1.46E+06	4.22E+09	V-49	1.21E+06	3.50E+09
V-49	1.37E+06	3.96E+09	Co-60	7.70E+05	2.23E+09
Co-60	7.87E+05	2.28E+09	H-3	7.11E+05	2.06E+09
H-3	7.18E+05	2.08E+09	Cr-51	6.94E+05	2.01E+09
V-48	4.76E+05	1.38E+09	Sc-46	1.65E+05	4.78E+08
Fe-59	3.28E+05	9.51E+08	Be-7	1.36E+05	3.93E+08
Be-7	2.96E+05	8.58E+08	Fe-59	1.29E+05	3.74E+08
Sc-46	2.71E+05	7.85E+08	Ni-63	9.01E+04	2.61E+08
Ni-63	9.01E+04	2.61E+08	V-48	3.52E+04	1.02E+08
Mn-52	5.66E+04	1.64E+08	Ca-45	2.89E+04	8.37E+07
Ca-45	3.73E+04	1.08E+08	Ar-37	9.63E+03	2.79E+07
Ar-37	3.16E+04	9.15E+07	S-35	8.22E+03	2.38E+07
S-35	1.32E+04	3.83E+07			
Ni-56	7.18E+03	2.08E+07			
Ag-105	5.14E+03	1.49E+07			
P-33	5.07E+03	1.47E+07			
Y-88	3.59E+03	1.04E+07			

Table 14.84: Cooling time of 6 months

6 months(15552000s)		
Nuclei	Bq/g	Bq
Co-57	1.33E+07	3.85E+10
Co-58	6.18E+06	1.79E+10
Fe-55	3.90E+06	1.13E+10
Mn-54	3.42E+06	9.90E+09
Co-56	2.50E+06	7.25E+09
V-49	1.00E+06	2.91E+09
Zn-65	9.53E+05	2.76E+09
Co-60	7.46E+05	2.16E+09
H-3	7.04E+05	2.04E+09
Ni-63	8.98E+04	2.60E+08
Sc-46	7.84E+04	2.27E+08
Cr-51	7.28E+04	2.11E+08
Be-7	4.21E+04	1.22E+08
Fe-59	3.18E+04	9.20E+07
Ca-45	1.97E+04	5.72E+07
S-35	4.04E+03	1.17E+07

14.3.6 300MeV

Table 14.85: Cooling time of EOB and 1 hour

EOB (0 s)			1 hour (3600s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cu-62	5.59E+07	3.94E+11	Cu-64	2.61E+07	1.84E+11
Cu-64	2.75E+07	1.94E+11	Co-58	1.97E+07	1.39E+11
Cu-61	2.35E+07	1.66E+11	Cu-61	1.91E+07	1.35E+11
Co-58	1.97E+07	1.39E+11	Co-57	1.14E+07	8.04E+10
Co-57	1.14E+07	8.04E+10	Co-58m	9.78E+06	6.90E+10
Co-58m	1.05E+07	7.44E+10	Co-56	6.88E+06	4.85E+10
Co-56	6.88E+06	4.85E+10	Cr-51	4.17E+06	2.94E+10
Cu-60	4.61E+06	3.25E+10	Mn-54	3.03E+06	2.14E+10
Cr-51	4.18E+06	2.95E+10	Cu-62	2.79E+06	1.97E+10
Zn-63	4.10E+06	2.89E+10	Fe-55	2.52E+06	1.78E+10
Mn-54	3.03E+06	2.14E+10	Zn-62	2.01E+06	1.42E+10
Co-60m	2.59E+06	1.83E+10	Mn-52	1.42E+06	1.00E+10
Fe-55	2.52E+06	1.78E+10	Zn-63	1.39E+06	9.81E+09
Zn-62	2.17E+06	1.53E+10	V-48	1.24E+06	8.73E+09
Co-61	1.64E+06	1.16E+10	Co-61	1.08E+06	7.60E+09
Mn-52	1.43E+06	1.01E+10	V-49	1.02E+06	7.17E+09
Cu-66	1.41E+06	9.97E+09	Ni-57	9.36E+05	6.60E+09
Mn-52m	1.30E+06	9.14E+09	Co-55	8.05E+05	5.68E+09
V-48	1.24E+06	8.74E+09	Mn-56	8.00E+05	5.64E+09
Mn-56	1.04E+06	7.37E+09	Cu-60	7.97E+05	5.62E+09
V-49	1.02E+06	7.17E+09	Zn-65	7.20E+05	5.08E+09
Fe-53	9.81E+05	6.92E+09	Co-60	4.89E+05	3.45E+09
Ni-57	9.54E+05	6.73E+09	H-3	4.44E+05	3.13E+09
Co-55	8.38E+05	5.91E+09	Ni-65	3.53E+05	2.49E+09
Zn-65	7.20E+05	5.08E+09	Fe-59	3.42E+05	2.41E+09
Mn-51	5.67E+05	4.00E+09	Sc-44	3.05E+05	2.15E+09
Cr-49	5.56E+05	3.92E+09	Be-7	2.79E+05	1.97E+09
Cu-59	5.09E+05	3.59E+09	Sc-46	2.64E+05	1.86E+09
Fe-53m	4.91E+05	3.46E+09	Mn-51	2.30E+05	1.62E+09
Co-60	4.89E+05	3.45E+09	Cr-49	2.08E+05	1.47E+09
Ni-65	4.65E+05	3.28E+09	Ti-45	1.97E+05	1.39E+09
H-3	4.44E+05	3.13E+09	Mn-52m	1.80E+05	1.27E+09
Fe-59	3.43E+05	2.42E+09	Sc-44m	1.64E+05	1.16E+09
Sc-44	3.32E+05	2.34E+09			
Mn-57	2.85E+05	2.01E+09			
Be-7	2.79E+05	1.97E+09			
Sc-46	2.64E+05	1.86E+09			
Sc-45m	2.62E+05	1.85E+09			
Zn-61	2.50E+05	1.76E+09			
Ti-45	2.48E+05	1.75E+09			
He-6	2.20E+05	1.55E+09			
V-47	2.16E+05	1.52E+09			
Co-62	1.74E+05	1.23E+09			
Co-62m	1.72E+05	1.21E+09			
Sc-44m	1.67E+05	1.18E+09			
V-52	1.53E+05	1.08E+09			
Sc-46m	1.47E+05	1.04E+09			

Table 14.86: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	1.96E+07	1.38E+11	Co-58	1.84E+07	1.30E+11
Co-57	1.14E+07	8.02E+10	Co-57	1.12E+07	7.90E+10
Cu-64	7.44E+06	5.25E+10	Co-56	6.47E+06	4.56E+10
Co-56	6.82E+06	4.81E+10	Cr-51	3.50E+06	2.47E+10
Cr-51	4.08E+06	2.88E+10	Mn-54	2.99E+06	2.11E+10
Mn-54	3.03E+06	2.14E+10	Fe-55	2.52E+06	1.78E+10
Fe-55	2.52E+06	1.78E+10	V-49	1.00E+06	7.07E+09
Co-58m	1.72E+06	1.21E+10	V-48	9.17E+05	6.47E+09
Mn-52	1.27E+06	8.94E+09	Zn-65	7.06E+05	4.98E+09
V-48	1.19E+06	8.38E+09	Mn-52	6.03E+05	4.25E+09
V-49	1.02E+06	7.16E+09	Co-60	4.88E+05	3.44E+09
Zn-65	7.19E+05	5.07E+09	H-3	4.44E+05	3.13E+09
Ni-57	5.98E+05	4.22E+09	Fe-59	3.08E+05	2.17E+09
Co-60	4.88E+05	3.44E+09	Be-7	2.55E+05	1.80E+09
H-3	4.44E+05	3.13E+09	Sc-46	2.48E+05	1.75E+09
Cu-62	3.60E+05	2.54E+09			
Zn-62	3.54E+05	2.50E+09			
Fe-59	3.37E+05	2.38E+09			
Co-55	3.25E+05	2.29E+09			
Be-7	2.76E+05	1.95E+09			
Sc-46	2.61E+05	1.84E+09			
Cu-61	1.60E+05	1.13E+09			

Table 14.87: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	1.47E+07	1.04E+11	Co-57	9.06E+06	6.39E+10
Co-57	1.06E+07	7.45E+10	Co-58	8.17E+06	5.76E+10
Co-56	5.26E+06	3.71E+10	Co-56	3.08E+06	2.17E+10
Mn-54	2.84E+06	2.00E+10	Mn-54	2.48E+06	1.75E+10
Fe-55	2.48E+06	1.75E+10	Fe-55	2.38E+06	1.68E+10
Cr-51	1.97E+06	1.39E+10	V-49	8.46E+05	5.97E+09
V-49	9.57E+05	6.75E+09	Zn-65	5.59E+05	3.94E+09
Zn-65	6.62E+05	4.67E+09	Co-60	4.74E+05	3.34E+09
Co-60	4.83E+05	3.41E+09	Cr-51	4.40E+05	3.10E+09
H-3	4.42E+05	3.12E+09	H-3	4.38E+05	3.09E+09
V-48	3.37E+05	2.38E+09	Sc-46	1.25E+05	8.82E+08
Fe-59	2.14E+05	1.51E+09	Be-7	8.68E+04	6.12E+08
Sc-46	2.06E+05	1.45E+09	Fe-59	8.44E+04	5.95E+08
Be-7	1.90E+05	1.34E+09	Ni-63	6.20E+04	4.37E+08
Ni-63	6.21E+04	4.38E+08	V-48	2.50E+04	1.76E+08
Mn-52	3.47E+04	2.45E+08	Ca-45	2.25E+04	1.59E+08
Ca-45	2.91E+04	2.05E+08			
Ar-37	2.76E+04	1.95E+08			

Table 14.88: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Co-57	<i>7.20E+06</i>	5.08E+10
Co-58	<i>3.39E+06</i>	2.39E+10
Fe-55	<i>2.24E+06</i>	1.58E+10
Mn-54	<i>2.04E+06</i>	1.44E+10
Co-56	<i>1.37E+06</i>	9.66E+09
V-49	<i>7.03E+05</i>	4.96E+09
Co-60	<i>4.58E+05</i>	3.23E+09
Zn-65	<i>4.32E+05</i>	3.05E+09
H-3	<i>4.32E+05</i>	3.05E+09
Ni-63	<i>6.20E+04</i>	4.37E+08
Sc-46	<i>5.94E+04</i>	4.19E+08
Cr-51	<i>4.62E+04</i>	3.26E+08
Be-7	<i>2.69E+04</i>	1.90E+08
Fe-59	<i>2.07E+04</i>	1.46E+08
Ca-45	<i>1.55E+04</i>	1.09E+08

14.3.7 350MeV

Table 14.89: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cu-62	<i>3.31E+07</i>	5.13E+11	Cu-64	<i>1.80E+07</i>	2.79E+11
Cu-64	<i>1.90E+07</i>	2.94E+11	Co-58	<i>1.16E+07</i>	1.79E+11
Cu-61	<i>1.34E+07</i>	2.07E+11	Cu-61	<i>1.08E+07</i>	1.68E+11
Co-58	<i>1.16E+07</i>	1.79E+11	Co-57	<i>6.58E+06</i>	1.02E+11
Co-57	<i>6.58E+06</i>	1.02E+11	Co-58m	<i>5.74E+06</i>	8.89E+10
Co-58m	<i>6.19E+06</i>	9.59E+10	Co-56	<i>3.95E+06</i>	6.12E+10
Co-56	<i>3.95E+06</i>	6.12E+10	Cr-51	<i>2.68E+06</i>	4.15E+10
Cr-51	<i>2.68E+06</i>	4.15E+10	Mn-54	<i>1.87E+06</i>	2.89E+10
Cu-60	<i>2.52E+06</i>	3.90E+10	Fe-55	<i>1.51E+06</i>	2.34E+10
Zn-63	<i>2.00E+06</i>	3.10E+10	Cu-62	<i>1.45E+06</i>	2.24E+10
Mn-54	<i>1.87E+06</i>	2.89E+10	Zn-62	<i>9.81E+05</i>	1.52E+10
Co-60m	<i>1.70E+06</i>	2.63E+10	Mn-52	<i>8.97E+05</i>	1.39E+10
Fe-55	<i>1.51E+06</i>	2.34E+10	V-48	<i>8.65E+05</i>	1.34E+10
Cu-66	<i>1.34E+06</i>	2.07E+10	Co-61	<i>7.29E+05</i>	1.13E+10
Co-61	<i>1.11E+06</i>	1.72E+10	V-49	<i>6.84E+05</i>	1.06E+10
Zn-62	<i>1.06E+06</i>	1.64E+10	Zn-63	<i>6.78E+05</i>	1.05E+10
Mn-52	<i>9.04E+05</i>	1.40E+10	Ni-57	<i>5.19E+05</i>	8.04E+09
V-48	<i>8.65E+05</i>	1.34E+10	Mn-56	<i>5.08E+05</i>	7.87E+09
Mn-52m	<i>8.13E+05</i>	1.26E+10	Co-55	<i>4.75E+05</i>	7.36E+09
V-49	<i>6.84E+05</i>	1.06E+10	Cu-60	<i>4.36E+05</i>	6.75E+09
Mn-56	<i>6.65E+05</i>	1.03E+10	Zn-65	<i>3.48E+05</i>	5.40E+09

Table 14.90: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	1.14E+07	1.77E+11	Co-58	1.08E+07	1.67E+11
Co-57	6.52E+06	1.01E+11	Co-57	6.44E+06	9.98E+10
Cu-64	5.12E+06	7.94E+10	Co-56	3.71E+06	5.75E+10
Co-56	3.92E+06	6.07E+10	Cr-51	2.25E+06	3.49E+10
Cr-51	2.61E+06	4.05E+10	Mn-54	1.84E+06	2.85E+10
Mn-54	1.87E+06	2.89E+10	Fe-55	1.50E+06	2.33E+10
Fe-55	1.51E+06	2.34E+10	V-49	6.78E+05	1.05E+10
Co-58m	1.01E+06	1.56E+10	V-48	6.41E+05	9.93E+09
V-48	8.33E+05	1.29E+10	Mn-52	3.79E+05	5.88E+09
Mn-52	8.00E+05	1.24E+10	Zn-65	3.42E+05	5.30E+09
V-49	6.84E+05	1.06E+10	Co-60	3.18E+05	4.93E+09
Zn-65	3.48E+05	5.39E+09	H-3	2.80E+05	4.34E+09
Ni-57	3.32E+05	5.14E+09	Fe-59	2.03E+05	3.15E+09
Co-60	3.19E+05	4.94E+09	Sc-46	1.81E+05	2.81E+09
H-3	2.81E+05	4.35E+09	Be-7	1.69E+05	2.62E+09
Fe-59	2.23E+05	3.46E+09	Ni-63	4.40E+04	6.82E+08
Co-55	1.91E+05	2.96E+09	Ar-37	3.81E+04	5.90E+08
Sc-46	1.90E+05	2.95E+09	Ni-56	3.32E+04	5.15E+08
Be-7	1.83E+05	2.83E+09	Sc-47	2.45E+04	3.79E+08
Cu-62	1.76E+05	2.73E+09	Ca-45	2.41E+04	3.74E+08
Zn-62	1.73E+05	2.68E+09	Ni-57	2.01E+04	3.11E+08
Sc-44	1.08E+05	1.67E+09	Sc-44	1.97E+04	3.06E+08
Sc-44m	9.94E+04	1.54E+09	Sc-44m	1.81E+04	2.81E+08
Cu-61	9.10E+04	1.41E+09	S-35	1.39E+04	2.16E+08
Sc-47	8.33E+04	1.29E+09	P-32	1.35E+04	2.09E+08
Ni-56	6.71E+04	1.04E+09	P-33	1.08E+04	1.68E+08
Ni-63	4.40E+04	6.82E+08	Sc-48	2.12E+03	3.28E+07
Ar-37	4.29E+04	6.64E+08	Cu-64	1.98E+03	3.07E+07
Ca-45	2.48E+04	3.84E+08	Rh-103m	1.88E+03	2.91E+07
Sc-48	2.08E+04	3.22E+08	Pd-103	1.87E+03	2.90E+07
P-32	1.81E+04	2.80E+08	Ag-105	1.85E+03	2.86E+07
S-35	1.46E+04	2.27E+08	Zr-88	1.22E+03	1.89E+07
Cr-48	1.37E+04	2.13E+08	Y-88	1.18E+03	1.83E+07
P-33	1.28E+04	1.98E+08	Na-22	9.10E+02	1.41E+07
K-42	1.05E+04	1.62E+08	Ag-106m	7.49E+02	1.16E+07
K-43	8.26E+03	1.28E+08	Sr-85	6.78E+02	1.05E+07

Table 14.91: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	8.65E+06	1.34E+11	Co-57	5.21E+06	8.08E+10
Co-57	6.08E+06	9.42E+10	Co-58	4.80E+06	7.43E+10
Co-56	3.02E+06	4.68E+10	Co-56	1.76E+06	2.73E+10
Mn-54	1.75E+06	2.71E+10	Mn-54	1.53E+06	2.37E+10
Fe-55	1.48E+06	2.29E+10	Fe-55	1.42E+06	2.20E+10
Cr-51	1.26E+06	1.96E+10	V-49	5.71E+05	8.84E+09
V-49	6.45E+05	9.99E+09	Co-60	3.08E+05	4.78E+09
Zn-65	3.20E+05	4.96E+09	Cr-51	2.82E+05	4.37E+09
Co-60	3.16E+05	4.89E+09	H-3	2.77E+05	4.29E+09
H-3	2.79E+05	4.33E+09	Zn-65	2.70E+05	4.19E+09
V-48	2.36E+05	3.66E+09	Sc-46	9.10E+04	1.41E+09
Sc-46	1.50E+05	2.32E+09	Be-7	5.74E+04	8.89E+08
Fe-59	1.42E+05	2.20E+09	Fe-59	5.58E+04	8.65E+08
Be-7	1.25E+05	1.94E+09	Ni-63	4.39E+04	6.81E+08
Ni-63	4.40E+04	6.82E+08	V-48	1.75E+04	2.71E+08
Ar-37	2.41E+04	3.74E+08	Ca-45	1.70E+04	2.63E+08
Mn-52	2.19E+04	3.40E+08	Ar-37	7.36E+03	1.14E+08
Ca-45	2.19E+04	3.40E+08	S-35	7.23E+03	1.12E+08
S-35	1.16E+04	1.80E+08	P-33	1.12E+03	1.73E+07
P-33	5.77E+03	8.94E+07	Y-88	1.05E+03	1.62E+07
P-32	4.42E+03	6.85E+07	Na-22	8.58E+02	1.33E+07
Ni-56	2.23E+03	3.46E+07	Zr-88	6.11E+02	9.47E+06
Ag-105	1.26E+03	1.95E+07	Sc-44	5.21E+02	8.08E+06
Y-88	1.17E+03	1.82E+07	Ti-44	5.21E+02	8.08E+06
Zr-88	1.01E+03	1.56E+07	Ag-105	4.59E+02	7.11E+06
Na-22	8.91E+02	1.38E+07	Ag-110m	3.90E+02	6.05E+06
Rh-103m	7.36E+02	1.14E+07	Sr-85	2.79E+02	4.33E+06
Pd-103	7.36E+02	1.14E+07	P-32	2.45E+02	3.79E+06

Table 14.92: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Co-57	<i>4.14E+06</i>	6.42E+10
Co-58	<i>1.99E+06</i>	3.08E+10
Fe-55	<i>1.33E+06</i>	2.06E+10
Mn-54	<i>1.25E+06</i>	1.94E+10
Co-56	<i>7.87E+05</i>	1.22E+10
V-49	<i>4.74E+05</i>	7.35E+09
Co-60	<i>2.99E+05</i>	4.63E+09
H-3	<i>2.73E+05</i>	4.23E+09
Zn-65	<i>2.09E+05</i>	3.24E+09
Ni-63	<i>4.39E+04</i>	6.80E+08
Sc-46	<i>4.33E+04</i>	6.71E+08
Cr-51	<i>2.97E+04</i>	4.60E+08
Be-7	<i>1.78E+04</i>	2.76E+08
Fe-59	<i>1.37E+04</i>	2.13E+08
Ca-45	<i>1.16E+04</i>	1.80E+08
S-35	<i>3.54E+03</i>	5.49E+07
Ar-37	<i>1.25E+03</i>	1.93E+07
Na-22	<i>8.00E+02</i>	1.24E+07
Y-88	<i>7.68E+02</i>	1.19E+07

