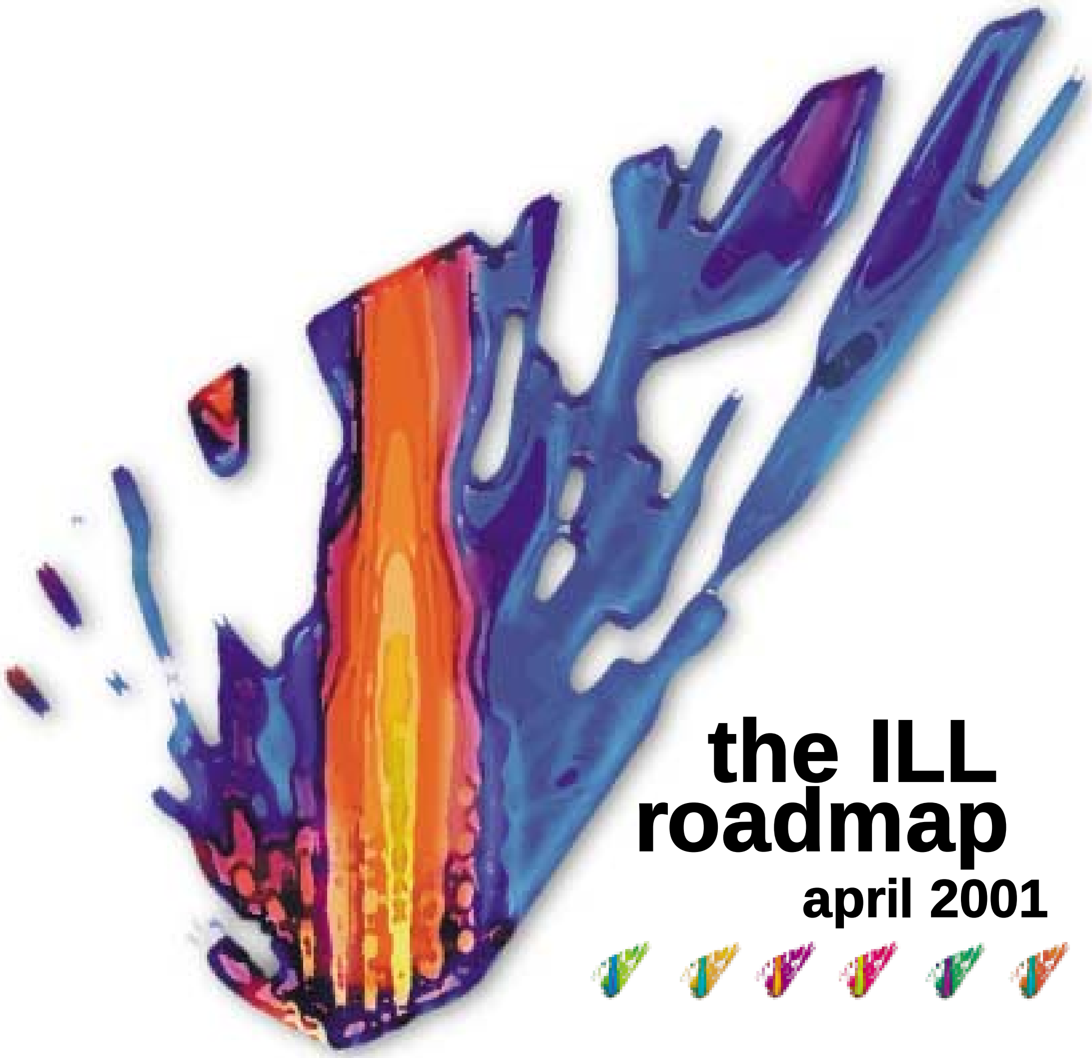

the ILL roadmap

april 2001

NEUTRONS
FOR SCIENCE

DD/bs, 8.3.2001

The ILL Roadmap

Neutron Science at
the Institut Laue-Langevin in Grenoble:

From year 2000 to 2010 and beyond

08/03/01

The ILL Roadmap

Executive Summary

The following document is addressed to the supervisory and decision-making bodies in charge of the Institut Max von Laue – Paul Langevin (ILL) and gives ILL Management's view of the future of neutron science at ILL. The document addresses in particular the question of how best to make use of the Institute's resources and which additional resources would be required to optimise the Institute's potential for great scientific discoveries. The report covers the coming decade up to the year 2010.

The report starts with a description of the ILL as it is at present, which may be summarised as follows.

- *The ILL operates the most powerful source of neutrons for scientific use in the world (Table 4, p. 22).* Every year well over a thousand scientists come to the Institute to experiment on one or several of its 34 different neutron instruments (25 public and 9 private) on problems encompassing virtually all fields of contemporary science.

- *The quality of the scientific output of the Institute is excellent.* The number of publications on neutron research in the world's leading journals is far higher than would be expected solely on the basis of the number of neutron scientists, and the number of ILL publications therein is again several times higher than that of the next-ranking neutron centre. With respect to the number of high-ranking publications, among all radiation facilities world wide ILL is equalled only by its neighbour ESRF (p. 25). On the average, one ILL scientist per year receives a prestigious science prize (Annex 2).

- *ILL is the only truly international neutron centre in the world (p. 16).* To date the Institute has served users from over a thousand different university institutes and research laboratories. Over 80% of the 750 experiments performed every year at the Institute involve collaborators of different nationalities. At the end of their contracts, the vast majority of ILL scientists take back to their home country the international experience gained at the Institute and have excellent career prospects. Many now occupy university chairs (p. 19).

- *ILL is an institution which is young at heart (p. 18).* The average age of its users is just over 30; the average age of its staff will fall below 40 by the end of 2003, after ILL's first wave of retirements. There are many indications of the high spirit of the Institute's workforce: the complete refurbishment of the reactor by our own staff in the mid-nineties, ILL's leading role in the development of new neutron tools, the recent launch of the ambitious "Millennium" renewal programme, the high satisfaction of ILL's visiting researchers, and the very low sick-leave statistics. ILL remains one of very few research facilities encountering no difficulties in attracting excellent young scientists for temporary staff positions.

We then describe ILL's place in the scientific landscape in general, and in the European network of neutron sources in particular.

- *At present, over 60% of ILL's instrument suite is classed as unique or "world-best"* (Annex 3b); its lead in neutron science is longest in such prospering fields as the life sciences, soft matter, glassy dynamics, and cosmology. Two-thirds of the work performed at ILL and, in particular the work carried out in the life sciences, imperatively requires the strong continuous beams delivered by ILL, and cannot be done at today's pulsed spallation neutron sources (p. 24).

- *The future number of neutron instruments available for the European neutron community will at best remain stable (p. 25).* This is found even in the most optimistic of scenarios with all larger existing or planned neutron sources (including ESS) running simultaneously.

For a variety of reasons, the renewal rate of ILL's instruments and infrastructure over the past decade has been far from adequate to do justice to the source's capabilities, so one main question is how to improve on this state of affairs. The main part of the report addresses the future of ILL and our findings are summarised as follows.

- *There is a long list of open and intriguing scientific questions, which can only be solved with the strong continuous neutron beams available at ILL (Table 5, p. 32).* In particular, the Institute has developed a rich variety of new tools for the life sciences, which are complementary to the tools existing at synchrotron or NMR facilities (p. 33). These neutron tools also have a high potential for the post-genome era. But the increasing complexity of these scientific investigations is placing increasing demands on the efficiency of neutron instruments.

- *The "Millennium" programme for instrument and infrastructure renewal as proposed (p. 35) will raise average instrument efficiency by a factor of sixteen (Figure 6, p. 39), and will boost the percentage of unique or "world-best" instruments amongst ILL's total suite of instruments to 90% (Annex 3c).*

- *It is essential, in cost-efficiency terms, that instruments be kept in the best possible shape at all times.* Instrument renewal should be planned as a continuous process, because, over its lifetime, the running of a neutron instrument is much more expensive than its actual construction (Annex 9).

- *The proposed renewal programme could be implemented over a period of eight years without overloading the Institute's facilities (p. 50),* and without imposing on the scientific user programme, while increase in staff positions would remain relatively moderate (Annex 11).

- *A 20% increase in the total number of ILL instruments is possible* without requiring changes to the basic technical structure of the Institute. Another 20% increase is possible if one decided to enlarge the Institute's structure (p. 37).

- *An institute like the ILL should aim not only for top quality research, but also for great discoveries (p. 27).* In order to enhance the Institute's potential for discovery, there is a need to set scientific priorities more vigorously than in the past, by focussing attention on a number of "Flagship Projects" which should receive special support (p. 46).

The cost of the full programme as proposed here amounts to 88 MEuro (Table 8, p. 53). Of this sum, 20 MEuro can be financed from the existing budget. 30% of the funds are foreseen for instrument renewal, 40% for infrastructure renewal, and 30% for the running of five additional scheduled instruments over the next decade. *This investment will allow ILL to stay the world-leading neutron centre for many years to come.*

Grenoble, 8 March 2001

Dirk Dubbers

Der ILL Fahrplan

Zusammenfassung

Dieser Bericht ist für die Aufsichts- und Entscheidungsgremien des Instituts Max von Laue-Paul Langevin (ILL) bestimmt und beschreibt die Zukunft der Neutronenwissenschaften am ILL aus der Sicht der Leitung des Instituts. Der Bericht behandelt insbesondere die Frage, wie die Mittel des ILL am besten eingesetzt werden sollen und welche zusätzlichen Mittel benötigt werden, um das Potential des ILL für große wissenschaftliche Entdeckungen zu maximieren. Der Bericht deckt das kommende Jahrzehnt bis zum Jahr 2010 ab.

Der Bericht beginnt mit einer Beschreibung des gegenwärtigen Zustandes des ILL, der sich wie folgt zusammenfassen läßt.

- *Das ILL betreibt die weltweit stärkste Neutronenquelle für wissenschaftliche Anwendungen (Tafel 4, S. 22).* Jedes Jahr kommen weit über 1000 Wissenschaftler an das Institut, um an einem oder mehreren der 34 verschiedenen Neutroneninstrumente (25 öffentliche und 9 private) Fragestellungen aus praktisch sämtlichen Gebieten der heutigen Naturwissenschaften zu untersuchen.

- *Die Qualität der wissenschaftlichen Produktion des Instituts ist hervorragend.* In den weltweit führenden Zeitschriften ist die Zahl der Veröffentlichungen auf dem Gebiet der Neutronenforschung insgesamt sehr viel höher als nach der Anzahl der Neutronenwissenschaftler zu erwarten wäre. Die Zahl der Veröffentlichungen aus dem ILL darin ist wiederum um ein Mehrfaches höher ist als die der nächstplazierten Neutronenquelle. Selbst unter allen Strahlungseinrichtungen weltweit wird das ILL hinsichtlich der Anzahl hochrangiger Veröffentlichungen nur von seinem Nachbarn ESRF erreicht (S. 25). Im Mittel erhält einmal pro Jahr ein ILL-Wissenschaftler einen ehrenvollen nationalen oder internationalen Wissenschaftspreis (Annex 2).

- *Das ILL ist weltweit das einzige wirklich internationale Neutronenzentrum (S. 16).* Das Institut hatte bisher Nutzer aus mehr als 1000 verschiedenen Universitätsinstituten und Forschungslabors zu Gast. An über 80% der 750 Experimente, die jedes Jahr am Institut ausgeführt werden, arbeiten Forscher verschiedener Nationalitäten zusammen. Die große Mehrheit der ILL-Wissenschaftler nimmt am Ende ihres Aufenthalts am ILL die in Grenoble gewonnene internationale Erfahrung mit nach Hause. Die Karriereaussichten der ehemaligen ILL-Wissenschaftler sind hervorragend, und viele haben heute einen Lehrstuhl (S. 19).

- *Das ILL ist heute ein ausgesprochen junges Institut (S. 18).* Das mittlere Alter seiner Nutzer liegt nur wenig über 30 Jahren. Das mittlere Alter der Belegschaft des ILL wird bis Ende 2003, wenn die erste Pensionierungswelle vorbei ist, unter 40 Jahren liegen. Es gibt viele Indikatoren für die hohe Leistungsbereitschaft des Personals: die vollständige Erneuerung des Reaktors durch ILL-eigenes Personal Mitte der 90er Jahre, ILLs führende Rolle in der Entwicklung neuer Neutroneninstrumentierung, der erfolgreiche Start des "Millennium"-Erneuerungsprogramms, die große Zufriedenheit der Nutzer des ILLs, sowie der ausgesprochen niedere Krankenstand. Das ILL ist eines der wenigen Forschungszentren, welches auch heute keine Schwierigkeiten hat, hervorragende junge Wissenschaftler auf Zeitstellen anzuwerben.

Anschliessend diskutieren wir die Stellung des ILL in der wissenschaftlichen Welt im allgemeinen und innerhalb des europäischen Netzwerks von Neutronenquellen im besonderen.

- *Gegenwärtig sind mehr als 60% der ILL-Instrumente als einzigartig oder weltbest einzustufen (Annex 3b).* Der Vorsprung des ILLs in der Neutronenforschung ist am größten in den zukunftsträchtigen Gebieten der Lebenswissenschaften, der weichen Materie, der glasartigen Dynamik sowie der Kosmologie. Zwei Drittel der am ILL ausgeführten Arbeiten, insbesondere auch die Arbeiten auf dem Gebiet der Lebenswissenschaften, sind auf die starken kontinuierlichen Neutronenstrahlen des ILLs angewiesen und können an keiner der bestehenden Spallations-Neutronenquellen ausgeführt werden (S. 24).

- *Die Gesamtzahl der europäischen Neutroneninstrumente wird auf absehbare Zeit bestenfalls konstant bleiben (S. 25),* und dies selbst in dem sehr optimistischen Szenario, daß alle größeren bestehenden oder geplanten Neutronenquellen einschließlich ESS in Zukunft gleichzeitig in Betrieb sein werden.

Während des vergangenen Jahrzehnts war die Erneuerungsrate für Instrumente und Infrastruktur des ILL völlig unzureichend, und das Potential des ILL wird heute bei weitem nicht ausgeschöpft. Die Frage ist daher, wie man diesem Zustand abhelfen kann. Der Hauptteil des vorliegenden Berichts befaßt sich mit der Zukunft des ILL und kann wie folgt zusammengefaßt werden.

- *Eine große Anzahl offener und aufregender wissenschaftlicher Fragen kann nur mit Hilfe der starken kontinuierlichen Neutronenstrahlen des ILLs gelöst werden (Tafel 5, S. 32).* Insbesondere hat das Institut in jüngster Zeit eine Anzahl neuer Untersuchungsmethoden für die Lebenswissenschaften entwickelt, die komplementär zu den Synchrotron und NMR-gestützten Methoden sind (S. 33). Diese Neutronenverfahren sind für die Nach-Genom Ära unersetzlich; die wachsende Komplexität der erforderlichen Untersuchungen stellt jedoch zunehmend hohe Ansprüche an die Effizienz der Neutroneninstrumente.

- *Das "Millennium" Programm zur Erneuerung der Instrumente und Infrastruktur des Instituts (S. 35) wird die mittlere Effizienz der ILL-Instrumente um das Sechszehnfache steigern (Figur 6, S. 39), und wird den Anteil der einzigartigen oder weltbesten Instrumente auf 90% erhöhen (Annex 3c).*

- *Aus Gründen der Kosteneffizienz sollten alle Instrumente des ILL stets im bestmöglichen Zustand gehalten werden,* d.h. die Instrumenterneuerung sollte als ein kontinuierlicher Prozeß angelegt sein. Dies ergibt sich daraus, daß, über die Lebensdauer eines Neutroneninstruments gerechnet, dessen Betriebskosten um ein Vielfaches höher sind als die ursprünglichen Baukosten (Annex 9).

- *Das vorgeschlagene Erneuerungsprogramm läßt innerhalb von acht Jahren realisieren, ohne die Strukturen des Instituts zu überlasten (S. 50),* und ohne das laufende wissenschaftliche Programm zu beeinträchtigen. Der hierzu erforderliche Zuwachs an Personalstellen ist moderat (Annex 11).

- *Die Gesamtanzahl der ILL-Instrumente kann um 20% erhöht werden,* ohne die grundlegende technische Struktur des Instituts zu ändern. Ein weiterer Anstieg von 20% ist möglich, wenn man bereit ist, diese Struktur zu erweitern (S. 37).

- *Eine Einrichtung wie das ILL sollte nicht nur Wissenschaft hoher Qualität, sondern auch bahnbrechende Entdeckungen anstreben (S. 27).* Um das Entdeckungspotential des Instituts zu erhöhen, müssen in Zukunft die wissenschaftlichen Prioritäten schärfer herausgearbeitet werden, z.B. durch die Auswahl und Förderung besonderer "Flagschiff-Projekte" (S. 46).

Die Kosten des vorgeschlagenen Erneuerungsprogramms belaufen sich auf 88 MEuro (Tafel 8, S. 53), wovon 20 MEuro aus dem bestehenden Budget des ILL finanziert werden können. 30% dieser Summe sind für Instrumenterneuerung vorgesehen, 40% für Infrastrukturerneuerung, und 30% für den Betrieb fünf weiterer ILL-Instrumenten über mehrere Jahre. Durch diese Investitionen wird das ILL für viele Jahre seine weltweit führende Stellung unter den Neutronenforschungszentren behaupten können.

Grenoble, den 8. März 2001

Dirk Dubbers

L'Itinéraire ILL

Résumé exécutif

Le document ci-joint est adressé aux organes de surveillance et aux organes décisionnels de l'Institut Max von Laue – Paul Langevin (ILL). Il présente le point de vue de la Direction de l'Institut sur l'avenir de la science neutronique à l'ILL. Le document aborde en particulier la question de savoir comment utiliser au mieux les ressources de l'Institut et quelles ressources supplémentaires seraient nécessaires pour optimiser le potentiel de l'Institut en vue de contribuer aux grandes découvertes scientifiques. Le rapport couvre la prochaine décennie jusqu'en 2010.

Le rapport commence par une description de la situation de l'ILL à l'heure actuelle, qui peut être résumée comme suit.

- *L'ILL exploite la source de neutrons à usage scientifique la plus intense au monde (Table 4, p. 22).* Chaque année, plus d'un millier de scientifiques viennent à l'ILL pour effectuer des expériences sur un ou plusieurs des 34 différents instruments neutroniques de l'ILL (25 publics, 9 privés) et étudier des problèmes qui couvrent pratiquement tous les domaines de la science contemporaine.

- *Les résultats scientifiques obtenus à l'ILL sont d'une grande qualité.* Le nombre de publications relatives à la recherche neutronique parues dans les principaux journaux mondiaux est étonnamment élevé comparé au nombre de neutroniciens. D'autre part, parmi ces publications, le nombre des publications de l'ILL est largement supérieur à celui du centre neutronique qui vient au second rang. A cet égard, parmi tous les centres de rayonnement dans le monde, l'ILL n'est égalé que par son voisin, l'ESRF (p. 25). En moyenne, un prix scientifique prestigieux est décerné chaque année à un scientifique de l'ILL (Annexe 2).

- *L'ILL est le seul centre neutronique véritablement international dans le monde (p. 16).* A ce jour, l'ILL a accueilli des utilisateurs provenant de plus de mille instituts universitaires et laboratoires de recherche différents. Plus de 80% des 750 expériences réalisées chaque année à l'ILL impliquent des collaborateurs de plusieurs nationalités. A la fin de leur contrat, la grande majorité des scientifiques de l'ILL retournent dans leur pays d'origine en ayant acquis une expérience internationale et ont d'excellentes perspectives de carrière. Beaucoup occupent actuellement une chaire à l'université (p. 19).

- *L'ILL est un institut qui peut être qualifié de jeune (p. 18).* L'âge moyen de ses utilisateurs dépasse à peine 30 ans et, d'ici la fin 2003, l'âge moyen du personnel sera inférieur à 40 ans suite à la première vague de départs à la retraite. De nombreux indicateurs prouvent l'engagement du personnel de l'Institut : la remise en état complet du réacteur par le personnel lui-même au milieu des années 90, le rôle prédominant de l'ILL dans le développement de nouveaux outils neutroniques, le récent lancement d'un programme ambitieux de renouvellement, le programme 'Millennium', le haut niveau de satisfaction des chercheurs invités, ainsi que l'absentéisme très faible du personnel. L'ILL reste l'un des rares centres de recherche qui ne rencontre aucune difficulté pour attirer de jeunes scientifiques de haut niveau sur des postes à durée déterminée.

Nous décrivons ensuite la place de l'ILL dans le paysage scientifique en général, et dans le réseau européen des sources neutroniques en particulier.

- *Actuellement, plus de 60% du parc instrumental de l'ILL est considéré comme unique ou inégalé dans le monde (Annexe 3b).* Dans les sciences neutroniques, la position dominante de l'ILL est la plus forte dans des domaines en plein essor tels que les sciences de la vie, la matière molle, la dynamique des verres et la cosmophysique. Les deux tiers des travaux effectués à l'ILL et, en particulier, les travaux concernant les sciences de la vie, nécessitent impérativement l'utilisation des faisceaux intenses et continus de neutrons disponibles à l'ILL et ne peuvent pas être réalisés dans les sources de neutrons de spallation pulsées actuelles (p. 24).

- *A l'avenir, le nombre d'instruments neutroniques disponibles pour la communauté neutronique européenne, au mieux, restera stable (p. 25),* même en prenant le scénario le plus optimiste, c'est-à-dire en supposant que toutes les grandes sources neutroniques existantes ou programmées (y compris l'ESS) fonctionnent simultanément.

Pour des raisons diverses, le taux de renouvellement des instruments et de l'infrastructure de l'ILL au cours de la dernière décennie était loin d'être adéquat comparé aux possibilités de la source de l'Institut. C'est pourquoi, l'un des sujets principaux du présent rapport est de trouver des moyens pour améliorer cette situation. La partie principale du rapport traite de l'avenir de l'ILL et les conclusions de nos réflexions sont résumées ci-dessous.

- *Il reste une longue liste de problèmes scientifiques passionnants non élucidés qui ne peuvent être résolus qu'à l'aide des faisceaux intenses et continus de neutrons disponibles à l'ILL (Table 5, p. 32).* En particulier, l'Institut a développé une large panoplie de nouveaux outils destinés aux sciences de la vie, qui sont complémentaires aux outils existant dans les installations synchrotron ou RMN (p. 33). Ces outils neutroniques ont également un potentiel élevé pour l'ère de la 'post-génomique'. Cependant, la complexité de plus en plus grande de ces expériences scientifiques entraîne des exigences croissantes en termes d'efficacité des instruments neutroniques.

- *Le programme 'Millenium' de renouvellement des instruments et de l'infrastructure de l'ILL, tel qu'il est proposé (p. 35), multipliera l'efficacité moyenne des instruments de l'Institut par un facteur seize (Figure 6, p. 39) de sorte que, sur l'ensemble du parc instrumental de l'ILL, le pourcentage d'instruments uniques au monde ou inégalés passera à 90% (Annexe 3c).*

- *Il est essentiel, en termes de rentabilité, de toujours maintenir les instruments dans le meilleur état possible.* Le renouvellement des instruments devrait être planifié comme un processus continu, parce que, si l'on considère la durée de vie d'un instrument neutronique, son exploitation est beaucoup plus onéreuse que sa construction (Annexe 9).

- *Le programme de renouvellement proposé pourrait être mis en place sur une période de huit ans sans surcharge des installations de l'ILL (p. 50)* et sans interférence avec le fonctionnement du programme scientifique des utilisateurs, l'augmentation des effectifs restant relativement modérée (Annexe 11).

- *Une augmentation de 20% du nombre global des instruments de l'ILL est possible sans qu'il soit nécessaire de modifier la structure technique de base de l'Institut*. Une autre augmentation de 20% est possible à condition de décider d'agrandir la structure de l'Institut (p. 37).

