REPORT

Independent Review of The GEANT4 Project June 18 – 22, 2001

February 19, 2002

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CERN, June 2001

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1 – Executive Summary

This report contains the results of the First Review of the GEANT4 Project held at CERN on June 18-22, 2001.

The committee would like to thank the GEANT4 Collaboration and CERN for their organization and support of the meeting, and their hospitality.

The GEANT4 project has been a tremendous success in its two and a half years of existence; the GEANT4 simulation toolkit is gaining widespread acceptance as the tool of choice. The review committee commends the entire collaboration. Our major conclusions deal with the changes engendered by this success:

- Adoption of GEANT4 by an expanding community means there are many more novice users with no previous ties to the developers of GEANT4. Special attention should be paid to the communication with and the support of users in general and newcomers in particular.

- The object-oriented design allows external code, e.g. visualization and physics models, to be more easily incorporated. Leveraging of external resources allows GEANT4 to rapidly expand its repertoire with modest impact on its resources. Every effort should be made to facilitate their incorporation.

- As GEANT4 moves from a phase of rapid core development to a phase where utilization, maintenance and improvement are the dominant activities, the current organizational structure may no longer be optimal. The Collaboration should review its long-term strategic plans, and reorganize as necessary to address the changing environment.

2 – Introduction

The GEANT4 Collaboration was established in late 1998 with the purpose of transferring the results of earlier R&D activities of the RD44 Project at CERN to a supported production service that would provide a software toolkit for simulation of the passage of particles through matter, and in particular would serve as a modern object-oriented (OO) toolkit to build particle detector simulation programs. To this effect, a number of institutions signed a Memorandum of Understanding (MoU) taking specific commitments and pledging resources towards the common goal. The MoU was for an initial period of two years, and is renewed in two-year increments. Such a renewal took effect at the beginning of 2001.

The Collaboration Board (CB) administratively manages the GEANT4 Collaboration, and a Technical Steering Board (TSB) manages the execution of the project. The Spokesperson of the GEANT4 Collaboration is also the chairperson of the TSB. The CB has its own chair.

The CB has decided to convene periodic external reviews to make an assessment of the collaboration activities and to provide feedback to the CB with the aims of improving the collaboration and guiding the choice of its future objectives. This is the first such review. The committee was not given an explicit charge in writing; it was invited to examine various areas of the project in as much detail as it felt necessary. These areas include but are not limited to management and organizational issues, physics and technical quality of the simulation toolkit, and the usage of GEANT4 inside and outside of the initial core user community in High Energy Physics (HEP).

The review was held at CERN on June 18-22, 2001. There were presentations on the history of GEANT4, the basic physics functionalities of the toolkit, software processes, comparisons of simulation with data, user related issues, and CB and TSB organizational issues. Additional discussions requested by the review committee were held on June 21. A preliminary review report was communicated to the GEANT4 Collaboration during the closeout session on June 22. A detailed agenda can be found in Appendix A. The committee also had informal discussions with various GEANT4 developers as well as members of the user community.

In addition, two documents were provided to the committee before the meeting:

- A draft “General Paper” addressing the scientific content of GEANT4; and
- An "Activity Report" addressing issues such as management and software process.

These presentations, discussions and reports formed the basis of the findings and recommendations of this review.

3 – Physics Models and Functionality of GEANT4

3.1 – Physics Models

The physics models are at the core of a detector simulation package. One of the strengths of the GEANT4 design strategy is its modularity. The package is designed to allow developers, and even users, to contribute their own physics models. Users can also choose amongst the available physics models those that are most appropriate for their applications.

This strength, however, has a potential danger. Specifically, it allows the GEANT4 development team to place the burden of creating and validating a complete physics list on the user. While it is essential for the physics community to collaborate strongly with the GEANT4 developers to develop and carry out a validation strategy, it remains the GEANT4 team's responsibility to articulate this strategy and to provide a baseline set of physics models that cover the energy range and use cases most important to their core user community. Such a strategy was not presented to the review committee and such a baseline does not yet appear to exist.