14.3.8 400MeV

Table 14.93: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cu-62	<i>2.26E+07</i>	6.52E+11	Cu-64	<i>1.44E+07</i>	4.17E+11
Cu-64	<i>1.52E+07</i>	4.40E+11	Co-58	<i>7.68E+06</i>	2.22E+11
Cu-61	<i>8.72E+06</i>	2.52E+11	Cu-61	<i>7.10E+06</i>	2.05E+11
Co-58	<i>7.68E+06</i>	2.22E+11	Co-57	<i>4.29E+06</i>	1.24E+11
Co-57	<i>4.29E+06</i>	1.24E+11	Co-58m	<i>3.81E+06</i>	1.10E+11
Co-58m	<i>4.12E+06</i>	1.19E+11	Co-56	<i>2.60E+06</i>	7.52E+10
Co-56	<i>2.60E+06</i>	7.52E+10	Cr-51	<i>1.94E+06</i>	5.59E+10
Cr-51	<i>1.94E+06</i>	5.60E+10	Mn-54	<i>1.30E+06</i>	3.76E+10
Cu-60	<i>1.56E+06</i>	4.52E+10	Fe-55	<i>1.01E+06</i>	2.92E+10
Cu-66	<i>1.38E+06</i>	3.98E+10	Cu-62	<i>8.72E+05</i>	2.52E+10
Mn-54	<i>1.30E+06</i>	3.76E+10	V-48	<i>6.65E+05</i>	1.92E+10
Co-60m	<i>1.23E+06</i>	3.55E+10	Mn-52	<i>6.27E+05</i>	1.81E+10
Zn-63	<i>1.15E+06</i>	3.32E+10	Zn-62	<i>5.54E+05</i>	1.60E+10
Fe-55	<i>1.01E+06</i>	2.92E+10	Co-61	<i>5.37E+05</i>	1.55E+10
Co-61	<i>8.20E+05</i>	2.37E+10	V-49	<i>5.19E+05</i>	1.50E+10
V-48	<i>6.65E+05</i>	1.92E+10	Zn-63	<i>3.91E+05</i>	1.13E+10
Mn-52	<i>6.30E+05</i>	1.82E+10	Mn-56	<i>3.63E+05</i>	1.05E+10
Zn-62	<i>5.99E+05</i>	1.73E+10	Ni-57	<i>3.29E+05</i>	9.50E+09
Mn-52m	<i>5.71E+05</i>	1.65E+10	Co-55	<i>3.08E+05</i>	8.90E+09
V-49	<i>5.19E+05</i>	1.50E+10	Cu-60	<i>2.71E+05</i>	7.82E+09
Mn-56	<i>4.74E+05</i>	1.37E+10	Co-60	<i>2.31E+05</i>	6.67E+09
Fe-53	<i>4.12E+05</i>	1.19E+10	Ni-65	<i>2.09E+05</i>	6.05E+09
Ni-57	<i>3.35E+05</i>	9.69E+09	Sc-44	<i>2.06E+05</i>	5.94E+09
Co-55	<i>3.21E+05</i>	9.26E+09	H-3	<i>2.04E+05</i>	5.90E+09
Cr-49	<i>2.77E+05</i>	8.00E+09	Zn-65	<i>2.01E+05</i>	5.80E+09
Ni-65	<i>2.76E+05</i>	7.97E+09	Fe-59	<i>1.63E+05</i>	4.71E+09
Mn-51	<i>2.54E+05</i>	7.33E+09	Sc-46	<i>1.55E+05</i>	4.48E+09
Co-60	<i>2.31E+05</i>	6.67E+09	Be-7	<i>1.43E+05</i>	4.12E+09
Sc-44	<i>2.24E+05</i>	6.47E+09	Ti-45	<i>1.22E+05</i>	3.52E+09
Fe-53m	<i>2.06E+05</i>	5.95E+09	Sc-44m	<i>1.11E+05</i>	3.21E+09
H-3	<i>2.04E+05</i>	5.90E+09	Cr-49	<i>1.04E+05</i>	2.99E+09
Zn-65	<i>2.01E+05</i>	5.80E+09	Mn-51	<i>1.03E+05</i>	2.98E+09
Cu-59	<i>1.70E+05</i>	4.91E+09	Sc-47	<i>8.41E+04</i>	2.43E+09
Fe-59	<i>1.63E+05</i>	4.71E+09	Mn-52m	<i>7.93E+04</i>	2.29E+09

EOB (0 s)			1 hour (3600 s)		
Sc-45m	1.56E+05	4.50E+09	Ni-56	4.98E+04	1.44E+09
Sc-46	1.55E+05	4.48E+09	Sc-43	4.60E+04	1.33E+09
Ti-45	1.53E+05	4.41E+09	Ar-37	3.91E+04	1.13E+09
Be-7	1.43E+05	4.12E+09	V-47	3.44E+04	9.95E+08
Mn-57	1.37E+05	3.96E+09	Ni-63	3.41E+04	9.86E+08
V-47	1.23E+05	3.56E+09	K-42	3.27E+04	9.45E+08
He-6	1.17E+05	3.37E+09	Sc-48	2.45E+04	7.09E+08
Sc-44m	1.13E+05	3.25E+09	Fe-52	2.39E+04	6.89E+08
Co-62	9.80E+04	2.83E+09	Co-60m	2.31E+04	6.67E+08
Co-62m	9.62E+04	2.78E+09	Cr-48	2.21E+04	6.37E+08
Sc-46m	8.65E+04	2.50E+09	P-32	2.05E+04	5.91E+08
Sc-47	8.48E+04	2.45E+09	Ca-45	1.96E+04	5.67E+08
V-52	7.72E+04	2.23E+09	S-35	1.61E+04	4.66E+08
Zn-61	7.10E+04	2.05E+09	P-33	1.30E+04	3.75E+08
C-11	5.61E+04	1.62E+09	K-43	1.27E+04	3.68E+08
Sc-43	5.54E+04	1.60E+09	C-11	7.27E+03	2.10E+08
Co-63	5.30E+04	1.53E+09	Co-62m	4.85E+03	1.40E+08
Ni-56	5.02E+04	1.45E+09	Si-31	4.60E+03	1.33E+08
Be-8	4.29E+04	1.24E+09	Fe-53	3.77E+03	1.09E+08
Ar-37	3.91E+04	1.13E+09	F-18	3.46E+03	1.00E+08
Li-8	3.67E+04	1.06E+09			

Table 14.94: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	7.62E+06	2.20E+11	Co-58	7.20E+06	2.08E+11
Co-57	4.29E+06	1.24E+11	Co-57	4.22E+06	1.22E+11
Cu-64	4.12E+06	1.19E+11	Co-56	2.45E+06	7.07E+10
Co-56	2.58E+06	7.46E+10	Cr-51	1.63E+06	4.70E+10
Cr-51	1.89E+06	5.46E+10	Mn-54	1.28E+06	3.70E+10
Mn-54	1.30E+06	3.75E+10	Fe-55	1.01E+06	2.91E+10
Fe-55	1.01E+06	2.92E+10	V-49	5.12E+05	1.48E+10
Co-58m	6.68E+05	1.93E+10	V-48	4.92E+05	1.42E+10
V-48	6.37E+05	1.84E+10	Mn-52	2.66E+05	7.68E+09
Mn-52	5.57E+05	1.61E+10	Co-60	2.30E+05	6.65E+09
V-49	5.16E+05	1.49E+10	H-3	2.04E+05	5.90E+09
Co-60	2.31E+05	6.67E+09	Zn-65	1.97E+05	5.69E+09
Ni-57	2.10E+05	6.07E+09	Sc-46	1.46E+05	4.23E+09
H-3	2.04E+05	5.90E+09	Fe-59	1.46E+05	4.22E+09
Zn-65	2.00E+05	5.79E+09	Be-7	1.31E+05	3.77E+09
Fe-59	1.61E+05	4.64E+09	Ni-63	3.41E+04	9.86E+08
Sc-46	1.54E+05	4.45E+09	Ar-37	3.40E+04	9.81E+08
Be-7	1.41E+05	4.07E+09	Ni-56	2.20E+04	6.35E+08
Co-55	1.24E+05	3.58E+09	Sc-47	2.02E+04	5.83E+08
Cu-62	9.93E+04	2.87E+09	Ca-45	1.91E+04	5.51E+08
Zn-62	9.76E+04	2.82E+09	Sc-44	1.68E+04	4.84E+08
Sc-44	9.17E+04	2.65E+09	Sc-44m	1.54E+04	4.46E+08
Sc-44m	8.48E+04	2.45E+09	S-35	1.53E+04	4.41E+08
Sc-47	6.92E+04	2.00E+09	P-32	1.46E+04	4.22E+08
Cu-61	5.92E+04	1.71E+09	Ni-57	1.27E+04	3.68E+08
Ni-56	4.43E+04	1.28E+09	P-33	1.07E+04	3.10E+08
Ar-37	3.81E+04	1.10E+09			

Table 14.95: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-58	$5.75E+06$	$1.66E+11$	Co-57	$3.41E+06$	$9.85E+10$
Co-57	$3.98E+06$	$1.15E+11$	Co-58	$3.19E+06$	$9.22E+10$
Co-56	$1.99E+06$	$5.76E+10$	Co-56	$1.16E+06$	$3.36E+10$
Mn-54	$1.22E+06$	$3.51E+10$	Mn-54	$1.07E+06$	$3.08E+10$
Fe-55	$9.90E+05$	$2.86E+10$	Fe-55	$9.52E+05$	$2.75E+10$
Cr-51	$9.14E+05$	$2.64E+10$	V-49	$4.33E+05$	$1.25E+10$
V-49	$4.88E+05$	$1.41E+10$	Co-60	$2.24E+05$	$6.46E+09$
Co-60	$2.28E+05$	$6.60E+09$	Cr-51	$2.04E+05$	$5.89E+09$
H-3	$2.04E+05$	$5.88E+09$	H-3	$2.01E+05$	$5.82E+09$
Zn-65	$1.85E+05$	$5.33E+09$	Zn-65	$1.55E+05$	$4.49E+09$
V-48	$1.81E+05$	$5.24E+09$	Sc-46	$7.37E+04$	$2.13E+09$
Sc-46	$1.21E+05$	$3.50E+09$	Be-7	$4.43E+04$	$1.28E+09$
Fe-59	$1.02E+05$	$2.95E+09$	Fe-59	$4.02E+04$	$1.16E+09$
Be-7	$9.66E+04$	$2.79E+09$	Ni-63	$3.41E+04$	$9.84E+08$
Ni-63	$3.41E+04$	$9.85E+08$	V-48	$1.34E+04$	$3.88E+08$
Ar-37	$2.15E+04$	$6.22E+08$	Ca-45	$1.34E+04$	$3.88E+08$
Ca-45	$1.73E+04$	$5.00E+08$	S-35	$7.93E+03$	$2.29E+08$
Mn-52	$1.54E+04$	$4.44E+08$	Ar-37	$6.58E+03$	$1.90E+08$
S-35	$1.27E+04$	$3.68E+08$			
P-33	$5.71E+03$	$1.65E+08$			
P-32	$4.78E+03$	$1.38E+08$			

Table 14.96: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Co-57	$2.71E+06$	$7.83E+10$
Co-58	$1.32E+06$	$3.82E+10$
Fe-55	$8.93E+05$	$2.58E+10$
Mn-54	$8.72E+05$	$2.52E+10$
Co-56	$5.19E+05$	$1.50E+10$
V-49	$3.60E+05$	$1.04E+10$
Co-60	$2.16E+05$	$6.25E+09$
H-3	$1.99E+05$	$5.74E+09$
Zn-65	$1.20E+05$	$3.48E+09$
Sc-46	$3.50E+04$	$1.01E+09$
Ni-63	$3.40E+04$	$9.83E+08$
Cr-51	$2.14E+04$	$6.19E+08$
Be-7	$1.37E+04$	$3.97E+08$
Fe-59	$9.87E+03$	$2.85E+08$
Ca-45	$9.17E+03$	$2.65E+08$
S-35	$3.88E+03$	$1.12E+08$

14.4 Iron

14.4.1 50MeV

Table 14.97: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-56	<i>2.06E+10</i>	1.59E+10	Co-56	<i>2.04E+10</i>	1.58E+10
Fe-55	<i>1.64E+10</i>	1.27E+10	Fe-55	<i>1.64E+10</i>	1.27E+10
Mn-54	<i>9.66E+09</i>	7.47E+09	Mn-54	<i>9.65E+09</i>	7.46E+09
Cr-51	<i>8.60E+09</i>	6.65E+09	Cr-51	<i>8.59E+09</i>	6.64E+09
Co-55	<i>5.30E+09</i>	4.10E+09	Co-55	<i>5.10E+09</i>	3.94E+09
Mn-52	<i>3.84E+09</i>	2.97E+09	Mn-52	<i>3.82E+09</i>	2.95E+09
Mn-52m	<i>3.60E+09</i>	2.78E+09	Mn-52m	<i>5.01E+08</i>	3.87E+08
Fe-53	<i>3.56E+09</i>	2.75E+09	Mn-51	<i>4.23E+08</i>	3.27E+08
Fe-53m	<i>1.77E+09</i>	1.37E+09	Co-57	<i>3.13E+08</i>	2.42E+08
Mn-51	<i>1.04E+09</i>	8.04E+08	V-48	<i>3.03E+08</i>	2.34E+08
Co-54	<i>3.29E+08</i>	2.54E+08	V-49	<i>2.41E+08</i>	1.86E+08
Co-54m	<i>3.29E+08</i>	2.54E+08	Mn-56	<i>9.33E+07</i>	7.21E+07
Co-57	<i>3.13E+08</i>	2.42E+08	Cr-49	<i>8.38E+07</i>	6.48E+07
V-48	<i>3.03E+08</i>	2.34E+08	Fe-52	<i>8.37E+07</i>	6.47E+07
V-49	<i>2.41E+08</i>	1.86E+08	Co-58	<i>6.20E+07</i>	4.79E+07
Cr-49	<i>2.24E+08</i>	1.73E+08	Fe-53	<i>3.26E+07</i>	2.52E+07
Mn-56	<i>1.22E+08</i>	9.43E+07	Co-58m	<i>3.08E+07</i>	2.38E+07
Fe-52	<i>9.09E+07</i>	7.03E+07	H-3	<i>8.49E+06</i>	6.56E+06
Fe-52m	<i>9.09E+07</i>	7.03E+07	Be-7	<i>6.47E+06</i>	5.00E+06
Co-58	<i>6.20E+07</i>	4.79E+07	Cr-48	<i>3.22E+06</i>	2.49E+06
Co-58m	<i>3.32E+07</i>	2.57E+07	Sc-44	<i>2.02E+06</i>	1.56E+06
Mn-50	<i>2.60E+07</i>	2.01E+07			
Mn-50m	<i>2.60E+07</i>	2.01E+07			
P-30	<i>1.11E+07</i>	8.57E+06			
H-3	<i>8.49E+06</i>	6.56E+06			
Mn-57	<i>7.76E+06</i>	6.00E+06			
Be-7	<i>6.47E+06</i>	5.00E+06			
C-11	<i>5.55E+06</i>	4.29E+06			
Co-53	<i>3.88E+06</i>	3.00E+06			
Co-53m	<i>3.88E+06</i>	3.00E+06			
Cr-48	<i>3.32E+06</i>	2.57E+06			
Sc-45m	<i>2.77E+06</i>	2.14E+06			
V-52	<i>2.21E+06</i>	1.71E+06			
V-47	<i>2.21E+06</i>	1.71E+06			
Sc-44	<i>2.20E+06</i>	1.70E+06			

Table 14.98: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-56	$2.03E+10$	$1.57E+10$	Co-56	$1.93E+10$	$1.49E+10$
Fe-55	$1.63E+10$	$1.26E+10$	Fe-55	$1.63E+10$	$1.26E+10$
Mn-54	$9.64E+09$	$7.45E+09$	Mn-54	$9.51E+09$	$7.35E+09$
Cr-51	$8.40E+09$	$6.49E+09$	Cr-51	$7.22E+09$	$5.58E+09$
Mn-52	$3.40E+09$	$2.63E+09$	Mn-52	$1.62E+09$	$1.25E+09$
Co-55	$2.06E+09$	$1.59E+09$	Co-57	$3.08E+08$	$2.38E+08$
Co-57	$3.12E+08$	$2.41E+08$	V-49	$2.37E+08$	$1.83E+08$
V-48	$2.90E+08$	$2.24E+08$	V-48	$2.24E+08$	$1.73E+08$
V-49	$2.39E+08$	$1.85E+08$	Co-58	$5.81E+07$	$4.49E+07$
Co-58	$6.16E+07$	$4.76E+07$	H-3	$8.47E+06$	$6.55E+06$
Fe-52	$1.22E+07$	$9.42E+06$	Co-55	$6.92E+06$	$5.35E+06$
H-3	$8.49E+06$	$6.56E+06$	Be-7	$5.90E+06$	$4.56E+06$
Be-7	$6.38E+06$	$4.93E+06$			
Co-58m	$5.39E+06$	$4.17E+06$			
Cr-48	$1.54E+06$	$1.19E+06$			

Table 14.99: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Fe-55	$1.60E+10$	$1.24E+10$	Fe-55	$1.54E+10$	$1.19E+10$
Co-56	$1.57E+10$	$1.21E+10$	Co-56	$9.15E+09$	$7.07E+09$
Mn-54	$9.03E+09$	$6.98E+09$	Mn-54	$7.90E+09$	$6.11E+09$
Cr-51	$4.06E+09$	$3.14E+09$	Cr-51	$9.06E+08$	$7.00E+08$
Co-57	$2.90E+08$	$2.24E+08$	Co-57	$2.48E+08$	$1.92E+08$
V-49	$2.26E+08$	$1.75E+08$	V-49	$2.01E+08$	$1.55E+08$
Mn-52	$9.33E+07$	$7.21E+07$	Co-58	$2.57E+07$	$1.99E+07$
V-48	$8.24E+07$	$6.37E+07$	H-3	$8.37E+06$	$6.47E+06$
Co-58	$4.63E+07$	$3.58E+07$	V-48	$6.09E+06$	$4.71E+06$
H-3	$8.45E+06$	$6.53E+06$	Be-7	$2.01E+06$	$1.55E+06$
Be-7	$4.37E+06$	$3.38E+06$			

Table 14.100: Cooling times of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	$1.45E+10$	$1.12E+10$
Mn-54	$6.48E+09$	$5.01E+09$
Co-56	$4.07E+09$	$3.15E+09$
Co-57	$1.98E+08$	$1.53E+08$
V-49	$1.66E+08$	$1.28E+08$
Cr-51	$9.52E+07$	$7.36E+07$
Co-58	$1.07E+07$	$8.25E+06$
H-3	$8.25E+06$	$6.38E+06$