- *Un Institut comme l'ILL ne devrait pas seulement avoir pour but de faire de la recherche de grande qualité, mais également de contribuer aux grandes découvertes (p. 27).* Afin d'accroître le potentiel de l'Institut en termes de découvertes scientifiques, il est nécessaire de fixer les priorités avec plus de rigueur que par le passé, en focalisant l'attention sur un certain nombre de projets phares qui recevraient un support spécifique (p. 46).

Le coût de l'ensemble du programme Millennium, tel qu'il est proposé, s'élève à 88 MEuros (Table 8, p. 53). Sur cette somme, 20 MEuros peuvent être financés à partir du budget existant. Il est prévu d'affecter 30% des fonds au renouvellement des instruments, 40% au renouvellement de l'infrastructure et 30% à l'exploitation de cinq instruments supplémentaires au cours de la prochaine décennie. *Cet investissement permettra à l'ILL de garder sa place de leader mondial en sciences neutroniques pendant de nombreuses années.*

Grenoble, le 8
mars 2001

Dirk Dubbers

The ILL Roadmap

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The ILL Roadmap

A. INTRODUCTION

The Institut Max von Laue - Paul Langevin (ILL) in Grenoble operates the 58 MW European high-flux reactor which serves as a uniquely powerful source of slow neutrons for scientific research. ILL’s member countries are France, Germany and the United Kingdom with Associate status, and, with a Scientific Member status, Austria, the Czech Republic, Italy, Russia, Spain and Switzerland.

At its June 2000 meeting [1], the Steering Committee asked ILL Management to sketch a Roadmap which could guide the Institute through the coming decade. This Roadmap should indicate how best use can be made of ILL facilities and, for the time being, should not be limited by financial constraints. The present document is intended to serve as a Roadmap for ILL for the next ten years and beyond.

The central element of the Roadmap is the Millennium Renewal Programme, which was initiated in autumn 1998, and launched in January 2000. This programme is based on an open list [2] of originally 29 proposals on instrument renewal and 5 proposals on infrastructure renewal (including new neutron guides). At the time the programme was started, only a small number of these proposals could be taken into serious consideration, in view of the tight budgetary situation of the Institute. Meanwhile, the instrument list has been consolidated [3], and the infrastructure list has been enlarged [4]. Furthermore, a strategy for the future of the life sciences has been developed [5]. All this has been integrated into the present Roadmap.

The paper is organised as follows. We first give, in Section B, a short survey of the tools at hand for the study of matter on a molecular scale, and then, in Section C, recall some basic facts about ILL. In Section D we describe how the Institute is positioned within the general scientific landscape, within the network of European neutron centres, and within the local scientific environment, and we dwell on the question of how many neutron sources will be needed in the future.

In Section E we give a short essay on the conditions for successful scientific innovation. In Section F follows a more thorough discussion of future scientific opportunities at ILL, with particular emphasis on the life sciences, and a discussion of the rôle of the Millennium Renewal Programme in turning these opportunities into reality.

In the last two sections, a specific scenario is presented on how ILL renewal could proceed over the next decade, both for instrument and for infrastructure renewal. In Section G we first discuss the maximum number of instruments which can possibly be installed at ILL. We then list the measures proposed in the fields of instrument and infrastructure renewal. In Section H we discuss the question of how fast these changes can be implemented, drawing on earlier experience, and what consequences this will have for the Institute's personnel. Finally, possible spending profiles are proposed for the period from now to the end of 2003, and for the period thereafter up to 2010.

As some of the findings of this report turned out to be quite unexpected we have included as an Annex a rather large number of internal working papers from which our results were derived.

The present report is a synthesis of two previous papers. One was submitted to the Steering Committee in June 2000 [6] (which comprised mainly Sections A to F), the other to the Subcommittee on Administrative Questions in October 2000 [7] (mainly Sections G and H), both of which were also presented to the Scientific Council in its October 2000 meeting. The language of the report is “International English”.

Thanks go to C. Carlile, C. Vettier, B. Dorner, K. Yvon, S. Lettow and E. Bauer for critical reading, useful comments and important contributions to the various versions of the report. In particular, Chapters 18 and 20 reproduce documents written by C. Carlile [4] and C. Vettier [5].

B. TOOLS OF SCIENTIFIC RESEARCH

1. Radiation Sources

To examine matter on a microscopic scale (i.e. atomic and molecular), scientists dispose of only a handful of different types of radiation.[1] They are given in **Table 1**.

Table 1: Types of Radiation used to Study Matter on a Molecular Scale

- Photons:
  - Radio and Microwaves
  - Light (Lasers)
  - x-Rays (Synchrotrons)
- Electrons
- Neutrons

The radiation, artificially produced in a radiation source (for instance neutrons in a reactor), is directed towards some highly specialised instruments on which the material probes can be studied. With the exception of neutrons, all the above types of radiation are also available on the small-laboratory scale.

Since the start-up of the ILL reactor in 1972, the production and use of each of these types of radiation has evolved considerably. A partial overlap between the expanding envelopes of the various fields has developed, in particular with the arrival of synchrotron x-ray sources, spallation neutron sources and also, to some extent, new radio-wave (NMR), laser, electron tunnelling and other microscopy techniques.

For the use of synchrotron radiation, seven powerful (more than 1 GeV) and relatively new (age below 20 years) synchrotrons are in operation in Europe, three more are under construction, and two are in the planning stage [8]. World-wide, there are 49 such synchrotron sources in operation or planned [9]. *All NMR, laser and microscopy installations,* on the other hand, can be handled at the small-laboratory level, and are standard equipment in most research institutions.

2. Neutron Sources

For the use of neutron beams, eleven high or medium flux reactors (more than 10 MW thermal power) are in operation *in Europe.* Seven of these date from the late fifties or early sixties. Two

[1] *For studies on* <u>*subatomic*</u> *scales, beams of fast protons and their secondary reaction products (muons, etc.) are also used, as well as various kinds of ion beams. Occasionally, such beams, as well as beams of positrons, are also used for studies in material sciences.*

further high-flux reactor sources are under construction (FRM2 in Germany and PIK in Russia). In addition, two spallation neutron sources are in operation (ISIS in UK and SINQ in Switzerland), and two more are in the planning phase (ESS and Austron) [10]. For ISIS, a second target station is in the planning. These sources will be discussed in more detail in Chapter 8 (p. 22).

Worldwide altogether twenty high or medium flux neutron sources are in operation, three of which are spallation sources (> 50 kW beam power). More than one half of these sources is expected to go out of service within the next ten years [10]. However, a new high-power (2 MW, possibly up to 5 MW) spallation neutron source (SNS) is under construction in the US and another in Japan (1 MW, KEK/JAERI joint project). In addition, new reactor sources have just been funded in Australia and in Taiwan.

All the reactor sources but one are continuous sources which deliver strong steady fluxes of neutrons for scientific experiments. *All the spallation sources but one are pulsed sources* which deliver short bursts of neutrons to the instruments. Today, the majority of all existing neutron applications need continuous sources like ILL (Chapter 8, p. 24).

C. STRUCTURAL ELEMENTS OF ILL

The organisational structure of the Institute as laid down in the inter-governmental convention on ILL comprises the Steering Committee and its Subcommittees, the Auditing Commission, the Scientific Council and its Subcommittees, and the ILL Management (see Annex 1). We shall not discuss this further. Instead we address those structural elements which are central to ILL’s role as an international laboratory for neutron research: The reactor, the instruments, the users and the staff of ILL.

3. The Reactor

ILL has had a new reactor since 1995. It is the most powerful neutron source for scientific research in the world. The first reactor was in service for 20 years, with typically more than 99% uptime, except for a one-year overhaul period in the mid-eighties. Care is also being taken that the reactor’s ancillary equipment is being systematically upgraded. It is therefore safe to assume that the technical lifetime of the new reactor will be at least as long as the lifetime of the first reactor, and that, having been replaced once, it can be replaced again.

The reactor has an impeccable safety record which has never been the subject of dispute, and there is no indication that this state of affairs will change. The nuclear inventory of the reactor has a mass of ten kilograms. By way of comparison, the nuclear inventory of nuclear power stations has a mass of several thousand kilograms.

The supply of nuclear fuel is secured by a Franco-Russian governmental agreement signed in 1996. This agreement covers the period up to 2005. In addition, a Memorandum of Understanding between the Associates of ILL and the US government foresees a future supply of nuclear fuel. Studies on the possible use of low enriched uranium are underway. So, all in all, the fuel situation looks secure in the long term.

In Grenoble, ILL is embedded in a rich scientific, industrial, cultural and natural environment, which is a necessary prerequisite for the success of such an installation. Among the Grenoble population ILL finds sympathy and pride.

4. The Instruments

At ILL about 35 neutron instruments are fed by the neutron beams coming from the reactor neutron source. These instruments run in parallel day and night for about 225 days a year. On each instrument, supported by ILL staff a group of external users works mostly around the clock and is replaced after some days by a fresh group of users tackling a different scientific problem. Each year, some 750 "small" experiments are done this way, resulting in about 400 publications. This is certainly not the only useful way to do science, but it is a rather *cost-effective* one. Most other "small-science" institutions with a similar number of supporting staff - and therefore a similar financial framework - have only a fraction of the scientific output of ILL, and hence a higher cost per experiment and per publication. This statement can be quantified. – In what concerns the quality of this output we refer the reader to the end of Chapter 8, p. 25.

Over the years, the beam time requested has been approximately twice that available. This overload factor of two seems to be a self-regulating "universal" number and is, broadly speaking, the same for all instruments which are therefore far from able to serve the demand. If, for a given instrument, the overload factor were to rise above two, then it would, for example, become too risky for a student to start thesis work on that instrument. He or she would therefore be directed elsewhere. In the past, even the appearance of strong competitors such as ISIS or ESRF has not affected the heavy demand for ILL instruments, and the same will probably remain true when the Munich reactor starts operation. This is the hallmark of unfulfilled demand. However, it is acknowledged that instrument overload in itself is not necessarily a measure of quality for scientific work and the virtues of the Institute's scientific programme will be discussed in later sections.

Historically, ILL started out with a futuristic instrument suite which still serves as a standard reference for other neutron research centres. Throughout the seventies, the number of operational instruments continued to rise to full capacity, reaching a maximum of 30 scheduled instruments in the early eighties. At this time an instrument renewal programme ("*deuxième souffle*") was embarked upon, which involved the construction of a second neutron guide hall and half a dozen new instruments. In the late eighties a "*troisième souffle*" renewal programme was proposed, but this was abandoned when the reactor was shut down for refurbishment in 1991.

In the early nineties, in response to the lowering of the British contribution, the number of scheduled public instruments was reduced to 25, while up to one dozen further instruments were allowed to be run by collaborating research groups (CRGs) on a private or semi-private basis.

With the start of the new millennium, another major renewal programme, the "Millennium Programme" [2] was launched (Chapter 15, p. 35) following a period of about a dozen years during which lack of funds had prevented ILL's instrument suite from remaining state-of-the-art. The aim of this programme is, among others, to renew the instrument suite and to strongly increase instrument efficiency implementing the latest ideas in neutron science and taking advantage of important technical advances, much of it achieved at the Institute itself.

ILL has always been a centre for the development of new neutron techniques. ILL scientists, engineers and technicians have developed many innovative devices and techniques. **Table 2** lists a few recent examples.

Table 2: Recent Innovative Neutron Devices and Techniques

- 3-D Neutron Polarimetry
- ^{3}He-Neutron Polarisers and Wide-Angle Polarisation Analysers
- Microstrip Neutron Detectors
- 1-D and 2-D Image-Plate Neutron Detectors
- High-Efficiency Neutron Supermirrors
- Onion-Skin Crystal Optics
- Cryogen-free Cryostats to 1 Kelvin
- Ballistic Supermirror Guides
- High-Speed Detector Read-out

Some of these techniques, although invented at ILL, have first been put into regular use at other neutron centres. On the other hand, the types of instrument in use at the Institute have changed only moderately since ILL moved from the development phase to the operational phase in the late seventies.

Neutron instrumentation is special in the sense that no commercial market for neutron instruments has developed, in contrast to other more frequently used types of instrumentation such as x-ray spectrometers, which have been developed and commercialised by industrial companies. *ILL supports efforts to commercialise the manufacture of existing neutron instrumentation*, as was underlined recently by the founding of the start-up company XENOCS which specialises in neutron optics. But in view of the small size of the neutron market, it cannot be expected that commercial companies will profitably invest in the development of new neutron instrumentation, which will therefore remain the domain of the research institutes themselves. Some specialisation by the various research centres in certain techniques is helpful and partly exists, and not every centre should develop the full panoply of instrumentation and components. On the other hand, it seems unlikely that the neutron research centres will be able to take on the large-scale manufacture of instrumentation on behalf of other neutron centres.

5. The Users

ILL has from the outset been a purpose-built international user-organisation, and has served as a model since. Historically, the Institute was built upon three foundation blocks, which have turned out to be the basis of its success:

- the reactor was exclusively dedicated to and optimised for neutron-beam experiments performed outside the reactor vessel;
- the suite of neutron instruments had a strongly futuristic component;
- the Institute was to be completely open to external scientists.

The last point means that in-house proposals were to be treated no differently from external proposals, all of which were to be examined by the external selection committees of the Scientific Council. Twice a year about one hundred eminent scientists meet at ILL for two days each to select the proposals submitted. They are divided into eight subcommittees, one for each field of science represented at the Institute.

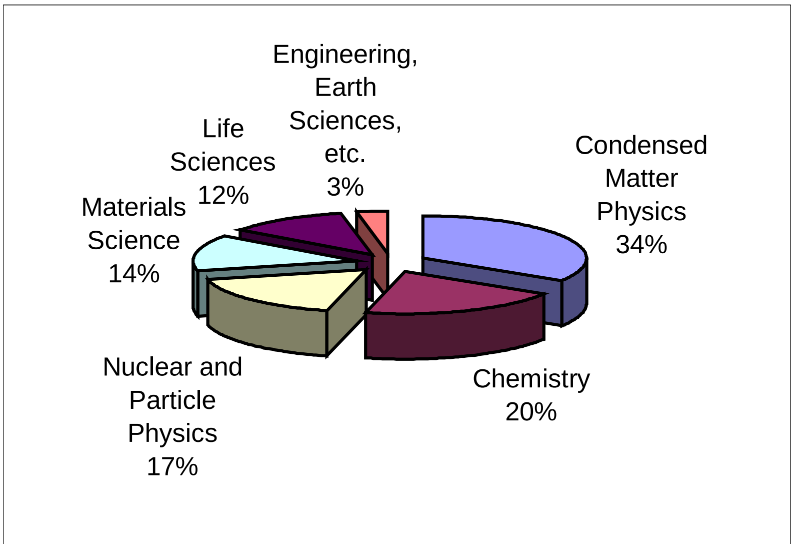
It was the advent of ILL which shifted the centre of gravity of neutron science to Europe. There are now approximately 4000 European scientific neutron users [11], of which about 1300 per year come to ILL to do one or several of the 750 experiments per year. These 4000 scientists are active neutron users and not dead files; for a cross-check, note that since 1997 over 2100 different scientists have used ILL, although the Institute provides only 20% of all European neutron instruments (Chapter 8, p. 22).

ILL and its user community are strongly interwoven, not only via the representatives of the neutron community to the Scientific Council and its Subcommittees, but also by the participation of ILL staff in national neutron committees, national user meetings, and by jointly organised scientific conferences, summer schools and workshops. In this way the scientific programme of the Institute and the instrument suite necessary to realise this programme are developed in collaboration with the user community in an organic process.

A typical user group consists of between two and five collaborating scientists, who typically come from two or three different university institutes or other small research units. *Altogether, the Institute has served users from more than 1100 different university institutes or research laboratories*.

These users belong to many different disciplines. In this respect, ILL differs from many other large-scale facilities which serve only a single field of research. ILL instrument-days are allocated to the various disciplines in the proportions given in **Figure 1** (based on accepted beam time for the year 2000).

Figure 1 : Scientific Disciplines served at ILL



ILL is the only truly international neutron facility in the world. 82 % of all experiments accepted in 1999 involved scientists of more than one nationality on the list of collaborators. Nevertheless, *some national strongholds can be identified at the Institute*. French users are strong in life sciences (with a 38 % participation in the total number of life science experiments in the years 1998, 1999 and 2000). German users are strong in soft matter (36 %), and have preferences somewhat complementary to UK users, in particular in the fields: magnetic crystalline diffraction (20 % Germany vs. 38 % UK), materials and surfaces (36 % vs. 17 %), liquids and glasses (31 % vs. 17 %), nuclei and particles (34 % v. 18 %). All other fields are roughly balanced (with percentages of participation mostly between 24% and 28 % of the total number of experiments in the field).

New neutron users face a barrier which users of other types of radiation do not. Except for neutron research centres, they have no possibility of gaining experience in neutron work, whereas other types of radiation such as x-rays are freely available at most small institutes and the transition from university-based research to facility-based research is simple. This handicap must be compensated for by investing in neutron *training courses* for university students, which is done extensively at ILL, and by offering newcomers exploratory beam time from the Director's discretionary budget.

ILL must offer its users a top-class service. Feedback from users is stimulated by the introduction in 2000 of a *user forum* and the systematic gathering of comments after each experiment. Efforts are under way to improve the availability of overnight and weekend technical services. Some research teams, in particular from chemistry and the life sciences would greatly benefit from a *fast access scheme* to the Institute, on the basis of a three-month instead of the present six-month cycle. This is to be implemented in 2001. One might also consider developing privileged relations with certain university-based user groups, in order to improve user involvement in the development of their field.

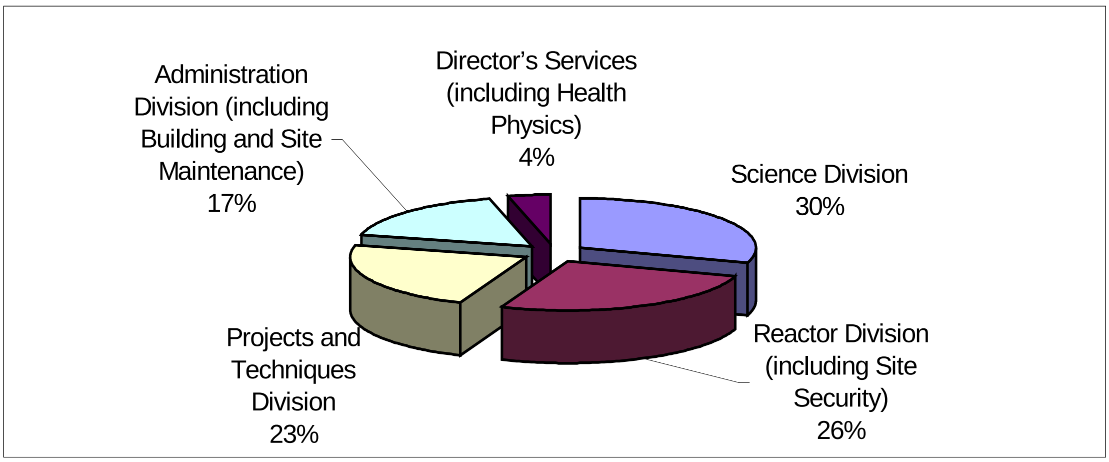
The industrial relevance of much of the work done at ILL is high, though difficult to quantify. An internal survey qualified as much as 35% of all proposals as of high industrial relevance, although this finding may have a subjective component. Direct industrial use of ILL today (i.e. with industrial companies as proposers) represents only 3% of its total use [12]. However, most industrial involvement in scientific neutron programmes is via contracts placed with university research groups and not by direct participation. In 1999 an *Industrial Liaison Group* was established at the Institute with the aim of increasing this figure. However, it should be recalled that the most lucrative route to additional income by industrial use, in-pile irradiation for industrial and medical purposes, has been blocked by early and irreversible decisions on ILL's role as a neutron *beam* facility, as compared to a neutron *irradiation* facility.

6. The Staff

ILL has 420 employees, including twenty thesis student posts. In the early nineties, the number of posts was cut by one fifth, following the reduction in the British Associate's grant. Personnel costs account for 52% of the total budget (which itself is presently of the order of 50 MEuro per year).

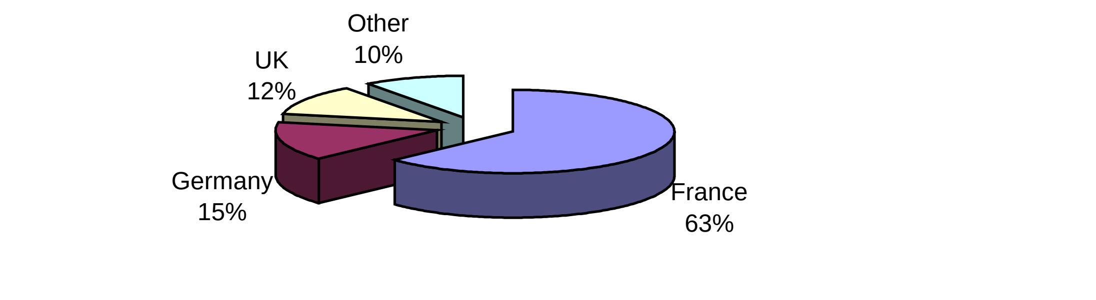
The breakdown of ILL staff by Division is given in **Figure 2**.

Figure 2 : The Divisions of ILL



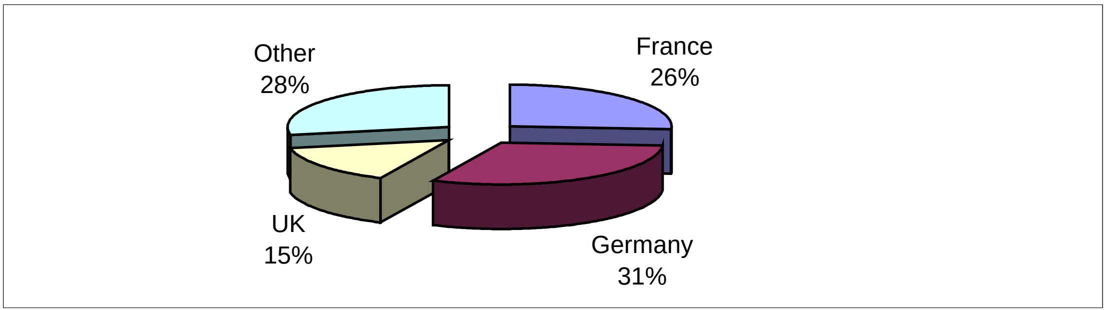
The breakdown of ILL staff by nationality is shown in **Figure 3**.

Figure 3 : National Origins of ILL Staff



Since its start-up ILL has been taking initiatives in an attempt to achieve a better balance between nationalities. In contrast, *the breakdown with regard to ILL's 60 scientists* in the Science Division as displayed in **Figure 4** seems to be well balanced,

Figure 4 : National Origins of ILL Scientists



In recent years the first generation of staff who helped to build ILL up from the beginning has gradually reached the age of retirement and is being replaced by a young group of staff of about thirty years of age. At present, the average age of the workforce is 43 years. By the end of 2003, about 100 new members of staff will have brought the average age of the personnel to below 40 years. The average age of ILL personnel will be therefore one of the lowest among all research centres.

The spirit of the workforce is impressively high. This is demonstrated by the:

- complete and successful refurbishment of the reactor by our own staff
- large number of new neutron devices invented
- setting up of the elaborate Millennium renewal programme, which relies mostly on in-house ideas, which continue to be in abundant supply
- satisfaction and happiness of the visiting researchers
- exceptionally low sick-leave.

