資料2－3

研究者コミュニティの要望書
と
国際社会の意向

平成１０年９月２６日

高エネルギー加速器研究機構
　菅原　寛孝　機構長殿

核物理委員長　石原　正泰

日本原子力研究所との共同によるＪＨＦ計画の推進についての見解と要望

９月２６日（土）に開催された核物理委員会において、高エネルギー加速器研究機構において、ＪＨＦ計画を日本原子力研究所東海地区（原研）で進める案が検討されているとの報告がありました。これは、きたる省庁再編を視野に入れた案であり、核物理コミュニティとしても真剣に対応すべきものと考えます。本核物理委員会におきましては議論の結果、５０ＧｅＶ陽子シンクロトロンを中心としたＪＨＦ計画の早期実現は核物理コミュニティにとって最重要の懸案であり、この原研敷地案はそれに向けた現実的な案として充分検討に値すると認識致しました。但し、ＪＨＦ計画を本来の趣旨に則り遂行するためには以下の諸条件が満たされることが必須であると考えます。これらの条件を遵守しつつ本計画が進められることを強く要望する次第です。

1　ＪＨＦ計画の目指すハドロン科学研究が達成されるために、５０ＧｅＶ陽子シンクロトロンを中心とした加速器及び実験施設が早期かつ全面的に実現されねばならない。

2　建設推進に当たっては、新計画推進室を現大型ハドロン計画推進室が中心となる形で正式発足させ、この推進室に加速器計画全体を企画・運営させる。その運営に当たっては利用者の意向を尊重し、計画決定、予算執行、人事選考等の諸権限を実質的に新計画推進室に委ねる。

3　ＪＨＦ計画は、全国の利用者の要求に基づいて作成された計画であり、国内外に開かれた共同利用体制を前提にしている。完成後の運営においては、この基本体制の維持は当然であるが、そこでの加速器維持・開発と物理研究は一体のものとして進めるべきである。また、研究計画、予算、人事を含む研究組織体制は重要であるので、その策定に当たっては核物理コミュニティの総意が充分反映されることが必要である。

4　今回の案は文部省と科学技術庁の統合を視野にいれたものと理解されるが、学問の進め方ならびに方向性の観点から見ると、科学技術庁傘下の理化学研究所（理研）との科学面における関連性、相補性への配慮も重要である。したがって、ＪＨＦ計画の推進にあたっては、理研の研究計画との整合性に留意し、同研究所の現加速器計画を一層進展させるという基本姿勢を尊重しつつ協力関係を築くべきである。

文部省国際学術局
　　局長　工藤智規　殿

要望書

今日の原子核物理学では、クォークレベルからハドロンや原子核の基本的性質を解明することが大きな課題となっています。そのためにはハドロンの構造、ストレンジネスをもつ原子核や高温高密度の核物質の研究、さらには安定領域から遠く離れた原子核などの研究が重要です。高エネルギー加速器研究機構から当初JHF（大型ハドロン計画）として提案され、現在原子力研究所の中性子科学研究計画との統合計画として提案されている大強度陽子加速器計画は、科学の総合的発展に大きく貢献するものですが、特にこれらの原子核物理学研究をわが国において世界の最高水準で行うことを可能にするものです。とりわけ50GeV陽子シンクロトロンで供給されるπ、K中間子や反陽子、ニュートリノなどの大強度の二次ビームは世界最高のビームとなり、クォークレベルからハドロンや原子核の性質を解明する上で世界的にも中心的な施設となります。また大強度のニュートリノやK中間子ビームは、素粒子の起源や時空の対称性といった基本的問題の解明にも用いられます。さらに3GeVシンクロトロンでつくられるミュオンや不安定核も今後の原子核物理学の進展に重要な役割を果たすものと考えています。

JHFはもともとわが国の原子核物理学の研究者組織である核物理委員会が中心となって、21世紀のわが国における原子核物理学の進展をはかるにはどのような加速器計画がふさわしいかを深く検討し、東京大学原子核研究所がその推進をはかってきたものです。長くわが国の原子核物理学研究の中心施設であった東京大学原子核研究所と高エネルギー研究所との統合を、全国の核物理研究者が支持し推進したのは、両研究所の力を合わせることによってJHFの早期実現とそれによる原子核物理学の飛躍的発展を期待したからに他なりません。さらにその後の原研の計画との統合はまさに国の総力をあげて計画の実現をはかろうとするもので、高エネルギー加速器研究機構と原子力研究所の英断をつよく支持するものです。

世界的には原子核物理学でも大型加速器が中心的役割を果たすようになってすでに久しく、この統合計画の早期実現にわが国の原子核物理学の将来がかかっているといっても過言ではありません。またわが国のみならず世界の核物理研究者から、21世紀の原子核物理学を切り拓く計画として強い支持と協力の申出がよせられています。

JHF計画を当初から推進してきた私たち核物理研究者は、政府当局がすみやかにこの統合計画の実現をはかって下さるよう強く訴えるものです。

平成１１年７月２１日
核物理委員会
　　委員長　石原正泰
　　（東京大学理学研究科 教授）

統合計画にいたる経緯

昭６１年　大型ハドロン計画が東大核研の将来計画として構想される。

平成６年　２１世紀ハドロン加速器検討委員会が核物理委員会のもとに発足。

平成７年　同検討委員会が50GeV PSを中心とする”大強度フロンティア”の物理の推進を提案。
核物理委員会は50GeV PSを中心とした大型ハドロン計画の推進を東京大学原子核研究所と高エネルギー研究所（当時）に勧告

平成９年　東京大学原子核研究所と高エネルギー研究所の統合と、
高エネルギー加速器研究機構の設立
大型ハドロン計画推進室の設置

平成１０年　JHF国際ワークショップ開催（参加442名うち外国人200名）
Mega Science Forum でJHFの国際的評価

平成１１年　大型ハドロン計画と原研の中性子研究計画との統合計画
（核物理委員会の見解と要望）

核物理委員会

石原正泰	東京大学理学研究科 教授	委員長
今井憲一	京都大学理学研究科 教授	幹事
笠木治郎太	東北大学理学研究科 教授	
岸本忠史	大阪大学理学研究科 教授	
酒井英行	東京大学理学研究科 教授	幹事
谷畑勇夫	理化学研究所 主任研究員	
千葉順成	KEK素粒子原子核研究所 助教授	
永井泰樹	大阪大学核物理研究センター長	
永宮正治	KEK素粒子原子核研究所 教授	
畑中吉治	大阪大学核物理研究センター 教授	
森義治	KEK素粒子原子核研究所 教授	
森信俊平	九州大学理学研究科 教授	
山田作衛	KEK素粒子原子核研究所 所長	
赤石義紀	KEK素粒子原子核研究所 教授	
土岐博	大阪大学核物理研究センター 教授	