14.4.2 100MeV

Table 14.101: Cooling times for EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.15E+09	3.10E+10	Cr-51	1.15E+09	3.09E+10
Fe-55	8.84E+08	2.38E+10	Fe-55	8.84E+08	2.38E+10
Mn-54	8.36E+08	2.25E+10	Mn-54	8.36E+08	2.25E+10
Co-56	7.47E+08	2.01E+10	Co-56	7.47E+08	2.01E+10
Fe-53	5.87E+08	1.58E+10	Mn-52	5.80E+08	1.56E+10
Mn-52	5.83E+08	1.57E+10	Co-55	2.26E+08	6.07E+09
Mn-52m	5.20E+08	1.40E+10	V-49	2.04E+08	5.49E+09
Fe-53m	2.94E+08	7.90E+09	V-48	1.94E+08	5.22E+09
Co-55	2.34E+08	6.31E+09	Mn-51	7.95E+07	2.14E+09
V-49	2.04E+08	5.49E+09	Mn-52m	7.25E+07	1.95E+09
Mn-51	1.96E+08	5.27E+09	Cr-49	5.09E+07	1.37E+09
V-48	1.94E+08	5.23E+09	Mn-56	2.73E+07	7.35E+08
Cr-49	1.36E+08	3.65E+09	Fe-52	2.46E+07	6.62E+08
Mn-56	3.57E+07	9.62E+08	Sc-46	1.36E+07	3.66E+08
Fe-52	2.68E+07	7.20E+08	Ti-45	1.24E+07	3.35E+08
Fe-52m	2.68E+07	7.20E+08	Co-57	1.13E+07	3.03E+08
V-47	2.39E+07	6.42E+08	Sc-44	9.85E+06	2.65E+08
Co-54	2.17E+07	5.83E+08	Cr-48	7.43E+06	2.00E+08
Co-54m	2.17E+07	5.83E+08	V-47	6.65E+06	1.79E+08
Ti-45	1.56E+07	4.19E+08	H-3	5.65E+06	1.52E+08
Sc-46	1.36E+07	3.67E+08	Fe-53	5.39E+06	1.45E+08
Sc-45m	1.27E+07	3.42E+08	Sc-44m	5.31E+06	1.43E+08
Co-57	1.13E+07	3.03E+08	Sc-47	3.22E+06	8.67E+07
Sc-44	1.07E+07	2.89E+08	Co-58	2.94E+06	7.90E+07
Cr-48	7.69E+06	2.07E+08	Be-7	2.44E+06	6.58E+07
Sc-46m	7.58E+06	2.04E+08	Sc-43	1.92E+06	5.16E+07
Mn-50	7.10E+06	1.91E+08	Co-58m	1.46E+06	3.93E+07
Mn-50m	7.10E+06	1.91E+08	Sc-48	6.91E+05	1.86E+07
V-52	5.91E+06	1.59E+08	K-42	5.72E+05	1.54E+07
H-3	5.65E+06	1.52E+08	Ca-45	5.46E+05	1.47E+07
Sc-44m	5.39E+06	1.45E+08	Ar-37	3.17E+05	8.53E+06
Sc-47	3.25E+06	8.74E+07	C-11	1.24E+05	3.34E+06
Co-58	2.94E+06	7.91E+07	S-35	1.13E+05	3.04E+06
Be-7	2.44E+06	6.58E+07	P-32	9.55E+04	2.57E+06
Sc-43	2.29E+06	6.17E+07	Na-24	9.10E+04	2.45E+06
V-46	1.85E+06	4.97E+07	F-18	6.54E+04	1.76E+06
Co-58m	1.58E+06	4.24E+07	K-43	6.17E+04	1.66E+06
Mn-57	1.27E+06	3.43E+07			
He-6	1.02E+06	2.74E+07			
C-11	9.55E+05	2.57E+07			
V-46m	9.25E+05	2.49E+07			
P-30	8.58E+05	2.31E+07			
V-53	7.32E+05	1.97E+07			
Sc-48	7.02E+05	1.89E+07			
K-42	6.06E+05	1.63E+07			
Ca-45	5.46E+05	1.47E+07			
Fe-51	5.42E+05	1.46E+07			

Table 14.102: Cooling times of 1 day and 1 week

1 day (86400s)			1 week (604800s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.12E+09	3.02E+10	Cr-51	9.66E+08	2.60E+10
Fe-55	8.84E+08	2.38E+10	Fe-55	8.81E+08	2.37E+10
Mn-54	8.36E+08	2.25E+10	Mn-54	8.25E+08	2.22E+10
Co-56	7.39E+08	1.99E+10	Co-56	7.02E+08	1.89E+10
Mn-52	5.16E+08	1.39E+10	Mn-52	2.45E+08	6.60E+09
V-49	2.04E+08	5.48E+09	V-49	2.01E+08	5.41E+09
V-48	1.86E+08	5.01E+09	V-48	1.44E+08	3.87E+09
Co-55	9.07E+07	2.44E+09	Sc-46	1.29E+07	3.46E+08
Sc-46	1.35E+07	3.64E+08	Co-57	1.10E+07	2.97E+08
Co-57	1.12E+07	3.02E+08	H-3	5.61E+06	1.51E+08
H-3	5.65E+06	1.52E+08	Co-58	2.75E+06	7.40E+07
Sc-44	4.38E+06	1.18E+08	Be-7	2.23E+06	6.01E+07
Sc-44m	4.05E+06	1.09E+08	Sc-44	8.03E+05	2.16E+07
Fe-52	3.59E+06	9.65E+07	Sc-47	7.62E+05	2.05E+07
Cr-48	3.55E+06	9.55E+07	Sc-44m	7.39E+05	1.99E+07
Co-58	2.92E+06	7.85E+07	Ca-45	5.31E+05	1.43E+07
Sc-47	2.64E+06	7.11E+07			
Be-7	2.42E+06	6.50E+07			
Ca-45	5.46E+05	1.47E+07			
Sc-48	4.79E+05	1.29E+07			

Table 14.103: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Fe-55	8.66E+08	2.33E+10	Fe-55	8.29E+08	2.23E+10
Mn-54	7.84E+08	2.11E+10	Mn-54	6.84E+08	1.84E+10
Co-56	5.72E+08	1.54E+10	Co-56	3.33E+08	8.97E+09
Cr-51	5.42E+08	1.46E+10	V-49	1.70E+08	4.57E+09
V-49	1.92E+08	5.16E+09	Cr-51	1.21E+08	3.26E+09
V-48	5.31E+07	1.43E+09	Co-57	8.95E+06	2.41E+08
Mn-52	1.42E+07	3.81E+08	Sc-46	6.47E+06	1.74E+08
Sc-46	1.06E+07	2.86E+08	H-3	5.57E+06	1.50E+08
Co-57	1.04E+07	2.80E+08	V-48	3.94E+06	1.06E+08
H-3	5.61E+06	1.51E+08	Co-58	1.22E+06	3.29E+07
Co-58	2.20E+06	5.91E+07	Be-7	7.58E+05	2.04E+07
Be-7	1.65E+06	4.45E+07	Ca-45	3.75E+05	1.01E+07
Ca-45	4.83E+05	1.30E+07	S-35	5.54E+04	1.49E+06
Ar-37	1.75E+05	4.71E+06	Ar-37	5.35E+04	1.44E+06
S-35	8.92E+04	2.40E+06			

Table 14.104: Cooling times of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	<i>7.80E+08</i>	2.10E+10
Mn-54	<i>5.61E+08</i>	1.51E+10
Co-56	<i>1.49E+08</i>	4.00E+09
V-49	<i>1.41E+08</i>	3.80E+09
Cr-51	<i>1.27E+07</i>	3.43E+08
Co-57	<i>7.10E+06</i>	1.91E+08
H-3	<i>5.46E+06</i>	1.47E+08
Sc-46	<i>3.07E+06</i>	8.27E+07
Co-58	<i>5.05E+05</i>	1.36E+07
Ca-45	<i>2.55E+05</i>	6.87E+06
Be-7	<i>2.35E+05</i>	6.33E+06
V-48	<i>7.88E+04</i>	2.12E+06

14.4.3 150MeV

Table 14.105: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	2.85E+08	6.93E+10	Cr-51	2.85E+08	6.92E+10
Mn-54	1.58E+08	3.83E+10	Mn-54	1.58E+08	3.83E+10
Fe-55	1.47E+08	3.57E+10	Fe-55	1.47E+08	3.57E+10
Mn-52	1.30E+08	3.15E+10	Mn-52	1.29E+08	3.13E+10
Fe-53	1.15E+08	2.80E+10	Co-56	9.54E+07	2.32E+10
Mn-52m	1.14E+08	2.76E+10	V-48	7.73E+07	1.88E+10
Co-56	9.54E+07	2.32E+10	V-49	6.25E+07	1.52E+10
V-48	7.78E+07	1.89E+10	Co-55	3.12E+07	7.59E+09
V-49	6.25E+07	1.52E+10	Mn-51	2.11E+07	5.14E+09
Fe-53m	5.76E+07	1.40E+10	Cr-49	1.60E+07	3.89E+09
Mn-51	5.18E+07	1.26E+10	Mn-52m	1.58E+07	3.84E+09
Cr-49	4.28E+07	1.04E+10	Mn-56	1.04E+07	2.53E+09
Co-55	3.25E+07	7.90E+09	Sc-44	9.30E+06	2.26E+09
Mn-56	1.36E+07	3.31E+09	Ti-45	8.39E+06	2.04E+09
V-47	1.27E+07	3.08E+09	Sc-46	6.66E+06	1.62E+09
Ti-45	1.05E+07	2.56E+09	Fe-52	6.46E+06	1.57E+09
Sc-44	1.01E+07	2.46E+09	Sc-44m	5.02E+06	1.22E+09
Sc-45m	7.82E+06	1.90E+09	V-47	3.54E+06	8.61E+08
Fe-52	7.04E+06	1.71E+09	Cr-48	2.97E+06	7.22E+08
Fe-52m	7.04E+06	1.71E+09	Sc-47	2.25E+06	5.47E+08
Sc-46	6.66E+06	1.62E+09	H-3	2.10E+06	5.11E+08
Sc-44m	5.10E+06	1.24E+09	Sc-43	1.87E+06	4.54E+08
Sc-46m	3.72E+06	9.05E+08	Co-57	1.52E+06	3.70E+08
Co-54	3.43E+06	8.34E+08	Be-7	1.34E+06	3.25E+08
Co-54m	3.43E+06	8.34E+08	Fe-53	1.06E+06	2.57E+08
Cr-48	3.07E+06	7.46E+08	Ar-37	7.49E+05	1.82E+08
Sc-47	2.27E+06	5.52E+08	Sc-48	5.88E+05	1.43E+08
Sc-43	2.23E+06	5.43E+08	Ca-45	5.51E+05	1.34E+08
V-52	2.23E+06	5.41E+08	K-42	4.94E+05	1.20E+08
Mn-50	2.22E+06	5.40E+08			
Mn-50m	2.22E+06	5.40E+08			
H-3	2.10E+06	5.11E+08			
Co-57	1.52E+06	3.70E+08			
Be-7	1.34E+06	3.25E+08			
V-46	1.32E+06	3.21E+08			
Ar-37	7.49E+05	1.82E+08			
V-46m	6.62E+05	1.61E+08			
Sc-48	5.97E+05	1.45E+08			
He-6	5.97E+05	1.45E+08			
Ca-45	5.51E+05	1.34E+08			
C-11	5.39E+05	1.31E+08			
K-42	5.22E+05	1.27E+08			
Mn-57	5.06E+05	1.23E+08			

Table 14.106: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	2.78E+08	6.76E+10	Cr-51	2.39E+08	5.82E+10
Mn-54	1.57E+08	3.82E+10	Mn-54	1.55E+08	3.77E+10
Fe-55	1.47E+08	3.57E+10	Fe-55	1.46E+08	3.56E+10
Mn-52	1.15E+08	2.79E+10	Co-56	8.97E+07	2.18E+10
Co-56	9.46E+07	2.30E+10	V-49	6.17E+07	1.50E+10
V-48	7.45E+07	1.81E+10	V-48	5.76E+07	1.40E+10
V-49	6.25E+07	1.52E+10	Mn-52	5.47E+07	1.33E+10
Co-55	1.26E+07	3.06E+09	Sc-46	6.29E+06	1.53E+09
Sc-46	6.62E+06	1.61E+09	H-3	2.10E+06	5.11E+08
Sc-44	4.16E+06	1.01E+09	Co-57	1.49E+06	3.63E+08
Sc-44m	3.83E+06	9.31E+08	Be-7	1.22E+06	2.97E+08
H-3	2.10E+06	5.11E+08	Sc-44	7.65E+05	1.86E+08
Sc-47	1.85E+06	4.49E+08	Sc-44m	6.95E+05	1.69E+08
Co-57	1.52E+06	3.69E+08	Ar-37	6.50E+05	1.58E+08
Cr-48	1.42E+06	3.45E+08	Sc-47	5.35E+05	1.30E+08
Be-7	1.32E+06	3.21E+08	Ca-45	5.35E+05	1.30E+08
Fe-52	9.42E+05	2.29E+08	Co-58	2.89E+05	7.03E+07
Ar-37	7.32E+05	1.78E+08	S-35	1.72E+05	4.17E+07
Ca-45	5.47E+05	1.33E+08	P-32	1.30E+05	3.17E+07
Sc-48	4.07E+05	9.90E+07	P-33	9.59E+04	2.33E+07
Co-58	3.07E+05	7.45E+07	Co-55	4.24E+04	1.03E+07
S-35	1.80E+05	4.37E+07	Sc-48	4.16E+04	1.01E+07
P-32	1.75E+05	4.25E+07	Ti-44	2.52E+04	6.13E+06
K-42	1.36E+05	3.30E+07	Cr-48	1.38E+04	3.36E+06
P-33	1.13E+05	2.75E+07	Fe-59	6.25E+03	1.52E+06
K-43	6.71E+04	1.63E+07	Na-22	3.82E+03	9.28E+05
Ti-45	4.73E+04	1.15E+07	Ca-47	2.42E+03	5.88E+05

Table 14.107: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Mn-54	1.47E+08	3.58E+10	Fe-55	1.38E+08	3.36E+10
Fe-55	1.44E+08	3.50E+10	Mn-54	1.29E+08	3.13E+10
Cr-51	1.35E+08	3.27E+10	V-49	5.18E+07	1.26E+10
Co-56	7.32E+07	1.78E+10	Co-56	4.28E+07	1.04E+10
V-49	5.88E+07	1.43E+10	Cr-51	3.00E+07	7.29E+09
V-48	2.11E+07	5.14E+09	Sc-46	3.17E+06	7.71E+08
Sc-46	5.22E+06	1.27E+09	H-3	2.07E+06	5.04E+08
Mn-52	3.16E+06	7.67E+08	V-48	1.57E+06	3.81E+08
H-3	2.09E+06	5.09E+08	Co-57	1.21E+06	2.94E+08
Co-57	1.41E+06	3.42E+08	Be-7	4.16E+05	1.01E+08
Be-7	9.05E+05	2.20E+08	Ca-45	3.76E+05	9.13E+07
Ca-45	4.85E+05	1.18E+08	Co-58	1.28E+05	3.12E+07
Ar-37	4.11E+05	1.00E+08	Ar-37	1.26E+05	3.06E+07
Co-58	2.31E+05	5.61E+07	S-35	8.89E+04	2.16E+07
S-35	1.43E+05	3.47E+07	Sc-44	2.51E+04	6.11E+06
P-33	5.10E+04	1.24E+07	Ti-44	2.51E+04	6.11E+06
P-32	4.28E+04	1.04E+07	P-33	9.92E+03	2.41E+06

Table 14.108: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	<i>1.30E+08</i>	3.15E+10
Mn-54	<i>1.06E+08</i>	2.57E+10
V-49	<i>4.32E+07</i>	1.05E+10
Co-56	<i>1.90E+07</i>	4.62E+09
Cr-51	<i>3.16E+06</i>	7.67E+08
H-3	<i>2.04E+06</i>	4.97E+08
Sc-46	<i>1.51E+06</i>	3.66E+08
Co-57	<i>9.63E+05</i>	2.34E+08
Ca-45	<i>2.57E+05</i>	6.24E+07
Be-7	<i>1.29E+05</i>	3.13E+07
Co-58	<i>5.31E+04</i>	1.29E+07
S-35	<i>4.36E+04</i>	1.06E+07
V-48	<i>3.15E+04</i>	7.66E+06
Sc-44	<i>2.50E+04</i>	6.08E+06
Ti-44	<i>2.50E+04</i>	6.08E+06
Ar-37	<i>2.13E+04</i>	5.17E+06

14.4.4 200MeV

Table 14.109: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.03E+08	1.12E+11	Cr-51	1.03E+08	1.12E+11
Mn-54	5.36E+07	5.82E+10	Mn-54	5.36E+07	5.82E+10
Fe-55	4.62E+07	5.02E+10	Fe-55	4.62E+07	5.02E+10
Mn-52	4.43E+07	4.81E+10	Mn-52	4.41E+07	4.79E+10
Mn-52m	3.88E+07	4.21E+10	V-48	3.43E+07	3.73E+10
Fe-53	3.70E+07	4.02E+10	V-49	2.57E+07	2.79E+10
V-48	3.44E+07	3.74E+10	Co-56	2.39E+07	2.60E+10
V-49	2.57E+07	2.79E+10	Co-55	8.35E+06	9.07E+09
Co-56	2.39E+07	2.60E+10	Mn-51	7.72E+06	8.38E+09
Mn-51	1.90E+07	2.06E+10	Cr-49	6.55E+06	7.11E+09
Fe-53m	1.85E+07	2.01E+10	Mn-56	5.83E+06	6.33E+09
Cr-49	1.75E+07	1.90E+10	Sc-44	5.63E+06	6.11E+09
Co-55	8.68E+06	9.43E+09	Mn-52m	5.40E+06	5.87E+09
Mn-56	7.62E+06	8.28E+09	Ti-45	4.51E+06	4.90E+09
V-47	6.41E+06	6.96E+09	Sc-46	3.52E+06	3.82E+09
Sc-44	6.13E+06	6.66E+09	Sc-44m	3.04E+06	3.30E+09
Ti-45	5.65E+06	6.14E+09	Fe-52	2.22E+06	2.41E+09
Sc-45m	4.37E+06	4.75E+09	V-47	1.79E+06	1.94E+09
Sc-46	3.52E+06	3.82E+09	Cr-48	1.43E+06	1.55E+09
Sc-44m	3.08E+06	3.34E+09	Sc-47	1.36E+06	1.48E+09
Fe-52	2.41E+06	2.62E+09	Sc-43	1.26E+06	1.37E+09
Fe-52m	2.41E+06	2.62E+09			
Sc-46m	1.96E+06	2.13E+09			
Sc-43	1.50E+06	1.63E+09			
Cr-48	1.47E+06	1.60E+09			
Sc-47	1.37E+06	1.49E+09			
V-52	9.67E+05	1.05E+09			
Co-54	9.58E+05	1.04E+09			
Co-54m	9.58E+05	1.04E+09			

Table 14.110: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.01E+08	1.10E+11	Cr-51	8.69E+07	9.44E+10
Mn-54	5.35E+07	5.81E+10	Mn-54	5.28E+07	5.73E+10
Fe-55	4.61E+07	5.01E+10	Fe-55	4.59E+07	4.99E+10
Mn-52	3.92E+07	4.26E+10	V-48	2.54E+07	2.76E+10
V-48	3.30E+07	3.58E+10	V-49	2.53E+07	2.75E+10
V-49	2.56E+07	2.78E+10	Co-56	2.26E+07	2.45E+10
Co-56	2.38E+07	2.58E+10	Mn-52	1.87E+07	2.03E+10
Sc-46	3.49E+06	3.79E+09	Sc-46	3.31E+06	3.60E+09
Co-55	3.36E+06	3.65E+09	H-3	9.06E+05	9.84E+08
Sc-44	2.51E+06	2.73E+09	Be-7	7.09E+05	7.70E+08
Sc-44m	2.31E+06	2.51E+09	Ar-37	5.95E+05	6.46E+08
Sc-47	1.11E+06	1.21E+09	Sc-44	4.63E+05	5.03E+08
H-3	9.07E+05	9.85E+08	Sc-44m	4.22E+05	4.58E+08
Be-7	7.67E+05	8.33E+08	Co-57	4.04E+05	4.39E+08
Cr-48	6.83E+05	7.42E+08	Sc-47	3.23E+05	3.51E+08
Ar-37	6.69E+05	7.27E+08	Ca-45	2.92E+05	3.17E+08
Co-57	4.11E+05	4.46E+08	P-32	1.40E+05	1.52E+08
Fe-52	3.23E+05	3.51E+08	S-35	1.24E+05	1.35E+08
Ca-45	2.99E+05	3.25E+08			
Sc-48	2.03E+05	2.21E+08			
P-32	1.87E+05	2.03E+08			
S-35	1.31E+05	1.42E+08			
K-42	9.67E+04	1.05E+08			