The sick leave numbers (including work accidents and maternity leave) are: ILL 3.0% [13], France private sector 4.8%, public sector 7.3% [14], Germany overall 5.4% [15]. Absences due to work accidents are only half that of the French private sector [13,14].

In France, by tradition, workers vigorously defend their interests by taking industrial action. However, once a conflict is settled, the same workers quickly recover their highly motivated professional attitude.

The in-house scientists support users of ILL in their experiments. As "Local Contacts" they organise, set up and help to run the experiments, identify and solve technical problems whenever they arise, and give support in the evaluation and interpretation of data. The Institute is doing its utmost to maintain and improve the high standard of this service. In addition, ILL scientists invent and develop new instrumentation, and are also expected by the community to develop the scientific case for each such new instrument. Most ILL scientists are internationally renowned in their field of research. *In fact, over the past fifteen years, more than one ILL scientist per year has on the average won a prestigious national or international science prize* (***Annex 2).***

About half of ILL scientists are on limited-term 5-year contracts. After their stay in Grenoble, these scientists take back to their home countries the international experience gained at ILL. In 1998 and 1999 alone, five ILL scientists (plus two former ILL scientists) became University Professors. If we focus, for example, on the 83 German experimental scientists formerly or presently at ILL, 18 *(21%) went on to become University Professors*[2], and another 20 (24%), have stayed on at ILL in permanent positions, while all have excellent opportunities in research or industry. In addition, a large number of university professors in theoretical physics spent their early days as members of ILL's world-renowned Theory Group. In conclusion, ILL scientists are of high quality and have good prospects in their scientific career.

Only a few years ago the number of posts at ILL was reduced by 19%. Furthermore, at the start of the year 2000, weekly working hours were reduced by French law to 35 hours. At ILL this loss will only partly be compensated by the recruitment of new staff. In addition to this, legal requirements on safety, radiation protection, quality assurance, reporting to public authorities, as well as demands by supervisory bodies for administrative traceability, general reporting and public relations are on the increase, and this increase can only partly be balanced by the general increase in productivity due to technical progress. *We do not wish to join in the general chorus of complaints, but if we take all these effects together, we can state that ILL's workforce is painfully lean, and that any further reduction in staff numbers would have a disproportionately destructive effect upon the functioning of the Institute.*

D. ILL'S PLACE IN SCIENCE

We next discuss the role of neutron physics in the general development of science. Then we describe ILL's place within the network of European neutron centres, say a word about publication statistics, discuss the probable development of future neutron supply, and describe the fields of cooperation with the neighbouring institutes.

7. The Neutron's Place in Science

Science advances at a fast pace. For most of the scientific problems being tackled today, the underlying questions had not even been formulated 25 years ago. Over this short period, the physicist's view of the world has profoundly changed, as has the biologist's capacity to unveil and control the basic processes of life.

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[2] *The example is chosen for ease of sampling : most high-ranking scientists in German research organisations also have a professorship in a university.*

When we look at the 20th century as a whole, we find that science all through the century has primarily been devoted to the exploration of the world on two extreme scales: the very small and the very large. *On the very small scale,* the aim has been to establish the atomic and molecular basis of all phenomena encountered in ordinary matter, be it in the realm of physics, chemistry or the life sciences. Here we are in the middle of an ongoing process with an ever-increasing number of open and sometimes disturbing questions. *Many of these questions are amenable to neutron physics,* and can be found in the list of topics given in Table 5, p. 32.

On the extremely small scale, the beautiful and awe-inspiring basic principles that govern the subatomic world have been partly disclosed, though not yet in a fully satisfactory way. *On the extremely large scale,* on the other hand, the origin, evolution and possible fate of the universe has been studied with increasingly refined and subtle methods. *In these fields, too, neutron experiments have provided indispensable data and precise tests, and will continue to do so.*

Towards the end of the 20th century, two new tendencies have been emerging: firstly, the physics of the extremely small appears to be intimately interwoven with the physics of the extremely large ("nuclear physics meets astrophysics", "particle physics meets cosmology"); secondly, bridging the very small atomic and subatomic world and the very large world of astrophysics, *there is a vast and largely unexplored field of the "complex".* This is the somewhat vague term for the many things "in between", which, surprisingly often prove to be accessible to scientific method, i.e. their properties show a certain, if limited, degree of universality within a given class of system.

The open questions in the vast field of the complex range from the old mysteries surrounding fully developed turbulence, the possible taming of deterministic chaos, the universality of phase transitions, the self-organisation of large interacting assemblies and, linked to this, the spontaneous formation of structure and of learning systems, all the way to the unknown reasons for the astonishing stability of living systems.

Many facets of modern science cannot be squeezed into the simplistic scheme sketched out here[3], and not all modern scientific questions are accessible to neutron science. *But neutron science has contributed decisively to many strands in this new development*. Thus, in past years, neutron science has moved away from the study of simple crystals and their lattice dynamics, and has turned to the study of disordered systems, complex chemical reactions and catalysis, and today finds its highlights in the fields of soft matter, self-assembling systems, and exotic electron systems. Furthermore, in the late eighties at ILL, a major part of the nuclear physics programme was superseded by a programme on particle physics and cosmology, while the remaining nuclear physics programme was increasingly oriented towards astrophysics problems.

The most noteworthy of all recent developments at ILL are those in the field of life sciences. Here neutron methods give new results that cannot be obtained using conventional x-ray (i.e. synchrotron) or NMR methods. In particular, the unique ability of the neutron to single out small and judiciously chosen parts of a given molecular assembly has enabled scientists for the first time to link the biological function of living matter to the molecular dynamics observed in neutron experiments, see for instance [16, 17] and references therein. These topics will be discussed in more detail in Chapters 14 and 20.

Hence, neutrons have proven to be one of the pillars of science in the search for a deeper understanding of the phenomena of nature. This is due to a number of special features that give

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[3] *Examples include the astonishing developments in futuristic devices, which range from one-atom masers and lasers, one-electron transistors, single-spin resonance devices all the way to quantum computers and new imaging devices.*

neutrons a unique status among the various types of radiation mentioned at the beginning of this report. These features are listed in **Table 3**.

Table 3: The Unique and Useful Properties of Slow Neutrons

• *Neutrons penetrate matter most easily,* and therefore the use of thick samples and of bulky sample environment poses no problems.

• *Radiation damage within the probe is minimal.*

• *Neutron scattering data are easily interpretable* because multiple scattering of neutrons is rare.

• *Slow neutrons provide us with a powerful and unique tool to determine the full space-time correlation functions of matter,* because they have de Broglie wavelengths that match to atomic dimensions and at the same time have kinetic energies that match to excitation energies of condensed matter.

• *Slow neutrons can distinguish between self-correlations and pair-correlations of particles in condensed matter*, due to the presence of both coherent and (spin and isotope) incoherent parts in neutron scattering.

• *Nuclear neutron scattering is due to a point like interaction,* therefore this scattering is easily measurable also at high momentum transfer, that is at high spatial resolution.

• *Magnetic neutron scattering is first-order and of same size as nuclear scattering,* therefore also subtle effects like magnetic excitations are easily measurable.

• *In neutron scattering different elements with similar atomic numbers are easily distinguishable, and light elements are easily measurable also in the presence of heavy elements,* because neutron cross sections vary strongly from element to element,

• *With neutrons powerful contrast variation techniques are possible,* because neutron cross sections vary strongly from isotope to isotope. This allows to make visible specific sub-units of macro-molecules, which is a decisive advantage also in post-genome research.

• *Slow neutrons induce a variety of nuclear reactions, with many types of secondary reaction products* (exotic nuclei, gamma rays, positrons, etc.) which give access to various fields of nuclear and interdisciplinary science as well as to industrial and medical applications.

• *Neutrons are ideal probes for the study of the fundamental interactions and symmetries* in low-energy particle physics, because, although neutral, they react to all known forces (electromagnetic, strong, weak, and gravitational) in nature.

Neutrons are a rare commodity, and their use therefore has usually been limited to cases where no alternative methods were available. In recent years, however, several "genuinely neutronic" fields have to a certain extent become accessible to other experimental methods. *However, it has become clear that, in order to understand the increasingly complex systems being studied today, all data from all available methods are needed, and that most of the methods in use today give complementary results. At the same time, the fields of neutron applications have themselves changed and grown substantially. All this explains why neutrons continue to be a rare commodity in high demand*.

8. ILL's place in Neutron Science

We will have a closer look at ILL's role within the network of European neutron sources. Again, we only refer to high and medium-flux sources. Low-flux sources serve as a valuable training ground and are indispensable as incubators of new ideas, but they have less importance in serving the neutron user community.

Seven of the neutron sources in operation are elderly medium-flux reactors all built around 1960 (plus or minus several years). They all have about the same source strength of 1 to $2x10^{14}$ neutrons per cm^2 per second. Three of them are in Russia, and one each in Denmark, Germany, Hungary and Sweden. Altogether, they supply 55 neutron instruments [10], which regularly produce very noteworthy scientific results (P.S.: the Denmark reactor with 8 world-class instruments was definitely and unexpectedly closed in October 2000).

The other six newer neutron sources were all either constructed or completely refurbished within the past twenty years. Altogether they supply 116 neutron instruments. These sources are listed in **Table 4**, together with future sources under construction or proposed. These future sources when fully commissioned could supply up to 113 neutron instruments.

Table 4: European Neutron Sources (after [10])
a) built or refurbished during the past twenty years, b) under construction, c) proposed

Source	Country	Type	Start of operation	Rebuilt in	Source strength (10^{15} neutrons cm^{-2} s^{-1}) Average	Peak	Number of instr.
a) in operation:							
ILL	European	High-flux reactor	1972	1995	1.2		35
LLB	France	Medium-flux reactor	1980		0.3		25
HMI	Germany	Medium-flux reactor	1973	1991	0.15		16
SINQ	Switzerland	Medium-flux spallation	1996		0.2		13
Dubna	Russia	Pulsed reactor	1984		0.02	10	11
ISIS	UK	Pulsed spallation source	1985		0.04	3	16
b) under construction:							
FRM2	Germany	High-flux reactor	2002		0.7		17
PIK	Russia	High-flux reactor	?		1.2		21
c) proposed:							
ISIS2	UK	Upgrade of ISIS	(2003)		0.06	10	20
ESS	Europe	Pulsed spallation source	(2010)		1	100	42
Austron	Central Europe	Pulsed spallation source	?		0.04	7.5	13

When discussing the relative merits of neutron installations, we cannot avoid going into some technical detail. We must clearly distinguish the different factors contributing to the overall efficiency of a given neutron installation:

Total efficiency = *neutron source strength*
x *neutron transport efficiency*
x *instrument efficiency* *(1)*

In most cases, the first factor in (1), the source strength or "flux" of a given installation, stays roughly the same over the life-time of the source, once the source is properly installed. By way of contrast, the second factor, the efficiency of the neutron transport and beam tailoring systems (which couple the source to the specific instruments) has a tendency slowly to deteriorate in the course of time and, more rapidly, to fall behind state-of-the-art technology. Even larger gains in efficiency are at stake in the third factor, the instruments, whose rapid evolution is limited only by the imagination and determination of the experimentalist. (Of course, also the quality of support, infrastructure and scientific 'ambiance' contribute to the total efficiency, but are less easily quantifiable.)

Among the six newer neutron sources in Table 4 there are three continuous medium-flux sources, **LLB, HMI** and **SINQ**, with source strengths four to eight times lower than that of ILL. The scientific programme on these sources falls into four categories: scientific studies of high current interest which do not need ILL's high flux; exploratory studies on new ideas prior to final studies to be carried out at ILL; studies performed on highly efficient new instruments whose total efficiency comes close to that of the older ILL instruments; studies on instruments that do not exist at ILL.

*While **ILL** is the strongest continuous neutron source in the world, **ISIS** is the strongest pulsed neutron source.* While neutron bursts at ISIS have three times less peak-flux than those at the **Dubna** reactor, the number of bursts per second at ISIS is ten times higher than at Dubna, and, crucially, pulses at ISIS are much shorter. In neutron research, two types of instrument are in use: time-average instruments and time-of-flight instruments. In principle, both types of instrument can be served by both types of sources. *However, time-average instruments are only found at continuous sources such as ILL, for the simple reason that continuous reactor beams are much stronger: ILL's neutron beams deliver 30 times more neutrons per second than do ISIS's beams.*

Time-of-flight instruments have also a long tradition at ILL, where three time-of-flight spectrometers plus five instruments with a time-of-flight option are in operation. The necessary pulsing is achieved at ILL by the mechanical periodic chopping of the continuous beam. Here ISIS has an initial advantage, at least at the higher neutron energies, since neutron pulses from its spallation source are about three times stronger than neutron pulses produced by beam-chopping at ILL. This advantage, however, is in part offset by the fact that the rhythm and resolution of beam pulses at ILL can be optimised to the specific instrument, while at ISIS this rhythm is imposed by the accelerator driving the source and is therefore the same for all instruments. *This explains why time-of-flight instruments at ILL are as popular today as they were before the advent of ISIS. They make up 15 percent of ILL's total activity.*

In addition to spectrometry, diffraction[4] is another field where time-of-flight instruments are in competition with time-average instruments. Here, by tradition and choice, ILL uses time-average instruments exclusively. The advantages of time-of-flight diffractometers at ISIS are their high resolution and highly symmetric and stationary instrument configuration. The advantages of time-

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[4] *While neutron spectrometry measures the movement of atoms (i.e. their "dynamics") diffraction measures their positions in space (i.e. their "structure")*

average diffractometers at ILL are better calibration values, source stability, signal shape and background conditions. Therefore ILL's time-average diffractometers remain in high demand even among users with easy access to ISIS. *This is true also for ILL's hot-source instruments, which once were believed to be doomed to extinction when the spallation-source instruments became operational.*

If we compare just the primary source strengths of ISIS and ILL, i.e. if we disregard the current state of perfection of the respective instruments, we find that work done on 9 out of the 26 presently scheduled ILL instruments, i.e. on about one third of all ILL instruments, can in principle also be done at a spallation source such as ISIS. (These 9 instruments are D2, D4, D9, D10, IN1, IN4, IN5, IN6 and IN10; ILL scientists consulted on this subject tend to subtract, ISIS scientists tend to add one or two instruments to this list). Within these instruments, interesting and significantly different qualities emerge. The remaining *two thirds of work done at ILL imperatively requires the strong continuous beams available at ILL. This work covers hot topics such as life sciences, soft matter, glassy dynamics as well as particle and astrophysics, fields where ILL excels and has few or no competitors*.

Not even the future U.S. spallation source SNS, although planned to be at least ten times stronger than ISIS, will become a serious competitor to ILL in many of these fields. In fact, a report of the Basic Energy Sciences Advisory Committee [18] of the U.S. Department of Energy commented the recent and unexpected closure of the main US continuous reactor neutron source, the High Flux Brookhaven Reactor (HFBR), as follows : "the capacity lost by the HFBR shutdown is in fact truly lost – it cannot be replaced in the short term by any feasible actions. Of course, when the SNS [the US Spallation Neutron Source under construction] comes on line powerful new capability will be available for neutron based research, but this will not completely substitute for the lost reactor based capabilities. We also conclude that the existing research programs at Brookhaven National Laboratory are critically important."

If, by way of contrast, we also take into account current instrument efficiency we find that ISIS has, as a result of recent massive investment (immense by ILL standards) in new and impressive instrumentation, gained a certain advantage even in fields such as inelastic neutron scattering[5], which, given adequate funding, would be better served by state-of-the-art reactor source instruments. A very positive aspect of this development at ISIS is that it paves the way for instrumentation for the future European Spallation Source ESS.

The new continuous reactor neutron source **FRM2** in Germany, which will become operational for users in 2002, will have about half of ILL's source strength. The spectrum of neutron applications at FRM2 differs considerably from that of ILL or ISIS. About 30% of all activities at FRM2 will be devoted to industrial or medical uses of neutron-nuclear reactions, such as silicon doping, trace analysis, materials tests, neutron tomography, medical radio-isotopes and tumour therapy. Another 20% of all activities is reserved for three other fields : research with extracted and post-accelerated unstable isotopes, particle physics with cold and ultra-cold neutrons, and research with strong beams of positrons. The relative weight of neutron scattering at FRM2 will therefore be lower than at ILL (where it makes up about 80% of all activities), and only 15% of the work programmed for FRM2 could also be done at ISIS. The **PIK** reactor in Russia has been under construction for many years and its future must be regarded as uncertain.

For the **Austron** pulsed source, a source strength two to three times higher than ISIS is planned. Its purpose is to make neutron-based research accessible to new regions of Europe. **ISIS2** will extend neutron spectroscopy to areas which have so far not been accessible to spallation neutron

[5] *With the impending transfer of polarised ^{3}He technology from ILL to ISIS the same may happen in the field of magnetic dynamics.*

instruments (lower neutron energies and higher energy resolution). *Finally **ESS** will bring huge benefits in pulsed-beam applications and, at the same time, will almost reach ILL quality in continuous-beam applications. ILL Management strongly supports the ESS case and participates actively in the ESS scientific and instrumental working groups. However, experience with existing spallation sources shows that it may take fifteen years or more until the benefits of a new and unproven source can be fully exploited.* It might be wise to consider whether research at ESS should merely cover the areas pursued at ILL, or whether a wider scope with a conscious degree of complementarity would be more appropriate.

The quality of the output of a scientific institution is notoriously difficult to quantify. The number of yearly publications produced, for instance, has its critics as a measure of quality. It is nevertheless interesting to note [19] that 720 out of the 11 000 publications appearing over the past ten years in what is uncontestedly the most prestigious physics journal, or almost 7%, are on neutron science. On the other hand, the percentage of "neutron chairs" at European science faculties is considerably lower than 7%. It should also be noted that the number of ILL contributions amongst these 720 publications is four times higher than the number of contributions of the next- ranking neutron centre. *In fact, among all radiation facilities worldwide that study matter on the molecular scale, ILL is equalled with respect to the number of high-level publications only by its neighbour ESRF. Indeed, on the average, every single weekly issue of Physical Review Letters contains one article from either ILL or ESRF, in about equal numbers.*

9. How many Neutron Sources will be needed in the Future?

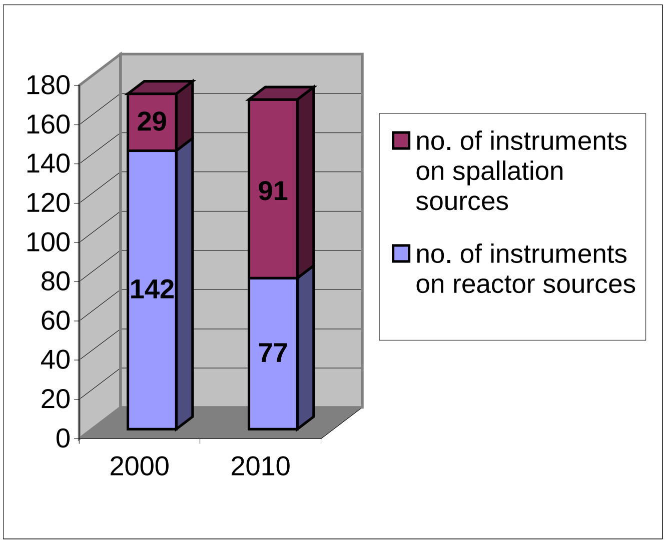
Technically, ILL can continue to operate under good conditions for decades. The real question is how many neutron sources will be needed in the future.

To answer this question we make a methodological digression. The question of the future need for neutrons was assessed before [10], and a future shortage in neutron supplies was predicted. The study in question was based on a rational though involved procedure of comparative weights and merits. This procedure is most useful when comparing sources and instruments at a given moment of time. In contrast, for an extrapolation into the future, weight and merit factors can safely be omitted, since future neutron installations are bound to be more efficient than contemporary installations if science of this quality is to continue, given that problems at the cutting-edge of science require increasingly demanding solutions. What really counts is the number of available instruments, and not so much the number of available sources (once a minimum diversity of neutron sources is guaranteed). Therefore, we base our predictions on a simple instrument count, confident that instrument and source performances will develop at a pace that is adequate to meet the growing requirements of science.

At present, the number of neutron instruments available at European medium and high-flux sources, old plus new, is 55 + 116 = 171 (see preceding Chapter 8). Let us make the somewhat arbitrary but optimistic assumption that at some future time, with all the smaller reactor sources closed down, the neutron sources ESS, ISIS + ISIS2, FRM2, SINQ, LLB and ILL will all be operational simultaneously. *On this basis, **Figure 5** shows that in 2010 a total of 168 neutron instruments would be available to the neutron community, which is about the same number as today. Even the addition to this list of other regional sources such as HMI, Austron or the PIK reactor would not essentially change this finding.*

Furthermore, a recent investigation [20] has shown that, under realistic conditions, even a 5 MW pulsed spallation source like ESS could not replace ILL in continuous-beam applications. And a *source like ILL, once given up, would probably never be built again. ILL will therefore remain indispensable for the well-being of European science far into the new Millennium.*

Figure 5 : Number of Neutron Instruments in Europe
Now and in 10 years
For 2010 it is assumed that all larger existing or planned neutron sources will all be operational simultaneously (see text).



10. ILL and its Neighbouring Institutes

In Grenoble ILL is embedded in a rich scientific environment. The Institute shares a common site with the European Synchrotron Radiation Laboratory (ESRF) and with the outstation of the European Molecular Biology Laboratory (EMBL). EMBL was built shortly after the start of ILL in the seventies. Construction of ESRF started in 1988 and it became operational in the early nineties. There is an intense collaboration between these institutes in many domains.

In the scientific domain, in 1999, 160 external ILL users also used beam time at ESRF. In the same year 16 ILL scientists (that is 27%) ran experiments at ESRF, while 12 ESRF scientists ran experiments at ILL. 35 joint ILL-ESRF publications appeared in 1999. Every year, several scientific workshops are co-organised between ILL and its neighbours. EMBL and ILL jointly operate two instruments in the life science sector (LADI and DB21), and have two joint projects in the Millennium Programme (VIVALDI and the Deuteration Facility, the latter probably also with ESRF). ILL and ESRF have a joint Theory Group of a total of 12 scientists. The three institutes operate a joint library with a joint library users' committee. They also have a joint scientific colloquium. Many seminars on the site are visited by scientists from all three (as well as other) laboratories.

In the technical domain, there are common projects: with ESRF, on cryogenics, detector development, glancing incidence optics and crystal optics, sample environment and on instrument simulation; with EMBL, on detector development and on sample preparation and deuteration, which includes a common chemistry laboratory.

In the administrative domain, the institutes share an on-site guest house, restaurant and cafeteria. ILL organises for its neighbours the joint medical service, the joint security service, the language courses, cultural events, the link to external computer networks, and offers recovery of cryogenic Helium gas, storage of radioactive samples, and supply of cooling water. This all is organised via a joint Administrative Liaison Group, which meets once a month, and which also exchanges information on personnel matters, legal matters, joint supply contracts, and international schooling . (Grenoble's "International School" defines its aim rather narrowly as "to facilitate the integration of foreign pupils in the French educational system" [21]).

However, in many respects, ESRF as a new institute strove to develop independently of ILL. ILL, for its part, was regularly encouraged to find common solutions with ESRF. ILL readily aligned with ESRF in cases where better solutions could be found, but preferred to adopt its own solutions when this was appropriate.

There exist very good and fruitful scientific collaborations with the CEA and CNRS Laboratories in Grenoble. In recent years, also groups from the neighbouring Institute for Biological Studies (IBS) have become very active at ILL, with a number of very successful proposals in the field of the life sciences, while EMBL had its main interest shifted to ESRF.

E. ON INNOVATION

The aim of science is to gain insight into the workings of nature and, as a consequence, to gain control over the processes of nature. A considerable part of today’s civilisation has been shaped by the scientific and technical innovations achieved in the past. Before we describe our plans for the future development of ILL we want to discuss the conditions which favour a good climate for innovation.