中　性　子　研　究　連　絡　会
会長　藤井保彦
Neutron Scattering Association of Japan
President　Yasuhiko FUJII
fujii@red.issp.u-tokyo.ac.jp

１９９８年１０月１日

高エネルギー加速器研究機構
　　機構長　　菅　原　寛　孝　殿
日本原子力研究所
　　理事長　　吉　川　允　二　殿

中性子研究連絡会
会長　　藤　井　保彦
（東京大学物性研究所教授）

大型加速器中性子線源建設に関する要望書

平素より、我が国の中性子散乱の研究には格別のご理解とご支援を頂き厚くお礼申し上げます。

中性子散乱研究者の全国組織である当中性子研究連絡会では、加速器中性子線源のパイオニアの我が国が、施設規模において近年欧米の後塵を拝していることを憂い、さらに国際的に拡大するニュートロンギャップを深刻に受け止め、かねてより大型加速器中性子線源の早期実現を要望して参りました。

一方、貴高エネルギー加速器研究機構では長年にわたり大型ハドロン計画（JHF）を、貴日本原子力研究所では中性子科学研究計画を推進してこられましたが、昨今の行財政改革・省庁統合など諸情勢の変化に鑑み、両計画の施設を統合して建設する可能性を探るべく、関係諸機関にて鋭意検討中であると伺っております。このような両施設計画を一本化して我が国の英知を結集して建設を目指すこのたびの英断に敬意を表すと共に、同計画の一日も早い実現を熱望しております。当中性子研究連絡会では、この計画が国内外に及ぼす広範な影響を考慮し、その推進並びに完成後の施設の在り方について、次のことを要望いたします：

事務局　　319-1106 茨城県那珂郡東海村白方　日本原子力研究所東海研究所　大学開放研究室気付
東京大学物性研究所中性子散乱研究施設事務室内
電話 (029) 282-5782, ファクス(029) 282-8907

（１）数ＭＷ中性子線源を建設して世界最高性能の中性子散乱研究施設を完成すること。そのため第一期計画として１ＭＷ程度の中性子線源と研究施設を早期に整備し、共同利用を開始すること。

（２）中性子散乱研究の特徴に鑑み、物理・化学・高分子・生物・薬学・材料等の諸科学、およびそれらの学際研究、工業的応用研究等の発展に資する研究施設とすること。

（３）全国共同利用研究施設とすること。

（４）国際的に開かれた研究施設とすること。

（５）両貴研究機関が中心になると思われる共同チームは、省庁間の枠を超えて最強の組織化を図り、内外の高い信頼を得て、強力なリーダーシップを発揮し、同計画を円滑に推進すること。また、中性子散乱研究施設のためのチーム編成は、中性子コミュニティーの意向を十分反映したものとすること。

諸情勢の厳しい折りですが、本計画の早期実現に向けて一層のご配慮下さるようお願い申し上げます。その実現のために、当中性子研究連絡会としてもできるだけの協力をいたす所存です。

以上

中性子研究連絡会
Neutron Scattering Association of Japan

平成11年6月9日

文部省 学術国際局
局長　工藤智規殿

科学技術庁 原子力局
局長　青江　茂殿

中性子研究連絡会
会長　藤井保彦
（東京大学物性研究所 教授）

大強度陽子加速器統合計画の推進（要望）

平素より、我が国の中性子散乱の研究には格別のご理解とご支援を頂き厚くお礼申し上げます。

中性子散乱研究者の全国組織である当中性子研究連絡会では、加速器中性子源のパイオニアである我が国が、近年施設規模において欧米の後塵を拝していることを憂い、さらに国際的に急増するニーズに反し減少する中性子源数、いわゆるニュートロン・ギャップを深刻に受け止め、かねてより大強度陽子加速器中性子源の早期実現を要望して参りました。

このような状況のもと、高エネルギー加速器研究機構においては長年にわたり大型ハドロン計画を、日本原子力研究所においては中性子科学研究計画を推進してこられましたが、今年3月に、両研究機関は同計画を統合して推進する旨の覚え書きを交され、まさに我が国の総力を結集してこの計画を推進されることになりました。当中性子研究連絡会は、かくのごとき英断に対し敬意を表するとともに、同計画の一日も早い実現を熱望しております。

同統合計画のうち中性子散乱研究施設は、第1期1MW、第2期5MWの世界最高出力の中性子源を建設する計画であり、国際的な一大研究センターが実現するものと期待しております。同様の計画は、米国のSNS (SpallationNeutronSource) 計画と欧州のESS (EuropeanSpallationSource) 計画がありますが、特に前者については既に今米国会計年度からオークリッジ国立研究所（テネシー州）で建設が開始されました。これらの計画は、いずれも「21世紀に一層の発展が確実視されている物質科学・生命科学の研究にとって、大強度中性子が決定的な役割を果たす」との認識から各国で立案されたものであります。現在我が国は、これら物質科学・生命科学の多くの分野で国際的にリーダーシップを握っておりますが、大強度中性子源の建設が遅れると、これらの分野における優秀な人材の流失やそれにともなう世界第一級の成果の国外への帰属が生じ、科学技術創造立国を目指す我が国にとって、その将来に重大な懸念が生じるものと言えます。

つきましては、諸情勢のたいへん厳しい折とは存じますが、世界を先導する本統合計画の建設が、ぜひとも平成12年度から開始されますよう、一層のご尽力を下さるよう切にお願い申し上げます。

中性子研究連絡会事務局　319-1195 茨城県那珂郡東海村白方白根 2-4
日本原子力研究所東海研究所 大学開放研究室 東京大学物性研究所中性子散乱研究施設内
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中性子研究連絡会
Neutron Scattering Association of Japan

平成１１年6月9日

科学技術庁 原子力局

局長　青 江　茂 殿

文部省 学術国際局

局長　工 藤 智 規 殿

中性子研究連絡会

会長　藤 井 保 彦

（東京大学物性研究所 教授）

大強度陽子加速器統合計画の推進（要望）

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このような状況のもと、日本原子力研究所においては中性子科学研究計画を、高エネルギー加速器研究機構においては長年にわたり大型ハドロン計画を推進してこられましたが、今年３月に、両研究機関は両計画を統合して推進する旨の覚え書きを交され、まさに我が国の総力を結集してこの計画を推進されることになりました。当中性子研究連絡会は、かくのごとき英断に対し敬意を表するとともに、同計画の一日も早い実現を熱望しております。

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中性子研究連絡会
Neutron Scattering Association of Japan