Table 14.111: Cooling times 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Mn-54	5.01E+07	5.44E+10	Mn-54	4.38E+07	4.76E+10
Cr-51	4.89E+07	5.31E+10	Fe-55	4.34E+07	4.71E+10
Fe-55	4.52E+07	4.91E+10	V-49	2.14E+07	2.32E+10
V-49	2.41E+07	2.62E+10	Cr-51	1.09E+07	1.18E+10
Co-56	1.83E+07	1.99E+10	Co-56	1.07E+07	1.16E+10
V-48	9.39E+06	1.02E+10	Sc-46	1.67E+06	1.81E+09
Sc-46	2.74E+06	2.98E+09	H-3	8.94E+05	9.71E+08
Mn-52	1.08E+06	1.17E+09	V-48	6.94E+05	7.54E+08
H-3	9.02E+05	9.80E+08	Co-57	3.27E+05	3.55E+08
Be-7	5.26E+05	5.71E+08	Be-7	2.41E+05	2.62E+08
Co-57	3.81E+05	4.14E+08	Ca-45	2.05E+05	2.23E+08
Ar-37	3.78E+05	4.10E+08	Ar-37	1.15E+05	1.25E+08
Ca-45	2.64E+05	2.87E+08			
S-35	1.04E+05	1.13E+08			

Table 14.112: Cooling time of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	<i>4.08E+07</i>	4.43E+10
Mn-54	<i>3.59E+07</i>	3.90E+10
V-49	<i>1.78E+07</i>	1.93E+10
Co-56	<i>4.77E+06</i>	5.18E+09
Cr-51	<i>1.14E+06</i>	1.24E+09
H-3	<i>8.82E+05</i>	9.58E+08
Sc-46	<i>7.93E+05</i>	8.61E+08
Co-57	<i>2.60E+05</i>	2.82E+08
Ca-45	<i>1.40E+05</i>	1.52E+08

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Table 14.113: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	4.78E+07	1.63E+11	Cr-51	4.78E+07	1.63E+11
Mn-54	2.48E+07	8.44E+10	Mn-54	2.48E+07	8.44E+10
Fe-55	2.00E+07	6.83E+10	Fe-55	2.00E+07	6.83E+10
Mn-52	1.94E+07	6.62E+10	Mn-52	1.93E+07	6.59E+10
V-48	1.71E+07	5.83E+10	V-48	1.71E+07	5.82E+10
Mn-52m	1.70E+07	5.79E+10	V-49	1.24E+07	4.24E+10
Fe-53	1.57E+07	5.37E+10	Co-56	8.48E+06	2.89E+10
V-49	1.24E+07	4.24E+10	Mn-56	3.75E+06	1.28E+10
Mn-51	8.74E+06	2.98E+10	Mn-51	3.55E+06	1.21E+10
Co-56	8.48E+06	2.89E+10	Sc-44	3.43E+06	1.17E+10
Cr-49	8.36E+06	2.85E+10	Cr-49	3.14E+06	1.07E+10
Fe-53m	7.86E+06	2.68E+10	Co-55	2.93E+06	1.00E+10
Mn-56	4.90E+06	1.67E+10	Ti-45	2.57E+06	8.77E+09
Sc-44	3.72E+06	1.27E+10	Mn-52m	2.37E+06	8.07E+09
V-47	3.31E+06	1.13E+10	Sc-46	2.02E+06	6.89E+09
Ti-45	3.23E+06	1.10E+10	Sc-44m	1.85E+06	6.30E+09
Co-55	3.05E+06	1.04E+10	Fe-52	9.77E+05	3.33E+09
Sc-45m	2.52E+06	8.60E+09	V-47	9.27E+05	3.16E+09
Sc-46	2.02E+06	6.89E+09	Sc-43	8.18E+05	2.79E+09
Sc-44m	1.87E+06	6.37E+09	Sc-47	7.92E+05	2.70E+09
Sc-46m	1.13E+06	3.84E+09	Cr-48	7.07E+05	2.41E+09
Fe-52	1.06E+06	3.62E+09	Be-7	4.81E+05	1.64E+09
Fe-52m	1.06E+06	3.62E+09	H-3	4.78E+05	1.63E+09
Sc-43	9.77E+05	3.33E+09	Ar-37	4.60E+05	1.57E+09
Sc-47	8.01E+05	2.73E+09	K-42	2.54E+05	8.66E+08
Cr-48	7.30E+05	2.49E+09	Ca-45	1.81E+05	6.17E+08
V-52	5.28E+05	1.80E+09	Sc-48	1.73E+05	5.91E+08
Be-7	4.81E+05	1.64E+09	P-32	1.67E+05	5.71E+08
H-3	4.78E+05	1.63E+09	Fe-53	1.45E+05	4.93E+08
Ar-37	4.63E+05	1.58E+09	Co-57	1.41E+05	4.81E+08
V-46	4.34E+05	1.48E+09	S-35	1.14E+05	3.88E+08
Mn-50	4.19E+05	1.43E+09	P-33	7.77E+04	2.65E+08
Mn-50m	4.19E+05	1.43E+09	K-43	7.54E+04	2.57E+08
Co-54	3.52E+05	1.20E+09			

Table 14.114: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	4.66E+07	1.59E+11	Cr-51	4.02E+07	1.37E+11
Mn-54	2.47E+07	8.42E+10	Mn-54	2.44E+07	8.31E+10
Fe-55	2.00E+07	6.82E+10	Fe-55	1.99E+07	6.80E+10
Mn-52	1.72E+07	5.87E+10	V-48	1.26E+07	4.31E+10
V-48	1.64E+07	5.59E+10	V-49	1.23E+07	4.18E+10
V-49	1.24E+07	4.23E+10	Mn-52	8.18E+06	2.79E+10
Co-56	8.39E+06	2.86E+10	Co-56	7.95E+06	2.71E+10
Sc-46	2.00E+06	6.83E+09	Sc-46	1.91E+06	6.50E+09
Sc-44	1.53E+06	5.20E+09	H-3	4.78E+05	1.63E+09
Sc-44m	1.41E+06	4.80E+09	Be-7	4.40E+05	1.50E+09
Co-55	1.18E+06	4.03E+09	Ar-37	4.02E+05	1.37E+09
Sc-47	6.51E+05	2.22E+09	Sc-44	2.81E+05	9.58E+08
H-3	4.78E+05	1.63E+09	Sc-44m	2.56E+05	8.74E+08
Be-7	4.75E+05	1.62E+09	Sc-47	1.88E+05	6.42E+08
Ar-37	4.52E+05	1.54E+09	Ca-45	1.76E+05	5.99E+08
Cr-48	3.37E+05	1.15E+09	Co-57	1.38E+05	4.72E+08
Ca-45	1.80E+05	6.14E+08	P-32	1.19E+05	4.07E+08
P-32	1.60E+05	5.45E+08	S-35	1.08E+05	3.67E+08
Fe-52	1.42E+05	4.85E+08	P-33	6.42E+04	2.19E+08
Co-57	1.41E+05	4.80E+08	Co-58		
Sc-48	1.20E+05	4.10E+08	Sc-48		
S-35	1.13E+05	3.85E+08	Ti-44		
P-33	7.57E+04	2.58E+08	Co-55		
K-42	6.98E+04	2.38E+08	Cr-48		
K-43	3.70E+04	1.26E+08	Fe-59		

Table 14.115: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Mn-54	2.32E+07	7.90E+10	Mn-54	2.03E+07	6.91E+10
Cr-51	2.26E+07	7.69E+10	Fe-55	1.88E+07	6.41E+10
Fe-55	1.96E+07	6.69E+10	V-49	1.04E+07	3.53E+10
V-49	1.17E+07	3.99E+10	Cr-51	5.01E+06	1.71E+10
Co-56	6.48E+06	2.21E+10	Co-56	3.78E+06	1.29E+10
V-48	4.66E+06	1.59E+10	Sc-46	9.59E+05	3.27E+09
Sc-46	1.58E+06	5.38E+09	H-3	4.72E+05	1.61E+09
H-3	4.75E+05	1.62E+09	V-48	3.46E+05	1.18E+09
Mn-52	4.72E+05	1.61E+09	Be-7	1.49E+05	5.09E+08
Be-7	3.26E+05	1.11E+09	Ca-45	1.24E+05	4.22E+08
Ar-37	2.55E+05	8.70E+08	Co-57	1.12E+05	3.82E+08
Ca-45	1.59E+05	5.43E+08	Ar-37	7.80E+04	2.66E+08
Co-57	1.31E+05	4.45E+08	S-35	5.57E+04	1.90E+08
S-35	8.97E+04	3.06E+08	Co-58	1.00E+04	3.42E+07
P-32	3.90E+04	1.33E+08	Sc-44	9.53E+03	3.25E+07
P-33	3.43E+04	1.17E+08	Ti-44	9.53E+03	3.25E+07
Co-58	1.80E+04	6.15E+07	P-33	6.63E+03	2.26E+07
Sc-44	9.94E+03	3.39E+07			
Ti-44	9.56E+03	3.26E+07			

Table 14.116: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	<i>1.77E+07</i>	6.03E+10
Mn-54	<i>1.66E+07</i>	5.66E+10
V-49	<i>8.59E+06</i>	2.93E+10
Co-56	<i>1.68E+06</i>	5.74E+09
Cr-51	<i>5.28E+05</i>	1.80E+09
H-3	<i>4.66E+05</i>	1.59E+09
Sc-46	<i>4.55E+05</i>	1.55E+09
Co-57	<i>8.92E+04</i>	3.04E+08
Ca-45	<i>8.45E+04</i>	2.88E+08
Be-7	<i>4.63E+04</i>	1.58E+08
S-35	<i>2.74E+04</i>	9.33E+07
Ar-37	<i>1.31E+04</i>	4.48E+07
Sc-44	<i>9.50E+03</i>	3.24E+07
Ti-44	<i>9.50E+03</i>	3.24E+07
V-48	<i>6.95E+03</i>	2.37E+07
Co-58	<i>4.16E+03</i>	1.42E+07

14.4.6 300MeV

Table 14.117: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	2.65E+07	2.18E+11	Cr-51	2.65E+07	2.18E+11
Mn-54	1.42E+07	1.17E+11	Mn-54	1.42E+07	1.17E+11
Fe-55	1.10E+07	9.02E+10	Fe-55	1.10E+07	9.02E+10
Mn-52	1.03E+07	8.47E+10	Mn-52	1.02E+07	8.43E+10
V-48	1.00E+07	8.23E+10	V-48	9.97E+06	8.21E+10
Mn-52m	9.03E+06	7.43E+10	V-49	7.12E+06	5.86E+10
Fe-53	8.35E+06	6.87E+10	Co-56	3.80E+06	3.13E+10
V-49	7.12E+06	5.86E+10	Mn-56	2.70E+06	2.22E+10
Cr-49	4.73E+06	3.89E+10	Sc-44	2.21E+06	1.82E+10
Mn-51	4.65E+06	3.83E+10	Mn-51	1.90E+06	1.56E+10
Fe-53m	4.17E+06	3.43E+10	Cr-49	1.77E+06	1.46E+10
Co-56	3.80E+06	3.13E+10	Ti-45	1.64E+06	1.35E+10
Mn-56	3.54E+06	2.91E+10	Co-55	1.38E+06	1.14E+10
Sc-44	2.42E+06	1.99E+10	Sc-46	1.28E+06	1.05E+10
Ti-45	2.05E+06	1.69E+10	Mn-52m	1.25E+06	1.03E+10
V-47	1.96E+06	1.61E+10	Sc-44m	1.20E+06	9.85E+09
Sc-45m	1.60E+06	1.32E+10	V-47	5.48E+05	4.51E+09
Co-55	1.43E+06	1.18E+10	Sc-43	5.43E+05	4.47E+09
Sc-46	1.28E+06	1.05E+10	Fe-52	5.10E+05	4.20E+09
Sc-44m	1.21E+06	9.97E+09	Sc-47	5.02E+05	4.13E+09
Sc-46m	7.14E+05	5.88E+09	Cr-48	4.13E+05	3.40E+09
Sc-43	6.49E+05	5.34E+09	Ar-37	3.62E+05	2.98E+09
Fe-52	5.55E+05	4.57E+09	Be-7	3.33E+05	2.74E+09
Fe-52m	5.55E+05	4.57E+09	H-3	2.92E+05	2.40E+09
Sc-47	5.07E+05	4.17E+09	K-42	1.80E+05	1.48E+09
Cr-48	4.26E+05	3.51E+09	P-32	1.38E+05	1.14E+09
Ar-37	3.62E+05	2.98E+09	Ca-45	1.23E+05	1.01E+09
V-52	3.46E+05	2.85E+09			
Be-7	3.34E+05	2.75E+09			
H-3	2.92E+05	2.40E+09			
V-46	2.60E+05	2.14E+09			
Mn-50	2.41E+05	1.98E+09			
Mn-50m	2.41E+05	1.98E+09			
K-42	1.91E+05	1.57E+09			
Co-54	1.68E+05	1.38E+09			
Co-54m	1.68E+05	1.38E+09			
He-6	1.47E+05	1.21E+09			
C-11	1.41E+05	1.16E+09			

Table 14.118: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	2.58E+07	2.12E+11	Cr-51	2.22E+07	1.83E+11
Mn-54	1.42E+07	1.17E+11	Mn-54	1.40E+07	1.15E+11
Fe-55	1.10E+07	9.02E+10	Fe-55	1.09E+07	8.98E+10
V-48	9.59E+06	7.89E+10	V-48	7.40E+06	6.09E+10
Mn-52	9.12E+06	7.51E+10	V-49	7.02E+06	5.78E+10
V-49	7.11E+06	5.85E+10	Mn-52	4.34E+06	3.57E+10
Co-56	3.77E+06	3.10E+10	Co-56	3.57E+06	2.94E+10
Sc-46	1.28E+06	1.05E+10	Sc-46	1.21E+06	9.95E+09
Sc-44	9.88E+05	8.13E+09	Ar-37	3.15E+05	2.59E+09
Sc-44m	9.11E+05	7.50E+09	Be-7	3.05E+05	2.51E+09
Co-55	5.56E+05	4.58E+09	H-3	2.92E+05	2.40E+09
Sc-47	4.12E+05	3.39E+09	Sc-44	1.82E+05	1.50E+09
Ar-37	3.55E+05	2.92E+09	Sc-44m	1.66E+05	1.37E+09
Be-7	3.29E+05	2.71E+09			
H-3	2.92E+05	2.40E+09			
Cr-48	1.97E+05	1.62E+09			
P-32	1.32E+05	1.09E+09			
Ca-45	1.23E+05	1.01E+09			

Table 14.119: Cooling Times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Mn-54	1.32E+07	1.09E+11	Mn-54	1.16E+07	9.58E+10
Cr-51	1.25E+07	1.03E+11	Fe-55	1.03E+07	8.48E+10
Fe-55	1.07E+07	8.84E+10	V-49	5.92E+06	4.87E+10
V-49	6.69E+06	5.51E+10	Cr-51	2.78E+06	2.29E+10
Co-56	2.90E+06	2.39E+10	Co-56	1.69E+06	1.39E+10
V-48	2.72E+06	2.24E+10	Sc-46	6.09E+05	5.01E+09
Sc-46	1.00E+06	8.23E+09	H-3	2.87E+05	2.36E+09
H-3	2.90E+05	2.39E+09	V-48	2.02E+05	1.66E+09
Mn-52	2.50E+05	2.06E+09	Be-7	1.04E+05	8.52E+08
Be-7	2.26E+05	1.86E+09	Ca-45	8.41E+04	6.92E+08
Ar-37	1.99E+05	1.64E+09	Ar-37	6.10E+04	5.02E+08
Ca-45	1.08E+05	8.92E+08	Co-57	4.96E+04	4.08E+08
S-35	6.96E+04	5.73E+08	S-35	4.33E+04	3.56E+08
Co-57	5.78E+04	4.76E+08			
P-32	3.22E+04	2.65E+08			
P-33	2.98E+04	2.45E+08			

Table 14.120: Cooling time of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	<i>9.67E+06</i>	7.96E+10
Mn-54	<i>9.52E+06</i>	7.84E+10
V-49	<i>4.92E+06</i>	4.05E+10
Co-56	<i>7.56E+05</i>	6.22E+09
Cr-51	<i>2.93E+05</i>	2.41E+09
Sc-46	<i>2.89E+05</i>	2.38E+09
H-3	<i>2.83E+05</i>	2.33E+09
Ca-45	<i>5.75E+04</i>	4.73E+08
Co-57	<i>3.95E+04</i>	3.25E+08
Be-7	<i>3.21E+04</i>	2.64E+08
S-35	<i>2.13E+04</i>	1.75E+08

14.4.7 350MeV

Table 14.121: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.58E+07	2.80E+11	Cr-51	1.58E+07	2.80E+11
Mn-54	8.92E+06	1.58E+11	Mn-54	8.92E+06	1.58E+11
Fe-55	6.61E+06	1.17E+11	Fe-55	6.61E+06	1.17E+11
V-48	6.10E+06	1.08E+11	V-48	6.10E+06	1.08E+11
Mn-52	5.99E+06	1.06E+11	Mn-52	5.99E+06	1.06E+11
Mn-52m	5.27E+06	9.33E+10	V-49	4.34E+06	7.68E+10
Fe-53	4.76E+06	8.43E+10	Mn-56	2.03E+06	3.60E+10
V-49	4.34E+06	7.68E+10	Co-56	1.88E+06	3.33E+10
Cr-49	2.84E+06	5.02E+10	Sc-44	1.45E+06	2.57E+10
Mn-51	2.74E+06	4.85E+10	Mn-51	1.11E+06	1.97E+10
Mn-56	2.65E+06	4.70E+10	Cr-49	1.06E+06	1.88E+10
Fe-53m	2.38E+06	4.21E+10	Ti-45	1.06E+06	1.87E+10
Co-56	1.88E+06	3.33E+10	Sc-46	8.47E+05	1.50E+10
Sc-44	1.58E+06	2.80E+10	Sc-44m	7.85E+05	1.39E+10
Ti-45	1.32E+06	2.34E+10	Mn-52m	7.34E+05	1.30E+10
V-47	1.21E+06	2.15E+10	Co-55	6.89E+05	1.22E+10
Sc-45m	1.04E+06	1.85E+10	Sc-43	3.71E+05	6.57E+09
Sc-46	8.47E+05	1.50E+10	Sc-47	3.43E+05	6.07E+09
Sc-44m	7.91E+05	1.40E+10	V-47	3.40E+05	6.02E+09
Co-55	7.17E+05	1.27E+10	Fe-52	2.91E+05	5.15E+09
Sc-46m	4.73E+05	8.38E+09	Ar-37	2.71E+05	4.79E+09
Sc-43	4.43E+05	7.85E+09	Cr-48	2.54E+05	4.50E+09
Sc-47	3.46E+05	6.12E+09	Be-7	2.31E+05	4.09E+09
Fe-52	3.16E+05	5.60E+09	H-3	1.90E+05	3.36E+09
Fe-52m	3.16E+05	5.60E+09	K-42	1.33E+05	2.35E+09
Ar-37	2.71E+05	4.79E+09	P-32	1.14E+05	2.01E+09
Cr-48	2.63E+05	4.65E+09	Ca-45	8.53E+04	1.51E+09
Be-7	2.31E+05	4.09E+09	Sc-48	7.62E+04	1.35E+09
V-52	2.28E+05	4.04E+09	S-35	7.00E+04	1.24E+09
H-3	1.90E+05	3.36E+09	P-33	5.76E+04	1.02E+09
V-46	1.72E+05	3.04E+09	Fe-53	4.37E+04	7.74E+08
K-42	1.41E+05	2.49E+09	K-43	4.01E+04	7.10E+08
Mn-50	1.41E+05	2.49E+09	Co-57	3.17E+04	5.61E+08
Mn-50m	1.41E+05	2.49E+09	Si-31	1.90E+04	3.37E+08
P-32	1.14E+05	2.02E+09	C-11	1.28E+04	2.26E+08
He-6	1.12E+05	1.98E+09	Na-24	9.83E+03	1.74E+08
C-11	9.83E+04	1.74E+09	Cl-38	9.83E+03	1.74E+08
V-46m	8.58E+04	1.52E+09	F-18	9.49E+03	1.68E+08
Ca-45	8.53E+04	1.51E+09	Ar-41	7.45E+03	1.32E+08
Co-54	8.41E+04	1.49E+09	Cl-34m	6.44E+03	1.14E+08
Co-54m	8.41E+04	1.49E+09	Co-58	6.44E+03	1.14E+08
Sc-48	7.74E+04	1.37E+09			
S-35	7.00E+04	1.24E+09			
Mn-57	6.78E+04	1.20E+09			
P-33	5.76E+04	1.02E+09			