Throughout its existence ILL has had strong periods of innovation. The early years of the Institute were marked by a period of intense innovation in *instrumental methodology* which, gradually, found its (at first often sceptical, then enthusiastic) user base. This period was followed by a long period of innovation in *scientific aims*, during which these new methods were successfully exploited for the advancement of science. During this exploitation period the development of new instruments naturally slowed down; in any case it was slower than in many other fields of science.

In the following Chapter 11 we shall discuss possible impediments to innovation of science in general and, in Chapter 12, impediments to innovation of instrumentation in particular.

11. Innovation of Science

While today the importance of innovation is widely acknowledged, the actual mechanisms by which innovation comes into existence remain obscure and only experience can guide us on how to proceed. For instance, it is well known that in nature (as well as in economics) the spontaneous emergence of novel patterns and structures is favoured in open self-organising systems. The same seems to be true in the domain of scientific innovation.

Some obstacles to innovation, on the other hand, have well known causes and are found in almost every organisation. For instance, real innovations are those involving issues or items which no one has so far felt the lack of, so that a client or user base does not yet exist for them. Furthermore, many organisations chronically lack funds and manpower to support existing structures, so why waste resources on unproven ideas? Finally, if new ideas need the consent of larger groups of experts, or must be part of some mainstream programme (predefined along yesterday’s innovations), those which find approval are often not the most original. In such a situation, it is often only the imperfections in the system which allow for genuine innovation, imperfections which tend to be weeded out in the course of time.

To create an innovative atmosphere in spite of these barriers, a number of minimum conditions must be met:

- The members of the organisation must know that new ideas are welcome;
- There must be the freedom to develop and test new ideas, even over extended periods;
- Because many new ideas fail, the organisation must tolerate failures;
- Successful innovation must be rewarded.

Science simultaneously proceeds at a variety of scales : by a multitude of small steps; by less frequent but more sizeable steps; and, from time to time, by large breakthroughs, called great discoveries. It turns out that *all* these different scales and frequencies of progress are necessary for healthy scientific development[6]. Nevertheless, at the end it is the great discoveries that will make the history of science. *Is ILL ready for great discoveries ?*

Great discoveries are not limited to those few cases that are sufficiently graphic to make headlines in next day's newspaper. A great discovery can be :

a) the slow emergence, often on a world-wide scale, of a deep, often abstract new principle, of high predictive power, and its experimental verification;
b) the observation of a new effect unexplained by existing theories;
c) the development of a new experimental tool that provides access to hitherto unexplorable fields of science;
d) the invention of a new process or device that finds useful applications outside the field of science.

Some of these great discoveries depend on the development of *new* instrumentation (in particular c) and d)), while others can be done using *existing* instrumentation (mostly from a) and b)). In the next Chapter 12 we shall discuss impediments to the development of new neutron instrumentation. In the present chapter we shall discuss the mode of scientific exploitation of existing ILL instruments.

Since in science there are small, medium sized and big problems to solve, one would expect that this should at least partly be reflected in the distribution of allocated beam time on ILL instruments. What is found, however, is that on most instruments almost every successful applicant receives about the same amount of beam time, plus or minus one day (see Annex 10). Allocation of more than twice the average amount of beam time practically never happens. This may indicate that current procedures at ILL in some cases act as a filter which mainly channels average-sized problems. (There are certainly exceptions to this. For instance, on the particle physics instruments beam time is allocated in proportion to the size of the problem; time is allocated for days, weeks or months, and has occasionally reached the order of years, in one case decades. In other cases, successive applications for several pieces of beam time may serve the same purpose.)

[6] *Nature and other successful systems abound with such "fractal" distributions, for which the abundance of structural elements varies with some inverse power of their size. The reason for this is that fractal structure gives us the ability to cope with challenges of all sizes and at the same time is minimally affected by partial destruction or amputation (both being due to their property of scale invariance and self-similarity). Unfortunately, for technical reasons, the size of neutron centres has no fractal distribution, as have x-ray and other radiation centres.*

Of course, this does not mean that major breakthroughs are all blocked. A rather randomly chosen list of very recent great discoveries in the field of neutron science is[7] :

1. Measurement of effects due to quantum critical points (a)
2. Invention of a new tool to identify the functional parts of bio-molecules (c)
3. Observation of quark-mixing at variance with the Standard Model of particle physics (b)
4. Development of polarized ^{3}He (c) and its application to medical imaging of the human lung (d)
5. Experimental verification of the celebrated reptation model for polymers (a)
6. Observation of neutron quantization in the earth's gravitational field (c)

However, all the examples given above have in common that experimenters were able to bypass the standard scheme of beam time distribution. The ways to escape the Institute's standard procedures were: work on privately owned instrument (items 2. and 5. of the above list), on test beams (4.), work in the particle physics sector (3. and 6.), or escape to other neutron centres where beam time is offered in proportion to the importance of the work (1.).

The filtering effect discussed above is part of a rather widespread phenomenon of contemporary science, and we shall take the liberty to expand somewhat on this topic. Many measures and rules introduced to improve the average quality of science have a pernicious tendency to prevent great discoveries. Today, while the number of scientists is decreasing, the number of persons involved in the reshaping and control of science (but having no own experience in the scientific discovery process) is increasing. This is a critical issue for the following reason. If conditions are right, scientists are attracted by hard work at low pay, and the miracle of a great discovery will happen from time to time. If conditions are not right, the miracles will not happen, even at high pay, and younger scientists will desert science. How to create these conditions is an empirical question not treated in textbooks on macroeconomics. Fortunately, ILL is still attractive to young scientists, and even larger miracles happen from time to time.

Another important question for an organisation like ILL is the choice of management structure, a question which is also linked to the main theme discussed here. At one end of the spectrum is the purely hierarchical structure, at the other the interacting-network type of structure. Hierarchical systems have proven their merits when difficult but well-defined tasks must be fulfilled along established rules and procedures. On the other hand, experience shows that great scientific discoveries predominantly emerge from self-organising systems where each member has the feeling (quite correctly) of being a main player. Such network systems (not to confound with democratic systems) are able to liberate enormous energies. Of course, the dynamic equilibrium typical of an interacting network has less inherent stability than the static equilibrium of a purely hierarchical system. – Such networking is also important to create links between different research centres.

ILL presents (and needs) features of both types of system. As a nuclear installation, but also as a service installation the Institute needs discipline and the compliance with a set of well-established rules, as are characteristic of an industrial environment. On the other hand, the features that are more typical of an interacting network like independent thinking, flexible response, and informal collaboration across the borders of divisions, are necessary prerequisites not only for great discoveries but simply for the delivery of a good service. To keep the right balance here will remain a predominant task for ILL management. The Institute must constantly be aware of this antagonism in order to avoid being caught in a purely formalistic structure.

[7] *The letters (a) through (d) refer to the classification scheme of discoveries given in Table 5.*

12. Innovation of Instrumentation

Throughout the history of science, it has often been through innovative instrumentation that new scientific applications have developed, and not vice versa, good examples being the development of synchrotron radiation, NMR, lasers, tunnelling microscopy, and, of course, neutron science itself. However, the development of new neutron instruments is hampered by the fact that worldwide the number of neutron beam stations is limited and even declining, and that all these stations are already well used by existing and generally overloaded instruments. As a rule, the use of neutron sources is organised by representatives of the existing user communities. In view of the general shortage of beam time, manpower and funds, *there is altogether little incentive to support diversification of the existing neutron instrument suite*.

In each individual case, such reasoning is perfectly sound - why should one give up funds, manpower or even a proven instrument in favour of a new type of instrument, unproven, and with no guaranteed user base? On a longer time scale, however, such reasoning may prove to be detrimental to the existing neutron communities and to their plans to obtain new neutron sources. The Millennium Programme is intended to remedy this.

There are also rather practical limitations to instrumental innovation. Innovation typically comes from young scientists with a rough idea for doing things better, and with the desire to build a scientific career on this idea. If this new idea can be realised with existing instrumentation, the visiting scientist is welcomed as a user of ILL, is transported, housed and fed and given all possible support. On the other hand, if the idea requires new instrumentation, a long uphill struggle begins. The difficulties are not only in the search for external funding and for technicians willing to work abroad; they also lie in the search for unoccupied neutron beams for testing and for support from the national and ILL committees. The most serious obstacle is that, by the time the scientist in question obtains his or her first results, colleagues who have restricted themselves to using existing technology will already have been given tenure. The young scientists in the field know this and adapt to the situation. – A similar development seems to be taking place at synchrotron radiation sources [22].

To remedy this dilemma, relatively small changes are needed: We must ensure that the minimum conditions for innovation mentioned above are met. Further, good neutron beam positions at ILL should be kept free for testing new ideas. One such position could be declared a public ILL instrument to be subsidised in the same way as the other public instruments. The funds needed to test new ideas are generally not excessive, but must be earmarked in the budget. In any case, the rewarding of successful innovation should not be forgotten. Some of these changes are already underway at ILL and serve as stimulants to the Millennium Programme.

F. FUTURE OPPORTUNITIES

We shall now try to assess ILL's future scientific potential. In Chapter 1 we saw that only a small number of competing types of radiation are available to mankind for looking deeper into matter. Neutron radiation is one of these pillars. Will it remain so? We first discuss future science at ILL in general, then the opportunities in the Life Sciences at ILL in particular, and then describe the aims of the Millennium Renewal Programme.

13. Examples of Future Science at ILL

The future potential of neutron science has been assessed in detail in recent reports [23-26]. We shall therefore restrict ourselves to giving readers a taste of what neutron science is about, presenting a (rather subjective) sample of open scientific questions which will be studied at ILL in the coming years. Most of these problems require neutrons for their solution. Many of the problems depend on the Institute's strong continuous neutron beams, in particular once ILL instruments have been given the major boost of the Millennium Programme.

Our list of open questions is given in **Table 5**. The topic of neutron uses in the life sciences will be expanded upon in the following chapter.

Table 5 shows that, in the years to come, there will be a large number of interesting phenomena to study with neutrons. Many of these studies will imperatively need the strong continuous neutron beams of ILL. A second look through Table 5 reveals that the majority of questions posed did not even exist at the beginning of the 1980s. Hence, by extrapolation we expect that the list of exciting open questions accessible to neutron methods will continue to grow with time, and will carry neutron science at ILL far into the future. For these studies, ILL will not only have the strongest neutron source worldwide for many years to come, but will, in a few years from now, also have the most avant-garde instrument suite in the world.

Of course, in the future as now, part of the work done at ILL will be labelled as standard or even routine work. For instance, the first thing a scientist needs to know about a new substance is the arrangement of the atoms within the solid, and if one is lucky this atomic structure can be determined using "standard" neutron methods. This type of work is also part of the role of a service institution such as ILL, and it will be performed with the same devotion and reliability as the experiments involving very "fancy" problems.

14. Life Sciences at ILL

In the following we take a closer look at the recent developments of neutron use in the life sciences. Our understanding of life processes at the molecular level has made extraordinary progress in the last few years. In particular, the elucidation of the role and the organisation of protein assemblies has been made possible by the conjunction of two major scientific developments: genetic analysis and the deciphering of the three-dimensional structures of biological macromolecules. The impact of these achievements on our daily life is such that concerted action has been taken at high political level.

Table 5: Examples of Open Scientific Questions Accessible at ILL

Understanding exotic electron systems
• Is the true zero-temperature ground state of metallic elements (anti-)ferromagnetic or superconducting – or perhaps both?
• Are there quantum-critical points near absolute zero temperature?
• What explains the basic mechanism of giant magneto-resistance recording devices?
• Do exotic electron systems violate time-reversal?

Studies in complex chemical and physical systems
• Can spin-wave turbulence be studied with neutrons?
• What is the phase diagram of a fluid or a glass composed of magnetic flux-lines?
• Does quasi-crystalline magnetic matter have spin-glass (i.e. neural-network) properties?
• What are the fractal dimensions of self-aggregated matter?
• To what extent do universality and scaling laws apply to soft matter?
• How are complex fluids absorbed in porous media (e.g. water in soil, oil in rock)?
• Do we understand the transition from three to two-dimensional universal behaviour?

Investigations in the life sciences
• What is the location of the key hydrogen atoms in the active sites of enzymes?
• How are the dynamics of large bio-molecules linked to their function?
• How do water molecules arrange themselves around bio-molecules in their natural aqueous environment?
• What are the structure and the dynamics of biological fibres?
• What are the transport mechanisms through cell membranes?
What drives the amazing "molecular machines"?

Problems in earth sciences
• Under what external conditions were the earth's minerals formed?
• Does earth-mantle water behave like a molten salt?
• Do protons initiate the depolymerisation of volcanic magmas?
• What are the processes which occur inside large planets?

Particle physics, cosmology and nuclear astrophysics
• Does electroweak quark-mixing proceed as required by the standard model of particle physics ?
• Does time-forward equal time-backward?
• Is left-right parity violated on a mesoscopic scale?
• Is the left-handedness of matter due to a phase transition of the vacuum in the early universe?
• Why is there so much matter in the universe and so little antimatter?
• How does element-breeding proceed in red giants and in supernova explosions?

Industrial applications
• What is the role of microemulsions and inverse microemulsions in industrial oil recovery?
• Why do additives change the rheological properties of paints?
• How do flaws and microcracks develop in brittle material?
• What stresses does a welded seam produce?
• How do various electrochemical reactions proceed in space and time?
• Why do molecular sieves work the way they do?

The recent developments in structural biology have been made possible by the parallel use of complementary experimental methods such as synchrotron x-rays, NMR, electron microscopy and neutron scattering. Neutrons provide unique information that cannot be obtained by other methods and strongly complement other investigations. A recent European Science Foundation (ESF) document [8] has emphasised the scientific value of neutron methods for life sciences. However, another recent survey by the ESF [23] has recognised that neutron methods are still considered as an emerging technique for biology and are not exploited to their full capacity. We are moving closer to a post-genome-sequencing era, where significant advances in life sciences will come from dissecting more and more complex systems, the understanding of whose functions will require not only the resting arrangement of macromolecules but also their dynamics and the kinetics of reactions, using a wide span of techniques. In this context, neutrons play a key role in the search for clues to protein-solvent interactions and the dynamics of biological molecules.

ILL and its biological research is recognised as being excellent and world class [27]. At present ILL is the only European neutron centre with a fully developed life-science programme. All major methods of neutron uses for the life sciences were pioneered at ILL. In 2000, 12% of beam time at the Institute was devoted to the life sciences, as compared to 2% in other neutron centres (for ESRF, the corresponding number is 19%), and 205 scientists from 60 different laboratories came to the Institute to do life science experiments. Almost half of all ILL instruments (12 scheduled and 2 CRG instruments) are used for the life sciences for more than ten percent of the time. Among these instruments, four are almost completely dedicated to the life sciences (LADI, IN13, DB21, D16).

At the Institute there are seven different types of neutron application in the field of the life sciences (see **Table 6**). One application is in Protein Crystallography, a field, however, whose main domain is in synchrotron radiation (more than forty relatively new high-power synchrotrons will be available worldwide for this purpose). The other six applications are genuinely neutron applications.

Table 6: Work in the Life Sciences at ILL

Method	Instruments	Objects of study
1. Protein Crystallography	LADI	Hydrogen-Bonds in Biomolecules
2. Small-Angle Scattering	D11, D22	Structure of Large Assemblies
3. Reflectometry	D17, ADAM	Membranes and their Interactions
4. Fibre Diffractometry	D19	H_2O-Sites in Biomolecules
5. Large-Cell-Volume Diffraction	D16, DB21	Structure of Large Assemblies
6. Quasielastic Spectroscopy	IN10, IN11, IN13, IN16	Link of Biological Function to Molecular Dynamics
7. Inelastic Spectroscopy	IN5, IN6	

1) Protein crystallography (ILL Instrument LADI) :

The functional parts of a protein often are linked to each other by hydrogen bonds. The main important application of neutrons in protein crystallography is the *determination of the position and orientation of these hydrogen bonds*. This unique method is applicable to middle-weight proteins which can be crystallised to volumes of typically a tenth to one cubic millimetre. A recent example is the location of the catalytically important proton in endothiapepsine.

2) *Small-angle scattering (D11, D22) :*

With this method one determines the *global structure of large molecular assemblies in their natural environment*. It is the method of choice either when proteins do not crystallise (40% of the genome is of this type), or when they are prone to radiation damage by synchrotron radiation (neutrons do not cause radiation damage), or when the molecule simply does not function when brought into the (rather unnatural) crystalline state. However, the method is most important when the structures are so large and complicated that they cannot be elucidated with crystallographic methods. A recent example from instrument D22 is the complete disclosure of the reaction cycle of the protein-folding machine “thermosome-chaperon”. In this case, synchrotron-radiation and electron-microscopy methods proved unable to solve the problem.

3) *Reflectometry (D16, D17, ADAM) :*

With this method one can study the structure *of cell membranes and their interaction with the environment*. A recent example is the establishment of a model for the transmission of messenger proteins through a cell membrane, based on data from instrument D16. It was found that a free membrane undergoes a gel-fluid phase transition, whose critical fluctuations lead to a roughening of the surface which then facilitates the penetration of the messenger molecule into the membrane.

4) *Fibre Diffractometry (D19) :*

ILL has a dedicated instrument for the study of biological fibres. One prominent example is the study of the “double helix” DNA (which stores all hereditary information). The structure of DNA has been known from x-ray studies for a long time. In order to understand the functioning of DNA in its natural aqueous environment one must know the *spatial arrangement of the water molecules* within and along the DNA strands. This can be studied only with neutrons. On the instrument D19 it was found that the H_2O molecules occupy four distinct sites : on three of the sites the H_2O molecules are arranged like pearls on a string in parallel to the DNA helices. On the fourth site there is a linear chain of H_2O molecules positioned along the central axes of the double helix. D19 is the only instrument in the world on which such measurements can be done.

5) *Large-Cell-Volume Diffractometry (D16, DB21) :*

Also on these instruments one studies the *global arrangement of molecular assemblies which are so large and complicated that they cannot be resolved with the methods of protein crystallography*. Recent studies include cryo-crystallography of purple membranes, bilayer interaction of peptide ion channels, and the arrangement of detergent molecules around membrane proteins.

6) *Quasi-elastic Spectroscopy (IN10, IN11, IN13, IN16) :*

The foregoing methods 1. through 5. are used to determine the *structure* of biological molecules. In order to determine the biological *function* of these molecules it is usually not sufficient to study their structure, but one must determine experimentally the individual movements of the molecular components. This can only be done with inelastic or quasi-elastic neutron scattering, where important progress has been made in very recent years [17]. As for the examples given above, the *unique neutron technique of isotope contrast variation makes it possible for neutrons to “see” only one selected subunit of the molecule under study; for instance, one can single out the biologically active functional part of the molecule and study its movements* (with Synchrotron Radiation one can neither study slow molecular motion, nor apply the contrast variation technique). In this way, on IN13 the valve function for vectorial proton transfer of bacterio-rhodopsin in purple membrane has been investigated for the first time.

7) Inelastic Spectroscopy (IN5, IN6) :

Finally, in a number of cases the *inter-atomic potentials seen by the sub-units of large molecules* have been derived from inelastic neutron spectroscopy done on Time-of-Flight instruments. Quasi-elastic or inelastic neutron spectroscopy for the life sciences is a widely open field which promises further exciting results for the future.

The genome project has not "decoded" the human genome in the proper sense of the word, but has only made it possible to recognise the sequence of “letters” of this previously unknown script. The post-genome era has the much more difficult task of understanding the meaning of the “words” and the “sentences” of this script, not to speak of the content and the wisdom of the whole book. To grasp the latter one probably requires not only the compilation of huge data banks but also some deep thinking. To be successful here physicists, chemists, mathematicians and informatics specialists will have to act not only as service providers to biologists, but also each contribute their specific way of thinking and approaches to problem solving.

In the post-genome era the problems to be solved will be such that the intense use of neutron methods will become absolutely mandatory, in order to resolve the global features of complicated molecular assemblies and of molecular motors, which are too large to be accessible to synchrotron crystallographic methods. However, there are a number of impediments to the large-scale use of neutrons in the life sciences. Proposals on how to cope with these impediments will be presented later in Chapter 20 (p. 47).

There seems to be a general tendency today requiring political impulsion to open up new avenues in science. For many centuries, it was bold young scientists who pushed science into realms not dreamt of before. Why do they need to be carried there today? Is it possible that today's political interventions are merely required to compensate for the adverse effects of previous interventions?

15. The Millennium Programme

The increasingly complex problems tackled by contemporary science require increasingly powerful experimental tools. It is clear that neutron science needs an installation such as ILL with all three parts of the formula (1) on p. 23 at their maximum potential. For a number of reasons (the costly refurbishment of the reactor, less than adequate funding, staff reductions, and also a certain lack of commitment by the neutron user community) it became clear towards the end of the nineties that ILL would not meet these requirements for very much longer if nothing was done to change the situation. Indeed, another delay in instrument renewal would, within a few years, leave the Institute effectively with the status of a medium-flux reactor. As there is, even in the longer term, no other institution in sight to take over the role of ILL, such a tendency would be to the detriment of the whole neutron research community.

For this reason, in September 1998 the Millennium Renewal Programme was launched, in the form of a letter to several thousand ILL users inviting ideas and also contributions in terms of personnel and material support for the programme. The programme has been taken up with enthusiasm and a large number of proposals came in on instruments as well as on infrastructure renewal [2], both of which have been enlarged in the meantime [3,4]. At the time when the programme started no extra funds were foreseen to finance this programme. Therefore, initially only proposals promising large gains in scientific potential at a low cost were implemented in the first stage of the programme.

The proposals on instruments come in two main categories: those built on new ideas, and those using state-of-the-art techniques to upgrade existing instruments.

For ILL Management, the choice of new instrumentation is based on the following criteria:

- potential for exciting new science
- attractiveness for new users (diversification)
- feasibility
- cost-effectiveness
- leverage effect due to external contributions

The Millennium proposals which are *based on principally new ideas* and which meet most of the above criteria are listed in **Table 7**:

Table 7: Some Highly Innovative Millennium Instrument Proposals

- The Cryopad / Cryopol / Decpol assembly for D3
- The PASTIS instrument proposal
- The NRSE proposal
- New Ultracold Neutron production scheme
- Flat-cone spectroscopy (invented at HMI)
- The TISANE method
- The VIVALDI instrument, based on LADI principle
- The Ballistic Neutron Guide concept

A significant impact will also be made by the *upgrading of existing instruments*. The systematic use of all recent new inventions in neutron instrumentation as displayed in Table 2 will lead to a large average gain in instrument efficiency (for details see Figure 6, p. 39 and Annex 3).

Another great push in efficiency is expected from the renewal of infrastructure, in the sectors of neutron guides, sample environment, advanced technologies, support laboratories, and others, which are described in Chapter 18.

The complete Millennium Programme will hence give a strong boost to ILL's scientific potential. While, at present, 60% of the Institute's instrument suite is classed “unique” in the world, or “world-best” among all existing instruments, this percentage will then rise up to 90%, and overall efficiency of ILL exploitation will be strongly enhanced.

G. A SCENARIO FOR THE COMING DECADE

In the following, we shall present a rather detailed proposal on how ILL's instruments and infrastructure should develop in the coming 10 years. This proposal is essentially based upon the existing Millennium programme [2,3] as well as upon further proposals on infrastructure renewal [4] and on the use of neutrons in the life sciences [5].

In the following Chapter 16 we shall estimate the total number of instruments which possibly can be installed at ILL. In Chapter 17 we then shall give two snapshots of ILL's instruments, one taken today and one 10 years from now, and enumerate the changes foreseen between these two dates. Infrastructure proposals will be discussed in Chapter 18. In Chapter 19 we shall comment on the scientific orientation reflected in our choice of instrument renewals and then propose to define a number of future flagship projects for ILL, and in Chapter 20 discuss the organisational measures required to promote the use of neutrons in the life sciences.