> *Recommendation 3.1*: A validation strategy is needed to insure that a novice user could run with a standard physics list that will provide adequate results, e.g. comparable to or better than the last CERN release of GEANT3, over a wide energy range. The limitations of this default physics list should be documented. The strategy should address the issue of estimating systematic uncertainties in the standard table(s). The GEANT4 collaboration should appoint a physics leader to develop (in conjunction with the GEANT4 developers and core users) this validation strategy and a corresponding set of milestones. The strategy, the milestones and the current status of the validation should be available openly from the GEANT4 web pages.

There are two electromagnetic (EM) working groups. The “Standard” EM group was formed at the inception of GEANT4. Its mandate was to develop, maintain and promote all the EM physics packages. The “Low Energy” EM group was formed in Spring 2000. Its original focus was on those processes of particular interest to the programs at the European Space Agency (ESA). Its scope has since evolved beyond the ESA packages to include hadrons and ions in addition to electrons and photons. Its user community has also grown to include HEP and medical fields. The “Standard” EM group currently has 8 members, representing approximately 3 FTE of effort. The “Low Energy” EM group reportedly has 53 members, and an estimated 20-25 FTE of effort. The demarcation in responsibility between the two groups was not made clear in the presentations. Discussions with the developers indicate that there is significant overlap in the validity ranges of the two codes. The “Low Energy” code is applicable up to ~100 GeV, while the “Standard” code is usable down to ~1 KeV. The “Low Energy” code is significantly more accurate than the “Standard” code for energies below 1 KeV. However, it runs much slower than the “Standard” code in the region of overlap.

> *Recommendation 3.2*: We recommend that the EM groups document the validity ranges of their models, and the tradeoffs where they overlap. We also recommend providing default configurations and guidelines for users in identifiable communities, e.g. HEP and medical applications.

The separation of the electromagnetic physics program into two, largely independent, physics working groups appears, at first sight, rather artificial. However, the two groups serve different user communities and therefore emphasize different regions of physics applications. Both groups have evolved in a productive manner. It should be noted, however, that the groups are of very different size and the momentum in the two groups appears to be rather different as well. Healthy competition between the two groups can lead to more vigorous development within both groups. The committee does not see a reason to force a merger at this time. Nevertheless, the duplication of effort and overlap of coverage should be evaluated in light of the limited resources of the Collaboration.

> *Recommendation 3.3*: We recommend that the GEANT4 Collaboration clearly define the (different) areas of responsibilities and physics coverage of the two EM groups. The CB should ensure that the relation between the two groups remain that of healthy competition and productive interaction.

There are a large number of hadronic models implemented in GEANT4. Each model has its own validity range, e.g. models based on parameterization of data are valid only where data are available. These ranges overlap. This wealth of choices empowers users to choose the ones most appropriate for their application and needs. Unfortunately, there is no clear and easily available documentation to guide the user.

> *Recommendation 3.4*: We recommend documenting the validity ranges of the various hadronic models. Where a particular energy range has multiple models, the tradeoffs should be clearly stated. We also recommend providing default configurations or guidelines for users in identifiable communities, e.g. HEP and medical applications.

Several projects have been initiated to validate the hadronic models by comparing simulation results with data. No actual comparison results were presented during the review. One particular project reported that results are expected by end of 2002 instead of 2001 as originally planned. While this is not fatal to the experiment performing the comparison, the committee is surprised by the apparent lack of concern on the part of GEANT4. We are troubled that the hadronic area in GEANT4 may be falling behind schedule. Comments from user groups reinforced our concern.

> *Recommendation 3.5*: The mission and schedule of the hadronics group should be clarified. The physics goals should be made clear. A coordinated validation program, driven by physics requirements and in the context of an overall strategy discussed above, is needed.