Table 14.122: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.54E+07	2.73E+11	Cr-51	1.33E+07	2.35E+11
Mn-54	8.92E+06	1.58E+11	Mn-54	8.81E+06	1.56E+11
Fe-55	6.61E+06	1.17E+11	Fe-55	6.55E+06	1.16E+11
V-48	5.82E+06	1.03E+11	V-48	4.50E+06	7.97E+10
Mn-52	5.31E+06	9.41E+10	V-49	4.28E+06	7.57E+10
V-49	4.33E+06	7.67E+10	Mn-52	2.52E+06	4.47E+10
Co-56	1.86E+06	3.30E+10	Co-56	1.77E+06	3.13E+10
Sc-46	8.41E+05	1.49E+10	Sc-46	8.02E+05	1.42E+10
Sc-44	6.44E+05	1.14E+10	Ar-37	2.35E+05	4.17E+09
Sc-44m	5.99E+05	1.06E+10	Be-7	2.11E+05	3.73E+09
Sc-47	2.81E+05	4.98E+09	H-3	1.90E+05	3.36E+09
Co-55	2.77E+05	4.91E+09	Sc-44	1.19E+05	2.11E+09
Ar-37	2.65E+05	4.70E+09	Sc-44m	1.08E+05	1.92E+09
Be-7	2.28E+05	4.03E+09	Ca-45	8.30E+04	1.47E+09
H-3	1.90E+05	3.36E+09	Sc-47	8.13E+04	1.44E+09
Cr-48	1.21E+05	2.15E+09	P-32	8.13E+04	1.44E+09
P-32	1.08E+05	1.92E+09	S-35	6.61E+04	1.17E+09
Ca-45	8.47E+04	1.50E+09			
S-35	6.95E+04	1.23E+09			

Table 14.123: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Mn-54	8.36E+06	1.48E+11	Mn-54	7.34E+06	1.30E+11
Cr-51	7.45E+06	1.32E+11	Fe-55	6.21E+06	1.10E+11
Fe-55	6.44E+06	1.14E+11	V-49	3.61E+06	6.39E+10
V-49	4.08E+06	7.22E+10	Cr-51	1.67E+06	2.95E+10
V-48	1.66E+06	2.94E+10	Co-56	8.41E+05	1.49E+10
Co-56	1.44E+06	2.55E+10	Sc-46	4.03E+05	7.13E+09
Sc-46	6.61E+05	1.17E+10	H-3	1.87E+05	3.32E+09
H-3	1.89E+05	3.35E+09	V-48	1.23E+05	2.18E+09
Be-7	1.56E+05	2.77E+09	Be-7	7.17E+04	1.27E+09
Ar-37	1.50E+05	2.65E+09	Ca-45	5.82E+04	1.03E+09
Mn-52	1.46E+05	2.58E+09	Ar-37	4.56E+04	8.08E+08
Ca-45	7.51E+04	1.33E+09	S-35	3.42E+04	6.06E+08
S-35	5.50E+04	9.74E+08	Co-57	2.52E+04	4.46E+08
Co-57	2.94E+04	5.20E+08	P-33	4.91E+03	8.69E+07
P-32	2.65E+04	4.70E+08	Sc-44	3.96E+03	7.02E+07
P-33	2.53E+04	4.48E+08	Ti-44	3.96E+03	7.02E+07

Table 14.124: Cooling time of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Mn-54	<i>5.99E+06</i>	1.06E+11
Fe-55	<i>5.82E+06</i>	1.03E+11
V-49	<i>3.00E+06</i>	5.31E+10
Co-56	<i>3.74E+05</i>	6.63E+09
Sc-46	<i>1.91E+05</i>	3.39E+09
H-3	<i>1.85E+05</i>	3.27E+09
Cr-51	<i>1.75E+05</i>	3.10E+09
Ca-45	<i>3.98E+04</i>	7.05E+08
Be-7	<i>2.22E+04</i>	3.93E+08
Co-57	<i>2.00E+04</i>	3.55E+08
S-35	<i>1.68E+04</i>	2.97E+08
Ar-37	<i>7.68E+03</i>	1.36E+08

14.4.8 400MeV

Table 14.125: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.06E+07	3.48E+11	Cr-51	1.06E+07	3.48E+11
Mn-54	6.29E+06	2.06E+11	Mn-54	6.29E+06	2.06E+11
Fe-55	4.52E+06	1.48E+11	Fe-55	4.52E+06	1.48E+11
V-48	4.09E+06	1.34E+11	V-48	4.09E+06	1.34E+11
Mn-52	3.88E+06	1.27E+11	Mn-52	3.88E+06	1.27E+11
Mn-52m	3.42E+06	1.12E+11	V-49	2.92E+06	9.57E+10
Fe-53	3.05E+06	1.00E+11	Mn-56	1.61E+06	5.29E+10
V-49	2.92E+06	9.58E+10	Co-56	1.08E+06	3.54E+10
Mn-56	2.11E+06	6.92E+10	Sc-44	1.07E+06	3.50E+10
Cr-49	1.86E+06	6.09E+10	Ti-45	7.42E+05	2.43E+10
Mn-51	1.77E+06	5.80E+10	Mn-51	7.20E+05	2.36E+10
Fe-53m	1.53E+06	5.02E+10	Cr-49	6.96E+05	2.28E+10
Sc-44	1.16E+06	3.81E+10	Sc-46	6.20E+05	2.03E+10
Co-56	1.08E+06	3.54E+10	Sc-44m	5.77E+05	1.89E+10
Ti-45	9.31E+05	3.05E+10	Mn-52m	4.76E+05	1.56E+10
V-47	8.30E+05	2.72E+10	Co-55	3.91E+05	1.28E+10
Sc-45m	7.51E+05	2.46E+10	Sc-43	2.72E+05	8.90E+09
Sc-46	6.20E+05	2.03E+10	Sc-47	2.57E+05	8.41E+09
Sc-44m	5.83E+05	1.91E+10	V-47	2.32E+05	7.59E+09
Co-55	4.06E+05	1.33E+10	Ar-37	2.17E+05	7.10E+09
Sc-46m	3.45E+05	1.13E+10	Fe-52	1.90E+05	6.22E+09
Sc-43	3.24E+05	1.06E+10	Be-7	1.76E+05	5.77E+09
Sc-47	2.59E+05	8.48E+09	Cr-48	1.70E+05	5.56E+09
Ar-37	2.17E+05	7.10E+09	H-3	1.40E+05	4.58E+09
Fe-52	2.06E+05	6.76E+09	K-42	1.05E+05	3.44E+09
Fe-52m	2.06E+05	6.76E+09	P-32	9.98E+04	3.27E+09
Be-7	1.76E+05	5.77E+09	Ca-45	6.32E+04	2.07E+09
Cr-48	1.75E+05	5.74E+09	S-35	6.13E+04	2.01E+09
V-52	1.72E+05	5.64E+09	Sc-48	5.74E+04	1.88E+09
H-3	1.40E+05	4.58E+09	P-33	5.10E+04	1.67E+09
V-46	1.18E+05	3.86E+09	K-43	3.45E+04	1.13E+09
K-42	1.11E+05	3.64E+09			
P-32	9.98E+04	3.27E+09			
Mn-50	9.22E+04	3.02E+09			
Mn-50m	9.19E+04	3.01E+09			
He-6	8.58E+04	2.81E+09			
C-11	8.15E+04	2.67E+09			
Ca-45	6.32E+04	2.07E+09			
S-35	6.13E+04	2.01E+09			
V-46m	5.89E+04	1.93E+09			
Sc-48	5.83E+04	1.91E+09			
Mn-57	5.16E+04	1.69E+09			
P-33	5.10E+04	1.67E+09			
Co-54	5.07E+04	1.66E+09			
Co-54m	5.07E+04	1.66E+09			
P-30	4.24E+04	1.39E+09			
Be-8	4.09E+04	1.34E+09			
Sc-42	3.72E+04	1.22E+09			
Sc-42m	3.72E+04	1.22E+09			
K-43	3.57E+04	1.17E+09			
Al-28	3.54E+04	1.16E+09			

Table 14.126: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.03E+07	3.39E+11	Cr-51	8.91E+06	2.92E+11
Mn-54	6.29E+06	2.06E+11	Mn-54	6.20E+06	2.03E+11
Fe-55	4.52E+06	1.48E+11	Fe-55	4.49E+06	1.47E+11
V-48	3.94E+06	1.29E+11	V-48	3.03E+06	9.94E+10
Mn-52	3.45E+06	1.13E+11	V-49	2.88E+06	9.44E+10
V-49	2.92E+06	9.56E+10	Mn-52	1.64E+06	5.36E+10
Co-56	1.07E+06	3.51E+10	Co-56	1.01E+06	3.32E+10
Sc-46	6.13E+05	2.01E+10	Sc-46	5.83E+05	1.91E+10
Sc-44	4.76E+05	1.56E+10	Ar-37	1.89E+05	6.18E+09
Sc-44m	4.39E+05	1.44E+10	Be-7	1.61E+05	5.27E+09
Ar-37	2.12E+05	6.96E+09	H-3	1.39E+05	4.57E+09
Sc-47	2.11E+05	6.90E+09	Sc-44	8.76E+04	2.87E+09
Be-7	1.74E+05	5.69E+09	Sc-44m	8.00E+04	2.62E+09
Co-55	1.57E+05	5.16E+09	P-32	7.11E+04	2.33E+09
H-3	1.40E+05	4.58E+09	Ca-45	6.13E+04	2.01E+09
P-32	9.52E+04	3.12E+09	Sc-47	6.13E+04	2.01E+09
Cr-48	8.09E+04	2.65E+09	S-35	5.80E+04	1.90E+09
Ca-45	6.29E+04	2.06E+09	P-33	4.21E+04	1.38E+09
S-35	6.07E+04	1.99E+09	Co-57	1.82E+04	5.97E+08
P-33	4.94E+04	1.62E+09	Sc-48	4.03E+03	1.32E+08
Sc-48	3.97E+04	1.30E+09	Co-58	3.48E+03	1.14E+08
K-42	2.89E+04	9.48E+08	Ti-44	2.86E+03	9.36E+07
Fe-52	2.77E+04	9.06E+08	Fe-59	2.59E+03	8.49E+07
Co-57	1.85E+04	6.07E+08	Na-22	1.58E+03	5.17E+07
K-43	1.69E+04	5.55E+08	Cr-48	7.90E+02	2.59E+07
Sc-43	4.52E+03	1.48E+08	Co-55	5.31E+02	1.74E+07
Ti-45	4.21E+03	1.38E+08	Ca-47	4.76E+02	1.56E+07
Co-58	3.66E+03	1.20E+08	Ar-39	4.03E+02	1.32E+07
Mn-56	3.33E+03	1.09E+08			
Na-24	3.14E+03	1.03E+08			

Table 14.127: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Mn-54	5.89E+06	1.93E+11	Mn-54	5.16E+06	1.69E+11
Cr-51	5.01E+06	1.64E+11	Fe-55	4.24E+06	1.39E+11
Fe-55	4.43E+06	1.45E+11	V-49	2.43E+06	7.96E+10
V-49	2.75E+06	9.00E+10	Cr-51	1.12E+06	3.66E+10
V-48	1.12E+06	3.66E+10	Co-56	4.82E+05	1.58E+10
Co-56	8.24E+05	2.70E+10	Sc-46	2.94E+05	9.63E+09
Sc-46	4.82E+05	1.58E+10	H-3	1.38E+05	4.51E+09
H-3	1.39E+05	4.56E+09	V-48	8.27E+04	2.71E+09
Ar-37	1.20E+05	3.92E+09	Be-7	5.46E+04	1.79E+09
Be-7	1.19E+05	3.90E+09	Ca-45	4.30E+04	1.41E+09
Mn-52	9.46E+04	3.10E+09	Ar-37	3.66E+04	1.20E+09
Ca-45	5.55E+04	1.82E+09	S-35	3.00E+04	9.84E+08
S-35	4.82E+04	1.58E+09	Co-57	1.47E+04	4.83E+08
P-32	2.33E+04	7.62E+08	P-33	4.33E+03	1.42E+08
P-33	2.24E+04	7.35E+08	Sc-44	2.85E+03	9.33E+07
Co-57	1.72E+04	5.63E+08	Ti-44	2.85E+03	9.33E+07
Sc-44	2.98E+03	9.76E+07	Co-58	1.54E+03	5.04E+07
Ti-44	2.85E+03	9.35E+07	Na-22	1.48E+03	4.86E+07
Co-58	2.77E+03	9.08E+07	P-32	1.28E+03	4.18E+07
Fe-59	1.81E+03	5.93E+07	Fe-59	7.11E+02	2.33E+07
Na-22	1.55E+03	5.08E+07	Ar-39	4.03E+02	1.32E+07
Sc-47	5.62E+02	1.84E+07			
Ar-39	4.03E+02	1.32E+07			

Table 14.128: Cooling times of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Mn-54	4.21E+06	1.38E+11
Fe-55	4.00E+06	1.31E+11
V-49	2.02E+06	6.62E+10
Co-56	2.15E+05	7.04E+09
Sc-46	1.39E+05	4.57E+09
H-3	1.36E+05	4.45E+09
Cr-51	1.18E+05	3.85E+09
Ca-45	2.95E+04	9.66E+08
Be-7	1.69E+04	5.55E+08
S-35	1.47E+04	4.82E+08
Co-57	1.17E+04	3.84E+08
Ar-37	6.16E+03	2.02E+08

14.5 Stainless Steel

14.5.1 50MeV

Table 14.129: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	<i>2.32E+10</i>	1.80E+10	Cr-51	<i>2.32E+10</i>	1.80E+10
Co-56	<i>1.65E+10</i>	1.28E+10	Co-56	<i>1.65E+10</i>	1.28E+10
Fe-55	<i>1.14E+10</i>	8.84E+09	Fe-55	<i>1.14E+10</i>	8.84E+09
Mn-54	<i>7.19E+09</i>	5.58E+09	Mn-54	<i>7.19E+09</i>	5.58E+09
Mn-52	<i>5.22E+09</i>	4.05E+09	Mn-52	<i>5.18E+09</i>	4.02E+09
Mn-52m	<i>4.98E+09</i>	3.86E+09	Co-55	<i>3.70E+09</i>	2.87E+09
Co-55	<i>3.86E+09</i>	2.99E+09	Co-57	<i>3.13E+09</i>	2.43E+09
Co-57	<i>3.13E+09</i>	2.43E+09	V-48	<i>1.86E+09</i>	1.44E+09
Fe-53	<i>2.68E+09</i>	2.08E+09	Ni-57	<i>1.47E+09</i>	1.14E+09
Mn-51	<i>2.62E+09</i>	2.03E+09	V-49	<i>1.18E+09</i>	9.13E+08
V-48	<i>1.86E+09</i>	1.44E+09	Mn-51	<i>1.06E+09</i>	8.24E+08
Ni-57	<i>1.50E+09</i>	1.16E+09	Mn-52m	<i>6.94E+08</i>	5.38E+08
Fe-53m	<i>1.34E+09</i>	1.04E+09	Co-58	<i>6.41E+08</i>	4.97E+08
V-49	<i>1.18E+09</i>	9.13E+08	Cr-49	<i>3.37E+08</i>	2.61E+08
Cr-49	<i>8.99E+08</i>	6.97E+08	Co-58m	<i>3.18E+08</i>	2.47E+08
Co-58	<i>6.41E+08</i>	4.97E+08	Cu-61	<i>1.50E+08</i>	1.16E+08
Co-58m	<i>3.44E+08</i>	2.67E+08	Ni-56	<i>1.30E+08</i>	1.01E+08
Cu-60	<i>3.03E+08</i>	2.35E+08			
Cu-62	<i>2.67E+08</i>	2.07E+08			
Co-54	<i>2.63E+08</i>	2.04E+08			
Co-54m	<i>2.63E+08</i>	2.04E+08			
Cu-58	<i>2.58E+08</i>	2.00E+08			
V-47	<i>2.22E+08</i>	1.72E+08			
Al-26m	<i>1.93E+08</i>	1.50E+08			
Si-27	<i>1.90E+08</i>	1.47E+08			
Cu-61	<i>1.84E+08</i>	1.43E+08			
Ni-56	<i>1.30E+08</i>	1.01E+08			

Table 14.130: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	<i>2.27E+10</i>	1.76E+10	Cr-51	<i>1.95E+10</i>	1.51E+10
Co-56	<i>1.64E+10</i>	1.27E+10	Co-56	<i>1.55E+10</i>	1.20E+10
Fe-55	<i>1.14E+10</i>	8.83E+09	Fe-55	<i>1.13E+10</i>	8.80E+09
Mn-54	<i>7.18E+09</i>	5.57E+09	Mn-54	<i>7.08E+09</i>	5.49E+09
Mn-52	<i>4.62E+09</i>	3.58E+09	Co-57	<i>3.08E+09</i>	2.39E+09
Co-57	<i>3.13E+09</i>	2.43E+09	Mn-52	<i>2.19E+09</i>	1.70E+09
V-48	<i>1.78E+09</i>	1.38E+09	V-48	<i>1.37E+09</i>	1.06E+09
Co-55	<i>1.50E+09</i>	1.16E+09	V-49	<i>1.16E+09</i>	9.00E+08
V-49	<i>1.17E+09</i>	9.11E+08	Co-58	<i>6.00E+08</i>	4.65E+08
Ni-57	<i>9.40E+08</i>	7.29E+08	Tc-95m	<i>5.91E+07</i>	4.58E+07
Co-58	<i>6.36E+08</i>	4.93E+08	Ni-56	<i>5.72E+07</i>	4.44E+07
Ni-56	<i>1.16E+08</i>	8.99E+07	Ni-57	<i>5.70E+07</i>	4.42E+07
Tc-96	<i>9.99E+07</i>	7.75E+07	Tc-97m	<i>4.19E+07</i>	3.25E+07
Tc-95m	<i>6.32E+07</i>	4.90E+07	Tc-96	<i>3.78E+07</i>	2.93E+07
Co-58m	<i>5.58E+07</i>	4.33E+07	Sc-46	<i>1.78E+07</i>	1.38E+07
Tc-97m	<i>4.38E+07</i>	3.40E+07	Nb-91m	<i>1.56E+07</i>	1.21E+07
Tc-95	<i>3.16E+07</i>	2.45E+07			
Nb-90	<i>2.31E+07</i>	1.79E+07			
Sc-47	<i>2.06E+07</i>	1.60E+07			
Sc-46	<i>1.87E+07</i>	1.45E+07			
Nb-91m	<i>1.68E+07</i>	1.30E+07			
Sc-44	<i>1.66E+07</i>	1.29E+07			
Sc-44m	<i>1.53E+07</i>	1.19E+07			
Cr-48	<i>1.38E+07</i>	1.07E+07			

Table 14.131: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Co-56	<i>1.26E+10</i>	9.80E+09	Fe-55	<i>1.07E+10</i>	8.30E+09
Fe-55	<i>1.12E+10</i>	8.66E+09	Co-56	<i>7.38E+09</i>	5.72E+09
Cr-51	<i>1.10E+10</i>	8.52E+09	Mn-54	<i>5.89E+09</i>	4.57E+09
Mn-54	<i>6.73E+09</i>	5.22E+09	Co-57	<i>2.50E+09</i>	1.94E+09
Co-57	<i>2.91E+09</i>	2.26E+09	Cr-51	<i>2.45E+09</i>	1.90E+09
V-49	<i>1.11E+09</i>	8.59E+08	V-49	<i>9.79E+08</i>	7.59E+08
V-48	<i>5.05E+08</i>	3.92E+08	Co-58	<i>2.66E+08</i>	2.06E+08
Co-58	<i>4.78E+08</i>	3.71E+08	V-48	<i>3.74E+07</i>	2.90E+07
Mn-52	<i>1.27E+08</i>	9.82E+07	Tc-95m	<i>2.30E+07</i>	1.78E+07
Tc-95m	<i>4.54E+07</i>	3.52E+07	Tc-97m	<i>2.22E+07</i>	1.72E+07
Tc-97m	<i>3.51E+07</i>	2.72E+07	Na-22	<i>1.13E+07</i>	8.74E+06
Sc-46	<i>1.47E+07</i>	1.14E+07	H-3	<i>9.15E+06</i>	7.10E+06