平成１１年６月９日

原子力委員会委員長代理
藤家洋一殿

中性子研究連絡会
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（東京大学物性研究所 教授）

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中性子散乱研究者の全国組織である当中性子研究連絡会では、加速器中性子源のパイオニアである我が国が、近年施設規模において欧米の後塵を拝していることを憂い、さらに国際的に急増するニーズに反し減少する中性子源数、いわゆるニュートロン・ギャップを深刻に受け止め、かねてより大強度陽子加速器中性子源の早期実現を要望して参りました。

このような状況のもと、日本原子力研究所においては中性子科学研究計画を、高エネルギー加速器研究機構においては長年にわたり大型ハドロン計画を推進してこられましたが、今年３月に、両研究機関は両計画を統合して推進する旨の覚え書きを交され、まさに我が国の総力を結集してこの計画を推進されることになりました。当中性子研究連絡会は、かくのごとき英断に対し敬意を表するとともに、同計画の一日も早い実現を熱望しております。

同統合計画のうち中性子散乱研究施設は、第１期１MW、第２期５MWの世界最高出力の中性子源を建設する計画であり、国際的な一大研究センターが実現するものと期待しております。同様の計画は、米国の SNS (SpallationNeutronSource) 計画と欧州の ESS (EuropeanSpallationSource) 計画がありますが、特に前者については既に今米国会計年度からオークリッジ国立研究所（テネシー州）で建設が開始されました。これらの計画は、いずれも「２１世紀に一層の発展が確実視されている物質科学・生命科学の研究にとって、大強度中性子が決定的な役割を果たす」との認識から各国で立案されたものであります。現在我が国は、これら物質科学・生命科学の多くの分野で国際的にリーダーシップを握っておりますが、大強度中性子源の建設が遅れると、これらの分野における優秀な人材の流失やそれにともなう世界第一級の成果の国外への帰属が生じ、科学技術創造立国を目指す我が国にとって、その将来に重大な懸念が生じるものと言えます。

つきましては、諸情勢のたいへん厳しい折とは存じますが、世界を先導する本統合計画の建設が、ぜひとも平成１２年度から開始されますよう、一層のご尽力を下さるよう切にお願い申し上げます。

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1998年10月3日

高エネルギー加速器研究機構長　菅原寛孝殿

中間子科学連絡会　会長　山崎敏光
副会長　秋光　純
副会長　矢嶋祐一

秋深まる折、ますます御清栄のこととお慶び申し上げます。

高エネルギー加速器研究機構の中間子科学研究施設においてミュオン実験のための共同利用が昨年度より順調に運営されていることは、誠に慶賀すべきことと存じます。また機構長におかれましては、従来より M アレナを含む大型ハドロン計画の推進に御尽力頂き、深く感謝しております。

高エネルギー加速器研究機構におけるミュオンビームを用いた科学研究の推進・学術交流・施設利用の円滑化を目的として作られた中間子科学連絡会といたしましては、中間子科学のさらなる発展を期待し切望しております。特に日本国内において、ミュオン実験ができる施設としては貴研究機構の中間子科学研究施設しか存在しない状況であり、20年前に作られたこのミュオンビーム施設に代って大強度のミュオンをつくり出し、ミュオンを用いた物性、核素粒子、原子分子、化学から生命科学の分野に到る広範な学際研究のできる新しい実験施設 M アレナの建設は必要不可欠です。

もし M アレナが直ちに着手されない場合には、現在の研究者の要求を満たすことはもとより、新しい他分野の研究者の参加の道を閉ざすことになり、貴研究機構が目指されている加速器を用いた学際的研究の発展を大きく阻害することになります。従いまして、可能なあらゆる方策をとられまして、大型ハドロン計画の柱の一つである M アレナの建設に早期に着手し、ミュオン科学の将来計画の早期実現を達成して頂けますよう、機構長を始め関係している方々にあらためて御願い申し上げる次第です。

言うまでもありませんが M アレナで展開される研究が多くの分野に亘っていることを考慮致しますと、貴研究機構でみられるような、広範な共同利用実験の体制の確立維持が不可欠であることを申し添えます。

なお 1998 年 9 月 26 日および 10 月 3 日に開かれました、中間子科学連絡会総会（分科会）におきまして、現在急ピッチに検討が進められております文部省と科学技術庁との間の将来の統合を見据えた特別な予算措置に係わる、将来計画に関する討議を致しました際、参加者全員の総意のもとに以下の声明をだすことを決定致しました。宜しく御理解頂けますようお願い申し上げます。

大型ハドロン計画実行委員会で提案されている4条件を基に中間子科学連絡会として次の5項目を要求する。

1．　M アレナを含む JHF 計画の早期実現。
2．　JHF における 4 つのアレナの展開。
3．　国内外に開かれた共同利用体制の実施および十分な技術系職員の配備、宿泊施設の整備等などの研究支援体制の確立。
4．　現在の JHF プロジェクト推進部隊が建設計画のリーダーシップをになう。
5．　実現の暁には人事等を含む運営が機構でなされ、十分な学術的自由が保証される事。

OECD MEGASCIENCE FORUM

Report of the

NEUTRON SOURCES WORKING GROUP

The Neutron Sources Working Group of the OECD's Megascience Forum has proposed a three-tier global strategy for the evolution of neutron facilities for neutron-scattering research. It notes that neutron scattering plays, and will continue to play, a crucial role in an extraordinarily diverse range of basic, strategic and applied research; that there is to be a dramatic, and inevitable, decline in the number of facilities worldwide, which requires urgent government attention; and that considerable benefits can be gained through international co-operation in the provision and utilisation of neutron sources.

Accordingly, the Working Group has proposed the following strategy as a basis for its conclusions and recommendations:

- to maintain, as far as appropriate, existing national sources, noting their importance for maintaining local neutron-scattering infrastructure;
- to maximise the utilisation of current front-rank facilities, noting their potential for refurbishment and up-grading which can lead to substantial increases in performance and efficiency;
- to prepare for provision of next-generation regional sources, noting the long lead times involved and the necessity to ensure that governments are appropriately informed of future proposals.

Contents

Introduction

1. The **Neutron Sources Working Group** was established by the Megascience Forum in January 1996 to consider the future evolution of facilities for neutron scattering research. It has the following aims:

   - to estimate the future level of neutron undersupply, giving consideration both to likely demand, and supply, over a 20-year timescale;

   - to establish what is required to meet the anticipated demands in terms of new and refurbished facilities and instrumentation;

   - to identify technical problems associated with the development or up-grading of new or existing neutron sources and to recommend, where appropriate, co-operative R&D activity to solve these problems.