3.2 – Functionality

The GEANT4 toolkit provides a rich set of classes to describe complex geometries. At the moment, however, the toolkit does not contain adequate mechanisms for validating these geometries. In presentations from GEANT4 users, this was among the most commonly cited problems associated with developing GEANT4 detector descriptions. Among the essential validation tools are:

- A tool to display the geometry hierarchy that allows the user to interact with elements of the hierarchy to get additional information. A minimal specification of the functionality of this tool is the DTree display in interactive GEANT3;

- A mechanism for detecting unintended overlaps between volumes; and

- A ray tracer that provides information about materials and volumes traversed by the ray. The information returned from the ray tracer should include, at a minimum, path length traversed per detector, radiation and interaction length traversed per detector, list of all volumes traversed, position of entrance and exit to each volume

Recommendation 3.6: The GEANT4 team should provide a basic set of tools to validate complicated detector geometries. These tools should be available to users not only as a set of C++ classes that the end user can access from his own application but also as part of an interactive geometry display package. A minimal set of requirements for interactive capabilities are those provided by interactive GEANT3.

The review committee understands from its discussions with representatives of the GEANT4 team that it is concerned such a tool will be dependent upon 3rd party graphics packages, and the complexity of supporting diverse packages. The committee believes these code management issues can be addressed by distributing the geometry validation tools in a similar manner to the current visualization tools.

3.3 – Usage Guideline and Licensing

The GEANT4 project was initially formed to provide the HEP community with a flexible toolkit for simulation software for physics experiments. The collaboration consisted of a number of HEP institutions, but soon expanded to include collaborators such as the European Space Agency. The culture of the two types of institutions was similar, and the extended collaboration was immediately successful. Recently, the collaboration has expanded to include institutions whose primary work is in medicine, and users now include industrial research and commercial applications. Further expansion appears likely. These organizations and new applications have interests that may sometimes be in conflict with the interests of the majority of the core physics collaborators. Potential

military applications concern some core developers as well as reviewers. The new applications represent a drift away from the initial HEP focus of GEANT4. While these may be a change for the better, there should be clearly enunciated Collaboration policies to guide this growth.

The HEP community has a history of cooperative development and free use of the resulting packages that has served them well. Licensing issues become a great concern as diverse groups such as commercial applications adopt the toolkit. While the Collaboration is aware of this issue, there are no definitive plans to address it. This is an urgent issue for the CB.

> *Recommendation 3.7*: The CB should evaluate what usage and licensing policies are appropriate, and develop the corresponding guidelines right away.

As a result of expanding the collaboration, the mission of GEANT4 has expanded over the last few years to include the development of software for the support of a large number of users in many areas including medical fields. Since the MoU and the scope of the project were originally defined to provide a simulation package for physics experiments, it is not clear that the issue of liability has been fully addressed by the collaboration or the Collaboration Board. Verification and validation of the simulation code is extremely important for all applications, but is of particular concern in medical applications. Although it was clear that some validation had been done, we did not find a clear plan for full testing and validation of the physics.

> *Recommendation 3.8*: The CB should address the liability issue, especially in relation to the medical fields, in addition to encouraging in-depth testing and validation.

4 – Software Engineering of GEANT4

4.1 – Release Process

There are two public releases a year. The schedule appears to be calendar driven. The general user community does not know the planned changes for each release, e.g. corrections, new features, functionalities, and additional physics models, beforehand. When there is a conflict between a calendar driven release date and the time necessary to implement an important feature or bug fix, it is not clear to the committee which consideration actually dominates.

This lack of transparency deprives users of information necessary to plan their own activities. It also deprives the GEANT4 team of valuable user input in discussions of the GEANT4 feature set, and the schedule for their adoption.

> *Recommendation 4.1*: We recommend a release schedule planned around a set of corrections and improvements. Both the schedule and the planned features should be readily accessible to all users and developers.

In addition to the public releases, a monthly reference release is provided to Collaboration members. Non-members do not have access to these releases.

The committee is dismayed to find that users sometimes have to wait long periods for a release that corrects a blocking problem, e.g. one of the biannual public releases. Together with the lack of a public schedule of fixes and improvements, users are seriously handicapped.

> *Recommendation 4.2*: We recommend the adoption of more frequent, though not necessarily fully tested, "beta" releases that address important blocking problems. They should be available to all users. These "beta" releases are in addition to having a stable and working version of the program at any time, with a documentation of all known bugs or deficiencies in that particular version.

GEANT4 is more than just the code. The entire product tree has a number of inter-related components:

- Code release;
- Documentation of the released code;
- Documentation of the physics underlying the code; and
- User Requirement Document that led to the implementations.