The proposals presented are intended to serve as a reference for future discussion and decisions. As the renewal of the Institute will be a continuous process, many of the choices need not be definitively fixed today but can be taken "along the road". Some of the proposals in the present Millennium Programme may be superseded by better ones. Furthermore, in our list of future instruments we left open positions "NN" for future ideas.

16. How many Instruments can be installed at ILL?

We start with the overall results of our deliberations and first give the total number of ILL instruments foreseen for 2010. In this instrument count we have assumed that the ratio of public "scheduled" instruments to private "CRG" instruments will remain roughly the same as in the past, for reasons given in Chapter 19 (p. 45).

In our scenario the number of scheduled instruments will rise by 20% from 25 to 30. The number of CRG instruments will rise from 9 to 11. Hence, the total number of instruments will rise from 34 to 41.

The total number of 41 instruments comes close to the maximum number of attractive instruments which one could reasonably install within the existing structure of ILL's beam holes and neutron guides. *In principle one could increase the total number of instruments by a further 20% (up to a total of 50 instruments) if one decided to enlarge the Institute's structure.*

This enlargement could be done in three different ways. One would be to build another neutron guide hall, fed by a new horizontal cold source and equipped with five instruments (minus the instrument lost on the reactor beam hole). The second would be to make use of state-of-the-art neutron optics to feed two additional instruments installed at a different horizontal level in a guide hall (as was done for the S50 experiment).

The third method would be to use short super-mirror guides with large critical angles of reflection for those "happy few" instruments which today are located very near to the reactor. This would allow these instruments to be installed a certain distance away from the reactor without loss of neutron intensity. In principle this should allow the number of these high-flux instruments to be doubled. In practice a maximum of three further instruments could be accommodated this way.

However, all three measures would be disproportionately expensive and could disrupt the ILL operations for a non-negligible period of time. Therefore these options will not be pursued further in this paper.

17. Instrument Renewal over the Next Decade

From 2000 to 2010 the global number of scheduled instruments would increase by 5, but in fact all instruments will be affected by the proposed programme. To begin with, **Annex 3a** gives a list of present instruments and their designation. **Annexes 3b and 3c** display in some more detail the instrument suite as it exists in 2000 and as is proposed for 2010. In the present chapter we enumerate the main changes proposed for the period between these two dates.

Six scheduled instruments are to be newly built. Three of these instruments are part of the original Millennium Programme, namely VIVALDI (formerly called Thermal LADI), Strain Scanner (both are under construction) and PASTIS. Of the other three instruments one is a new type of reflectometer for the life sciences, one an instrument "NN" still to be invented, and one is not an instrument as such but simply a well-equipped polarised beam position, supported and subsidized like half a scheduled instrument, and open for testing and developing new ideas, as proposed in Chapter 11.

Five new instruments are foreseen in the CRG sector. These are the Brillouin instrument BRISP (under construction), an ultra-small angle instrument USANS (as part of the existing CRG S18), a fast tomography and phase-contrast station, and two instruments "NN" still to be invented.

Four scheduled instruments existing today are assumed to be closed by 2010. Further, it is likely that several CRG instruments will go out of service in the years to come. These instruments, while not all being in the "world’s best" category, are still in high demand and do world-class science, and their closure so far has neither been recommended by the Scientific Council nor has this possibility been evoked with the in-house scientists concerned. The closures are envisaged here in order to focus efforts on similar instruments with better performance, and in order to respond to instrument development in other neutron centres. As a further possibility such an instrument may be replaced by an instrument "NN" mentioned above.

Four more existing instruments change character due to the implementation of devices newly invented (at ILL or elsewhere). These are D3 (Cryopad etc.), IN20 (Flat-Cone), PN1 (Miniball) and PF2 (new type of UCN source).

In three cases new options for existing instruments (NRSE, PSD for TAS, TISANE) will allow new types of experiments to be performed, in addition to the present use of these instruments.

Three instruments will be promoted to full instruments (LADI, DB21, IN15). Today these instruments are in use only during a fraction of reactor up-time (in part alternating with other instruments) . The first two are specialised on life science problems, and today use each only a quarter of available reactor time (possibly DB21 can be replaced by a more efficient life science NN instrument). The workload on these instruments is expected to increase considerably once the proposed deuteration facility (see below) is in operation. IN15 will become the workhorse for the study of slow movements of large molecules.

Finally, the scientific power of ILL will receive a large boost due to the systematic upgrading of almost all instruments. The benefits of new instrumentation cannot be described by one single figure, but to keep things simple, we shall concentrate our discussion to one single parameter, which is neutron-count efficiency. As shown in the Millennium proposal, the systematic implementation of all recently invented neutron devices will lead to a more than tenfold gain in the average neutron-count efficiency of scheduled instruments, as compared to 1997. Neutron guide renewal will bring another threefold average gain in efficiency for almost one half of all scheduled instruments (for details see Annex 4, and next chapter). *The total gain averaged over all instruments will be sixteen-fold, as shown in* ***Figure 6****, which is derived from the calendar of efficiency gains in Annexes 3b and 3c.*

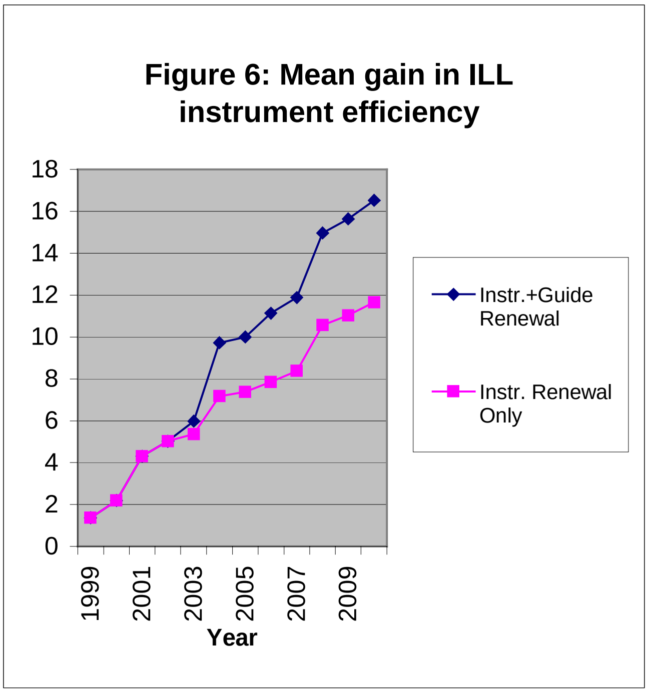


Figure 6: Mean gain in ILL instrument efficiency

Today many of ILL's instruments are either in the category "unique" (i.e. exist only at ILL) or "world's best" (i.e. others also exist, though less powerful). The measures planned will ensure that ten years from now an even larger proportion of instruments will belong to these two categories, even after the rise of strong competitors in the US and elsewhere, see also Annexes 3b and 3c. It must, however, be kept in mind that some instruments which are in neither of these categories are nevertheless highly important because they do cover existing users' needs.

18. Infrastructure Renewal over the Next Decade

Not only ILL's instruments, but also its general infrastructure must be kept at an optimum level. The reactor vessel was renewed in 1995, but the general infrastructure was neglected for similar reasons as for the instruments. The following list includes infrastructure items which are no longer state-of-the-art, as well as a number of new technologies not yet implanted at ILL, some of which may seem futuristic today, but which will be standard equipment several years from now.

a) Exceptional expenses for the reactor

Installations with lifetime of less than 10 years *18 MF*

There are some reactor installations which have a known lifetime of less than 10 years, and whose finance is not foreseen in the normal budget. They are listed in **Annex 5**.

Installations with uncertain lifetimes *10 MF*

Other reactor components are known to have a limited lifetime of unknown duration (similar to the hot source which is at present being renewed). Their cost amounts to 30 MF, as detailed in Annex 5, and we assume that one third of them will fail over the next 10 years.

Further possible expenses for the reactor which may arise due to changing external conditions will be dealt with in a risk study on ILL, see end of this chapter.

b) The efficient delivery of neutrons to the instrument suite

The status of ILL's neutron guides in 2000 and in 2010 (projected) is displayed in **Annexes 4a and 4b**. Of the 14 neutron guides installed at ILL, seven guides date from the beginning of ILL. Four other guides, dating from 1985, are half as old. Another three guides have received supermirror coatings in very recent years, mainly financed from external sources.

The benefits of super-mirror guides depend on the type of instrument, the neutron wavelength used, and the length of the guide (supermirror guides transport higher neutron fluxes, but at the same time have higher neutron losses along the guide than have conventional guides). The efficiency gain due to neutron guide renewal is given for each instrument on the right-hand side of the third-last column of Annexes 3b and 3c. For comparison, the gain due to instrument renewal is given on the left-hand side of the same column. An asterisk ∗ indicates that the instrument in question is installed close to the reactor and needs no neutron guide. In the last column of Annex 3c the cost of both types of renewal is displayed in an analogous fashion.

- *The renewal of the guides in the first guide hall* *60 MF*

  A marked deterioration of the neutron guides over the 30 years of their life has been observed. This fall is about 25%. In addition, with the improvement in technology 30 years on, merely replacing like for like, would give a further 25% improvement. The utilisation of appropriate supermirrors developed since the installation of the guides would give further gains of between 2 and 6 on the different instruments.

- *The upgrade of the vacuum systems for the guides* *2 MF*

  The vacuum pumps for the guides are oil-based. Today's technology, much more easily maintained, would dictate the use of turbo-molecular pumps. The almost imperceptible back-flow of oil vapour into the guide system has contributed to their degradation over the years.

- *The renewal of the guides in the second guide hall* *10 MF*

  Although these guides are newer than those in the 1st guide hall, a significant advantage would be obtained by their replacement immediately following the replacement programme in the 1st guide hall. The use of supermirrors would bring the same benefit.

- *Programmed systematic renewal of the noses of the guides* *In present budget*

  Development work is in place to create radiation-hard supermirror neutron guides for the nose sections. This would enhance the illumination of the proposed new guides. This development programme can be absorbed into the present budget.

c) Associated ancillary instrument equipment

- *A renewal of all vacuum equipment* *5 MF*

  At the last count there were 54 oil diffusion pumps in the Institute. Not only are these out of date but they require significant maintenance. The replacement over two or three years of these pumps would both increase efficiency and release manpower for more important jobs.

- *Earthquake simulation of instruments* *2 MF*

  It is evident that a full simulation of the instrument suite with respect to its resistance to earthquakes will become increasingly important. As a result an in-house programme, prior to an expert final analysis, is already yielding benefits. If we are to move ahead with this quickly, a modest investment will be required.

- *Investment for reliability* *25 x 400 KF = 10 MF*

  We have currently launched a review of all instruments in the Institute. A remarkable amount of equipment on the instruments is still a quarter of a century old. Here we can cite motors, encoders, choppers, detectors, amplifiers etc. We estimate 400 KF per instrument to eliminate unreliable equipment from the instrument suite.

- *The modernisation of half of the instrument control cabins* *2 MF*

  A significant proportion of the instrument cabins falls below acceptable standards. Cabins have been built in an organic rather than a systematic manner. It is clear that with the increasing computerisation of neutron instrumentation, the cabin becomes the home of the user for the period of their stay at the Institute. We wish to upgrade the cabins.

- *Insulation and partial air conditioning of the neutron guide halls* *8 MF*

  The day-to-night and season-to-season fluctuations in the temperature of both neutron guide halls fall well below modern building standards. In fact the 2nd guide hall is of a lower standard than the earlier 1st guide hall. This is not simply a question of human efficiency, although this is important, but the fluctuations in temperature during the summer in particular have begun to affect the precision of measurements, for example on the interferometers.

d) Development work into instrumental methods and components

- *Advanced polarised neutron technology* *500 KF p.a. = 5 MF*

  The ILL has pioneered the development of multi-layer, monochromator and ^{3}He polarisers. We are best placed to capitalise upon these developments. It is essential that this work continues. It will be remembered that in particular the work on ^{3}He has reached its current state by injections of capital and manpower from French, German and British sources.

- *Advanced cabling & wireless technology* *12 MF*

  With the increasing number of detector channels, and on certain instruments, time-of-flight channels, the reliable and economic transfer of data and of communication with the instrument can be radically upgraded with the use of field buses and possibly the use of wireless technology. Currently only little progress has been made in this area despite the existence of the technology and we plan to benefit from advances made or proposed in other fields.

- *Auto diagnostic control & monitoring methods* *9 MF*

  As we build more complex instruments to utilise better the output of the neutron source, the reliance on human surveillance to manage the instrument operation becomes less efficient. Software auto-pilots which would continuously survey parameters of the instruments, e.g. non-operational or noisy detectors, de-phasing choppers, worsening positions of stepper motors etc., is well within current technology. Such continuous health checks can be used to alert instrument scientists and users locally and, centrally, the Technical Services responsible for the efficient operation of the instruments.

- *Simulation protocols for instrument design and operation* *6 MF*

  The Monte-Carlo simulation of instrument performance is still something of a cottage industry. Networks and workshops are raising consciousness in this area. It is essential however, for the optimum benefit of the Millennium Programme, to secure first-class capabilities in this area. In the not-too-distant future the on-line simulation of experiments will be run in parallel to the actual experiment, alerting researchers to those interesting deviations of experiment from simulation.

- *The GRID* *Bid for grants*

  When the GRID will supplant the Internet then ILL has a high interest to participate in the first row. To this end one of ILL's head informaticians is already now concentrating on a strategy for the future of data networking and the embedding of ILL therein.

- *High resolution, high count rate area detectors* *Present budget*

  The on-going development of detectors has been and will remain an important element in the ILL's development programme in order better to exploit the output of instruments.

- *Cooled monochromators* *Present budget*

  With the need to improve signal to background on instruments the use of cold monochromators, with all the focusing complexities which we are used to in the room temperature versions, will pay dividends, particularly in the areas of large area analysers, monochromators for medium and high energy neutrons and the search for more effective polarising monochromators. Both of these areas will be absorbed into the present budget.

e) User support facilities such as sample environment equipment and computing capabilities

- *A transition to liquid-helium-free cryostats* *150 KF x 20 = 3 MF*

  The variable temperature orange cryostat developed at the ILL has been a great success. It utilises reservoirs of liquid nitrogen and liquid helium. The filling of such cryostats, whilst partially automated, is nevertheless expensive in the use of staff time. A recent development at the ILL has been the addition of a Joule-Thompson expansion coil to a closed circuit refrigerator, which uses no liquid cryogens, and reaches a base temperature around 2°. A gradual replacement of old cryostats with modern J-T refrigerators would deliver greater reliability and release manpower.

- *17T cryo-magnets* *4 MF*

  The cryo-magnets at the ILL are old; their power supplies are even older, of the order of 20 years. Their replacement must be considered. In addition the raising of the upper magnetic field limit has now become technologically feasible. The sharing of such facilities around Europe raises anxieties of damage to unique equipment in transit – witness the Calberson situation. A new high-field magnet for the ILL is therefore proposed.

- *Virtual experimental teams by video network* *6 MF*

  Video conferencing capabilities are evolving rapidly. It is perfectly feasible today to install cameras in cabins and to view, from different corners of the world, data as they are being collected, instruments and experimental teams. The implementation and the further development of such techniques would enable research teams to collaborate at a distance and to aid training of students in the methods of neutron scattering remotely. Such advanced methods are already in use in the astronomical and earth observation communities and form part of European informatics initiatives.

- *Further cryo-magnets* *3 x 3 MF = 9 MF*

  This item has been addressed above. Three replacement cryomagnets are envisaged.

- *Sample changers* *Present budget*

  The ILL has not embraced the use of sample changers in the past except in specific cases. An examination of the benefits to be gained by the use of sample changers, allowing optimum partition of beam time, will be implemented.

- *High pressure cells* *Present budget*

  In the early days of the ILL the development of high-pressure cells was a central part in the sample environment programme. In recent years this development has not progressed as far as would be liked. With the attraction to neutron scattering of earth and planetary scientists and chemists interested in reactions under moderate pressures, this work will be re-launched. Both these items can be dealt with within the present budget. Collaborations with external expert groups will be encouraged.

f) Support laboratories

- *Chemistry Support laboratory* *2 MF*

  The Chemistry Support Laboratory has remained at the same level as it was when the EMBL building was constructed. An investment of funds into this area is urgently required.

- *A modern detector laboratory* *4 MF*

  The current exciting developments in detector technology necessitate a requirement for significantly improved working conditions. Specifically dust-free clean rooms and the ability to manipulate large detectors with high precision in a shock-free manner is necessary. In addition a regrouping of the optics laboratories will be carried out within our current budget.

- *Insulation and partial air-conditioning of support laboratories* — *4 MF*

  The working environment in the support laboratories where temperatures exceeding 30°C are common in the summer months does not fit well with high technology work. A modernisation of the support laboratories should therefore be envisaged.

g) Offices

- *Air-conditioning* — *10 MF*

  The office accommodation at the ILL compares poorly with that of the ESRF. It also compares poorly to the standards which are commonly taken as standard in public and private transport – Grenoble buses and private cars are nowadays air-conditioned. Ample evidence exists from ergonomic studies that the working efficiency of staff improves considerably when ambient comfort levels are improved. This is not a question of luxury, temperatures in Grenoble in the summer regularly climb to 35°C.

- *Regrouping and rationalisation* — *Present budget*

  Organic growth, as referred to above, has resulted in a less than efficient distribution of services around the site. Many groups work from four or five different centres. In the coming months a re-examination of the grouping around the site will be made. This will be financed from within the present budget.

h) The evolution of links with the ESRF, EMBL and the potential for setting up specialist centres of scientific support

- *Bacteriological deuteration facility* — *Bid for grant + 4 MF*

  The application of physical expertise to biological research is a central theme in the research priorities of many countries. A concerted effort to underpin the potential benefits to biology of neutron scattering is therefore essential. The deuteration facility is but one of these facilities.

- *Facility for Materials & Engineering* — *Bid for grant + 4 MF*

  Instrumental improvements for engineering and materials science in recent years has been impressive. We are still at an early stage however in exploiting these facilities for the materials and engineering community. An initiative for a welcome centre for such scientists as a joint ESRF/ILL project is timely.

i) Risks

A study has been started to assess risks which might befall the Institute under the following headings:

- Nuclear Technology
- Instruments
- Earthquakes
- Terrorism
- Crucial supplies
- Accidents

We plan to report on this study in spring 2001.

19. Scientific Priorities

We now comment on the scientific preferences on which our scenario is based. As a preliminary remark, we shall not speculate much on future CRG instruments. Annex 3c tentatively assigns various future CRG instruments to the different instrument groups. The names of existing CRG instruments are quoted in parentheses, but only for purposes of identification.

In our scenario, the percentage of CRG instruments is kept stable, but the rationale for their existence has changed. Originally CRG instruments were introduced mainly to cope with budgetary limitations. In the future, however, it will be more the possibility of running extended original research programmes that justifies their existence, and the main criterion for the installation of a CRG instrument should be its innovation potential. In any case, for ILL a "mixed economy" seems to be preferable to a purely "public" scientific enterprise.

The different instrument groups will develop at slightly different speeds. **Annex 6** shows the breakdown of the number of instruments by instrument group, both for 2000 and 2010. Most CRG instruments are also partly in public use, cf. Annex 3. The ratio of CRG to all instruments and the extent of their private use are also displayed in Annex 6. These percentages are kept stable from 2000 to 2010.

The instrument group ***Diffraction*** *(DIF) works in priority on the determination of atomic and magnetic structures of "hard" matter* in the domains of condensed matter physics, solid state chemistry and materials science. The total number of DIF instruments will rise from 10 to 10.5 (the “one half” instrument being due to the time-sharing of neutron beams). Hence the relative weight of the Diffraction group will remain stable, within the expanding suite of instruments. However, all DIF instruments profit strongly from the renewal programme. With the new Strain Scanner and the upgraded D20 the Diffraction group will strengthen its *industrial applications* sector. For *basic sciences* unique opportunities open up with the novel techniques developed for D3 and for VIVALDI. Also the fibre diffractometer D19, which produces highly visible and exciting results in the field of the *life sciences* (hydration of DNA and other bio-molecules), will be upgraded as soon as this is financially possible.

In the ***Large-Scale Structure*** *group (LSS) much of the life science work at ILL is being done, but also fundamental studies on "soft" matter and on thin organic and magnetic layers.* The greatest change in the number of instruments is foreseen in this group. The number of scheduled LSS instruments is growing from 4.5 to 6.5, and the total number of LSS instruments from 6.5 to 8, all of which will gain considerably in efficiency. In recent years the group has added to its array powerful instruments like D22, D17 and LADI. These are the workhorses for life science studies. After the installation of the Deuteration Facility this application will be further intensified. Another reflectometer is foreseen whose main use will be in cell membrane studies. (Today cold neutron reflectometers use about the same neutron phase-space density as ultracold neutron (UCN) reflectometers would do. If, as is likely, UCN fluxes can be increased by a factor of 100 in the years to come, then this new reflectometer should be installed on an UCN beam.)

The ***Three-Axis group*** *(TAS) has its stronghold in magnetic dynamics, mostly in the study of exotic electron systems.* Its activities will be concentrated on the TAS instruments IN1, IN8, IN14 and IN20 (for hot, thermal, cold and polarized thermal neutrons, respectively) each instrument being world-best in its class. These instruments will be considerably upgraded, so that the total power of the group will go up, even if the total number of TAS instruments decreases from 5.5 to 4.5.

The ***Time-of-Flight and High-Resolution*** *group (TOF+HR) traditionally works on the dynamics of disordered systems (in particular, on the slow dynamics of large molecules). In this group a recent and rather unexpected breakthrough in new life science applications has been achieved,* with newly discovered links between biological function and molecular dynamics. The efficiency of the key instruments of the TOF+HR group will be greatly improved. The relative weight of the group will roughly stay the same. In the HR sector, there will be a shift from traditional molecular dynamics experiments (which possibly will progressively be replaced by computer simulation studies) to experiments on the dynamics of bio-active molecular sub-units.

The ***Nuclear and Particle Physics group*** *(NPP) runs a broad programme ranging from exotic nuclei, astrophysics, particle physics, cosmology, tests on quantum mechanics and the measurement process, hard inter-atomic potentials, all the way to applied studies on nuclear incineration.* The efficiency of the NPP instrument group can be strongly enhanced with a relatively modest investment. The neutron tomography station opens possibilities far beyond existing ones. Non-interferometry phase-contrast neutron radiography was shown to be feasible very recently. In all, the *applied physics* sector of the group will increase, while its relative weight stays the same. By tradition, the neutron-particle physics community exclusively works with home-built instruments brought temporarily to ILL, so their requests to the Millennium Programme is limited to improved neutron beams for PF1 and PF2.

We add here a comment on the question of the relative virtues of "pure" and "applied" sciences, which is a frequent topic of debate at ILL as elsewhere. At first sight, there seems to be a major antagonism between the two modes of science. Crudely speaking, the main driving force of scientists is intellectual pleasure (in some minor cases, add to this the human need for recognition). On the other hand, the main driving forces for sponsoring science are, in historical terms: the prospect of making gold; defeating the enemy; predicting the future[8]; promoting the glory of the court; and, more recently, prolonging the human life-span (hopefully to eternity).