2. The Working Group consists of some 35 national delegates, comprising both government officials and government-designated scientists, from the following countries:

Australia	Germany	Portugal
Austria	Hungary	Russia
Belgium	Italy	Sweden
Canada	Japan	Switzerland
Denmark	Korea	United Kingdom
France	Netherlands	United States

3. The Working Group has met on four occasions, in Lisbon (May 1996), Interlaken (October 1996), Toronto (August 1997) and Tokyo (April 1998). The Group established individual panels to investigate specific areas of its remit, concerned with (a) the refurbishment and up-grading of existing facilities, (b) international co-operation in the development of neutron instrumentation, and (c) opportunities for international co-operation in the development of new neutron sources. Consultants have been commissioned to conduct a survey of future prospects for neutron scattering facilities (see paragraph 13 below).

4. This report is concerned with facilities for neutron scattering research, and is largely concerned with dedicated high-flux reactor and accelerator-driven (spallation) sources. We recognise that this omits many areas for which neutron sources are of fundamental importance, including radiation damage studies, reactor experiments, neutron nuclear physics, isotope production, activation analysis and others. This omission should not be taken as a judgement on the merits of these fields, but as a response to the mandate of the Megascience Forum itself. In these fields, multipurpose reactors with large irradiation volumes and high neutron flux will continue to play a strong role for the foreseeable future.

Background

5. **Neutron scattering** is a widely-applied tool in condensed matter research, and many reports[1] [9] have detailed the applications of the technique, along with the future opportunities offered with more powerful sources. The introduction to the European Spallation Source report[4] summarises the situation as follows:

"Much of what underpins our present-day quality of life depends upon our understanding, and consequent control, of the behaviour of materials. Ultimately, this behaviour is dictated by their structure and dynamics at the atomic and mesoscopic level and our knowledge of these comes from a wide range of sophisticated scientific techniques.... The neutron is, in many ways, the ideal probe for the investigation of condensed matter, having significant advantages over other forms of radiation in the study of microscopic structures and dynamics.

Neutron scattering has consequently made outstanding contributions to our detailed understanding at a microscopic level of technically important material such as plastics, proteins, polymers, fibres, liquid crystals, ceramics, hard magnets, and superconductors as well as to our understanding of fundamental phenomena such as phase transitions, quantum fluids and spontaneous ordering. The 1994 Nobel Prize in Physics to Brockhouse and Shull for their pioneering efforts in the 1950s was a public acknowledgement of the importance of neutron scattering to the scientific community."

6. The utility of neutron beams arises from the **physical properties of the neutron** itself, ranging from the ability sensitively to observe atomic or molecular magnetism, to the ability to observe the details of atomic and molecular motions in both space and time, to the ability to use atomic isotopic substitution to label particular regions of complex structures. Indeed the importance of neutron scattering as a research technique is emphasised by the breadth and depth of its application to problems in virtually all areas important to a technologically advanced society. But for many advanced applications, the utility of neutron scattering is limited by the intensity available at existing sources.

7. At the present time a **world-wide scientific community** of the order of 6000 scientists uses neutron scattering for research across a wide spectrum of scientific disciplines. This multidisciplinary character of neutron scattering research was recently documented in a survey[6] by the European Neutron Scattering Association which revealed the distribution of neutron users in Europe to be physics 46%, chemistry 27%, materials science 19%, biology 4%, engineering 3% and earth sciences 1%, with a tendency to broaden even further. Another aspect of the neutron scattering community is their prevailing youth. More than half are PhD students and postdoctorals, who in addition to carrying out frontline research are being educated in the international environment of the large neutron establishments thereby preparing them for the challenges of professional activity in an increasingly global scientific and industrial world.

8. A study[3] published by the European Science Foundation and the European Neutron Scattering Association in 1996 (usually referred to as the *Autrans Report*) provided a forward look at the likely development of the demand for neutron scattering. It convincingly demonstrated that research using neutrons can be expected to continue to grow both in traditional fields like solid state physics, materials science and physical chemistry, and also in new and rapidly developing areas for neutron research like biology, engineering and earth sciences. This will involve an increase in the

complexity and sophistication of the scientific work rather than a mere growth in the number of experiments. Entirely new and exciting results can be expected from development of novel measurement techniques and data analysis methods.

9. The Autrans Report concluded that non-neutron tools for matter investigation, such as synchrotron radiation, cannot substitute the future use of neutron beams.[not] Even in the long term, both neutron scattering and synchrotron radiation research will continue to be indispensable, because the two techniques cannot replace each other (nor be replaced by third methods); indeed they complement and extend each other's range and opportunities.

10. The importance of the results obtained using neutron scattering techniques lies not only in their significant - often crucial - contribution to the corpus of scientific knowledge, but equally to their impact on a remarkably wide diversity of technological and industrially important areas. Present and future examples that can be cited include biotechnology, drug design, pharmacology, materials processing, environmental technologies, catalysis, energy storage, new materials, energy transmission, transport, data storage, quantum devices, all covering crucially important aspects of modern civilisation.

11. There are currently about 25 major sources in the world which produce neutron beams for condensed matter research. Though the leading installations are in the large - "megascience" - category, neutron scattering experiments at these centres are typically carried out by small research teams based at universities, research institutes and industrial laboratories, and constitute the kind of research that is generally considered to be "small science". The majority of users require recurrent short-term access to the facilities, often for no more than a few days at a time. The research carried out at these sources contributes to the scientific and technological infrastructure in the regions, and indeed it is this endeavour, rather than the sources themselves, which underpins the industrial competitiveness in the region.

How can the demand for neutrons be met?

12. Most of today's neutron sources are based on **nuclear reactors**; additionally there are a number of **accelerator-based sources** which produce neutrons by the nuclear **spallation** process. Most of the reactor sources were built in the 1950s and 1960s, and will come to the end of their useful lives in the next ten years or so; in fact some time between the years 2010 and 2020 the presently-installed capacity of neutron sources for beam research will decrease to a level below one third of that today.

13. To provide an estimate of the extent of the "neutron gap" - the increasing divergence between neutron demand and neutron supply - the Megascience Forum has commissioned a detailed study by D Richter and T Springer *"A Twenty Years Forward Look at Neutron Scattering Facilities in the OECD Countries and Russia"*.[7] Their report quantifies the decline in existing sources indicated above, and provides a global overview of the planned sources and their impact.