Table 14.132: Cooling times of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	1.01E+10	7.80E+09
Mn-54	4.82E+09	3.74E+09
Co-56	3.29E+09	2.55E+09
Co-57	1.99E+09	1.54E+09
V-49	8.14E+08	6.31E+08
Cr-51	2.58E+08	2.00E+08
Co-58	1.10E+08	8.55E+07
Tc-97m	1.11E+07	8.58E+06
Na-22	1.05E+07	8.18E+06
H-3	9.03E+06	7.00E+06
Tc-95m	8.26E+06	6.41E+06
Zn-65	6.46E+06	5.01E+06
Sc-46	4.24E+06	3.29E+06
W-181	3.46E+06	2.68E+06
Nb-91m	2.18E+06	1.69E+06
Co-60	1.84E+06	1.43E+06
Y-88	1.82E+06	1.41E+06

14.5.2 100MeV

Table 14.133: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.62E+09	4.95E+10	Cr-51	1.62E+09	4.94E+10
Co-56	6.43E+08	1.96E+10	Co-56	6.43E+08	1.96E+10
Fe-55	5.71E+08	1.74E+10	Fe-55	5.71E+08	1.74E+10
Mn-54	5.45E+08	1.66E+10	Mn-54	5.45E+08	1.66E+10
Mn-52	4.69E+08	1.43E+10	Mn-52	4.66E+08	1.42E+10
Mn-52m	4.23E+08	1.29E+10	V-48	3.41E+08	1.04E+10
Fe-53	3.77E+08	1.15E+10	V-49	3.16E+08	9.64E+09
V-48	3.41E+08	1.04E+10	Co-57	1.78E+08	5.42E+09
V-49	3.16E+08	9.64E+09	Co-55	1.74E+08	5.30E+09
Cr-49	2.16E+08	6.57E+09	Ni-57	1.01E+08	3.09E+09
Mn-51	2.01E+08	6.12E+09	Mn-51	8.17E+07	2.49E+09
Fe-53m	1.88E+08	5.72E+09	Cr-49	8.07E+07	2.46E+09
Co-55	1.81E+08	5.51E+09	Mn-52m	5.90E+07	1.80E+09
Co-57	1.78E+08	5.42E+09	Co-58	4.59E+07	1.40E+09
Ni-57	1.03E+08	3.15E+09	Sc-46	2.98E+07	9.07E+08
V-47	4.76E+07	1.45E+09	Ti-45	2.85E+07	8.69E+08
Co-58	4.59E+07	1.40E+09	Sc-44	2.75E+07	8.39E+08
Ti-45	3.58E+07	1.09E+09	Co-58m	2.28E+07	6.96E+08
Sc-45m	3.07E+07	9.35E+08	Fe-52	1.79E+07	5.45E+08
Sc-44	3.00E+07	9.14E+08	Mn-56	1.67E+07	5.08E+08
Sc-46	2.98E+07	9.08E+08	Ni-56	1.56E+07	4.77E+08
Co-58m	2.46E+07	7.51E+08	Sc-44m	1.49E+07	4.53E+08
Mn-56	2.18E+07	6.65E+08	V-47	1.33E+07	4.06E+08
Fe-52	1.94E+07	5.92E+08	Cr-48	1.24E+07	3.78E+08
Fe-52m	1.94E+07	5.92E+08	Sc-47	9.19E+06	2.80E+08
Sc-46m	1.66E+07	5.06E+08	Cu-61	6.66E+06	2.03E+08
Ni-56	1.57E+07	4.80E+08	H-3	5.08E+06	1.55E+08
Co-54	1.53E+07	4.66E+08	Nb-90	5.02E+06	1.53E+08
Co-54m	1.53E+07	4.66E+08	Sc-43	4.40E+06	1.34E+08
Al-26m	1.53E+07	4.65E+08	Zr-89	4.03E+06	1.23E+08
Si-27	1.51E+07	4.59E+08	Y-89m	4.03E+06	1.23E+08
Sc-44m	1.51E+07	4.59E+08	Tc-96	3.64E+06	1.11E+08

V-52	<i>1.45E+07</i>	4.41E+08	Fe-53	<i>3.44E+06</i>	1.05E+08
Cu-62	<i>1.42E+07</i>	4.32E+08	Cu-64	<i>3.31E+06</i>	1.01E+08
Cr-48	<i>1.28E+07</i>	3.90E+08	Be-7	<i>3.31E+06</i>	1.01E+08
Cu-60	<i>1.08E+07</i>	3.28E+08			
Cu-58	<i>1.03E+07</i>	3.14E+08			
Sc-47	<i>9.25E+06</i>	2.82E+08			
Mn-50	<i>9.15E+06</i>	2.79E+08			
Mn-50m	<i>9.15E+06</i>	2.79E+08			
Cu-61	<i>8.20E+06</i>	2.50E+08			
Sc-43	<i>5.25E+06</i>	1.60E+08			
Nb-90	<i>5.18E+06</i>	1.58E+08			
H-3	<i>5.08E+06</i>	1.55E+08			
Mo-91	<i>4.20E+06</i>	1.28E+08			
V-46	<i>4.20E+06</i>	1.28E+08			
Y-89m	<i>4.10E+06</i>	1.25E+08			
Zr-89	<i>4.07E+06</i>	1.24E+08			
Tc-96	<i>3.64E+06</i>	1.11E+08			
Cu-64	<i>3.51E+06</i>	1.07E+08			
Tc-93	<i>3.48E+06</i>	1.06E+08			
Be-7	<i>3.31E+06</i>	1.01E+08			

Table 14.134: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	<i>1.58E+09</i>	4.82E+10	Cr-51	<i>1.36E+09</i>	4.15E+10
Co-56	<i>6.36E+08</i>	1.94E+10	Co-56	<i>6.04E+08</i>	1.84E+10
Fe-55	<i>5.71E+08</i>	1.74E+10	Fe-55	<i>5.68E+08</i>	1.73E+10
Mn-54	<i>5.45E+08</i>	1.66E+10	Mn-54	<i>5.38E+08</i>	1.64E+10
Mn-52	<i>4.17E+08</i>	1.27E+10	V-49	<i>3.12E+08</i>	9.50E+09
V-48	<i>3.27E+08</i>	9.96E+09	V-48	<i>2.52E+08</i>	7.68E+09
V-49	<i>3.16E+08</i>	9.62E+09	Mn-52	<i>1.97E+08</i>	6.02E+09
Co-57	<i>1.77E+08</i>	5.41E+09	Co-57	<i>1.75E+08</i>	5.34E+09
Co-55	<i>6.99E+07</i>	2.13E+09	Co-58	<i>4.30E+07</i>	1.31E+09
Ni-57	<i>6.50E+07</i>	1.98E+09	Sc-46	<i>2.81E+07</i>	8.57E+08
Co-58	<i>4.56E+07</i>	1.39E+09	Ni-56	<i>6.92E+06</i>	2.11E+08
Sc-46	<i>2.95E+07</i>	9.00E+08	H-3	<i>5.08E+06</i>	1.55E+08
Ni-56	<i>1.40E+07</i>	4.26E+08	Ni-57	<i>3.94E+06</i>	1.20E+08
Sc-44	<i>1.23E+07</i>	3.74E+08	Be-7	<i>3.02E+06</i>	9.20E+07
Sc-44m	<i>1.13E+07</i>	3.45E+08	Tc-95m	<i>2.62E+06</i>	7.98E+07
Sc-47	<i>7.51E+06</i>	2.29E+08	Sc-44	<i>2.26E+06</i>	6.90E+07
Cr-48	<i>5.90E+06</i>	1.80E+08	Sc-47	<i>2.18E+06</i>	6.65E+07
H-3	<i>5.08E+06</i>	1.55E+08	Sc-44m	<i>2.06E+06</i>	6.29E+07
Co-58m	<i>4.00E+06</i>	1.22E+08	Nb-91m	<i>2.02E+06</i>	6.17E+07
Zr-89	<i>3.31E+06</i>	1.01E+08	Zr-88	<i>1.88E+06</i>	5.74E+07
Y-89m	<i>3.31E+06</i>	1.01E+08	Ca-45	<i>1.82E+06</i>	5.54E+07

Table 14.135: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	<i>7.64E+08</i>	2.33E+10	Fe-55	<i>5.35E+08</i>	1.63E+10
Fe-55	<i>5.58E+08</i>	1.70E+10	Mn-54	<i>4.46E+08</i>	1.36E+10
Mn-54	<i>5.12E+08</i>	1.56E+10	Co-56	<i>2.87E+08</i>	8.74E+09
Co-56	<i>4.92E+08</i>	1.50E+10	V-49	<i>2.63E+08</i>	8.02E+09
V-49	<i>2.98E+08</i>	9.07E+09	Cr-51	<i>1.71E+08</i>	5.20E+09
Co-57	<i>1.65E+08</i>	5.04E+09	Co-57	<i>1.42E+08</i>	4.32E+09
V-48	<i>9.28E+07</i>	2.83E+09	Co-58	<i>1.91E+07</i>	5.82E+08
Co-58	<i>3.44E+07</i>	1.05E+09	Sc-46	<i>1.41E+07</i>	4.31E+08
Sc-46	<i>2.32E+07</i>	7.08E+08	V-48	<i>6.89E+06</i>	2.10E+08
Mn-52	<i>1.14E+07</i>	3.48E+08	H-3	<i>5.02E+06</i>	1.53E+08
H-3	<i>5.05E+06</i>	1.54E+08	Na-22	<i>1.47E+06</i>	4.49E+07
Be-7	<i>2.24E+06</i>	6.82E+07	Y-88	<i>1.47E+06</i>	4.47E+07
Tc-95m	<i>2.02E+06</i>	6.15E+07	Ca-45	<i>1.28E+06</i>	3.90E+07
Ca-45	<i>1.65E+06</i>	5.03E+07	Be-7	<i>1.03E+06</i>	3.13E+07
Y-88	<i>1.59E+06</i>	4.85E+07	Tc-95m	<i>1.02E+06</i>	3.11E+07
Nb-91m	<i>1.56E+06</i>	4.75E+07	Zr-88	<i>9.45E+05</i>	2.88E+07
Zr-88	<i>1.55E+06</i>	4.74E+07	Nb-91m	<i>7.87E+05</i>	2.40E+07
Na-22	<i>1.54E+06</i>	4.69E+07	Tc-97m	<i>7.22E+05</i>	2.20E+07
Tc-97m	<i>1.15E+06</i>	3.50E+07			
Ar-37	<i>9.45E+05</i>	2.88E+07			
Ni-56	<i>4.63E+05</i>	1.41E+07			
W-181	<i>3.58E+05</i>	1.09E+07			
Zn-65	<i>3.48E+05</i>	1.06E+07			

Table 14.136: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	<i>5.02E+08</i>	1.53E+10
Mn-54	<i>3.67E+08</i>	1.12E+10
V-49	<i>2.18E+08</i>	6.66E+09
Co-56	<i>1.28E+08</i>	3.90E+09
Co-57	<i>1.13E+08</i>	3.44E+09
Cr-51	<i>1.79E+07</i>	5.47E+08
Co-58	<i>7.91E+06</i>	2.41E+08
Sc-46	<i>6.72E+06</i>	2.05E+08
H-3	<i>4.95E+06</i>	1.51E+08
Na-22	<i>1.38E+06</i>	4.20E+07
Y-88	<i>1.10E+06</i>	3.36E+07
Ca-45	<i>8.76E+05</i>	2.67E+07
Zr-88	<i>4.46E+05</i>	1.36E+07
Tc-95m	<i>3.67E+05</i>	1.12E+07
Tc-97m	<i>3.61E+05</i>	1.10E+07

14.5.3 150MeV

Table 14.137: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	3.78E+08	9.21E+10	Cr-51	3.77E+08	9.20E+10
Mn-54	1.18E+08	2.87E+10	Mn-54	1.18E+08	2.87E+10
V-48	1.12E+08	2.72E+10	V-48	1.12E+08	2.72E+10
Fe-55	1.09E+08	2.66E+10	Fe-55	1.09E+08	2.66E+10
Mn-52	1.09E+08	2.66E+10	Mn-52	1.09E+08	2.65E+10
Co-56	1.05E+08	2.56E+10	Co-56	1.05E+08	2.56E+10
Mn-52m	9.72E+07	2.37E+10	V-49	8.94E+07	2.18E+10
V-49	8.94E+07	2.18E+10	Co-57	3.59E+07	8.76E+09
Fe-53	8.65E+07	2.11E+10	Co-55	3.02E+07	7.36E+09
Cr-49	5.95E+07	1.45E+10	Ni-57	2.25E+07	5.48E+09
Mn-51	5.08E+07	1.24E+10	Cr-49	2.22E+07	5.42E+09
Fe-53m	4.35E+07	1.06E+10	Mn-51	2.07E+07	5.06E+09
Co-57	3.59E+07	8.76E+09	Sc-44	1.68E+07	4.09E+09
Co-55	3.14E+07	7.66E+09	Mn-52m	1.35E+07	3.30E+09
Ni-57	2.29E+07	5.58E+09	Ti-45	1.35E+07	3.29E+09
V-47	1.94E+07	4.73E+09	Sc-46	1.21E+07	2.94E+09
Sc-44	1.82E+07	4.45E+09	Co-58	1.00E+07	2.44E+09
Ti-45	1.69E+07	4.13E+09	Sc-44m	9.06E+06	2.21E+09
Sc-45m	1.39E+07	3.38E+09	Mn-56	7.05E+06	1.72E+09
Sc-46	1.21E+07	2.94E+09	V-47	5.41E+06	1.32E+09
Co-58	1.00E+07	2.44E+09	Co-58m	4.96E+06	1.21E+09
Mn-56	9.27E+06	2.26E+09	Fe-52	4.80E+06	1.17E+09
Sc-44m	9.14E+06	2.23E+09	Cr-48	4.39E+06	1.07E+09
Sc-46m	6.72E+06	1.64E+09	Sc-47	4.35E+06	1.06E+09
Co-58m	5.37E+06	1.31E+09			
V-52	5.29E+06	1.29E+09			
Fe-52	5.21E+06	1.27E+09			
Fe-52m	5.21E+06	1.27E+09			
Cr-48	4.55E+06	1.11E+09			
Sc-47	4.39E+06	1.07E+09			

Table 14.138: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	3.68E+08	8.98E+10	Cr-51	3.17E+08	7.73E+10
Mn-54	1.17E+08	2.86E+10	Mn-54	1.16E+08	2.83E+10
Fe-55	1.09E+08	2.66E+10	Fe-55	1.09E+08	2.65E+10
V-48	1.07E+08	2.61E+10	Co-56	9.88E+07	2.41E+10
Co-56	1.04E+08	2.54E+10	V-49	8.82E+07	2.15E+10
Mn-52	9.68E+07	2.36E+10	V-48	8.28E+07	2.02E+10
V-49	8.94E+07	2.18E+10	Mn-52	4.59E+07	1.12E+10
Co-57	3.59E+07	8.75E+09	Co-57	3.54E+07	8.63E+09
Ni-57	1.44E+07	3.50E+09	Sc-46	1.14E+07	2.77E+09
Co-55	1.21E+07	2.96E+09	Co-58	9.39E+06	2.29E+09
Sc-46	1.19E+07	2.91E+09	H-3	2.04E+06	4.98E+08
Co-58	9.92E+06	2.42E+09	Ni-56	1.64E+06	3.99E+08
Sc-44	7.46E+06	1.82E+09	Be-7	1.57E+06	3.83E+08
Sc-44m	6.89E+06	1.68E+09	Sc-44	1.37E+06	3.35E+08
Sc-47	3.56E+06	8.67E+08	Ar-37	1.32E+06	3.21E+08
Ni-56	3.31E+06	8.08E+08	Sc-44m	1.25E+06	3.06E+08
Cr-48	2.10E+06	5.12E+08	Sc-47	1.03E+06	2.51E+08
H-3	2.05E+06	4.99E+08	Ca-45	9.23E+05	2.25E+08
Be-7	1.70E+06	4.14E+08	Ni-57	8.69E+05	2.12E+08
Ar-37	1.48E+06	3.61E+08	Zr-88	6.40E+05	1.56E+08
Zr-89	1.05E+06	2.56E+08	Y-88	5.17E+05	1.26E+08
Y-89m	1.05E+06	2.56E+08	Nb-91m	4.84E+05	1.18E+08
Ca-45	9.43E+05	2.30E+08			
Co-58m	8.73E+05	2.13E+08			
Fe-52	6.97E+05	1.70E+08			
Zr-88	6.72E+05	1.64E+08			
Sc-48	6.31E+05	1.54E+08			
Y-87	5.33E+05	1.30E+08			
Nb-91m	5.21E+05	1.27E+08			
Nb-90	5.17E+05	1.26E+08			
Y-88	5.08E+05	1.24E+08			
Tc-96	4.39E+05	1.07E+08			

Table 14.139: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.78E+08	4.35E+10	Fe-55	1.03E+08	2.50E+10
Mn-54	1.10E+08	2.69E+10	Mn-54	9.64E+07	2.35E+10
Fe-55	1.07E+08	2.61E+10	V-49	7.42E+07	1.81E+10
V-49	8.41E+07	2.05E+10	Co-56	4.72E+07	1.15E+10
Co-56	8.04E+07	1.96E+10	Cr-51	3.97E+07	9.69E+09
Co-57	3.34E+07	8.14E+09	Co-57	2.87E+07	6.99E+09
V-48	3.05E+07	7.43E+09	Sc-46	5.70E+06	1.39E+09
Sc-46	9.39E+06	2.29E+09	Co-58	4.14E+06	1.01E+09
Co-58	7.46E+06	1.82E+09	V-48	2.26E+06	5.50E+08
Mn-52	2.66E+06	6.48E+08	H-3	2.02E+06	4.92E+08
H-3	2.03E+06	4.96E+08	Ca-45	6.48E+05	1.58E+08
Be-7	1.16E+06	2.84E+08	Be-7	5.33E+05	1.30E+08
Ca-45	8.37E+05	2.04E+08	Y-88	4.88E+05	1.19E+08
Ar-37	8.37E+05	2.04E+08	Na-22	3.48E+05	8.49E+07
Zr-88	5.29E+05	1.29E+08	Zr-88	3.21E+05	7.83E+07
Y-88	5.25E+05	1.28E+08	Ar-37	2.55E+05	6.21E+07

Table 14.140: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	9.64E+07	2.35E+10
Mn-54	7.87E+07	1.92E+10
V-49	6.19E+07	1.51E+10
Co-57	2.28E+07	5.55E+09
Co-56	2.10E+07	5.11E+09
Cr-51	4.18E+06	1.02E+09
Sc-46	2.71E+06	6.62E+08
H-3	1.99E+06	4.85E+08
Co-58	1.72E+06	4.20E+08
Ca-45	4.43E+05	1.08E+08
Y-88	3.68E+05	8.98E+07
Na-22	3.26E+05	7.95E+07
Be-7	1.65E+05	4.03E+07
Zr-88	1.52E+05	3.71E+07
S-35	6.97E+04	1.70E+07