In reality, the rapid technical progress of modern times is due to a more or less happy symbiosis of these disparate driving forces. If, for instance, in the past, chemists had limited their interest to what were then useful substances, they would neither have discovered the periodic table of elements nor the panoply of other useful substances. Wise sponsors have always known this. On the other hand, most researchers feel great intellectual pleasure when they find useful applications of their discoveries. And often it is the most fundamental studies that require the development of the most sophisticated instrumentation, which then will become part of the technical heritage. Recent examples include the many new Medical Imaging techniques most of which originally were developed for basic science (for instance tomography of the human lung relying on polarized ^{3}He). The antagonism therefore is not so much between applied and pure science but between interesting and not so interesting science.

At ILL there is a reasonable mixture of highly interesting studies which have a high potential for application over a wide spectrum of time scales. To get a higher and faster return on investment one should give increased weight to projects of both high scientific interest and reasonable return times. The life sciences provide a good example of this type of project.

Coming back to the problems addressed in Chapter 11 (p. 27) we propose that ILL, advised by the Scientific Council, should, from time to time, identify a number of scientific Flagship Projects (and single out certain groups of scientists associated with these projects). For an extended though defined period of time, such projects should get increased support. For these projects it should be possible to allocate larger blocks of beam time even on instruments on which it is now customary to hand out only small equal doses of beam time. We show below with a few examples what might

[8] *This aim is futile : the faster science progresses, the less foreseeable the future becomes.*

potentially be Flagship Projects. They are chosen from the long list of future scientific highlights presented in Table 5 (p. 32).

The first example is on the general problem of exotic electron systems. The interaction of electrons is responsible for practically everything going on earth and elsewhere (the only exception being purely nuclear processes). It is highly disturbing that even in a rather simple setting of a limited number of electrons (i.e. systems which for the past fifty years had been believed to be well understood) the strangest things can happen which are not at all explained by today's physical theory. The studies of such systems already offer major commercial impact today (giant magnetic resistivity), or in some not too distant future (high temperature superconductivity and quantum Hall effects).

The second example is from the field of the life sciences. Here neutrons offer very interesting possibilities, as detailed in Chapter 14 (p. 31), see also the following Chapter. But often time-consuming exploratory studies are necessary. For most biologists neutrons are rather unknown exotic objects, so biologists need extended help from the neutron specialists. Some earlier neutron users from biology feel that ILL and its committees do not do enough for them. Here one or several Flagship Projects should be identified and receive special attention.

Our last example is on the borderline between particle physics and cosmology. The problems studied with cold and ultracold neutrons are at the origin of some of the spectacular symmetry violations in nature (the extreme asymmetry between the amount of matter and antimatter in the universe, as well as the extreme asymmetry of the electroweak interaction with respect to left and right, which both probably developed in the very early universe). Here, too, neutrons will provide unique insight.

The setting of such (or other) priorities will not significantly disrupt the normal activities and services delivered by ILL, but may help to get ILL out of its present equilibrium state. In any case, scientists know that most of the interesting things in nature happen far away from equilibrium.

20. Optimising the Use of Neutrons at ILL in the Life Sciences

In Chapter 14 (p. 31) we described present and future possibilities for the life sciences at ILL. In the present chapter, which is taken from [5], we discuss what organisational measures are required to promote the use of neutrons in the life sciences.

The ILL focuses on four important issues that may be regarded as impediments to a more efficient and productive use of neutrons by the life sciences community:

- There is a general lack of publicity for the importance of neutron results to the life sciences community. The simple fact that neutron beams can only be generated in central large scale facilities such as the ILL is itself an obstacle.
- The current ILL instruments do not provide detected neutron count rates capable of attracting a large enough number of biophysicists.
- The shortage of scientists with dual expertise in neutron methods and biology imposes constraints on ILL scientists and reduces research flexibility. This problem is accentuated by the heterogeneity of the user community.
- The present system for beam time allocation is not adapted to biologists who require frequent short-notice access and whose research proposals are often assessed by physicists.

ILL takes the view that the use of ILL resources by biologists can only be increased if a positive, pro-active approach is taken. The Institute therefore proposes the four-pronged strategy below:

- A pro-active in-house programme of biological research at ILL.
- Instrument improvement (including infrastructure renewals).
- Stronger links with research organisations, and the active promotion of neutron methods.
- Modification of the beam time allocation system.

Implications and consequences are summarised in **Annex 7**. We also propose a time scale for the implementation and evaluation of these measures.

a) A pro-active in-house programme of biological research at ILL

The biological research carried out at ILL is recognised as excellent and internationally renowned. This has nevertheless not yet sufficed to make of ILL an attractive venue for biologists. In contrast to synchrotron x-ray methods, neutrons are important to biology for the wide range of techniques to be exploited, and this requires the presence of in-house specialists. We propose encouraging even more productive biological research at the Institute by the creation of an ILL research group dedicated to structural biology, making the most of ILL neutron facilities and the proposed deuteration laboratory discussed below. This group will be composed of an ILL scientist and one or more post-doctoral researchers, possibly with external funding. At least two ILL studentships will also be needed. Beam time will be allocated for the research activities of the group.

A stronger in-house programme will lead to increased visibility for ILL in biology, whilst at the local level it will foster closer collaboration with the ESRF and the EMBL. Furthermore, the presence of a dedicated research group for biology will facilitate innovation in both methodology and instrumentation.

b) Instrument and infrastructure improvements

(i) *Most neutron-scattering experiments are intensity limited*; biological experiments suffer more than others, owing to the low scattering power and dilution of the samples. The UFI programme led to the important upgrade programme for the D16 diffractometer, followed by the detector modernisation, and the construction of the D17 reflectometer, which is now up and running.

(ii) *The Millennium Programme of instrument renewal [2] includes several projects involving instruments for biological studies*. Faster acquisition rates will be obtained with the new SANS detector. The ILL Management recommended that the D19 fibre diffractometer be made a fully viable instrument through significant extension of the detector bank and improvements to its sample environment facilities. The Laue diffractometer LADI, which is used extensively, will be relocated on a higher flux beam; it will benefit from an internal image plate read-out and focussing optics, as soon as the new deuteration laboratory becomes operational. Furthermore, it is proposed to upgrade the neutron flux on the IN13 CRG instrument by renewing the neutron guide H24. These proposed upgrades (UFI and Millennium programme) will bring at least ten-fold gains in the detected neutron count rates.

(iii) *The ILL Management strongly supports the setting up of a laboratory for the deuteration of biological macromolecules*. Such a laboratory will act as a centre for users and will nucleate the in-house research activity. It will also benefit from the expertise available at the EMBL. This project is also supported by the EMBL. The ILL is pursuing collaboration with ESRF on the construction and installation of this laboratory. It should be noted incidentally that major synchrotron centres are planning to host laboratories dedicated to biological studies.

c) Stronger links with research organisations and the promotion of neutron methods

(i) *In order to increase the scientific appeal of ILL's neutrons, it is proposed that closer links be created with non-neutron experts in the field of biology*. Participation at workshops and meetings organised by national learned societies or organisations will be encouraged. ILL will seek partnerships with other organisations with a view to working together on biological programmes. One field of activity will be training for potential users. The general training of students is already underway, through the international HERCULES courses organised by ILL, ESRF, EMBL and the Grenoble J. Fourier University. ILL is ready to take part in international and/or national training sessions involving research organisations in member countries.

(ii) *The promotion of neutrons as an invaluable tool for biological research will be effected through the publication of specialised papers* in prominent journals and by the presentation of neutron results in general and topical conferences. More specialised workshops are to be organised at ILL, to demonstrate and popularise neutron techniques. In 2001, the ILL will publish a brochure dedicated to the use of neutron methods in the life sciences.

d) Modification of the beam time allocation system

The ILL is setting up a modified beam time allocation system. This will allow faster access to beam time through the electronic submission of proposals and the holding of two extra sessions per year to review the proposals submitted. This procedure is to be restricted to those research areas, such as chemistry and biology, which require the allocation at frequent intervals of short sessions of beam time. A system of block allocation guaranteeing beam time allocation for extended periods of time has been set up by the synchrotron x-ray establishments; this combines fair treatment with efficiency, due to the high number of first-class proposers. In the case of neutrons, the key issue is flexibility, and the fast access mode is more appropriate.

e) Recommendations

The ILL Management proposes a strategy which implies a reorganisation of scientific activity at ILL, the upgrading of instruments and infrastructure, and a modification of beam time allocation. An estimate of the consequences in budgetary terms is presented in **Annex 7**. These costs are included in the Roadmap.

Such a strategy would need to be evaluated and its effects monitored. We propose that the activities proposed be reviewed within a period of 4 to 5 years. Adequate adjustments would then be made. ILL Management suggests that this strategy be adopted as soon as possible to enhance the potential for neutron techniques in the life sciences.

H. IMPLEMENTATION OF THE PROGRAMME

In the preceding Section G we have proposed a number of instrument and infrastructure renewal measures which will be necessary to promote the science opportunities described in Section F. In the present section we shall discuss the practical implementation of this proposal over the coming decade.

We first make a global check whether development capacities available at the Institute are sufficient to run the renewal programme as proposed. To this end we retrace the history of ILL renewal measures and compare it with planned measures (Chapter 21), followed by a discussion of the implications for ILL personnel (Chapter 22). In the final Chapter 23 we then discuss the financial implications of our proposal, for four different scenarios, ranging from the full (100%) implementation of the Roadmap proposal at maximum speed (Scenario 1) all the way to a merely 50% implementation at reduced speed (Scenario 4).

21. At what Speed can Renewal proceed ?

How fast can the renewal programme proceed without over-stretching ILL's development capacities and without compromising the on-going user programme ? To answer this question we first look back over the full *history* of ILL and compare past and future rates of construction and renewal of instruments and neutron guides, as well as the rates of capital investment. Following these more global considerations we shall, in the next two Chapters, look in more detail at the manpower and budgetary consequences of the proposed renewal programme.

If we count only newly built instruments then we obtain the time sequence of ***Annex 8c***, which covers four decades, and which is based on the past and projected history of ILL renewal displayed in Annexes 8a and 8b. In the second half of the seventies ILL already ran a full user programme and in parallel built nine new instruments. The period of the "deuxième souffle" in the eighties is not remembered as a time of over-extensive instrument building, although eleven instruments were either newly built or completely rebuilt (of these instruments three were finished only by the mid-nineties). In addition, a new guide hall with neutron guides, and both a cold and an ultra-cold neutron source were built. In view of this the planned rate of future instrument building does not seem over-ambitious.

However, we should not only count new instruments, but should look at all major renewal activities involving ILL's technical and scientific services (DPT and DS). If we assume that (on the average) two instrument upgrades or two neutron guide renewals are equivalent to the construction of one new instrument, then we arrive at the time sequence of **Annex 8d**. It again appears that the renewal rate foreseen in the Millennium Programme will not be very different from that of the 1980s and late 1990s. It must be kept in mind, though, that in the 1980s the number of ILL posts was higher then than it is now; the question of staff needed will be discussed in the next chapter.

Annex 8e *shows the average yearly capital investment in instruments and neutron guides for the past three decades and for the decade to come.* The rate of future investment does not seem unreasonable as compared to the 1970s and 1980s. The nineties were a time of very modest investment in instruments, mainly due to reactor renewal and to a reduction of funds. It may seem astonishing that, nevertheless, the late nineties show considerable renewal activity (cf. Annex 8d). This is due to the fact that the new super-mirror guides installed then were mainly financed from external sources, and that the two new instruments chosen to be built (LADI and D17) were rather inexpensive.

22. Implications for the Personnel

We now discuss the implications in human resource terms of: **(a)** the proposed intensification of the renewal activity and **(b)** the proposed increase in the total number of scheduled instruments. The cost of the latter is taken from **Annex 9**. We discuss personnel needs separately for the different divisions of ILL.

Most scientists *in the Science Division* (DS) are assigned to *one* instrument. Therefore, if **(a)** the programme of instrument renewal is extended then more of ILL's scientists will be involved (but these will be different individuals than the ones already involved). For an experimental scientist, instrument development is part of normal professional life, and the extra load is balanced by a temporary decrease in other scientific output. This is the way instrument renewal is handled world-wide. So no additional scientist will in fact be required. However, ILL has a serious handicap : due to lack of opportunity, ILL scientists under the age of 50 have (with some very remarkable exceptions) little experience in instrument development. This, however, could be made up for if the postdoctoral fellowship programme proposed below is approved. On the other hand, if **(b)** the number of ILL scheduled instruments is increased by five, then this would require a larger increase in the number of DS staff, as detailed in Annex 9.

Most staff *in the Projects and Techniques Division* (DPT) work for *many or all* ILL instruments. Therefore, **(a)** a widening of the renewal activity will increase the general load on the DPT staff, mainly in the *development* sector of DPT. However, the rejuvenated staff of DPT could cope with this (see also Table "Technical Synthesis", pages 17-20 of [2]). **(b)** An increase in instrument number would mainly affect the *service* sector of DPT, although recent and planned improvements in standardisation and quality of instrument components will partly offset this, in particular if some of the proposals on infrastructure renewal (namely those on auto-diagnostics, simulation and reliability, see Chapter 18, p. 41, 42) are adopted.

The Reactor and Administration Divisions (DRe and DA) will also be affected by the proposed renewal programme, but again to a lesser degree than DS. Extra personnel is therefore needed mainly in DS for the operation of extra instruments, and to a smaller extent also in the other divisions.

We further propose to support a "postdoctoral fellowship" programme as exists at ESRF. This programme would allow ILL to invite (for periods of typically two years) up to ten selected young scientists to pursue new ideas and to use, support and develop instruments.

Annex 11 *lists the extra personnel needed to carry out the Millennium Programme* for the two cases: number of instruments increased to 30, and number of instruments kept at 25. In the latter case nine additional staff are requested to carry out the renewal programme. In the former case 30 more staff are requested for the running of five more instruments, mainly in conformity with the results of Annex 9.

Further, there are several functions which are no longer being carried out but which are important at ILL (independent of the number of instruments in operation). Firstly, a nuclear installation like ILL needs scientists that can calculate neutron and gamma ray fields in complex geometries. They are cost-efficient because radiation shields are expensive and must be properly optimised, as must any change in the beam tube configuration of the reactor. The three posts that ILL had in this field were abandoned in the early 1990s, and the loss is unsustainable in the long run.

Secondly, mathematical methods play an increasingly important role in the study of complex systems, in particular in the life sciences. Since the early 1990s, ILL has had no mathematician and it badly needs one.

Not so long ago it was discovered that science needs professional public relations services. The argument is that while science is about facts, political decisions are based on (public) opinions about facts[9]. How many resources should be invested in public relations ? The recent UNESCO World Conference on Science (Budapest 2000) recommended that science invest 1% of its resources in public relations. This figure is high for several reasons : firstly, the entertainment value of science is limited, and saturation will be reached soon ; secondly, scientists are becoming a rare commodity, so pressure to justify their existence will diminish; finally, there is a limit of decency on how much a publicly financed institution should spend to convince the taxpayer of the institution's own usefulness. ILL's spending on PR of 0.1% seems low in comparison (1/2 post since mid-2000) and is much less than what is spent by ILL's main competitors.

Finally, in the early nineties the institution of “Senior Scientists” (5 posts then) was abandoned, too. In order to strengthen the level of science within ILL we propose (as recommended by the Scientific Council) to partly re-establish these posts.

We propose adding one staff post for each of the three fields mentioned above, plus two posts for Senior Scientists. As shown in Annex 11, 44 extra posts are required for the full realisation of our scenario, and 14 posts if instrument renewal is carried out with the number of ILL instruments kept at 25.

ILL should offer technical services for users on-call overnight and at weekends. This would increase operational efficiency by an estimated 5%. Such a service would require another five technician posts, but we shall try first to solve this problem with existing means by offering financial compensation to our instrument technicians for extra shift services.

23. Implications for the Budget

The implications for the ILL budget are summarised in the following four tables, for four different scenarios. In Scenario 1, shown in **Table 8**, it is assumed that 100% of the proposals in this Roadmap are realised at the maximum possible speed, cf. Chapter 21. In the second column of this table, the instrument projects for a given year are listed, as chosen from the list of instrument proposals in **Annex 12a**. In the third column the cost of these instruments is quoted. Columns four and five do the same for the infrastructure projects, as taken from **Annex 12b**. The next column gives the cost of the 14 additional staff needed if the number of instruments stays constant at 25. This is followed by a column on the cost of operating up to five additional instruments. The total cost is given in MF and in MEuro. The accumulated instrument renewal cost, the infrastructure renewal cost, and the running costs of up to five additional instruments represent 29% , 41%, and 30% of the grand total, respectively.

In Scenario 2, shown in **Table 9**, 100% of the Roadmap are realised, like in Scenario 1, but it is assumed that up to the end of 2003 we follow the Multi-annual Financial Estimates (MFE) presented in year 2000 [29]. The MFE figures for the Millennium Programme are given in the last column of this table. Columns two and four give the instrument and infrastructure projects which

[9] *A word of caution : whilst in commercial and political advertising it is sufficient when people believe in the quality of a product, this is less evident in scientific advertising ; on the contrary, through past centuries doubt and understatement have been essential elements of scientific style and in the long run have strengthened the value of scientific advice.*

can be financed from these funds. From 2004 onward, the remainder of the Roadmap proposals is realised at a constant rate of spending.

In Scenario 3, shown on **Table 10**, only 75% of the Roadmap is realised (the period 2000 to 2003 being as in Scenario 2). This is achieved by reducing instrument expenditure and infrastructure expenditure to 78% of their full values in Scenario 2 and by reducing the number of additional instruments to 60% (3 instead of 5 additional scheduled instruments).

In Scenario 4, shown in **Table 11**, only 50% of the Roadmap is realised. In this scenario, instrument renewal, infrastructure renewal and running of additional instruments are reduced to 44%, 56%, and 40% of their values in Scenario 2. In this last scenario, ILL would fall short of exploiting its full capacities.

In the budget for year 2000 an amount of 12.8 MF was foreseen to finance the UFI and the Millennium Programme. If we take this as a baseline, then, from the existing budget, only 128 MF can be expected to finance the ten-year programme described in this Roadmap. *So what is needed in **extra funds** for Scenario 1 is 579 – 128 = 451 MF, that is 69 MEuro, or about 7 MEuro per year until 2010.*

Table 8: Spending Profile
Scenario 1: 100% of Roadmap at Maximum Speed

Year*)	Instr.**)	Capital MF	Infrastr.**)	Capital MF	14 addit. Staff MF	No. of Addit. Instr.	Running Cost***) MF	Total cost MF
2000	5,9	5						5
2001	2,3	6	29	4				10
2002	1,7,12,13	15	1,11,12	17	5	+2	9	46
2003	4,6,8	14	2,3,4	30	5	+3	13	62
2004	10,11,15	8	13,14,21,24	24	5	+4	18	55
2005	18,22,26	19	5,6,7,25	20	5.5	+5	22.5	67
2006	14,16,21	28	8,9,10,15	14	5.5	+5	22.5	70
2007	19,20	18	16,18,22,26	28	5.5	+5	22.5	74
2008	17,23,25	21	17,19,20,27	24	5.5	+5	22.5	73
2009	24,27	13	23,28,30	20	5.5	+5	22.5	61
2010			31,32	28	5.5	+5	22.5	56
Total:		**147 MF**		**209 MF**	**48 MF**		**175 MF**	**579 MF**
		22.4 M€		**31.9 M€**	**7.3 M€**		**26.7M€**	**88.3 M€**

*) For a given project, the date given is the "centre of gravity" of the spending profile; the date may differ from the "year of construction or renewal" in Annex 3c, which refers to the date of availability.
**) For meaning of numbers see Annexes 12a,b.
***) Two thirds of instrument running cost is personnel cost, one sixth each is capital and recurrent cost (Annex 9)

Table 9: Spending Profile
Scenario 2: 100% of Roadmap at Reduced Speed

Year*)	Instr.**)	Capital MF/year	Infrastr.**)	Capital MF/year	14 addit. Staff MF/year	No. of Addit. Instr.	Running Cost MF/year	Total cost MF/year
Period 2000 to 2003 as in MFE 2000:								
2000	1-8		1,3,29					6
2001								9
2002								19
2003								20
Subtotal:		32 MF		22 MF				54 MF
Period 2004 to 2010 at constant budget:								
2004 - 2010	9-27	16.4	2,4-28, 30-32	26.7	5.5	+5	22.5	71
Subtotal:		115 MF		187 MF	38 MF		157 MF	497 MF
Total:		**147 MF**		**209 MF**	**38 MF**		**157 MF**	**551 MF**
		22.4 M€		**31.9 M€**	**5.8 M€**		**23.9 M€**	**84.0 M€**

Table 10: Spending Profile
Scenario 3: 75% of Roadmap

Year*)	Instr.**)	Capital MF/year	Infrastr.**)	Capital MF/year	14 addit. Staff MF/year	No. of Addit. Instr.	Running Cost MF/year	Total cost MF/year
Period 2000 to 2003 as in Table 9:								
2000 - 2003	1-8	8	1,3,29	5.5				13.5
Subtotal:		32 MF		22 MF				54 MF
Period 2004 to 2010:								
2004 - 2010	9-17, 20,22,26	11.7	2,4-14,17-22, 30-32	20.1	5.5	+3	13.5	50.8
Subtotal:		82 MF		141 MF	38 MF		94 MF	355 MF
Total:		**114 MF**		**163 MF**	**38 MF**		**94 MF**	**409 MF**
		17.4 M€		**24.8 M€**	**5.8 M€**		**14.3 M€**	**62.3 M€**

Table 11: Spending Profile
Scenario 4: 50% of Roadmap

Year*)	Instr.**)	Capital MF/year	Infrastr.**)	Capital MF/year	10 addit. Staff MF/year	No. of Addit. Instr.	Running Cost MF/year	Total cost MF/year
Period 2000 to 2003 as in Table 9:								
2000 - 2003	1-8	8	1,3,29	5.5				13.5
Subtotal:		32 MF		22 MF				54 MF
Period 2004 to 2010:								
2004 - 2010	9-13,15, 16,22,26	4.7	2,4-7,11,12, 14, 22,30-32	13.7	4	+2	9	31.4
Subtotal:		33 MF		96 MF	28 MF		63 MF	220 MF
Total:		**65 MF**		**118 MF**	**28 MF**		**63 MF**	**274 MF**
		9.9 M€		**18.0 M€**	**4.3 M€**		**9.6 M€**	**41.8 M€**

I. CONCLUSION

For an additional cost of about 45 MF per year, that is 6.9 MEuro per year (or 13% of ILL's present budget) over a period of 10 years, ILL's instruments and infrastructure could be profoundly renewed, its average instrument efficiency increased sixteen-fold, and total ILL activities substantially expanded. This investment will allow ILL to stay the world-leading neutron centre for many years to come.