The documentation for GEANT4 is generally well designed and the initial documentation for the product was good, but unfortunately not complete. The documentation has not been updated regularly since the first production release, and in general, has fallen far behind.

> *Recommendation 4.3*: We recommend defining and managing the complete product tree, including documentation as well as the code, as part of a release. If the documentation is not ready, the release cannot be deemed to be ready.

4.2 - Documentation

The GEANT4 Collaboration recognizes the importance of documentation. The committee finds the overall documentation tree to be about right.

User Requirement Document (URD) is the reference for what functions GEANT4 will implement. They are also the basis for testing. A set of URD's was written at the inception of this project. However, it is not complete, and has not been updated. Without these documents, the overall coherence and maintainability of GEANT4 are at risk.

> *Recommendation 4.4*: URD's are an integral part of the documentation and product trees. A coherent set covering all of GEANT4 must be finished and put in place expeditiously.

Accurate documentation is an integral part of any software package. Unfortunately, product developers are not always the most skilled at writing these documents. A technical writer could be used to update much of the documentation, particularly the user support documents. The technical writer would need to work in close contact with members of the Collaboration to insure the accuracy and completeness of the final documents.

The documentation for the physics processes will require the attention of the physics coordinators. This should be one of the highest priorities for the physics groups in the coming year.

> *Recommendation 4.5*: We recommend that the Collaboration periodically review and update the entire documentation tree.

4.3 – Software Design

The object oriented design approach adopted by the GEANT4 Collaboration has proven to be a good choice. It has been the key to the success of handling the highly complex physics code while at the same time allowing the flexibility required to interface between the many developers in the international community of GEANT4. We commend the

Collaboration on the very successful toolkit development with good software engineering practice, leading to a long-term maintainable product.

Although the GEANT4 collaboration has developed a good and consistent class design, there will inevitably be cases where the physics community needs to use 3rd party software that does not follow the GEANT4 design. One notable example of this is the Fluka hadronic physics package. We strongly encourage the GEANT4 collaboration to find constructive and maintainable mechanisms for incorporating such software. This is most naturally done using a policy of "loose integration" where the GEANT4 team provides an abstract interface to plug such a component into the GEANT4 toolkit but does not itself take responsibility for the 3rd party software. The successful integration of 3rd party graphics packages into the visualization part of the toolkit provides an excellent paradigm for such loose integration.

The GEANT4 collaboration recognizes that it cannot develop all the code itself, and that many external packages will be incorporated into GEANT4. We applaud the practice of giving proper credit to the original authors. This should be done not only in the documentation and the source code, but in presentations also. A transparent attribution helps the user grasp the underlying algorithm, past usage, earlier validations and probable validity range.

> *Recommendation 4.6*: We recommend a greater willingness to incorporate 3rd party software such as Fluka or HETC, perhaps using a "loose integration" model. The attributions for these packages must be made more transparent, for example by incorporating the original package name in GEANT4 such as GEANT4HadronicFluka or GEANT4HadronicHETC.

Software design appears to be moving more and more to individual working groups. The TSB may have been informed of the addition of a new process or functionality, but does not appear to be strongly coupled in some of the major decisions of the working groups. No clear overall design authority exists.

Flexibility within the working group is helpful for small design changes, but can lead to serious problems if not coordinated properly. The project is becoming quite diverse which puts a burden on the core software team and seriously complicates the documentation, testing and validation of the full product. The working groups seem to have been able to operate at times quite independently of any central design considerations.

> *Recommendation 4.7*: There should be an overall design authority to coordinate and review the design from individual working groups.

5 – User Community

5.1 – Communication with Users

GEANT4 is a simulation toolkit rather than a monolithic program. Users are expected to select the appropriate pieces for his specific application. It is therefore important that users have access to all the information needed to make such a decision, e.g. range of applicability of a specific physics model. The ever-broader adoption of GEANT4 will inevitably lead to requests for new features and functionalities. It is important that users can find out if these changes are already planned, and how to influence future changes. This calls for good communications between the developers and all users, whether or not they are members of development teams.