14. Given the long lead time from the conceptual design to the commissioning of a new source - at least 10 years - political decisions on new facilities are necessary in the next few years, and certainly before 2005. Otherwise, vital areas of science and technology

will be deprived of an important and unique research tool. The Working Group has considered three scenarios to face the future demand:

a) No further investment in major new facilities. The inevitable result of such inaction would be the decrease in the number of sources to less than a third of the present worldwide inventory, in the face of increasing demands for higher intensity and higher quality neutron facilities. Refurbishments and upgrades of the best existing facilities could alleviate the situation in the short to medium term, but would not prevent an eventual widening gap between supply and demand. The Working Group believes this is an unacceptable option.

b) A second option might be to build a single, extremely high-power, source to serve worldwide needs at the highest possible intensities, while letting existing sources decline as in option (a). Given the diverse character of the user community and the effects of cross-disciplinary interactions, the societal and industrial impact of the scientific activities at the "super source" would be significantly higher in the host region than in other parts of the world. It could also lead to a situation where the use would be essentially limited to a small elite coterie of scientists. The Working Group does not support this option.

c) A third and preferred option is to adopt a strategy based on a regional provision of sources, where in each significant world region - Europe, North America, the Asia/Pacific area - there would be at least one major next-generation source. Such a strategy would provide access to quality facilities for the vast majority of scientists requiring neutrons for their research. It would support numerous research teams working in a variety of fields and providing a critical research infrastructure throughout the different regions of the world. We note that this strategy is consistent with present plans and proposals to provide new (accelerator-based) sources in Europe, the United States, and Japan, and is the way synchrotron radiation sources are distributed worldwide.

Next-generation sources

15. The next generation of neutron sources will create significant new scientific opportunities - it is not simply a case of compensating for sources that have shut down. Most of the projects under contemplation have incorporated special features that will enhance their performance and potential when compared with present day sources. This means that plans for projects often venture into undeveloped areas of technology which require R&D for proof of concepts, design, testing and validation, as well as prototyping.

The most important class of next-generation sources consists of the accelerator-based spallation facilities, whose increased power will lead to improvements in the quantity and quality of research, and enable expansion into new scientific areas. At present a number of specific projects are in the planning stage: in Europe the European Spallation Source, ESS, and an Austrian proposal, AUSTRON; in North America the Spallation Neutron Source, SNS; and in Japan the Japan Hadron Facility, JHF, and the Neutron Science Research Program, NSRP. However the earliest realistic date that any of these facilities could be operational would be after 2005, with the most significant scientific and technological impacts following a decade or more later. It is because of this long lead-time that plans to fill the intervening gap are crucial to satisfy the scientific need.

How to fill the gap

16. There is certain to be a critical period in the early years of the next century when a majority of today's existing sources have shut down, and before the next generation of new sources are fully in operation. The Working Group has given attention to the problem of filling this "neutron gap". It is believed that the situation can be alleviated by the completion of new facilities that are already under construction, and those that have already been approved, by the up-grading of existing front-rank sources, and by improvements in neutron scattering instrumentation. This strategy will reduce the impact of the neutron gap and at the same time provide the network of well-equipped intermediate sized sources needed to serve national communities as home base for the large class of experiments which do not need the highest flux, and for the development of new techniques.

17. In Europe, the Swiss Spallation Source, SINQ, started operation in 1996, and a new German reactor, FRM-II is under construction with a planned start date in 2001. In addition there are plans to increase the power of the UK's ISIS facility, which could be further augmented with the addition of a second target station. At the ILL and Orphée-LLB reactors, current instrument upgrades promise considerable gains in intensity and efficiency, and there is scope for the installation of new instruments, which will increase the user capacity. In North America there are approved projects under way to enhance substantially the capability of the LANSCE accelerator-based facility, and the HFIR and NIST reactors. There are plans to upgrade the HFBR reactor, and to construct a new research reactor, the IRF, in Canada. In Australia the HIFAR reactor is to be replaced by a research reactor of increased capacity by 2005. In Russia a new small spallation source IN-06 at the Moscow Meson Factory will start in 1998. There are plans to enhance the capability of the IBR-2 pulsed reactor and to complete a new research reactor PIK at St Petersburg. All these projects, coupled with continuing improvements in instrumentation, will provide a network of sources which is part of the scientific and technological infrastructure of the different OECD countries. They will allow a continuous exploitation of neutrons through the critical time of the neutron gap and serve as an integral part of the world's neutron infrastructure once the new next-generation sources are operational.

Scope for international co-operation

18. The necessary R&D to achieve the above aims is costly and often requires access to unique facilities. Sharing of tasks and costs and avoidance of duplication are clear benefits from co-operation. The Working Group is convinced of the value of international co-operation in the provision of new sources, in the up-grading of existing facilities, and in the development of new instrumentation. To this end, formal co-operation networks might be established for each topical area, each being open to participation by institutions that are active in the respective fields.

19. There will be a need to help the formation of such networks and to monitor their progress. It may also be appropriate from time to time to negotiate the incorporation of such networks into existing frameworks for international co-operation. In Europe, in particular, it will be useful to maintain a forum for consultation at governmental level to achieve a proper balance between national and regional priorities in decisions concerning neutron sources. The user communities represented by their regional

organisations should participate in this process. Both of these functions could be taken care of by the OECD Megascience Forum or a similar organ.

20. The proposed co-ordination of effort in the R&D stages would lead to considerable savings in both cost and time, and also offers the possibility of even greater gains in the construction phases. Adoption of standard solutions for all three regional sources would increase the market for global competitive bidding on a range of components, and co-ordinated purchases could enhance this effect. It has been estimated that this could reduce construction costs by at least 10% and R&D costs by as much as 40%. The Working Group has not looked in detail into this perspective, but it could serve as an inspiration for a future phase of the Group's activities.

21. Indicative costs for neutron facilities are as follows:

FACILITY	EXAMPLES	COST
Next-generation spallation sources	ESS, JHF,NSRP,SNS	$1 - 1.5 bn
New reactors, spallation sources	AUSTRON, FRM-II, HIFAR-II, IRF	$200 - 400M
Up-grades to existing sources	ISIS-II, LANSCE	$50 - 200M
Replacement instrument suites	ILL, NIST, etc	$10 - 50 M

23. Topics which require significant levels of R&D, and which could benefit from international collaborative activities, have already been identified in the following areas:
- accelerator technology
- spallation target technology
- research reactor design
- neutron scattering instrumentation

24. In this context, the Working Group has already initiated some preliminary studies, sponsoring two international collaborative activities. In September 1997 it supported a workshop on cold moderators for pulsed neutron sources, which has already led to the formation of an international task group. And it has supported the AGS Spallation Target Experiment at Brookhaven National Laboratory, which is providing fundamental data for the next generation of high-power spallation sources.