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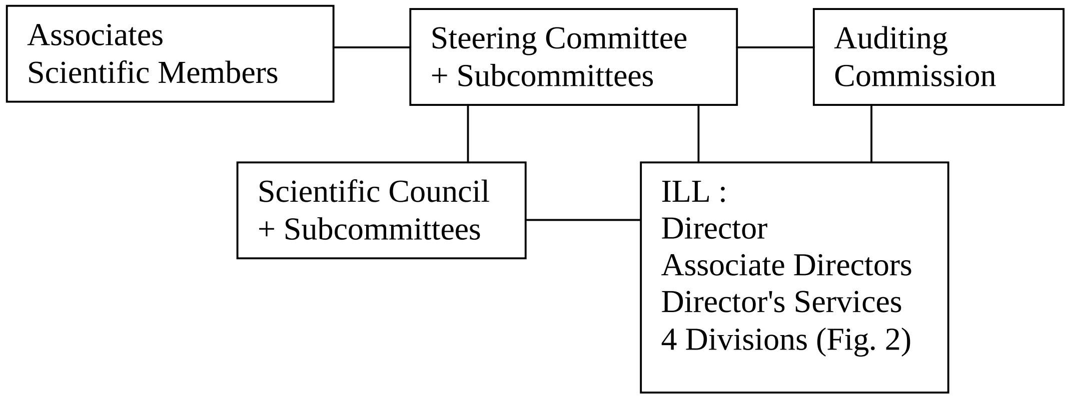
The ILL Roadmap

ANNEXES

Annex 1 : Organisational Structure of the Association



Annex 2: List of ILL Science-Prize Winners

Year	Name	Name of prize/award
1985	P. Nozières	Prix Wolf (Jerusalem)
	F. Mezei	Hewlett-Packard-Prize
1986	P. Ageron	Prix Foucault (SFP)
1987	D. Richter	Walter-Schottky-Preis (DPG)
1988	P. Nozières	Médaille d'or du CNRS
1989	R. Currat	Prix Ancel (SFP)
1990	H. Börner	Roentgenpreis Univ. Giessen
1991	W. Mampe and D. Dubbers	Stern-Gerlach-Preis (DPG)
1994	J. Pannetier	Prix Paul Pascal (Académie des Sciences)
1995	C. Janot	Prix Winter-Klein (Académie des Sciences)
	C. Janot	Médaille Chevenard (SFMM)
1996	A. Oed	Robert-Wiechard-Pohl Preis (DPG)
	R. Scherm	Gentner-Kastler-Preis (SFP/DPG)
	P. Ageron	Prix Frank (Dubna)
	P. Nozières	Holweck (IUP+SFP)
1997	M. de Boissieu*	Médaille de Bronze du CNRS
1998	W. Heil	Körber prize

* prize obtained after leaving ILL

Annex 3: Instruments – Present Status and Possible Scenario

Annex 3a: Designation of existing ILL Instruments

	Powder diffractometers
D1A	high-resolution 2-axis diffractometer
D1B	2-axis diffractometer (CRG)
D2	high-resolution 2-axis diffractometer
D4	diffractometer for liquids and amorphous substances
D20	high-flux 2-axis diffractometer
	Single-crystal diffractometers
D3	polarised hot neutrons for magnetisation density maps
D9	hot neutrons
D10	4-circle & 3-axis
D15	thermal neutron normal-beam diffractometer (CRG)
D19	4-circle for large unit cells
D23	2-axis spectrometer with polarisation analysis (CRG)
	Large-scale structure diffractometers
D11	small-angle neutron scattering (SANS)
D16	small momentum transfer diffractometer
D22	universal high dynamic range small-angle scattering
DB21	4-circle low-resolution diffractometer
LADI	Laue diffractometer
	Reflectometers
ADAM	advanced diffractometer for the analysis of materials (CRG)
D17	reflectometer
EVA	evanescent wave diffractometer (CRG)
	3-axis spectrometers
IN1	hot neutron 3-axis spectrometer
IN8	thermal neutron 3-axis spectrometer
IN12	cold neutron 3-axis spectrometer (CRG)
IN14	cold neutron 3-axis spectrometer
IN20	3-axis spectrometer with polarisation analysis
IN22	3-axis spectrometer with polarisation analysis (CRG)
	Time-of-flight spectrometers
IN4	thermal neutron time-of-flight spectrometer
IN5	cold neutron multi-chopper TOF spectrometer
IN6	cold neutron time-focussing TOF spectrometer
D7	diffuse scattering spectrometer
	High-resolution spectrometers
IN10	backscattering spectrometer
IN11	spin-echo spectrometer
IN13	backscattering spectrometer (CRG)
IN15	spin-echo spectrometer
IN16	backscattering spectrometer
	Fundamental and nuclear physics
PF1	cold polarised beam
PF2	UCN beam facility
PN1	fission product spectrometer (Lohengrin)
PN3	gamma-ray spectrometer
S18	thermal neutron interferometer (CRG)

Annex 3b: ILL Instruments – Present Status 2000

Instr. Group	Instr. Name	Instrument Count					Instrument Details			
		1. Sched.	2. CRG public use	3. CRG private use	4. total public 1+2	5. total 1+2+3	Year*) of constr. or renewal	Efficiency gain instr./guide**)	Comment	
Diffraction	Powder									
	D1A	0.5								
	D2	1.0						*		
	D4	0.5					2000	x 9 *	world's best	
	D20	1.0					1997	x 10 *	unique	
	D1B		0.5	0.5						
	Crystal									
	D3	1.0						*		
	D9	1.0						*		
	D10	1.0								
	D19	1.0						*	unique	
	D15		0.3	0.7				*		
	D23		0.3	0.7			1998	x 3		
	Total # :	**7.0**	**1.1**	**1.9**	**8.1**	**10.0**				

*) the date given is the year of **renewal** if next column has an entry under "instrument efficiency gain" ; it is the year of **construction** otherwise

) gain due to **instrument renewal on the left-hand side ; gain due to **guide** renewal on the right-hand side ; an asterisk * means that there is no neutron guide

Status 2000 cont'd.

Instr. Group	Instr. Name	Instrument Count					Instrument Details			
		1. Sched.	2. CRG public use	3. CRG private use	4. total public 1+2	5. total 1+2+3	Year of constr. or renewal	Efficiency gain instr./guide (* no guide)	Comment	
Large-scale structures	Diffracto-meters									
	D11	1.0							world's best	
	D16	1.0					2000	x 4		
	D22	1.0					1995		world's best	
	LADI	0.25					1996		unique	
	DB21	0.25								
	Reflecto-meters									
	D17	1.0					2000	x 5 x 2		
	ADAM		0.3	0.7			1997			
	EVA		0.3	0.7						
	Total # :	**4.5**	**0.6**	**1.4**	**5.1**	**6.5**				
Three-Axis Spectro-meters										
	IN1	0.5						*	unique	
	IN8	1.0					2000	x 8 *	world's best	
	IN14	1.0					1990		world's best	
	IN20	1.0						*	world's best	
	IN12		0.3	0.7						
	IN22		0.3	0.7			1998	x 3		
	Total # :	**3.5**	**0.6**	**1.4**	**4.1**	**5.5**				

Status 2000 cont'd.

Instr. Group	Instr. Name	Instrument Count					Instrument Details			
		1. Sched.	2. CRG public use	3. CRG private use	4. total public 1+2	5. total 1+2+3	Year of constr. or renewal	Efficiency gain instr./guide (* no guide)	Comment	
Time-of-flight + High Res.	TOF									
	IN4	1.0					2000	x 10 *		
	IN5	1.0					2001	x 10 x 2	world's best	
	IN6	1.0							world's best	
	D7	1.0							world's best	
	H-R									
	IN10	1.0								
	IN11	1.0							world's best	
	IN15	0.5					1995		world's best	
	IN16	1.0					1995			
	IN13		0.5	0.5					world's best	
	Total # :	**7.5**	**0.5**	**0.5**	**8.0**	**8.5**				
Nuclear + Particle Physics										
	PF1	1.0					2000	x 4	world's best	
	PF2	1.0							world's best	
	PN1	1.0						*	unique	
	PN3	1.0					1999	x 5 *	unique	
	S18			1.0			1998	x 3	world's best	
	Total # :	**4.0**		**1.0**	**4.0**	**5.0**				
	Grand Total :	**26.5***)	**2.8**	**6.2**	**29.3**	**35.5**				

*) While the number of **existing** instruments is 26.5, the average number of **scheduled** instruments over recent years [28] is below 25.

Annex 3c: ILL Instruments – Possible Scenario in 2010

Instr. Group	Instr. Name	Instrument Count					Instrument Details			
		1. Sched.	2. CRG public use	3. CRG private use	4. total public 1+2	5. total 1+2+3	Year*) of constr. or renewal	Efficiency gain instr./guide*)	Comment	Capital needed instr./guide
Diffraction	Powder									
	D2	1.0					2004	x 12 *	world's best	6 MF
	D4	0.5					2000	x 9 *	world's best	
	D20	1.0					1997	x 10 *	unique	
	Strain Scanner	1.0					2003	x 5 x 4		3 MF 5 MF
	CRG (D1B)		0.5	0.5						
	Crystal									
	D3	1.0					2004	x 5 *	unique	5 MF
	D9	1.0					2010	x 4 *		10 MF
	D19	1.0					2005	x 25 *	unique	4 MF
	VIVALDI	1.0					2001	x 50 x 4	unique	4 MF 5 MF
	CRG (D15)		0.3	0.7				*		
	CRG (D23)		0.3	0.7			1998	x 3		
	Total # :	**7.5**	**1.1**	**1.9**	**8.6**	**10.5**				**32 MF 10 MF**

*) see footnotes to Annex 3b

Scenario 2010 cont'd.

Instr. Group	Instr. Name	Instrument Count					Instrument Details			
		1. Sched.	2. CRG public use	3. CRG private use	4. total public 1+2	5. total 1+2+3	Year of constr. or renewal	Efficiency gain instr./guide (*no guide)	Comment	Capital needed instr./guide
Large-scale structures	Diffracto-meters									
	D11	1.0					2010	x 3	world's best	10 MF
	D16	1.0					2000	x 4 x 3		3 MF
	D22	1.0					2004	x 3 x 2	world's best	4 MF 5 MF
	+ Tisane						2007	x 100	unique	7 MF
	LADI	1.0					2003	x 4	unique	5 MF
	DB21 or NN	0.5								
	USANS(S18)		0.5				2001		world's best	
	Reflecto-meters									
	D17	1.0					2000	x 5 x 2		
	(UCN-)Refl.	1.0					2008	x 100	world's best	3 MF
	CRG (ADAM)		0.3	0.7			1997			
	Total # :	**6.5**	**0.8**	**0.7**	**7.3**	**8.0**				**29 MF 8MF**
Three-Axis Spectromet.										
	IN1	0.5					2008	x 8 *	unique	3 MF
	IN8	1.0					2000	x 8 *	world's best	
	IN14	1.0					2003	x 4	world's best	2 MF 2 MF
	IN20	1.0					2002	x 10 *	world's best	3 MF
	+ NRSE						2002		world's best	1 MF
	+PSD/Flat Cone						2009		world's best	4 MF
	CRG(IN22)		0.3	0.7			1998	x 3		
	Total # :	**3.5**	**0.3**	**0.7**	**3.8**	**4.5**				**13 MF 2 MF**

Scenario 2010 cont'd.

Instr. Group	Instr. Name	Instrument Count					Instrument Details			
		1. Sched.	2. CRG public use	3. CRG private use	4. total public 1+2	5. total 1+2+3	Year of constr. or renewal	Efficiency gain instr./guide (*no guide)	Comment	Capital needed instr./guide
Time-of-flight + High Res.	TOF									
	IN4	1.0					2000	x 10 *		
	IN5	1.0					2001	x 10 x 3	world's best	4 MF
	IN6	1.0						x 3	world's best	4 MF
	D7	1.0					2003	x 40 x 3	world's best	23 MF 5 MF
	PASTIS	1.0					2007	x 10 x 4	unique	16 MF 10 MF
	H-R									
	IN15	1.0					2007	x 4 x 2	world's best	3 MF 4 MF
	IN16	1.0					2008	x 20 x 2	world's best	5 MF 4 MF
	CRG (IN13)		0.5	0.5				x 3	world's best	
	BRISP		0.3	0.7					unique	
	Total # :	**7.0**	**0.8**	**1.2**	**7.8**	**9.0**				**47 MF 31 MF**
Nuclear + Particle Physics										
	PF1	1.0					2002	x 3 x 4	world's best	2 MF
	PF2	1.0					2005	x 100 x 2	unique	2 MF 3 MF
	PN1Miniball	1.0					2003	x 30 *	unique	5 MF
	PN3	1.0					2004	x 5 *	unique	2 MF
	High-Speed Tomogr. and Phase-Contrast		0.5	0.5			2003	x 10 *	world's best	
	CRG (S18)			0.5			1998	x 3	world's best	
	Total # :	**4.0**	**0.5**	**1.0**	**4.5**	**5.5**				**11 MF 3 MF**

Scenario 2010 cont'd.

Instr. Group	Instr. Name	Instrument Count								
		1. Sched.	2. CRG public use	3. CRG private use	4. total public 1+2	5. total 1+2+3	Year of constr. or renewal	Efficiency gain instr./guide	Comment	Capital needed instr./guide
NN										
	Sched. NN	1.0					2005	x 3	unique	15MF 11 MF
	CRG-NN		0.3	0.7			2006	x 3	unique	
	CRG-NN		0.3	0.7			2008	x 3	unique	9 MF
Development Beam		0.5					2002			
	Total # :	**1.5**	**0.6**	**1.4**	**2.1**	**3.5**				**15 MF 20 MF**
	Grand Total :	**30.0**	**4.1**	**6.9**	**34.1**	**41.0**				**147 MF 76 MF**
										22.4 M€ 11.5 M€

Annex 4a: ILL Neutron Guides – Present Status 2000

Guide	**Length of Guide**	**Coating of Guide**	**Year of installation**	**Instruments on guide** (and their distance to reactor) (Scheduled Instruments **bold**)
Cold Guides in Old Guide Hall :				
H14	120 m	Nickel	1972	**IN11** (85m), IN12 (100m), ¼ **Cold LADI** (120m)
H15	100 m	Nickel	1972	**IN6** (50m), **D7** (60m), ¼ **DB21** (70m), **IN10** (75m), **D11** (100m)
H16	45 m	Nickel	1972	**IN5** (45m)
H17	35 m	Nickel	1972	**D16** (35m)
H18	30 m	Partly Supermirror	1997	**D17** (30m)
H113	75 m	Ballistic Supermirror	1999	
Thermal Guides in Old Guide Hall :				
H22	105 m	Nickel	1972	**D1A** (85m), D1B (85m)
H23	100 m	Nickel	1972	Test for DPT (90 to 100m)
H24	105 m	Nickel	1972	IN13 (80m), **D10** (95m)
H25	65 m	Supermirror	1997	S18 (55m), D23 (60m), IN22 (65m)
Cold Guides in New Guide Hall :				
H53	65 m	Enriched Nickel	1985	**IN14** (20m), **IN16** (55m), EVA (60m), ADAM (65m), **PF1** (65m)
H511	42 m	Nickel	1985	**IN15** (42m)
H512	55 m	Nickel	1985	**D22** (55m)
Guide to UCN Turbine :				
TGV	13 m	Nickel	1985	**PF2** (13m)
Total Length : 955 m				

Annex 4b: ILL Neutron Guides - Possible Scenario in 2010

Guide	**Length of Guide**	**Coating of Guide**	**Year of installation**	**Instruments on guide** (and their distance to reactor) (Scheduled Instruments **bold**)	**Cost** at 90kF/m
Cold Guides in Old Guide Hall :					
H14	120 m	Ballistic Supermirror	2006	**NN** (85m), NN (100m)	11 MF
H15	100 m	Supermirror	2006	**IN6** (50m), **D7** (60m), **DB21** (90m), **D11** (100m)	9 MF
H16	45 m	Supermirror	2001	**IN5** (45m)	4 MF
H17	35 m	Nickel	2006	**D16** (35m)	3 MF
H18	30 m	partly Supermirror	1997	**D17** (30m)	
H113	75 m	Ballistic Supermirror	1999	**PF1** (75m)	
Thermal Guides in Old Guide Hall :					
H22	105 m	Ballistic Supermirror	2003	D1B? (85m), **Strain Scanner** (100m), **Th. LADI** (105m)	10 MF
H23	100 m	Ballistic Supermirror	2003	Test for DPT (90 to 100m), NN (100m)	9 MF
H24	105 m	Ballistic Supermirror	2003	IN13? (80m), **PASTIS** (105m)	10 MF
H25	65 m	Supermirror	1997	USANS/S18? (55m), D23? (60m), IN22 ? (65m)	
Cold Guides in New Guide Hall :					
H53	65 m	Supermirror	2003	**IN14** (15m), **IN16** (55m), ADAM? (65m), **Development** (65m)	6 MF
H511	42 m	Supermirror	2006	**IN15** (42m)	4 MF
H512	55 m	Supermirror	2006	**D22** (55m)	5 MF
Guide to UCN Turbine :					
TGV	13 m	Nickel	2005	**PF2** (13m)	3 MF
To be renewed : 785 m				**Total Renewal Cost :**	**74 MF**

Annex 5: Exceptional Expenses for the Reactor

Installations with lifetimes of less than 10 years

5 absorbents for safety rod (lifetime 4 years):	4 MF
3 absorbents for control rod (5 y):	1 MF
1 take-over control (8-10 y):	4 MF
10 neutron chambers (8-10 y):	1 MF
10 analogue buses (8-10 y):	2 MF
reactor channel H1/H2 (8 y):	6 MF

Installations with uncertain lifetimes

Horizontal cold source:	2 MF
Vertical cold source:	5 MF
Turbines for cold sources:	3 MF
Heat exchangers for cold sources:	1 MF
Heat exchangers D_2O/H_2O:	2 MF
Total cranes:	1 MF
Cryogenic detritiation:	4 MF
Strengthening of buildings next to reactor:	10 MF
Ceiling of reactor building:	2 MF

Annex 6: ILL Instrument Count*) Now and in 10 Years

Breakdown by ILL Instrument Group

	Year 2000			Year 2010		
Instr. Group**)	Sched.	CRG	Total	Sched.	CRG	Total
DIF	7	3	10	7.5	3	10.5
LSS	4.5	2	6.5	6.5	1.5	8
TAS	3.5	2	5.5	3.5	1	4.5
TOF+HR	7.5	1	8.5	7	2	9
NPP	4	1	5	4	1.5	5.5
NN				1	2	3
Development				0.5		0.5
Total :	**26.5*****)	**9**	**35.5**	**30**	**11**	**41**
CRG/Total :	**25 %**			**27 %**		
Private/Total:	**17 %**			**16 %**		

*) cf. Annexes 3b and 3c
**) acronyms explained in text of Chapter 19
***) The average number of scheduled instruments over recent years [28] is 25.

Annex 7: Costs and Time Estimates for Life Science Programme

		Starting date	Duration (years)	Cost (MF)
In-house research	Additional ILL scientist for biochem./struct.	2001	5	2.0
	2 ILL Ph.D studentships	2002	6	1.4
Instrument upgrades	D22 detector	2000	5	4
	Cold LADI	2002	2	5
	D19	2003	2	4
	H24 neutron guide	2003		9
Biochemistry/ Deuteration laboratory	Capital costs	2001	1	4
	Recurrent costs	2001	5	External (EU)
	Technician	2001		External (EU)
	Post-doc Biochem./neutron expert	2002	2/3	0.6
Promotion of neutron methods	Conferences, workshops, Brochures	2001	5	0.5

Annex 8a: History of ILL Renewal

Period/Programme	Measures taken	No. of Instrument Equivalents
1971 – 1980 Building of ILL	30 New Instruments	30
	8 New Guides	4
		Total Instrument Equivalents : 34 = **3.4 per year**
		Total Investment : ~ 400 MF = **40 MF per year***)
1981 – 1990 « 2ème souffle »	11 New Instruments**) (IN1, D4, PN8, IN20, D19, D2B, D20, IN14, IN15, IN16, D22)	11
	6 Instr. Upgrades (D7, D20, IN20, D16, PF1, GAMS4)	3
	3 New Guides (H53, H511, H512)	2
	New UCN Facility (PF2)	2
		Total Instrument Equivalents : 18 = **1.8 per year**
		Total Investment : 240 MF = **24 MF per year*****)
1991 – 1995 Renewal of Reactor Vessel	No Instrument Renewal	
		Total Investment : 170 MF = **17 MF per year**
1996 – 2000 « UFI » :	1 New Instrument (D17)	1
	4 Instr. Upgrades (D4, D16, IN8, IN5)	2
	4 New Guides (3 Super-mirror) (H17, H18, H25, H113)	2
Other :	2 New Instruments (LADI, IN4)	2
	2 Upgrades (D20, PN3)	1
		Total Instrument Equivalents: 8 = **1.6 per year**
		Total Investment : 25 MF = **5 MF per year**

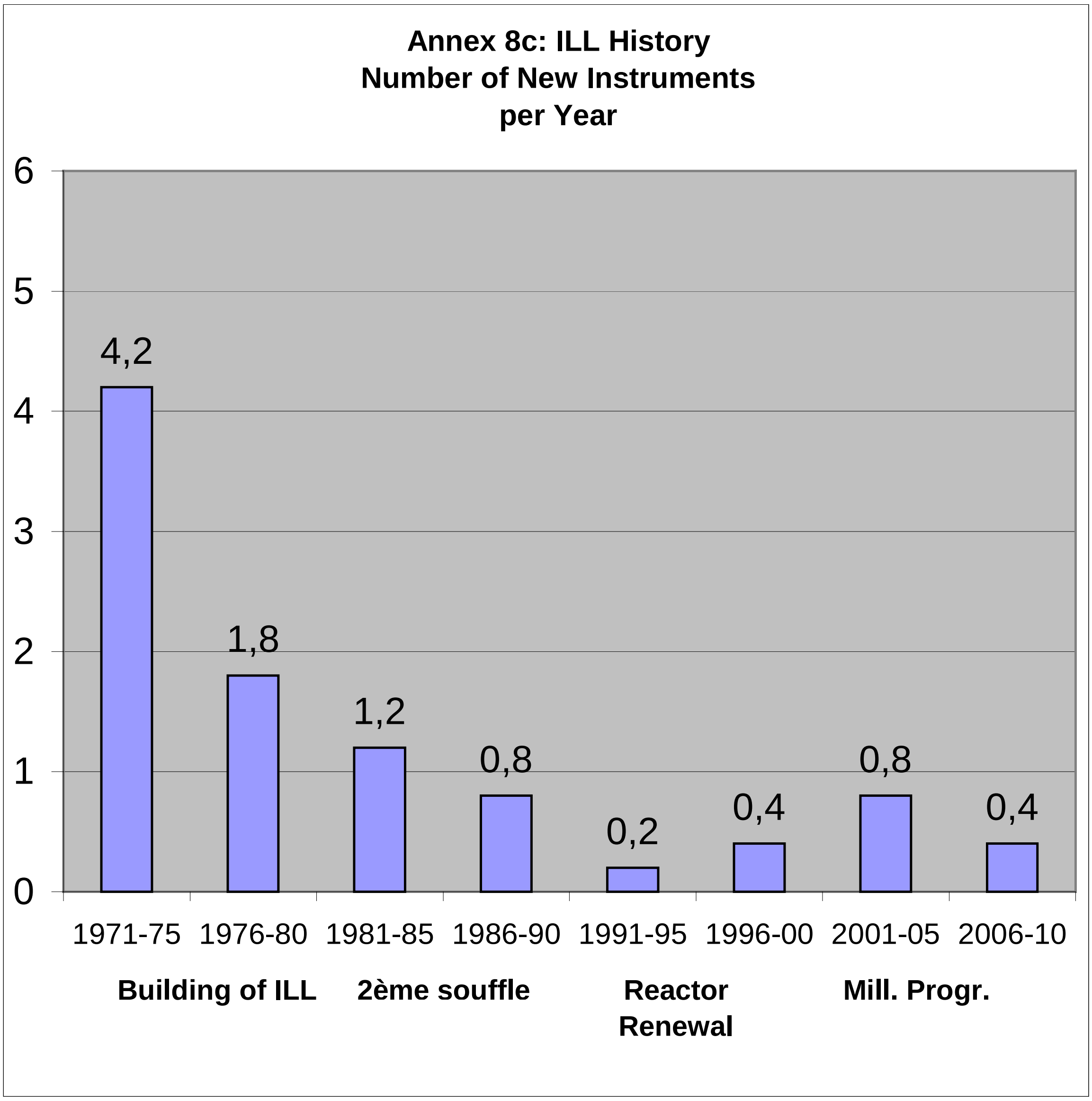
*) This number is an estimate based on figures for the new Munich reactor ; all expenditures are given in 1999 MF