It is vital that GEANT4 is presented to the user community in as open and transparent a manner as possible, as in a producer-customer relation. The committee is perplexed by the GEANT4 Collaboration's decision to make much of its web documentation available only to members of the Collaboration. The web pages are the best mechanism for promoting the GEANT4 product and encouraging its acceptance by the community.

> *Recommendation 5.1*: All of the GEANT4 web pages (aside from those related to personnel or management of the collaboration, and those pages that would violate relevant licensing agreements) should be world readable. These web pages should be updated frequently, and should be reviewed each time a new release is frozen. The pages should contain links to relevant third party software that is not itself part of the GEANT4 release, e.g. visualization and graphics libraries and their documentation, and Fluka documentation once a Fluka interface has been developed.

5.2 – User and Product Support

The rapidly growing user community is a clear indication of the success of the product and, at the same time, guarantees that GEANT4 will be tested in many different applications. It is a concern that the increasing user community in addition to the growth of the physics scope may strain the core development team.

> *Recommendation 5.2*: We recommended that the Collaboration provide sufficient resources to the core development team to allow for the support of a growing user community. We believe this will happen to some extent quite naturally, because many of the new users will become developers with time.

GEANT4 as a simulation toolkit has been a success so far, due primarily to the efforts of the developers and a core group of users that work intimately with the developers. As the toolkit gains wider acceptance and sees broader usage, it is likely that many users will not have previous contact with the developers. It is also likely that a smaller percentage of them will contribute to GEANT4 development.

It was reported that users who are not collaborators do not have ready access to patches. So a user who discovers and reports a problem is precluded from the process of resolution and validation. We believe that a user's status as a collaborator is largely irrelevant in such cases. It is to the benefit of both the user and GEANT4 to have broader access to patches, which are not part of a fully validated release. The committee considers it very important that formal hurdles, like the becoming a full member of the Collaboration, do not become requirements for user support.

> *Recommendation 5.3*: We recommend that GEANT4 adopt a more flexible approach in its interaction with users. The GEANT4 Collaboration should examine its support structure, and in particular, improve its support of those users that are not affiliated with development team.

It is inevitable that changes to the initial User Requirements are required. The committee heard reports that the procedure to implement these changes can be quite time consuming, with estimates of 6 to 9 months even for well motivated and fairly urgent physics needs. Physics ideas are first discussed with a TSB member. The TSB representative then presents proposals at a TSB meeting, where both physics priority and technical issues of implementation are discussed. This ultimately leads to a design, which is then implemented.

The committee believes that many of the changes do not involve the entire membership of the TSB. They can be handled more expeditiously by the relevant subset of the TSB, together with the original proponent. The pace of change will no longer be driven by TSB meetings, which are necessarily not very frequent.

There is a strong concern that reasonable requests for support or enhancement of the GEANT4 functionality may be rejected for purely formal reasons. This policy is considered to be wrong. Decisions on which algorithms to implement and which user requests to fulfill as well as their relative priorities have to be based purely on physics arguments. Furthermore, the process must be transparent. Otherwise, the acceptance of GEANT4 will decrease rapidly, and very likely this will lead to the ultimate failure of the project.

> *Recommendation 5.4*: We recommend a more flexible approach with fewer formal barriers where users help set the physics requirements and priorities. High priority items should be implemented expeditiously. We further recommend that the process be open and transparent to all users.

The bug reporting and tracking system "Bugzilla" used by the GEANT4 collaboration for customer support seems to be working reasonably well. Bug reports are automatically assigned to the responsible persons through this system and it is possible to track their resolution. This system is flexible and the collaboration is making an effort to continually improve it.

The other parts of customer support were found to be weak. Many users have complained that there is not a straightforward way to communicate with the developers of GEANT4 or the experts on GEANT4 applications. There are also complaints that they have not had adequate or timely response to questions. These complaints have come from users in experiments both inside and outside the collaboration. It is noticeably easier for users to get help if they have direct contacts in the core team, and this direct line of communication seems to work but is not always efficient. Individuals in the GEANT4 team have been responsive when directly asked for support, but there is no comprehensive plan for user support and no forum for questions. The result is that the response time appears to be too slow for most users. Some have become frustrated and abandoned the product; others have found that their application development has been slowed significantly because of the lack of user support.