Summary: findings and recommendations

25. By the year 2020 more than two-thirds of the world's neutron sources for beam research will have been shut down. Given the long lead time from the conceptual design to the commissioning of a new source (at least 10 years), firm political action to avert the threatened shortage of neutrons is recommended. **Commitments on new facilities are necessary in the next few years, and certainly before the year 2005.** Otherwise, vital areas of science and technology will be deprived of a crucial and unique research tool.

26. The next generation of neutron sources will create significant new scientific and engineering opportunities as well as replace the capacity that will be lost by the shutdown of existing sources over the next twenty years. **The Neutron Sources Working Group recommends a scenario which aims at the construction of advanced neutron sources in each of the three regions Asia/Pacific rim, Europe and North America, to be operational within 20 years, and catering for regional needs in a wide range of scientific and technological applications.** This is consistent with the plans for next generation multi-megawatt spallation sources which are already at advanced stages of planning in Europe, Japan and the USA. The Working Group also recommends that the new advanced sources be supplemented by a network of new and/or upgraded existing sources as required to serve both regional and national science and technology needs. In each case, the justification for the operation of such sources should be on the basis of the excellent science and technology that is being supported, as well as other national goals as appropriate.

27. Steps should be taken to compensate for the potential "neutron gap" in the interim years early in the next century when a majority of today's sources have been shut down and before the new advanced sources are in operation. Although new facilities are currently entering service (SINQ), are under construction (FRM II), or are planned (HIFAR-II and IRF), **urgent attention must be given to refurbishing or up-grading front-line facilities such as ILL and ISIS in Europe, and HFBR, HFIR, LANSCE and NIST in the USA. Consideration should be given to achieving this aim on an international basis.** Coupled with continuing improvements in instrumentation, such projects would compensate in part for the projected decline in available neutron capabilities over the next two decades, and would be the foundation for the network of local sources needed to supplement the major new sources recommended above.

28. The development of the advanced sources as well as the up-grading of existing ones and the continued development of instrumentation requires R&D for proof of concepts, design, testing and validation as well as prototyping. **International collaboration and task-sharing is strongly recommended in order to achieve technical synergy and cost reductions.**

29. **Consideration should be given to the establishment of a global network - a follow-on body to the Neutron Sources Working Group, perhaps, but not necessarily, under the OECD umbrella - in order to achieve the aims of the Working Group.**

References

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3) *Scientific prospects for neutron scattering with present and future sources,* European Science Foundation (May 1996)

4) *ESS A next generation source for Europe* (March 1997)

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6) *The ENSA survey of the European neutron scattering community and European neutron facilities* (December 1997)

7) D Richter and T Springer, *A twenty years forward look at neutron scattering facilities in the OECD countries and Russia,* OECD (to be published)

8) *Report of the Basic Energy Sciences Advisory Committee on neutron source facility upgrades and the technical specifications for the Spallation Neutron Source,* DOE (March 1998)

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The OECD Megascience Forum

Report of the Working Group on Nuclear Physics

January 1999

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996) and the Republic of Korea (12th December 1996). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

An electronic version of the report is available at the OECD's web site: http://www.oecd.org/dsti/sti/s_t/ms/news/cont_e.htm

TABLE OF CONTENTS

FOREWORD

On behalf of the OECD Working Group on Nuclear Physics, I am pleased to put into the hands of the public our report. We present here, for the first time at the world scale, a shared future vision of an optimised ensemble of national and regional facilities for a well co-ordinated advance among the principle sub-fields of nuclear science.

The OECD Megascience Forum decided to create a Working Group on Nuclear Physics in June 1996. Since 1992, the OECD Megascience Forum has been a venue for regular meetings of senior science policy officials of the OECD Member countries. Through its deliberations and the subsidiary activities that it authorises, the Megascience Forum seeks to strengthen international consultation, co-ordination and co-operation in the planning, development and utilisation of programmes and very large research facilities. The Megascience Forum is a deliberative and consultative body. Thus, it does not fund or manage scientific research. Existing co-operative projects may be strengthened (or new ones created) as a result of its work, but negotiations and funding decisions have to take place in an appropriate venue outside the context of the OECD. The Megascience Forum is a subsidiary body of the OECD Committee on Scientific and Technological Policy, to which it regularly submits progress reports.

The role and significance of megascience projects and programmes continues to evolve, based on the changing needs of scientists and of policy makers. Many researchers in fields that were traditionally considered to be "small science" (for example, condensed matter research) are now the primary users of very large facilities (such as neutron sources and synchrotron radiation sources). In public policy, in areas such as health, food production, or environmental protection, there is a growing need for the results of large-scale research (for example, genome mapping projects and Earth-observing systems). Research budgets are under scrutiny in many OECD countries, and governments face the challenge of maintaining strong megascience programmes. Because of the world-wide distribution of resources, information and talent, international consultations by science policy officials are essential for undertaking timely, informed decisions on megascience policy issues.

One of the major topics in deliberations is the extent to which the research projects can and should be pursued as international collaborations, to optimise the use of funds and to avoid unnecessary duplication. The scientific community has already created many formal and informal channels for building international connections. To be successful, however, these efforts must be complemented by equally fruitful interactions among government science policy officials. Failing that, even the most scientifically promising collaborations can fail for a variety of budgetary, political or bureaucratic reasons. International co-operation in science is rarely easy or straightforward, since individual countries (and regional organisations) have created their own structures for setting priorities, schedules, funding and evaluation. These must be harmonised and co-ordinated before joint international efforts can take place.

The Members of the Megascience Forum are the governments of: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. The European Commission participates in the work with the same status as a Member government. Israel, the Russian Federation, and the Slovak Republic have Observer status in the Forum, and can fully participate in its activities. Together, members and observers account for over 90 per cent of global investments in research and development.

In 1995, ministers imposed a set of requirements on its activities:

- Working groups must generate value-added, policy-relevant information that participating governments can use as they develop priorities, plans and funding decisions over medium and long terms.
- Working groups must have a well-defined mandate and finite life-time. Topics for consideration should be proposed and chosen by the Forum members, and each group should be led by a designated country.
- Although the working groups are convened and lead by government officials, they must seek and incorporate input from the scientific community. Scientific issues *per se* should not be debated; ideally, a consensus of scientific opinion should exist before a working group is created and the group's task should be to explore the policy implications of new developments and trends, and prospects for international co-operation.

This report is written to be understandable to everyone who is concerned with long-term priority-setting and funding decisions. It accurately reflects the scientific rationale for the findings and recommendations of our Working Group. We explain the fundamental role of nuclear physics to explore the nature of matter, the structure and history of the Universe. We believe that a programme of sustained and balanced investments in nuclear physics is a natural integral part of an overall programme of basic scientific research and education.

Some of the important fundamental questions addressed today by the scientific community are the following.