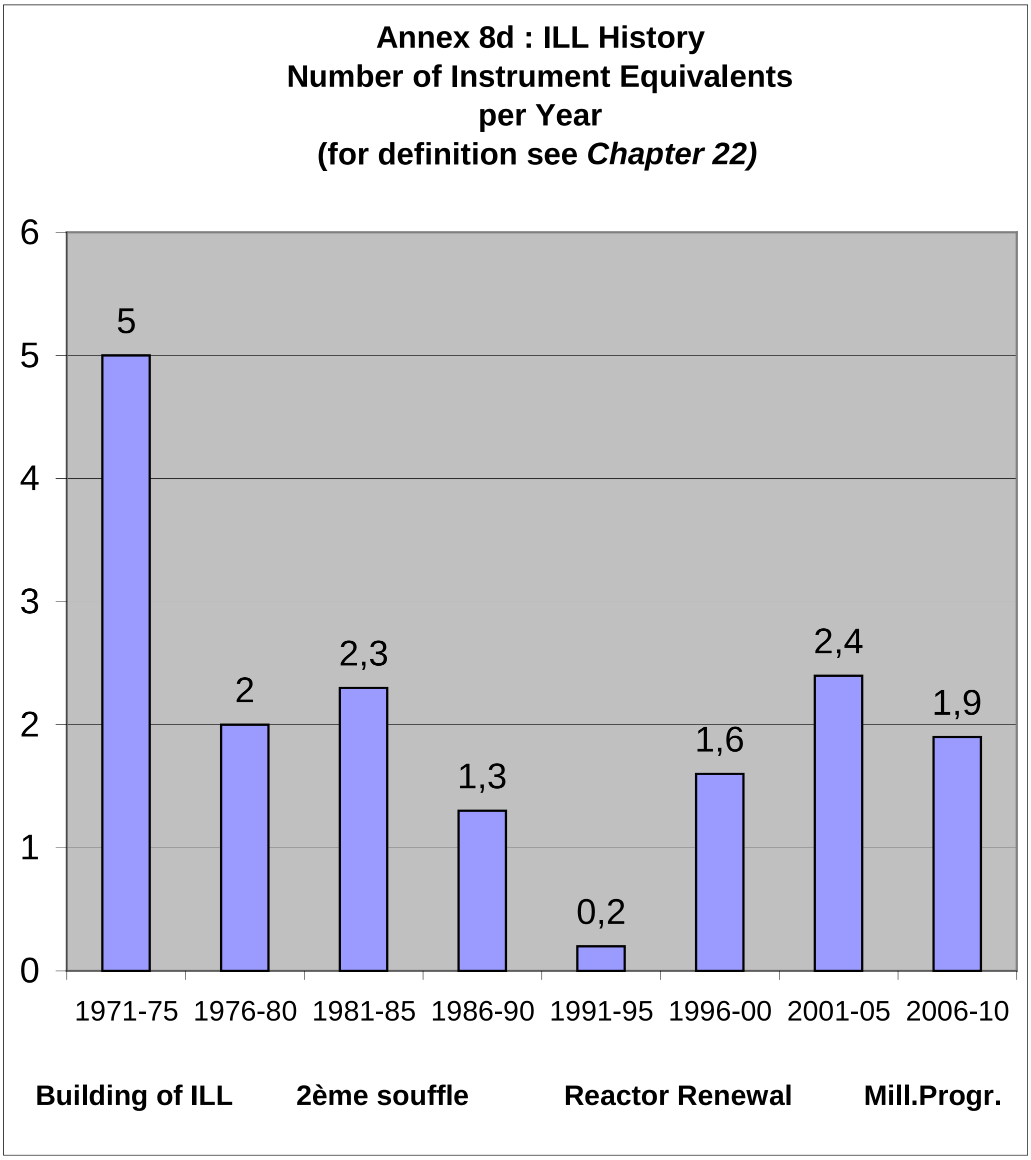
**) The last three instruments went into operation only after the reactor restart in 1995

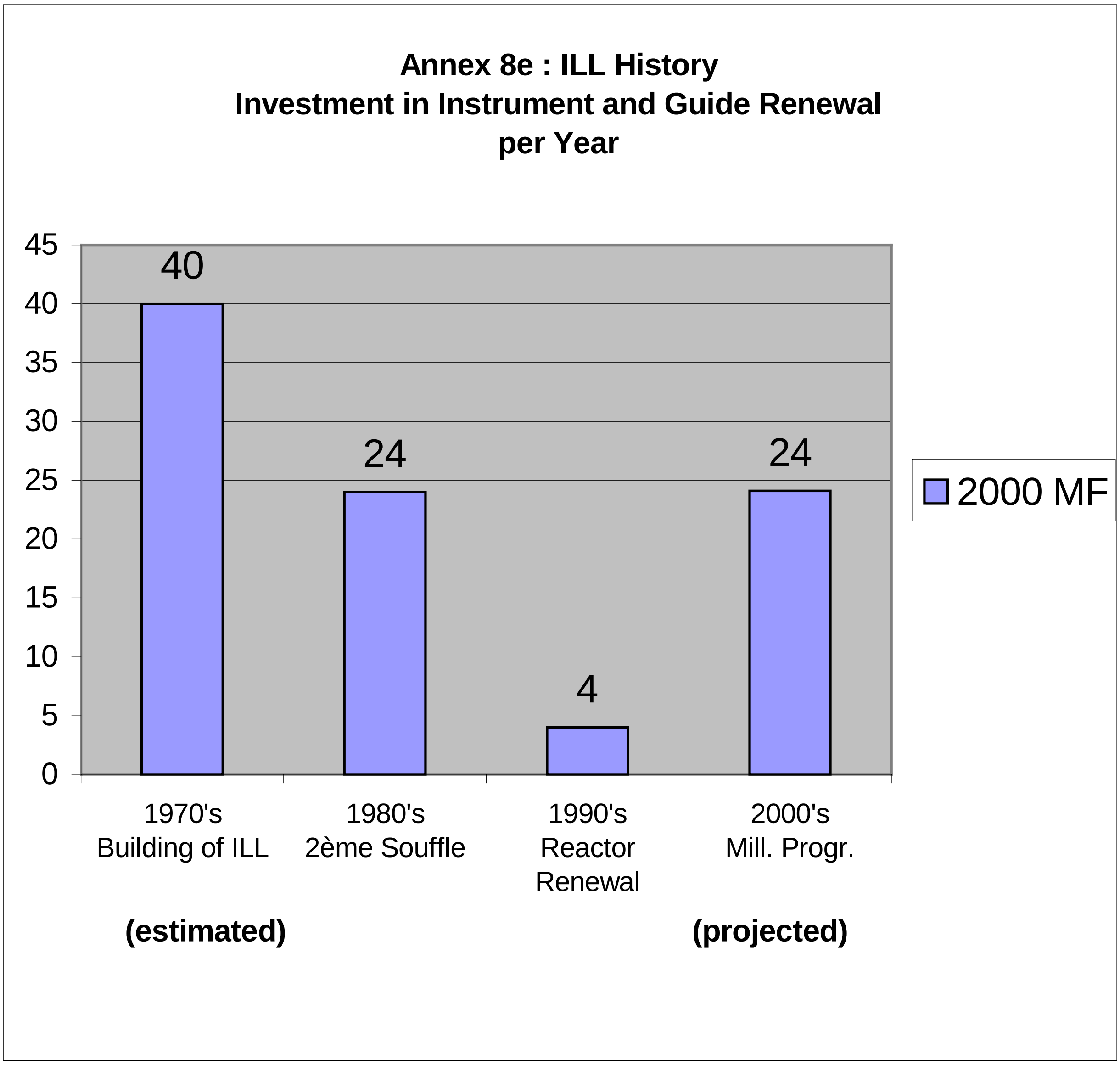
***) This number includes investment for the second neutron guidehall and for the second cold source

Annex 8b: Projected History of ILL Renewal

Period/Programme	Measures taken	No. of Instrument Equivalents
2001 – 2005 « Millennium »		
Accepted :	2 New Instruments (Th. LADI, Strain Scanner)	2
	3 Upgrades (D3, D22, IN20)	1.5
Recommended Next:	1 New Instrument (UCN)	1
	4 Upgrades (D7, PN1, D2, NRSE)	2
	1 Supermirror Guide (IN14/H53)	0.5
Wishlist :	1 New Instrument (NN)	1
	4 Upgrades (Cold LADI, D19, USANS, PF1)	2
	4 Super-mirror Guides (H14, H22, H23, H24)	2
Total Instrument Equivalents: 12 = **2.4 per year**		
Total Investment : 120 MF = **24 MF per year**		
2006 – 2010 « Millennium »		
Wishlist, cont'd. :	2 New Instruments (PASTIS, UCN Refl.)	2
	9 Upgrades (PSD, Flat-cone, IN1, IN15, IN16, PN3, Tisane, D9, D11)	4.5
	4 Super-mirror + 2 Nickel Guides (H15, H17, H511, H512, H16 and TGV)	3
Total Instrument Equivalents: 9.5 = **1.9 per year**		
Total Investment : 85 MF = **17 MF per year**		


Annex 8c: ILL History
Number of New Instruments
per Year
6
5
4
3
2
1
0
4,2
1,8
1,2
0,8
0,2
0,4
0,8
0,4
1971-75
1976-80
1981-85
1986-90
1991-95
1996-00
2001-05
2006-10
Building of ILL
2ème souffle
Reactor
Renewal
Mill. Progr.


Annex 8d : ILL History
Number of Instrument Equivalents
per Year
(for definition see Chapter 22)
6
5
4
3
2
1
0
5
2
2,3
1,3
0,2
1,6
2,4
1,9
1971-75
1976-80
1981-85
1986-90
1991-95
1996-00
2001-05
2006-10
Building of ILL
2ème souffle
Reactor Renewal
Mill.Progr.


Annex 8e : ILL History
Investment in Instrument and Guide Renewal
per Year
45
40
35
30
25
20
15
10
5
0
40
24
4
24
2000 MF
1970's
Building of ILL
1980's
2ème Souffle
1990's
Reactor
Renewal
2000's
Mill. Progr.
(estimated)
(projected)

Annex 9: The Operating Cost of ILL Instruments

We estimate the average annual incremental cost of running one more scheduled ILL instrument in addition to the 25 instruments existing (excluding the cost of instrument building). We do this cost estimate separately for each Division of ILL. The estimate is based on the assumption that ILL's total expenditure can be divided into two parts: fixed costs, which do not depend on the number of instruments, and instrument operating costs, which are directly proportional to the number of instruments.

Science Division (DS)

Personnel: 90 out of 128.5 staff, including thesis students, i.e. 70% of DS staff, are fully (to 100%) linked to instrument operation. The remaining 30% of DS staff, namely theory group, library, scientific computing, some thesis students, and others depend only weakly (to 20%) on the number of instruments in operation. Hence, one additional instrument (plus 4%) requires 0.04 x (0.70 + 0.20 x 0.30) x 128.5 = 3.9 more staff in DS, at a cost of 1.7 MF per year [30].

Recurrent: 70 % of recurrent costs in DS are fully (to 100%) associated with instrument operation, primarily to cover visits by ILL users. The remaining 30% of recurrent costs, namely for scientific journals, Scientific Council, seminars, etc., are linked to a much lesser extent (to 30%) to instrument operation. Hence, the extra recurrent needed in DS for one additional instrument is 0.04 x (0.70 + 0.30 x 0.30) x 11 MF = 350 KF per year.

Capital: Here again 70 % of costs concern investment for the operation of existing instruments. The remaining 30 % are earmarked for renewal activities in the framework of the "UFI" and Millennium programmes which are not connected with the operation of instruments. Hence, the extra capital needed for one additional instrument is 0.04 x 0.70 x 15 MF = 420 KF per year.

Projects and Techniques Division (DPT)

Personnel: 70 % of the division’s activities are associated with the provision of services, while 30 % is linked to development work which is unrelated to the number of instruments. Of the service activities, 80 % depend on the number of instruments, while the rest is related to general infrastructure. Hence, the additional personnel needed in DPT is 0.04 x 0.70 x 0.80 x 99 = 2.2 staff, or 860 KF per year per instrument.

Recurrent: About the same percentage as for DPT personnel, i.e. 2.2 % x 11 MF = 240 KF per year per instrument, is linked to instrument operation.

Capital: Here most investment goes into instrument development and building, and only 30 % into instrument operation. The latter gives 0.04 x 0.30 x 16 MF = 190 KF per year per instrument.

Reactor Division (DRe)

The security guard services in DRe are slightly affected by a rise in the number of instruments in operation, due to the accompanying rise in the number of ILL staff and visitors on site. The rise per instrument is small, but 5 more instruments may justify another post here.

Administration Division (DA)

Personnel: Altogether 45 % of DA activities are directly or indirectly linked to the number of instruments in operation: about 15 % of DA activities are directly linked to the number of instruments, mainly in the Purchasing, Stores and Site Maintenance services; another 20 % are linked to the total number of ILL staff, mainly in the Personnel and Finance services; another 10 % are linked to the number of visitors, mainly in Travel and related services. If the number of instruments increases by 4 %, then the number of visitors increases by 4 % and the number of staff by 2 % (see below). Hence, the additional staff needed is (0.04 x 0.15 + 0.04 x 0.10 + 0.02 x 0.20) x 66 = 0.9 staff or 320 KF per year per instrument.

Recurrent: This will rise by the same proportion, namely 0.014 x 14 MF = 200 KF per year per instrument; the effects on DA capital are negligible.

Director's Services (DIR)

In DIR, it is mainly the Health Physics services which are affected. 35 % of their activity is linked to instrument operation and 65 % to general reactor operations. The additional personnel needed is 0.04 x 0.35 x 13 = 0.18 staff or 70 KF per year per instrument. Extra recurrent and capital costs are negligible, as most of these costs are linked to reactor operations.

The following Table summarizes these findings.

Incremental Annual Operating Cost of one Additional ILL Scheduled Instrument

ILL Division	Personnel number	Personnel Cost MF	Recurrent MF	Capital MF
DS	3.9	1.70	0.35	0.42
DPT	2.2	0.86	0.24	0.19
DRe	0.2	0.06	-	-
DA	0.9	0.32	0.20	-
DIR	0.2	0.07	-	-
Total	7.4	3.01	0.79	0.61
Grand Total:		**4.5 MF per year per instrument**		

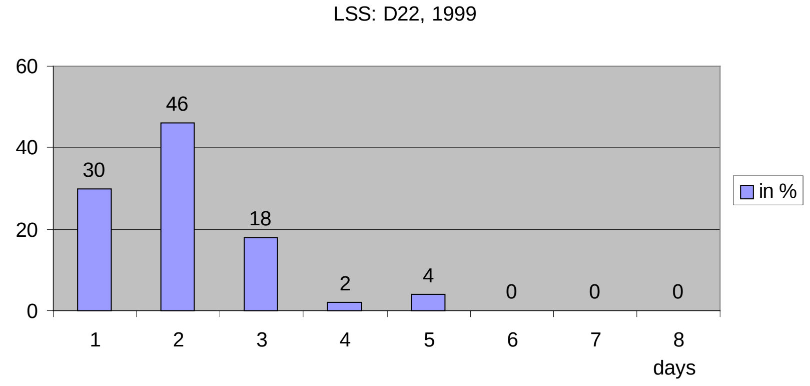
In conclusion, we find that the operation of one additional ILL instrument (+ 4 % of instrument suite) requires 7.4 extra staff (+ 1.8 %), at a cost of 3.0 MF per year, plus about 800 KF in recurrent and 600 KF in capital. In total, the cost is rounded to

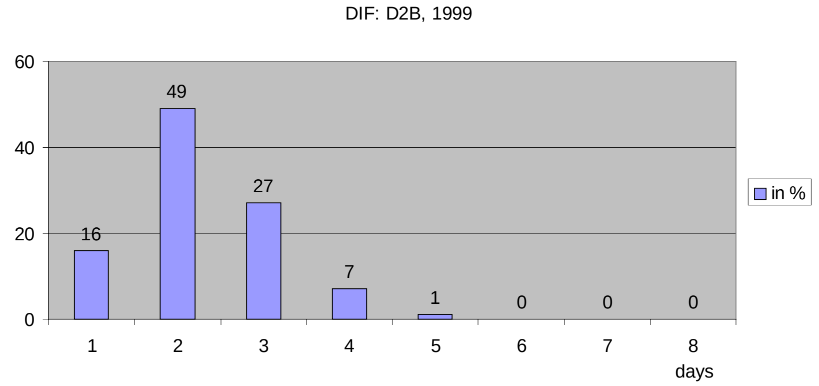
4.5 MF or 0.7 MEuro per year per instrument,

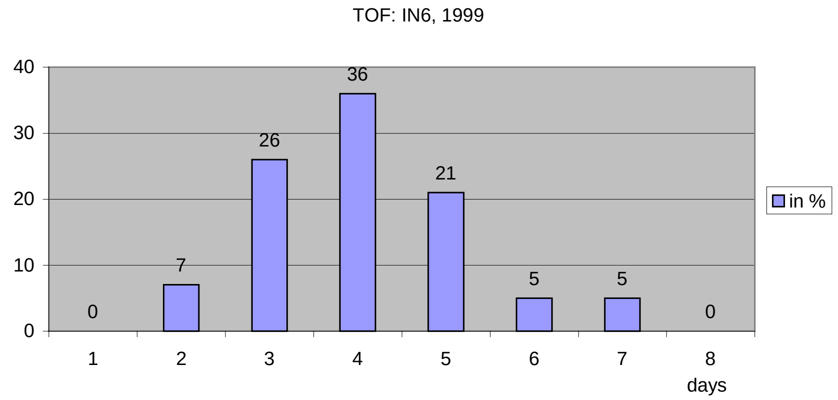
which is 1.3 % of the current ILL budget. This means that at present, with 25 scheduled instruments, about 33% or one-third of ILL’s budget is used to operate and maintain the scheduled instruments, while two-thirds correspond to fixed costs (when we include also CRG instruments fixed costs become 60%).

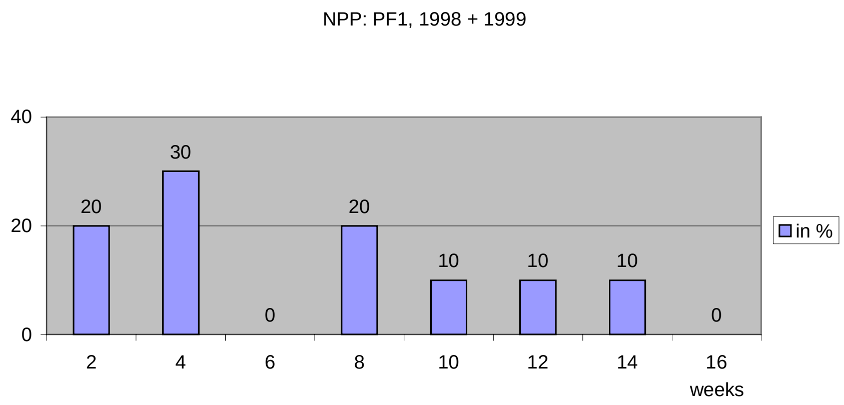
Of course, this analysis only gives the incremental cost when one more instrument is added. The true average annual cost per instrument is closer to the figure: total budget divided by total number of instruments. This gives running costs of about twice those estimated here.

Annex 10: Distribution of Allocated Beam Time on various ILL Instruments (in %)









Annex 11: Extra Personnel needed

Type of staff	No. of staff	
	30 scheduled instruments	**25** scheduled instruments
To build and run new instruments		
DS : Instr. Scientists	7	-
Technicians	5	-
Postdoctoral Fellows	10	4
DPT : Engineers	3	1
Technicians	8	3
DRe : Security Officer	1	-
DA : Non-cadres	4	-
DIR : Health Physics Techn.	1	1
for special tasks		
Radiation Scientist	1	1
Mathematician	1	1
Public Relations Officer	1	1
Senior Scientists	2	2
Total Number :	**44**	**14**

Annex 12a: List of Instrument Proposals

No	Instrument	Capital
		(in 2000 MF)
1	D3	5
2	IN20	3
3	Strain Scanner	3
4	SANS Detector D22	4
5	VIVALDI (= Th. LADI)	4
6	D7 phase 1	5
7	D2 phase 1	3
8	PN1 (= Miniball)	5
9	NRSE	1
10	IN14	2
11	UCN PF2	2
12	LADI	5
13	PF1	2
14	D7 phase 2	18
15	D19	4
16	D2 phase 2	3
17	NN	15
18	IN16	5
19	PN3	2
20	PASTIS	16
21	TISANE	7
22	PSD – Flat Cone	4
23	IN15	3
24	IN1	3
25	(UCN-)Reflectometer	3
26	D11	10
27	D9	10
Total Instruments:		**147 MF**
		22.4 M€

Annex 12b: List of Infrastructure Proposals

No	Infrastructure Measure	Capital
		(in 2000 MF)
1	Neutron Guide H22	10
2	Neutron Guide H24	10
3	Neutron Guide H23	9
4	Neutron Guide H14	11
5	Neutron Guide H15	9
6	Neutron Guide H17	3
7	Neutron Guide H53	6
8	Neutron Guide TGV	3
9	Neutron Guide H511	4
10	Neutron Guide H512	5
11	Guide Vacuum System	2
12	General Vacuum Equipment	5
13	Earthquake Simulation	2
14	Reliability Investment	10
15	Control Cabins	2
16	Air Conditioning of Guide Halls	8
17	Polarisation Technology	5
18	Advanced Cabling and Wireless Technology	12
19	Auto-Diagnostic Control	9
20	Simulation Protocol	6
21	Helium-Free Cryostats	3
22	17 Tesla Cryomagnet	4
23	Virtual Experiments	6
24	Further Cryomagnets	9
25	Chemistry Laboratory	2
26	Detector Laboratory	4
27	Air Conditioning of support laboratories	4
28	Office Air Conditioning	10
29	Deuteration Facility	4
30	Materials & Engineering Facility	4
31	Reactor Installations with lifetimes <10y	18
32	Reactor Installations with unknown lifetimes	10
Total Infrastructure:		**209 MF**
		31.9 M€

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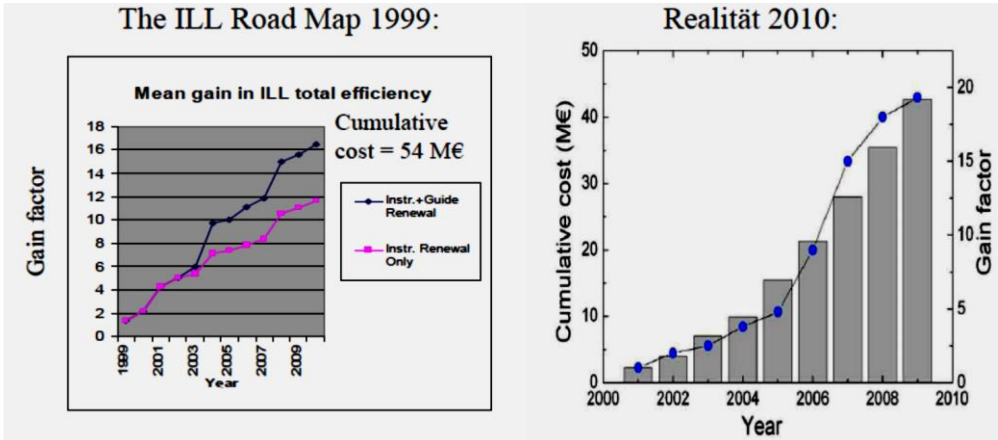

The ILL Millennium Program:

Left: The predictions of the ILL-Roadmap of 1999
on neutron gain and costs for the decennium 2000-2010.
Right: The predictions are surpassed by the results obtained in 2010.