User support should be distinct from product support (i.e. bug report), and should be combined with other outreach efforts such as user forums, tutorials, etc. It is an important part of making a successful product and an increased level of effort should be placed in the area of general support. Quick response to questions and user requests is essential for the success of the product.

The success of GEANT4 depends crucially on the user support policy adopted by the Collaboration. It is mandatory that user support be handled in a very transparent and open manner. Decisions on which physics models and functionalities will be implemented have to be presented publicly. This also applies to requests of users who are not (yet) members of the GEANT4 Collaboration. Those users are candidates to become member of the Collaboration and help to improve the broad acceptance of the product.

5.3 – Education and Outreach

One measure of the success of GEANT4 is the size and vitality of its user community. Animating and motivating a user group is therefore an integral part of GEANT4's mission.

While *BABAR* is currently using GEANT4 at a production level, application development at the other large experiments has been progressing slowly. There are concerns about user support, and adequate and prompt response to user requests coming from the simulation/software coordinators at the major LHC experiments. The next few years are a critical time for the development of production software for these large experiments that are the major clients for GEANT4. A larger and more concentrated effort should be put together to reach out to that community over the next few years. More resources will probably be required on both sides. This effort should bring the simulation software developers, the test beam teams and the physics coordinators inside the experiments in close regular contact with the core members of the GEANT4 team. The Atlas validation projects seem to be a major step in the right direction.

The GEANT4 toolkit represents a tremendous effort on the part of its collaborators. If GEANT4 is to be accepted as a standard in the physics community, it is important that

the physics models be discussed and understood by the community of scientists working in the relevant fields (simulation and the modeling of physics processes). The collaboration is therefore to be congratulated on setting up HyperNews to improve communication with users.

Other groups using HyperNews more actively have found that it fosters user-to-user communications, which often results in reduced support needed from the core team. This tool needs to be made more widely known in the user community. It is also important that developers participate, and follow up quickly on issues raised by users. The developers can demonstrate their commitment to this public forum and openness in general by using HyperNews for their own exchanges.

> *Recommendation 5.5*: We recommend that GEANT4 collaborators increase their participation in appropriate workshops and that they publish both their models and the validation results in refereed journals. We also recommend a wider adoption of HyperNews or similar tools for communication.

GEANT4 has been made part of some educational programs in Japan. In addition to the immediate educational value, the students are likely to adopt GEANT4 in their professional careers, thus expanding the eventual user pool. GEANT4 tutorials and training classes have been well received by the physics community. These efforts should continue.

> *Recommendation 5.6*: Tutorials and Training classes are an important means to promote the product and to improve its acceptance. We recommend continuing to give tutorials and training classes with priority.

6 – Management, Organization and Resource Issues

The current organizational structure, involving the CB and TSB and as formalized in the MoU, has proven quite successful. The Collaboration was created, a simulation toolkit has been developed and continues to develop, and a vibrant community has been built up. Core development has made great strides, thanks to the intimate working relationship between the design authority and the physics authority. Nevertheless, it is useful to consider if changes would be helpful in the context of an evolving product and a growing community.

6.1 – Collaboration Board

The Collaboration Board is the top management for the Collaboration. It is responsible for setting strategic goals and guidelines, and for providing the resources necessary for the execution of the project. The CB is composed of representatives from the major collaborating institutions. To ensure a broad strategic view, there is an informal understanding that CB representatives are not personally active in GEANT4 development. The CB elects its own Chair.

The size of the CB increases as more institutions join the Collaboration. The recent growth of the Collaboration is turning the CB into a rather large and somewhat ponderous body. While there are concerns that further increases in size may render the CB dysfunctional as a management body, the committee did not hear any plans of reorganization. We note that the management body does not have to be the same as the sum of all the stakeholders.

> *Recommendation 6.1*: We recommend that the GEANT4 Collaboration evaluate the appropriate makeup of the CB as a management body in light of a growing collaboration.

6.2 – Technical Steering Board

The Technical Steering Board is made up of representatives from the major experiments, members of the participating institutions and Working Group coordinators. The TSB reports to the CB through the Spokesperson. The Spokesperson is responsible for overall project execution, and chairs the TSB.