- What are the constituents of matter, how do they interact, and how do they form nuclei?
- What are the limits of nuclear stability?
- What happens to matter at extreme pressures and temperatures?
- What is the origin of the chemical elements in the cosmos?

The long-term perspective of this report presents national and regional plans from a global point of view. The development of new facilities is proposed to address questions that cannot be answered by the present generation of facilities. We discuss the growing critical role of large facilities and identify the four types of future facilities that will require international co-operation: radioactive nuclear beams, electron beams, Japan Hadron Facility, ultra relativistic heavy ions.

Nuclear science continues to make important contributions to society via the development of important applications and spin-offs. The Working Group also considered a number of applications of nuclear physics, based on their importance to society. The group believes that they deserve the special attention of policy makers who will be deciding on nuclear physics priorities and investments for the next 10-20 years. Progress in these fields requires the existence of a dynamic nuclear physics community whose primary mission is basic research.

I would like to give the Members of the Megascience Forum special thanks for their interest in the work of this group, for their stimulation and very valuable feedback to the periodic progress reports

All the members of our group are pleased by the importance and the quality of the work achieved together. It was a great experience for me to chair the Working Group on Nuclear Physics. I am most grateful to the delegates and the members of the scientific community who were such a vital part of the work.

Bernard Frois
Chairman of the Working Group on Nuclear Physics

I. SUMMARY

The OECD Megascience Forum established the Working Group on Nuclear Physics in June 1996. Working Group member countries were: France (lead country), Belgium, Canada, Finland, Germany, Greece, Italy, Japan, the Netherlands, Portugal, Russia, Spain, Sweden, Switzerland, the United Kingdom, the United States and the European Commission. Invited participants came from CERN, the OECD Nuclear Energy Agency (NEA), NuPECC (on behalf of the European Commission) and, in selected sub-groups, China, India, the ISTC (Moscow), and the Thomas Jefferson Laboratory (USA).

Europe, Japan and the United States have developed detailed long-range nuclear physics plans, which the Group discussed and compared. From a scientific point of view, an important finding is that there exists world-wide agreement on the directions for future research. The Working Group recognised the need for the following future facilities:

- High-intensity radioactive nuclear beam facilities.
- Intense high-energy continuous electron beam facilities.
- Multi-purpose hadron facilities with a wide variety of secondary particle beams
- Facilities for heavy ion collisions at very high energies.

The Working Group believes that nuclear physics will continue to provide new and important direct benefits for society in the 21st century. The specific topics listed below were examined in detail, and recommendations were developed as follows:

Radioactive Nuclear Beam (RNB) Facilities

1. The Working Group recognises the importance of radioactive nuclear beam facilities for a broad programme of research in fundamental nuclear physics and astrophysics, as well as applications of nuclear science. A new generation of high-intensity RNB facilities of each of the two basic types, ISOL and In-Flight, should be built on a regional basis. Interested governments are encouraged to undertake the necessary decisions within the next few years, and the facilities themselves should become operational in five to ten years.

2. The Working Group recommends the establishment of a contact group consisting of government appointed programme managers and other scientific and technical experts from countries that are actively involved in planning and implementing new (or upgraded) RNB facilities, to provide a venue for accurate and timely exchange of information regarding decisions, priorities, schedules and progress being made in the three major regions of the world.

Electron Facilities

The Working Group found that a consensus exists in the scientific community on the importance of using high-energy continuous electron beams as probes of nuclear and hadronic structures at the level of quarks and gluons.

1. The proposed evolutionary upgrade of CEBAF at the Jefferson Laboratory to 12 GeV by 2005 would give the scientific community the opportunity to enter the high-intensity, high energy domain at a reasonable cost, at the right time.

2. Regarding possibilities for a 25-30 GeV facility, the Working Group recommends that discussions in the scientific community continue, accompanied, as needed, by consultations with national/regional planning and funding bodies. At the appropriate time, consultations should occur to encourage co-ordination and, if appropriate, collaboration to take maximum advantage of international opportunities and resources.

Hadron Facilities

1. The Working Group emphasises the scientific importance of the Japan Hadron Facility (JHF) proposed by the KEK laboratory, which will attract a world-wide scientific community. Interested agencies and laboratories are encouraged to consider forming partnerships for developing instrumentation and detectors to take advantage of the facility.

2. The Working Group welcomes the initiative by the JHF proponents to open it to the international users' community and to stimulate the formation of collaborations for its experimental exploitation in accordance with accepted and applied policies for access to large nuclear physics facilities world-wide.

Heavy Ion Collisions at Brookhaven and CERN

1. Given the challenges and the pre-eminent importance of heavy ion collisions in the pursuit of the ultimate quark matter physics goals, significant benefits would be realised from an enhanced level of international collaboration.

2. The Working Group recommends that scientific and technical groups, in co-ordination with the relevant funding agencies, maintain the productive contacts that began under the aegis of the Working Group. Enhanced co-ordination and collaboration will strengthen the world-wide effort in this field, and, in particular, the collaboration between the RHIC and ALICE communities.

Applications of Nuclear Physics

The Working Group focused on three promising topics: accelerator-driven transmutation of nuclear wastes, medical imaging, and cancer therapy.

In recent years, accelerator-driven transmutation has emerged as a potentially complementary technology for radioactive waste handling, by transmuting the longest-lived radioactive isotopes into short lived or stable ones. This technology could have a significant synergy with other megascience-scale projects, such as neutron sources and high-intensity accelerators.

- The Working Group found that, if called upon, nuclear scientists are willing to contribute to the development of this potential solution to an important problem in many OECD Member countries.

- As research progresses, there is an increasing possibility that important avenues of investigation will remain unexplored, or that unnecessary duplication will occur. To make optimum use of available intellectual and financial resources, it may be necessary to strengthen existing co-operative mechanisms, or to create new ones. In particular, the

Working Group recognised that the OECD Nuclear Energy Agency (NEA) is an existing structure that could be broadened and adapted to play a larger role in co-ordinating international activities. While recognising the diversity of national policies in the area of nuclear waste management, the Working Group encourages interested countries to co-ordinate their efforts.

For cancer therapy, optimised medical synchrotrons for light ion therapy have recently been designed by CERN and GSI. New techniques of more accurate beam delivery and precise control permit the treatment of tumours in critical locations such as the brain or the vicinity of the spinal cord.

Significant progress can be expected in the next few years in the domain of medical imaging in terms of spatial resolution and sensitivity. Novel detection techniques will considerably improve the early detection of tumours.