14.5.4 200MeV

Table 14.141: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.30E+08	1.42E+11	Cr-51	1.29E+08	1.41E+11
V-48	4.47E+07	4.87E+10	V-48	4.46E+07	4.86E+10
Mn-54	4.00E+07	4.36E+10	Mn-54	4.00E+07	4.36E+10
Mn-52	3.65E+07	3.98E+10	Mn-52	3.64E+07	3.97E+10
Fe-55	3.43E+07	3.74E+10	Fe-55	3.43E+07	3.74E+10
V-49	3.39E+07	3.69E+10	V-49	3.39E+07	3.69E+10
Mn-52m	3.23E+07	3.52E+10	Co-56	2.89E+07	3.15E+10
Co-56	2.89E+07	3.15E+10	Co-57	1.17E+07	1.27E+10
Fe-53	2.80E+07	3.05E+10	Co-55	8.68E+06	9.46E+09
Cr-49	2.19E+07	2.39E+10	Sc-44	8.42E+06	9.17E+09
Mn-51	1.74E+07	1.90E+10	Cr-49	8.22E+06	8.96E+09
Fe-53m	1.39E+07	1.52E+10	Ni-57	7.56E+06	8.24E+09
Co-57	1.17E+07	1.27E+10	Mn-51	7.09E+06	7.73E+09
Sc-44	9.16E+06	9.98E+09	Ti-45	6.53E+06	7.11E+09
Co-55	9.03E+06	9.84E+09	Sc-46	5.62E+06	6.12E+09
V-47	8.23E+06	8.97E+09	Sc-44m	4.54E+06	4.95E+09
Ti-45	8.17E+06	8.90E+09	Mn-52m	4.50E+06	4.90E+09
Ni-57	7.71E+06	8.40E+09	Mn-56	4.11E+06	4.48E+09
Sc-45m	6.61E+06	7.20E+09	Co-58	3.52E+06	3.84E+09
Sc-46	5.63E+06	6.13E+09	V-47	2.30E+06	2.51E+09
Mn-56	5.38E+06	5.86E+09	Sc-47	2.13E+06	2.32E+09
Sc-44m	4.60E+06	5.01E+09	Sc-43	1.91E+06	2.08E+09
Co-58	3.52E+06	3.84E+09	Cr-48	1.82E+06	1.98E+09
Sc-46m	3.14E+06	3.42E+09	Co-58m	1.75E+06	1.91E+09
V-52	2.75E+06	3.00E+09	Fe-52	1.70E+06	1.85E+09
Sc-43	2.29E+06	2.49E+09	Ni-56	1.22E+06	1.33E+09
Sc-47	2.15E+06	2.34E+09	Ar-37	1.06E+06	1.16E+09
Co-58m	1.89E+06	2.06E+09	Be-7	9.64E+05	1.05E+09
Cr-48	1.88E+06	2.05E+09	H-3	9.18E+05	1.00E+09
Fe-52	1.84E+06	2.01E+09			
Fe-52m	1.84E+06	2.01E+09			
Ni-56	1.22E+06	1.33E+09			
Si-27	1.17E+06	1.27E+09			
Al-26m	1.16E+06	1.26E+09			
Ar-37	1.06E+06	1.16E+09			
V-46	1.05E+06	1.14E+09			
Be-7	9.64E+05	1.05E+09			
Mn-50	9.64E+05	1.05E+09			
Mn-50m	9.64E+05	1.05E+09			
H-3	9.18E+05	1.00E+09			

Table 14.142: Cooling times 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.27E+08	1.38E+11	Cr-51	1.09E+08	1.19E+11
V-48	4.29E+07	4.67E+10	Mn-54	3.94E+07	4.29E+10
Mn-54	3.99E+07	4.35E+10	Fe-55	3.41E+07	3.72E+10
Fe-55	3.43E+07	3.74E+10	V-49	3.33E+07	3.63E+10
V-49	3.38E+07	3.68E+10	V-48	3.30E+07	3.60E+10
Mn-52	3.24E+07	3.53E+10	Co-56	2.73E+07	2.97E+10
Co-56	2.87E+07	3.13E+10	Mn-52	1.54E+07	1.68E+10
Co-57	1.17E+07	1.27E+10	Co-57	1.15E+07	1.25E+10
Sc-46	5.57E+06	6.07E+09	Sc-46	5.30E+06	5.78E+09
Ni-57	4.84E+06	5.27E+09	Co-58	3.30E+06	3.60E+09
Sc-44	3.75E+06	4.09E+09	Ar-37	9.27E+05	1.01E+09
Co-58	3.50E+06	3.81E+09	H-3	9.18E+05	1.00E+09
Co-55	3.50E+06	3.81E+09			
Sc-44m	3.46E+06	3.77E+09			
Sc-47	1.74E+06	1.90E+09			
Ni-56	1.09E+06	1.19E+09			
Ar-37	1.05E+06	1.14E+09			
Be-7	9.54E+05	1.04E+09			
H-3	9.18E+05	1.00E+09			

Table 14.143: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	6.13E+07	6.68E+10	Mn-54	3.28E+07	3.57E+10
Mn-54	3.74E+07	4.08E+10	Fe-55	3.22E+07	3.51E+10
Fe-55	3.36E+07	3.66E+10	V-49	2.82E+07	3.07E+10
V-49	3.18E+07	3.47E+10	Cr-51	1.37E+07	1.49E+10
Co-56	2.22E+07	2.42E+10	Co-56	1.29E+07	1.41E+10
V-48	1.22E+07	1.33E+10	Co-57	9.27E+06	1.01E+10
Co-57	1.08E+07	1.18E+10	Sc-46	2.67E+06	2.91E+09
Sc-46	4.39E+06	4.78E+09	Co-58	1.47E+06	1.60E+09
Co-58	2.63E+06	2.87E+09	H-3	9.09E+05	9.91E+08
H-3	9.18E+05	1.00E+09	V-48	9.01E+05	9.82E+08
Mn-52	8.90E+05	9.70E+08	Ca-45	3.50E+05	3.81E+08
Be-7	6.55E+05	7.14E+08	Be-7	3.00E+05	3.27E+08
Ar-37	5.88E+05	6.41E+08	Y-88	2.37E+05	2.58E+08
Ca-45	4.52E+05	4.92E+08	Ar-37	1.80E+05	1.96E+08
Y-88	2.55E+05	2.78E+08	Zr-88	1.54E+05	1.68E+08
Zr-88	2.53E+05	2.76E+08	Na-22	1.17E+05	1.28E+08
S-35	1.62E+05	1.76E+08	S-35	1.00E+05	1.09E+08
Nb-91m	1.56E+05	1.70E+08			
Na-22	1.23E+05	1.34E+08			

Table 14.144: Cooling time of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	<i>3.03E+07</i>	3.30E+10
Mn-54	<i>2.68E+07</i>	2.92E+10
V-49	<i>2.34E+07</i>	2.55E+10
Co-57	<i>7.38E+06</i>	8.04E+09
Co-56	<i>5.77E+06</i>	6.29E+09
Cr-51	<i>1.44E+06</i>	1.57E+09
Sc-46	<i>1.27E+06</i>	1.38E+09
H-3	<i>8.97E+05</i>	9.77E+08
Co-58	<i>6.08E+05</i>	6.62E+08
Ca-45	<i>2.40E+05</i>	2.61E+08
Y-88	<i>1.78E+05</i>	1.94E+08
Na-22	<i>1.10E+05</i>	1.20E+08
Be-7	<i>9.27E+04</i>	1.01E+08

14.5.5 250MeV

Table 14.145: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	6.25E+07	2.01E+11	Cr-51	6.25E+07	2.01E+11
V-48	2.26E+07	7.27E+10	V-48	2.26E+07	7.26E+10
Mn-54	1.96E+07	6.30E+10	Mn-54	1.96E+07	6.30E+10
Mn-52	1.69E+07	5.43E+10	V-49	1.68E+07	5.41E+10
V-49	1.68E+07	5.41E+10	Mn-52	1.68E+07	5.40E+10
Fe-55	1.59E+07	5.10E+10	Fe-55	1.59E+07	5.10E+10
Mn-52m	1.48E+07	4.77E+10	Co-56	1.19E+07	3.83E+10
Fe-53	1.27E+07	4.10E+10	Co-57	5.44E+06	1.75E+10
Co-56	1.19E+07	3.83E+10	Sc-44	5.07E+06	1.63E+10
Cr-49	1.08E+07	3.47E+10	Cr-49	4.04E+06	1.30E+10
Mn-51	8.27E+06	2.66E+10	Ti-45	3.64E+06	1.17E+10
Fe-53m	6.37E+06	2.05E+10	Ni-57	3.51E+06	1.13E+10
Sc-44	5.50E+06	1.77E+10	Co-55	3.48E+06	1.12E+10
Co-57	5.44E+06	1.75E+10	Mn-51	3.36E+06	1.08E+10
Ti-45	4.54E+06	1.46E+10	Sc-46	3.11E+06	1.00E+10
V-47	4.35E+06	1.40E+10	Mn-56	2.86E+06	9.20E+09
Mn-56	3.73E+06	1.20E+10	Sc-44m	2.73E+06	8.79E+09
Sc-45m	3.73E+06	1.20E+10	Mn-52m	2.07E+06	6.65E+09
Co-55	3.64E+06	1.17E+10	Co-58	1.72E+06	5.52E+09
Ni-57	3.61E+06	1.16E+10	Sc-47	1.24E+06	3.98E+09
Sc-46	3.11E+06	1.00E+10	V-47	1.22E+06	3.91E+09
Sc-44m	2.76E+06	8.89E+09	Sc-43	1.16E+06	3.74E+09
Sc-46m	1.74E+06	5.59E+09	Cr-48	9.11E+05	2.93E+09
V-52	1.72E+06	5.54E+09	Co-58m	8.55E+05	2.75E+09
Co-58	1.72E+06	5.52E+09	Fe-52	8.21E+05	2.64E+09
Sc-43	1.39E+06	4.48E+09	Ar-37	7.15E+05	2.30E+09
Sc-47	1.25E+06	4.01E+09	Be-7	5.91E+05	1.90E+09
Cr-48	9.42E+05	3.03E+09	Ni-56	5.47E+05	1.76E+09
Co-58m	9.20E+05	2.96E+09	H-3	5.04E+05	1.62E+09
Fe-52	8.92E+05	2.87E+09	K-42	4.26E+05	1.37E+09
Fe-52m	8.92E+05	2.87E+09			
Ar-37	7.15E+05	2.30E+09			
Be-7	5.91E+05	1.90E+09			
V-46	5.63E+05	1.81E+09			
Al-26m	5.53E+05	1.78E+09			
Ni-56	5.50E+05	1.77E+09			
Si-27	5.47E+05	1.76E+09			
H-3	5.04E+05	1.62E+09			
Mn-50	4.66E+05	1.50E+09			
Mn-50m	4.66E+05	1.50E+09			
K-42	4.51E+05	1.45E+09			
Cu-62	3.76E+05	1.21E+09			
Co-54	3.48E+05	1.12E+09			
Co-54m	3.48E+05	1.12E+09			

Table 14.146: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	6.09E+07	1.96E+11	Cr-51	5.25E+07	1.69E+11
V-48	2.17E+07	6.97E+10	Mn-54	1.93E+07	6.20E+10
Mn-54	1.95E+07	6.28E+10	V-48	1.67E+07	5.38E+10
V-49	1.68E+07	5.40E+10	V-49	1.66E+07	5.34E+10
Fe-55	1.59E+07	5.10E+10	Fe-55	1.58E+07	5.08E+10
Mn-52	1.50E+07	4.81E+10	Co-56	1.12E+07	3.61E+10
Co-56	1.18E+07	3.80E+10	Mn-52	7.12E+06	2.29E+10
Co-57	5.41E+06	1.74E+10	Co-57	5.35E+06	1.72E+10
Sc-46	3.09E+06	9.94E+09	Sc-46	2.94E+06	9.46E+09
Sc-44	2.25E+06	7.25E+09	Co-58	1.61E+06	5.17E+09
Ni-57	2.25E+06	7.24E+09	Ar-37	6.22E+05	2.00E+09
Sc-44m	2.08E+06	6.70E+09	Be-7	5.38E+05	1.73E+09
Co-58	1.70E+06	5.48E+09	H-3	5.04E+05	1.62E+09
Co-55	1.41E+06	4.52E+09	Sc-44	4.13E+05	1.33E+09
Sc-47	1.01E+06	3.26E+09	Sc-44m	3.79E+05	1.22E+09
Ar-37	7.00E+05	2.25E+09			
Be-7	5.81E+05	1.87E+09			
H-3	5.04E+05	1.62E+09			
Ni-56	4.88E+05	1.57E+09			
Cr-48	4.35E+05	1.40E+09			

Table 14.147: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	2.95E+07	9.50E+10	Mn-54	1.60E+07	5.16E+10
Mn-54	1.83E+07	5.89E+10	Fe-55	1.49E+07	4.79E+10
V-49	1.58E+07	5.09E+10	V-49	1.40E+07	4.50E+10
Fe-55	1.55E+07	5.00E+10	Cr-51	6.59E+06	2.12E+10
Co-56	9.14E+06	2.94E+10	Co-56	5.35E+06	1.72E+10
V-48	6.16E+06	1.98E+10	Co-57	4.32E+06	1.39E+10
Co-57	5.04E+06	1.62E+10	Sc-46	1.48E+06	4.76E+09
Sc-46	2.43E+06	7.82E+09	Co-58	7.15E+05	2.30E+09
Co-58	1.28E+06	4.13E+09	H-3	4.97E+05	1.60E+09
H-3	5.04E+05	1.62E+09	V-48	4.57E+05	1.47E+09
Mn-52	4.10E+05	1.32E+09	Ca-45	2.09E+05	6.72E+08
Be-7	3.98E+05	1.28E+09	Be-7	1.83E+05	5.88E+08
Ar-37	3.95E+05	1.27E+09	Ar-37	1.20E+05	3.87E+08
Ca-45	2.69E+05	8.66E+08	Y-88	1.18E+05	3.78E+08
S-35	1.36E+05	4.37E+08	S-35	8.43E+04	2.71E+08
Y-88	1.28E+05	4.12E+08	Zr-88	7.46E+04	2.40E+08
Zr-88	1.23E+05	3.95E+08	Na-22	5.63E+04	1.81E+08
Nb-91m	8.15E+04	2.62E+08	Nb-91m	4.10E+04	1.32E+08
P-32	6.28E+04	2.02E+08			
Na-22	5.88E+04	1.89E+08			
P-33	5.57E+04	1.79E+08			
Sr-85	4.88E+04	1.57E+08			

Table 14.148: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	<i>1.40E+07</i>	4.50E+10
Mn-54	<i>1.31E+07</i>	4.22E+10
V-49	<i>1.16E+07</i>	3.74E+10
Co-57	<i>3.45E+06</i>	1.11E+10
Co-56	<i>2.38E+06</i>	7.66E+09
Sc-46	<i>7.03E+05</i>	2.26E+09
Cr-51	<i>6.93E+05</i>	2.23E+09
H-3	<i>4.91E+05</i>	1.58E+09
Co-58	<i>2.96E+05</i>	9.51E+08
Ca-45	<i>1.43E+05</i>	4.59E+08
Y-88	<i>8.80E+04</i>	2.83E+08
Be-7	<i>5.66E+04</i>	1.82E+08
Na-22	<i>5.25E+04</i>	1.69E+08
S-35	<i>4.13E+04</i>	1.33E+08
Zr-88	<i>3.54E+04</i>	1.14E+08

14.5.6 300MeV

Table 14.149: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	3.26E+07	2.69E+11	Cr-51	3.26E+07	2.69E+11
V-48	1.21E+07	9.96E+10	V-48	1.20E+07	9.94E+10
Mn-54	1.07E+07	8.81E+10	Mn-54	1.07E+07	8.81E+10
V-49	8.86E+06	7.32E+10	V-49	8.86E+06	7.32E+10
Mn-52	8.44E+06	6.97E+10	Mn-52	8.40E+06	6.94E+10
Fe-55	8.16E+06	6.74E+10	Fe-55	8.16E+06	6.74E+10
Mn-52m	7.41E+06	6.12E+10	Co-56	5.50E+06	4.54E+10
Fe-53	6.35E+06	5.24E+10	Sc-44	2.92E+06	2.41E+10
Cr-49	5.57E+06	4.60E+10	Co-57	2.82E+06	2.33E+10
Co-56	5.50E+06	4.54E+10	Cr-49	2.08E+06	1.72E+10
Mn-51	4.12E+06	3.40E+10	Ti-45	2.06E+06	1.70E+10
Sc-44	3.18E+06	2.63E+10	Mn-56	1.94E+06	1.60E+10
Fe-53m	3.16E+06	2.61E+10	Ni-57	1.79E+06	1.48E+10
Co-57	2.82E+06	2.33E+10	Sc-46	1.79E+06	1.48E+10
Ti-45	2.58E+06	2.13E+10	Mn-51	1.67E+06	1.38E+10
Mn-56	2.53E+06	2.09E+10	Co-55	1.61E+06	1.33E+10
V-47	2.36E+06	1.95E+10	Sc-44m	1.57E+06	1.30E+10
Sc-45m	2.14E+06	1.77E+10	Mn-52m	1.03E+06	8.53E+09
Ni-57	1.83E+06	1.51E+10	Co-58	9.17E+05	7.57E+09
Sc-46	1.79E+06	1.48E+10	Sc-47	7.46E+05	6.16E+09
Co-55	1.67E+06	1.38E+10	Sc-43	7.06E+05	5.83E+09
Sc-44m	1.60E+06	1.32E+10	V-47	6.60E+05	5.45E+09
V-52	1.08E+06	8.95E+09	Cr-48	4.87E+05	4.02E+09
Sc-46m	9.97E+05	8.23E+09	Ar-37	4.76E+05	3.93E+09
Co-58	9.17E+05	7.57E+09	Co-58m	4.57E+05	3.77E+09
Sc-43	8.44E+05	6.97E+09	Fe-52	4.13E+05	3.41E+09
Sc-47	7.52E+05	6.21E+09	Be-7	3.54E+05	2.92E+09
Cr-48	5.03E+05	4.15E+09	H-3	2.92E+05	2.41E+09
Co-58m	4.92E+05	4.06E+09	K-42	2.77E+05	2.29E+09
Ar-37	4.77E+05	3.94E+09	Ni-56	2.72E+05	2.25E+09
Fe-52	4.49E+05	3.71E+09	P-32	1.93E+05	1.59E+09
Fe-52m	4.49E+05	3.71E+09	Ca-45	1.86E+05	1.54E+09
Be-7	3.54E+05	2.92E+09	Sc-48	1.77E+05	1.46E+09
V-46	3.22E+05	2.66E+09	Zr-89	1.22E+05	1.01E+09

Al-26m	<i>2.94E+05</i>	2.43E+09	Y-89m	<i>1.22E+05</i>	1.01E+09
K-42	<i>2.93E+05</i>	2.42E+09	Nb-90	<i>1.22E+05</i>	1.01E+09
H-3	<i>2.92E+05</i>	2.41E+09			
Ni-56	<i>2.74E+05</i>	2.26E+09			
Si-27	<i>2.70E+05</i>	2.23E+09			
Mn-50	<i>2.40E+05</i>	1.98E+09			
Mn-50m	<i>2.40E+05</i>	1.98E+09			
Al-28	<i>2.07E+05</i>	1.71E+09			
Cu-62	<i>1.96E+05</i>	1.62E+09			
P-32	<i>1.94E+05</i>	1.60E+09			
Ca-45	<i>1.86E+05</i>	1.54E+09			
Sc-48	<i>1.80E+05</i>	1.49E+09			
He-6	<i>1.61E+05</i>	1.33E+09			
V-46m	<i>1.61E+05</i>	1.33E+09			
Co-54	<i>1.60E+05</i>	1.32E+09			
Co-54m	<i>1.60E+05</i>	1.32E+09			
C-11	<i>1.60E+05</i>	1.32E+09			

Table 14.150: Cooling times of 1 day and 1 month

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	<i>3.17E+07</i>	2.62E+11	Cr-51	<i>2.74E+07</i>	2.26E+11
V-48	<i>1.16E+07</i>	9.55E+10	Mn-54	<i>1.05E+07</i>	8.67E+10
Mn-54	<i>1.06E+07</i>	8.79E+10	V-48	<i>8.92E+06</i>	7.37E+10
V-49	<i>8.85E+06</i>	7.31E+10	V-49	<i>8.74E+06</i>	7.22E+10
Fe-55	<i>8.16E+06</i>	6.74E+10	Fe-55	<i>8.13E+06</i>	6.71E+10
Mn-52	<i>7.48E+06</i>	6.18E+10	Co-56	<i>5.17E+06</i>	4.27E+10
Co-56	<i>5.45E+06</i>	4.50E+10	Mn-52	<i>3.56E+06</i>	2.94E+10
Co-57	<i>2.82E+06</i>	2.33E+10	Co-57	<i>2.79E+06</i>	2.30E+10
Sc-46	<i>1.77E+06</i>	1.46E+10	Sc-46	<i>1.68E+06</i>	1.39E+10
Sc-44	<i>1.30E+06</i>	1.07E+10	Co-58	<i>8.59E+05</i>	7.09E+09
Sc-44m	<i>1.20E+06</i>	9.92E+09	Ar-37	<i>4.15E+05</i>	3.43E+09
Ni-57	<i>1.14E+06</i>	9.44E+09	Be-7	<i>3.23E+05</i>	2.67E+09
Co-58	<i>9.09E+05</i>	7.51E+09	H-3	<i>2.92E+05</i>	2.41E+09
Co-55	<i>6.47E+05</i>	5.34E+09	Sc-44	<i>2.40E+05</i>	1.98E+09
Sc-47	<i>6.11E+05</i>	5.05E+09	Sc-44m	<i>2.19E+05</i>	1.81E+09
Ar-37	<i>4.67E+05</i>	3.86E+09	Ca-45	<i>1.80E+05</i>	1.49E+09
Be-7	<i>3.49E+05</i>	2.88E+09	Sc-47	<i>1.77E+05</i>	1.46E+09
H-3	<i>2.92E+05</i>	2.41E+09	P-32	<i>1.38E+05</i>	1.14E+09
Ni-56	<i>2.43E+05</i>	2.01E+09			
Cr-48	<i>2.32E+05</i>	1.92E+09			
Ca-45	<i>1.85E+05</i>	1.53E+09			
P-32	<i>1.84E+05</i>	1.52E+09			
Sc-48	<i>1.24E+05</i>	1.02E+09			