The TSB is responsible for setting priorities within the collaboration and responding to requests for new features. The representatives from the experiments are asked to make formal requests for new features at the TSB meetings. It was not clear that the Working Group coordinators followed this same procedure regarding the addition of new physics models. The formal request procedure does not seem to be well matched to the response

time required by the experiments. Often it would be more appropriate for the project management to handle the requests directly in order to avoid delays.

The coordinator of each Working Group in Geant4 is a member of the TSB. Some of these Working Groups are focused on technical issues, and several are focused on the physics processes that are simulated by GEANT4. The Working Groups and the other members of the TSB often have very different concerns and priorities; thus too many different types of issues are discussed at the TSB meetings. As a result, the board does not appear to be strongly coupled into some of the major decisions that are made inside the Working Groups.

The committee has a concern that the scope of the GEANT4 project has expanded without a global plan. The Working Groups seem to have been able to define their own goals at times.

> *Recommendation 6.2*: GEANT4 should have a clearly defined scope and a corresponding long term plan. This allows the individual working groups to develop consistent goals and plans.

6.3 – Evolution of Organization

The upcoming physics experiments at the LHC and elsewhere are the major stakeholders in the GEANT4 product. They depend on GEANT4 for the success of their projects. They are, however, not always shareholders in the project, and do not have adequate control of the direction of the product. The committee is deeply concerned that only one major HEP experiment (*BABAR*) is currently using GEANT4 at a production level and they are, in fact, using a locally modified version of the code.

The focus of GEANT4 is now turning to maintenance and product evolution, e.g. detailed validation of the various physics models, comparison of simulation with data, etc. With a broader user base, it is natural that additional requirements will be developed, and they will often involve people not as closely coupled to the design team.

A different organizational structure may be more appropriate for this new phase. We suggest one possible implementation with a Design Leader and a Physics Leader reporting to a Project Coordinator. The Physics Leader and his team are responsible for physics requirements and model validation. They are also responsible for promotion in and support of the user community. The Design Leader and his team are responsible for producing URD's based on the physics requirements, software verification, integration, and release management. They also handle bug reports. The CB will continue to define the long-term vision and goals for the overall GEANT4 project, establish policies, set milestones, and provide the resources necessary for the successful execution of this project.

Periodic reviews are useful evaluation tools to ensure that the Collaboration is responsive to the evolving user community, and is well structured to carry out its many tasks.

7 – Summary of Recommendations

Recommendation 3.1: A validation strategy is needed to insure that a novice user could run with a standard physics list that will provide adequate results, e.g. comparable to or better than the last CERN release of GEANT3, over a wide energy range. The limitations of this default physics list should be documented. The strategy should address the issue of estimating systematic uncertainties in the standard table(s). The GEANT4 collaboration should appoint a physics leader to develop (in conjunction with the GEANT4 developers and core users) this validation strategy and a corresponding set of milestones. The strategy, the milestones and the current status of the validation should be available openly from the GEANT4 web pages.

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Recommendation 4.2: We recommend the adoption of more frequent, though not necessarily fully tested, "beta" releases that address important blocking problems. They should be available to all users. These "beta" releases are in addition to having a stable and working version of the program at any time, with a documentation of all known bugs or deficiencies in that particular version.

Recommendation 4.3: We recommend defining and managing the complete product tree, including documentation as well as the code, as part of a release. If the documentation is not ready, the release cannot be deemed to be ready.

Recommendation 4.4: URD's are an integral part of the documentation and product trees. A coherent set covering all of GEANT4 must be finished and put in place expeditiously.

Recommendation 4.5: We recommend that the Collaboration periodically review and update the entire documentation tree.

Recommendation 4.6: We recommend a greater willingness to incorporate 3rd party software such as Fluka or HETC, perhaps using a "loose integration" model. The attributions for these packages must be made more transparent, for example by incorporating the original package name in GEANT4 such as GEANT4HadronicFluka or GEANT4HadronicHETC.

Recommendation 4.7: There should be an overall design authority to coordinate and review the design from individual working groups.