Table 14.151: Cooling times of **1 month** and **3 months**

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	<i>1.54E+07</i>	1.27E+11	Mn-54	<i>8.73E+06</i>	7.21E+10
Mn-54	<i>9.98E+06</i>	8.24E+10	Fe-55	<i>7.66E+06</i>	6.33E+10
V-49	<i>8.34E+06</i>	6.89E+10	V-49	<i>7.37E+06</i>	6.09E+10
Fe-55	<i>7.99E+06</i>	6.60E+10	Cr-51	<i>3.43E+06</i>	2.83E+10
Co-56	<i>4.21E+06</i>	3.48E+10	Co-56	<i>2.46E+06</i>	2.03E+10
V-48	<i>3.29E+06</i>	2.72E+10	Co-57	<i>2.25E+06</i>	1.86E+10
Co-57	<i>2.63E+06</i>	2.17E+10	Sc-46	<i>8.49E+05</i>	7.01E+09
Sc-46	<i>1.39E+06</i>	1.15E+10	Co-58	<i>3.81E+05</i>	3.15E+09
Co-58	<i>6.85E+05</i>	5.66E+09	H-3	<i>2.88E+05</i>	2.38E+09
H-3	<i>2.91E+05</i>	2.40E+09	V-48	<i>2.43E+05</i>	2.01E+09
Ar-37	<i>2.63E+05</i>	2.17E+09	Ca-45	<i>1.27E+05</i>	1.05E+09
Be-7	<i>2.40E+05</i>	1.98E+09	Be-7	<i>1.10E+05</i>	9.06E+08
Mn-52	<i>2.06E+05</i>	1.70E+09	Ar-37	<i>8.03E+04</i>	6.63E+08
Ca-45	<i>1.65E+05</i>	1.36E+09	Y-88	<i>6.74E+04</i>	5.57E+08
S-35	<i>9.47E+04</i>	7.82E+08	S-35	<i>5.88E+04</i>	4.86E+08
Y-88	<i>7.34E+04</i>	6.06E+08	Zr-88	<i>4.31E+04</i>	3.56E+08
Zr-88	<i>7.10E+04</i>	5.86E+08	Na-22	<i>3.04E+04</i>	2.51E+08
P-32	<i>4.50E+04</i>	3.72E+08	Nb-91m	<i>2.05E+04</i>	1.69E+08
P-33	<i>4.14E+04</i>	3.42E+08	Sr-85	<i>1.49E+04</i>	1.23E+08
Nb-91m	<i>4.06E+04</i>	3.35E+08			
Na-22	<i>3.17E+04</i>	2.62E+08			
Sr-85	<i>2.83E+04</i>	2.34E+08			
Nb-95	<i>1.96E+04</i>	1.62E+08			
Rb-83	<i>1.67E+04</i>	1.38E+08			

Table 14.152: Cooling time of **6 months**

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Fe-55	<i>7.20E+06</i>	5.95E+10
Mn-54	<i>7.14E+06</i>	5.90E+10
V-49	<i>6.13E+06</i>	5.06E+10
Co-57	<i>1.79E+06</i>	1.48E+10
Co-56	<i>1.10E+06</i>	9.07E+09
Sc-46	<i>4.03E+05</i>	3.33E+09
Cr-51	<i>3.61E+05</i>	2.98E+09
H-3	<i>2.83E+05</i>	2.34E+09
Co-58	<i>1.57E+05</i>	1.30E+09
Ca-45	<i>8.69E+04</i>	7.18E+08
Y-88	<i>5.05E+04</i>	4.17E+08
Be-7	<i>3.40E+04</i>	2.81E+08
S-35	<i>2.88E+04</i>	2.38E+08
Na-22	<i>2.85E+04</i>	2.35E+08
Zr-88	<i>2.03E+04</i>	1.68E+08
Ar-37	<i>1.36E+04</i>	1.12E+08

14.5.7 350MeV

Table 14.153: Cooling time of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	2.03E+07	3.45E+11	Cr-51	2.03E+07	3.45E+11
V-48	7.52E+06	1.28E+11	V-48	7.52E+06	1.28E+11
Mn-54	6.93E+06	1.18E+11	Mn-54	6.93E+06	1.18E+11
V-49	5.59E+06	9.52E+10	V-49	5.59E+06	9.52E+10
Fe-55	5.09E+06	8.67E+10	Fe-55	5.09E+06	8.67E+10
Mn-52	5.04E+06	8.58E+10	Mn-52	5.02E+06	8.54E+10
Mn-52m	4.42E+06	7.52E+10	Co-56	3.14E+06	5.34E+10
Fe-53	3.76E+06	6.40E+10	Sc-44	1.96E+06	3.33E+10
Cr-49	3.46E+06	5.89E+10	Co-57	1.76E+06	3.00E+10
Co-56	3.14E+06	5.34E+10	Mn-56	1.47E+06	2.50E+10
Mn-51	2.46E+06	4.18E+10	Ti-45	1.34E+06	2.28E+10
Sc-44	2.13E+06	3.63E+10	Cr-49	1.29E+06	2.20E+10
Mn-56	1.92E+06	3.27E+10	Sc-46	1.20E+06	2.05E+10
Fe-53m	1.88E+06	3.20E+10	Ni-57	1.10E+06	1.87E+10
Co-57	1.76E+06	3.00E+10	Sc-44m	1.06E+06	1.80E+10
Ti-45	1.68E+06	2.86E+10	Mn-51	9.98E+05	1.70E+10
V-47	1.50E+06	2.55E+10	Co-55	9.05E+05	1.54E+10
Sc-45m	1.43E+06	2.44E+10	Mn-52m	6.17E+05	1.05E+10
Sc-46	1.20E+06	2.05E+10			
Ni-57	1.12E+06	1.90E+10			
Sc-44m	1.07E+06	1.82E+10			
Co-55	9.40E+05	1.60E+10			
V-52	7.93E+05	1.35E+10			
Sc-46m	6.70E+05	1.14E+10			

Table 14.154: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.98E+07	3.37E+11	Cr-51	1.70E+07	2.90E+11
V-48	7.22E+06	1.23E+11	Mn-54	6.81E+06	1.16E+11
Mn-54	6.87E+06	1.17E+11	V-48	5.58E+06	9.50E+10
V-49	5.58E+06	9.50E+10	V-49	5.52E+06	9.39E+10
Fe-55	5.09E+06	8.67E+10	Fe-55	5.07E+06	8.63E+10
Mn-52	4.47E+06	7.61E+10	Co-56	2.95E+06	5.03E+10
Co-56	3.11E+06	5.30E+10	Mn-52	2.13E+06	3.62E+10
Co-57	1.76E+06	3.00E+10	Co-57	1.74E+06	2.96E+10
Sc-46	1.20E+06	2.04E+10	Sc-46	1.14E+06	1.94E+10
Sc-44	8.75E+05	1.49E+10	Co-58	5.49E+05	9.35E+09
Sc-44m	8.05E+05	1.37E+10	Ar-37	3.14E+05	5.34E+09
Ni-57	6.99E+05	1.19E+10	Be-7	2.39E+05	4.07E+09
Co-58	5.82E+05	9.91E+09	H-3	1.99E+05	3.38E+09
Sc-47	4.22E+05	7.19E+09	Sc-44	1.60E+05	2.73E+09
Co-55	3.64E+05	6.19E+09	Sc-44m	1.47E+05	2.50E+09
Ar-37	3.53E+05	6.01E+09	Ca-45	1.30E+05	2.22E+09
Be-7	2.58E+05	4.40E+09	Sc-47	1.23E+05	2.09E+09
H-3	1.99E+05	3.38E+09	P-32	1.09E+05	1.86E+09
P-32	1.46E+05	2.49E+09	S-35	8.81E+04	1.50E+09
Cr-48	1.46E+05	2.48E+09	Ni-56	7.05E+04	1.20E+09
Ni-56	1.42E+05	2.42E+09	P-33	6.52E+04	1.11E+09
Ca-45	1.34E+05	2.28E+09			
S-35	9.22E+04	1.57E+09			
Sc-48	8.75E+04	1.49E+09			
P-33	7.69E+04	1.31E+09			
Zr-89	6.17E+04	1.05E+09			
Y-89m	6.17E+04	1.05E+09			

Table 14.155: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	9.57E+06	1.63E+11	Mn-54	5.66E+06	9.64E+10
Mn-54	6.46E+06	1.10E+11	Fe-55	4.79E+06	8.15E+10
V-49	5.26E+06	8.95E+10	V-49	4.65E+06	7.92E+10
Fe-55	4.99E+06	8.49E+10	Cr-51	2.13E+06	3.63E+10
Co-56	2.41E+06	4.10E+10	Co-57	1.41E+06	2.40E+10
V-48	2.06E+06	3.50E+10	Co-56	1.40E+06	2.39E+10
Co-57	1.64E+06	2.79E+10	Sc-46	5.73E+05	9.75E+09
Sc-46	9.40E+05	1.60E+10	Co-58	2.44E+05	4.15E+09
Co-58	4.38E+05	7.46E+09	H-3	1.96E+05	3.34E+09
Ar-37	1.99E+05	3.39E+09	V-48	1.52E+05	2.59E+09
H-3	1.98E+05	3.37E+09	Ca-45	9.22E+04	1.57E+09
Be-7	1.77E+05	3.01E+09	Be-7	8.11E+04	1.38E+09
Mn-52	1.23E+05	2.09E+09	Ar-37	6.05E+04	1.03E+09
Ca-45	1.19E+05	2.02E+09			
S-35	7.34E+04	1.25E+09			

Table 14.156: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Mn-54	<i>4.63E+06</i>	7.89E+10
Fe-55	<i>4.49E+06</i>	7.65E+10
V-49	<i>3.86E+06</i>	6.58E+10
Co-57	<i>1.12E+06</i>	1.91E+10
Co-56	<i>6.28E+05</i>	1.07E+10
Sc-46	<i>2.72E+05</i>	4.63E+09
Cr-51	<i>2.24E+05</i>	3.82E+09
H-3	<i>1.93E+05</i>	3.29E+09
Co-58	<i>1.01E+05</i>	1.72E+09
Ca-45	<i>6.28E+04</i>	1.07E+09
Y-88	<i>3.13E+04</i>	5.33E+08
Be-7	<i>2.51E+04</i>	4.28E+08
S-35	<i>2.23E+04</i>	3.80E+08
Na-22	<i>1.79E+04</i>	3.05E+08
Zr-88	<i>1.25E+04</i>	2.13E+08
Ar-37	<i>1.02E+04</i>	1.74E+08
Co-60	<i>6.58E+03</i>	1.12E+08
Ar-39	<i>5.93E+03</i>	1.01E+08

14.5.8 400MeV

Table 14.157: Cooling times of EOB and 1 hour

EOB (0 s)			1 hour (3600 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	<i>1.32E+07</i>	4.33E+11	Cr-51	<i>1.32E+07</i>	4.32E+11
V-48	<i>4.90E+06</i>	1.60E+11	V-48	<i>4.86E+06</i>	1.59E+11
Mn-54	<i>4.71E+06</i>	1.54E+11	Mn-54	<i>4.71E+06</i>	1.54E+11
V-49	<i>3.64E+06</i>	1.19E+11	V-49	<i>3.64E+06</i>	1.19E+11
Fe-55	<i>3.37E+06</i>	1.10E+11	Fe-55	<i>3.37E+06</i>	1.10E+11
Mn-52	<i>3.15E+06</i>	1.03E+11	Mn-52	<i>3.15E+06</i>	1.03E+11
Mn-52m	<i>2.77E+06</i>	9.07E+10	Co-56	<i>1.88E+06</i>	6.13E+10
Fe-53	<i>2.36E+06</i>	7.71E+10	Sc-44	<i>1.34E+06</i>	4.37E+10
Cr-49	<i>2.19E+06</i>	7.16E+10	Co-57	<i>1.16E+06</i>	3.78E+10
Co-56	<i>1.88E+06</i>	6.13E+10	Mn-56	<i>1.14E+06</i>	3.73E+10
Mn-51	<i>1.53E+06</i>	5.00E+10	Ti-45	<i>8.96E+05</i>	2.93E+10
Mn-56	<i>1.49E+06</i>	4.88E+10	Sc-46	<i>8.26E+05</i>	2.70E+10
Sc-44	<i>1.46E+06</i>	4.76E+10	Cr-49	<i>8.20E+05</i>	2.68E+10
Fe-53m	<i>1.18E+06</i>	3.85E+10	Sc-44m	<i>7.22E+05</i>	2.36E+10
Co-57	<i>1.16E+06</i>	3.78E+10	Ni-57	<i>6.91E+05</i>	2.26E+10
Ti-45	<i>1.12E+06</i>	3.67E+10	Mn-51	<i>6.21E+05</i>	2.03E+10
V-47	<i>9.76E+05</i>	3.19E+10	Co-55	<i>5.29E+05</i>	1.73E+10
Sc-45m	<i>9.64E+05</i>	3.15E+10	Co-58	<i>3.98E+05</i>	1.30E+10
Sc-46	<i>8.29E+05</i>	2.71E+10	Mn-52m	<i>3.85E+05</i>	1.26E+10
Sc-44m	<i>7.31E+05</i>	2.39E+10	Sc-47	<i>3.70E+05</i>	1.21E+10
Ni-57	<i>7.07E+05</i>	2.31E+10	Sc-43	<i>3.30E+05</i>	1.08E+10
V-52	<i>6.00E+05</i>	1.96E+10			
Co-55	<i>5.51E+05</i>	1.80E+10			
Sc-46m	<i>4.62E+05</i>	1.51E+10			
Co-58	<i>3.98E+05</i>	1.30E+10			
Sc-43	<i>3.95E+05</i>	1.29E+10			
Sc-47	<i>3.73E+05</i>	1.22E+10			

Table 14.158: Cooling times of 1 day and 1 week

1 day (86400 s)			1 week (604800 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	1.29E+07	4.22E+11	Cr-51	1.11E+07	3.63E+11
Mn-54	4.68E+06	1.53E+11	Mn-54	4.62E+06	1.51E+11
V-48	4.68E+06	1.53E+11	V-48	3.61E+06	1.18E+11
V-49	3.61E+06	1.18E+11	V-49	3.58E+06	1.17E+11
Fe-55	3.37E+06	1.10E+11	Fe-55	3.37E+06	1.10E+11
Mn-52	2.80E+06	9.16E+10	Co-56	1.77E+06	5.77E+10
Co-56	1.86E+06	6.08E+10	Mn-52	1.33E+06	4.36E+10
Co-57	1.15E+06	3.77E+10	Co-57	1.14E+06	3.72E+10
Sc-46	8.20E+05	2.68E+10	Sc-46	7.80E+05	2.55E+10
Sc-44	5.97E+05	1.95E+10	Co-58	3.73E+05	1.22E+10
Sc-44m	5.51E+05	1.80E+10	Ar-37	2.33E+05	7.61E+09
Ni-57	4.44E+05	1.45E+10	Be-7	1.80E+05	5.87E+09
Co-58	3.95E+05	1.29E+10	H-3	1.40E+05	4.57E+09
Sc-47	3.03E+05	9.92E+09	Sc-44	1.10E+05	3.58E+09
Ar-37	2.62E+05	8.57E+09	Sc-44m	1.00E+05	3.27E+09
Co-55	2.14E+05	6.99E+09	P-32	9.12E+04	2.98E+09
Be-7	1.94E+05	6.34E+09	Sc-47	8.84E+04	2.89E+09
H-3	1.40E+05	4.57E+09	Ca-45	8.81E+04	2.88E+09
P-32	1.22E+05	3.98E+09	S-35	6.67E+04	2.18E+09
Cr-48	9.15E+04	2.99E+09	P-33	5.35E+04	1.75E+09
Ni-56	9.06E+04	2.96E+09	Ni-56	4.47E+04	1.46E+09
Ca-45	9.03E+04	2.95E+09	Zr-88	3.30E+04	1.08E+09
S-35	7.01E+04	2.29E+09			
P-33	6.30E+04	2.06E+09			
Sc-48	6.24E+04	2.04E+09			
K-42	4.31E+04	1.41E+09			
Zr-89	3.98E+04	1.30E+09			
Y-89m	3.98E+04	1.30E+09			
Zr-88	3.49E+04	1.14E+09			
Co-58m	3.46E+04	1.13E+09			

Table 14.159: Cooling times of 1 month and 3 months

1 month(2592000 s)			3 months(7776000 s)		
Nuclei	Bq/g	Bq	Nuclei	Bq/g	Bq
Cr-51	6.24E+06	2.04E+11	Mn-54	3.85E+06	1.26E+11
Mn-54	4.41E+06	1.44E+11	Fe-55	3.18E+06	1.04E+11
V-49	3.43E+06	1.12E+11	V-49	3.02E+06	9.86E+10
Fe-55	3.30E+06	1.08E+11	Cr-51	1.39E+06	4.55E+10
Co-56	1.44E+06	4.71E+10	Co-57	9.21E+05	3.01E+10
V-48	1.33E+06	4.35E+10	Co-56	8.41E+05	2.75E+10
Co-57	1.07E+06	3.51E+10	Sc-46	3.92E+05	1.28E+10
Sc-46	6.46E+05	2.11E+10	Co-58	1.66E+05	5.41E+09
Co-58	2.98E+05	9.73E+09	H-3	1.38E+05	4.51E+09
Ar-37	1.48E+05	4.83E+09	V-48	9.85E+04	3.22E+09
H-3	1.39E+05	4.55E+09	Ca-45	6.18E+04	2.02E+09
Be-7	1.33E+05	4.35E+09	Be-7	6.09E+04	1.99E+09
Ca-45	7.99E+04	2.61E+09	Ar-37	4.50E+04	1.47E+09
Mn-52	7.71E+04	2.52E+09	S-35	3.46E+04	1.13E+09
S-35	5.57E+04	1.82E+09			

Table 14.160: Cooling time of 6 months

6 months(15552000 s)		
Nuclei	Bq/g	Bq
Mn-54	<i>3.15E+06</i>	1.03E+11
Fe-55	<i>2.97E+06</i>	9.72E+10
V-49	<i>2.51E+06</i>	8.20E+10
Co-57	<i>7.34E+05</i>	2.40E+10
Co-56	<i>3.76E+05</i>	1.23E+10
Sc-46	<i>1.87E+05</i>	6.10E+09
Cr-51	<i>1.47E+05</i>	4.79E+09
H-3	<i>1.36E+05</i>	4.45E+09
Co-58	<i>6.85E+04</i>	2.24E+09
Ca-45	<i>4.22E+04</i>	1.38E+09
Y-88	<i>1.97E+04</i>	6.44E+08
Be-7	<i>1.89E+04</i>	6.18E+08
S-35	<i>1.69E+04</i>	5.54E+08
Na-22	<i>1.21E+04</i>	3.96E+08
Zr-88	<i>7.86E+03</i>	2.57E+08
Ar-37	<i>7.59E+03</i>	2.48E+08
Co-60	<i>4.83E+03</i>	1.58E+08
Ar-39	<i>4.68E+03</i>	1.53E+08
Sc-44	<i>3.46E+03</i>	1.13E+08
Ti-44	<i>3.46E+03</i>	1.13E+08
Nb-91m	<i>3.06E+03</i>	1.00E+08

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