Recommendation 5.1: All of the GEANT4 web pages (aside from those related to personnel or management of the collaboration, and those pages that would violate relevant licensing agreements) should be world readable. These web pages should be updated frequently, and should be reviewed each time a new release is frozen. The pages should contain links to relevant third party software that is not itself part of the GEANT4 release, e.g. visualization and graphics libraries and their documentation, and Fluka documentation once a Fluka interface has been developed.

Recommendation 5.2: We recommended that the Collaboration provide sufficient resources to the core development team to allow for the support of a growing user

community. We believe this will happen to some extent quite naturally, because many of the new users will become developers with time.

Recommendation 5.3: We recommend that GEANT4 adopt a more flexible approach in its interaction with users. The GEANT4 Collaboration should examine its support structure, and in particular, improve its support of those users that are not affiliated with development team.

Recommendation 5.4: We recommend a more flexible approach with fewer formal barriers where users help set the physics requirements and priorities. High priority items should be implemented expeditiously. We further recommend that the process be open and transparent to all users.

Recommendation 5.5: We recommend that GEANT4 collaborators increase their participation in appropriate workshops and that they publish both their models and the validation results in refereed journals. We also recommend a wider adoption of HyperNews or similar tools for communication.

Recommendation 5.6: Tutorials and Training classes are an important means to promote the product and to improve its acceptance. We recommend continuing to give tutorials and training classes with priority.

Recommendation 6.1: We recommend that the GEANT4 Collaboration evaluate the appropriate makeup of the CB as a management body in light of a growing collaboration.

Recommendation 6.2: GEANT4 should have a clearly defined scope and a corresponding long term plan. This allows the individual working groups to develop consistent goals and plans.

8 – Conclusions

The international collaboration GEANT4 has been very successful in creating both the GEANT4 simulation toolkit, and the community behind it. GEANT4 has grown rapidly from an R&D phase to the product stage. A fully operational and internationally recognized product now exists with impressive capabilities in High Energy Physics and other fields. Attention to professional software engineering methods has led to a maintainable and high-quality software product. The investments early in the project to adopt modern software engineering methods are clearly paying off.

The future success of GEANT4 crucially depends on the broad acceptance by the user community, in particular the High Energy Physics experiments. Therefore it should be the goal of the GEANT4 Collaboration that in future all HEP experiments will use GEANT4 as their simulation tool as they have used GEANT3 in the past. To this end, GEANT4 should strive for the greatest possible openness and transparency to users, and the best possible customer support.

9 – Appendix A: Review Agenda

Monday, June 18

History of GEANT4	J. Apostolakis

Tuesday, June 19

Part I: Focus on Functionality	
Status and Evolution in 1999/2000	
Introduction	J. Apostolakis
Kernel Capabilities	M. Asai
Electromagnetic Physics	
Standard	M. Maire
Low Energy	M.G. Pia
Hadronic Physics	J.P. Wellisch
Interactivity	Y. Hajime
Part II: Focus on Primary Lifecycle Processes	
Software Process (Global context)	G. Cosmo
Software Process (Work groups/issues)	
Kernel	M. Asai
Physics	M.G. Pia
Interactivity	H. Yoshida
Integration Testing	S. Sadilov
Configuration Management	G. Folger
Part III: User / Supplier Processes	
Documentation	K. Amako
Training Kits	H. Yoshida
User Support	J. Apostolakis

Wednesday, June 20

Part IV: Experiments: Comparison Projects	
ATLAS:	
ATLAS Geant4 Overview	N. McCubbin
GEANT4 Physics Comparison Projects	K. Amako
GEANT4 Validation in the ATLAS Liquid Argon Calorimeter	J. Collot
CMS	
BaBar	D. Wright
Part V: Utilization of GEANT4 by Other Partners	

Activities of Japanese Users	H. Yoshida

Part VI: User Support Process

Thursday, June 21

Organization of GEANT4

Technical Steering Board	M. Asai
Collaboration Board	R. Mount

Additional Presentations

Hadronic Models	J.P. Wellisch
ALICE Collaboration	F. Carminati
Fluka	P. Sala

Friday, June 22

Meeting with Collaboration Board

Close Out