2. SCOPE AND GOALS OF THE WORKING GROUP

Nuclear physics is the study of the properties of atomic nuclei and the way they are built up from elementary constituents through the action of one of the three currently known fundamental forces of nature - the so-called "strong" force.* The field is linked to other branches of physics, providing a testing ground for new theories, and making valuable contributions to other domains, such as condensed matter physics, cosmology, and astrophysics.

Nuclear physics is pursued in all OECD Member countries (and in many other countries), with a global annual investment of about one billion dollars. Nuclear physics has a major impact on technology and society: energy production, biological research, medical imaging, cancer treatment, semiconductor manufacturing, materials science, food processing, environmental monitoring and protection, preservation of art works, archaeology, and anthropology

As scientists probe ever deeper into the structure of nuclear matter, they require larger and increasingly complex facilities and equipment. In most cases, these are unique, dedicated facilities, distinct from those of other fields such as high-energy physics. The long lead times and considerable resources needed for cutting-edge projects and programmes call for strategic decision making and long-range planning, with careful consideration of the scientific, technological, economic and social benefits of nuclear research. These requirements are especially critical now, when research budgets are under pressure in most countries.

In addition to the ongoing exchanges within the world-wide scientific community, there is a clear need for an informed, constructive interaction between the responsible government officials from countries that wish to maintain vigorous nuclear science programmes. Recognising this need, the OECD Megascience Forum established the Working Group on Nuclear Physics in June 1996.

The goals of the Working Group were:

1. To provide an international forum for government officials (supported, as appropriate, by representations of their scientific communities) to exchange information about priorities, programmes and plans, and to explore opportunities for international collaboration that can

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* Of the other two forces, the "electroweak" interaction does have an effect on the stability of nuclei, while the third fundamental force – gravity – plays no role in nuclear physics

be considered by interested governments in planning their nuclear science investments during the next 10-20 years. The activities of the group were directed towards ensuring a sustained and balanced programme of nuclear physics research, with particular attention to the role of large facilities and programmes that would benefit from international co-operation.

2. To examine the policies and practices that govern access to large facilities by international scientists, and to assess the impact of current and future trends on the users and providers of international facilities.

3. To explore specific opportunities for collaboration in research and development related to nuclear physics facilities, detector systems, and associated technologies.

3. COMPOSITION AND ACTIVITIES OF THE WORKING GROUP

Working Group member countries were: France (lead country), Belgium, Canada, Finland, Germany, Greece, Italy, Japan, the Netherlands, Portugal, Russia, Spain, Sweden, Switzerland, the United Kingdom, the United States and the European Commission. Invited participants came from CERN, the OECD Nuclear Energy Agency (NEA), NuPECC (on behalf of the European Commission) and, in selected sub-groups, China, India, the ISTC (Moscow), and the Thomas Jefferson Laboratory (USA). Thus, the group included all the countries that have a significant activity in nuclear physics.

The Working Group was authorised for a period of two years. Shortly after being established, it convened an organisational meeting to develop its work programme and to elect a chairperson - Dr. Bernard Frois. Six sub-groups were formed, and held meetings as needed. The full Working Group met on five occasions: Paris (November 1996), Vancouver (May 1997), Paris (November 1997), Washington (May 1998), and Paris (November 1998). Contacts were established with the Megascience Forum Working Group on Removing Obstacles to International Megascience Co-operation.

4. GENERAL FINDINGS

The shared future vision that emerged from the deliberations of the Working Group involves an optimised, balanced ensemble of national and regional facilities, taking into account the following factors: a broad, co-ordinated advance among the principle sub-fields of nuclear science, harmonisation with related domains (for example, particle physics, astronomy), development of new facilities in a timely manner to address questions that cannot be answered by the present generation of facilities, replacement of facilities that have become obsolete, avoidance of unnecessary duplication on a global scale, advanced training for a new generation of nuclear physicists, and ensuring that the most outstanding research proposals can be accommodated at the most suitable experimental facilities.

The Working Group believes that nuclear physics research will continue to provide new and important direct benefits for society in the 21st century, with applications in medicine, environmental research, food processing, material science, accelerator technology, fabrication of microchips, biology, oil prospecting, and the development of clean energy technologies.

The members of the Working Group noted the considerable diversity in priority setting and funding mechanisms among the OECD Member countries. Europe, Japan and the United States have developed detailed long-range plans, which the Group discussed and compared. From a scientific point of view, an important finding is that there exists world-wide agreement on the directions for future research in nuclear physics. A remarkable consensus was observed regarding scientific opportunities and the need for the following future facilities:

- High-intensity radioactive nuclear beam facilities.
- Intense high-energy continuous electron beam facilities.
- Multi-purpose hadron facilities with a wide variety of secondary particle beams.
- Facilities for heavy ion collisions at very high energies.

The Working Group discussed the prospects for international co-ordination and co-operation in the planning, design, construction, and utilisation of new facilities. Specific findings and recommendations are enumerated in Section 7 of this report. Although no single research facility was identified that would require international collaboration in its design, construction and funding, many benefits can be expected from global co-ordination and collaboration.

The Working Group noted that international collaboration in nuclear physics has been extremely lively and productive at the scientist-to-scientist level. The scientific community continuously develops new tools for research and, in the next 10-20 years, a new generation of higher performance detectors, accelerators, computers, and theoretical models will be used to generate new insights into fundamental physical processes and a deeper understanding of the basic structure of matter. The Working Group has also observed the increasing scale and complexity of major facilities and instruments. The resulting need to optimise the available time for research at large-scale facilities presents both challenges and opportunities to scientists, programme managers, and facility administrators.

The Working Group found no evidence of significant problems regarding access of scientists to nuclear physics facilities. At existing national facilities, foreign scientists can usually obtain beam time, based on the scientific merit and feasibility of the proposed work, without the requirement to pay for the operating costs of the facility. In general, users contribute to the construction and development of the experimental equipment.

Participation by smaller nations in international projects is most welcome, but efforts should be undertaken by these countries to develop a national home base to train students and technicians. It is desirable that large national facilities promote their programmes among smaller countries at their request, in order to broaden the international participation of students and researchers on a global basis.

5. FUNDAMENTAL SCIENTIFIC ISSUES IN NUCLEAR PHYSICS

The fundamental goal of nuclear physics is to understand the properties of nuclear matter, atomic nuclei and how nuclei are built up from elementary constituents. Nuclear physics involves the study of diverse phenomena at vastly different scales, from the interaction of elementary entities (quarks and gluons) inside nucleons or nuclei, to the formation of elements via nuclear synthesis in stars and supernovae, or the characteristics of hot, dense nuclear matter as it occurred in the early Universe.

The properties of nuclei and nuclear matter are explored by high-precision experiments under a variety of conditions, measuring how nuclei decay, how they transform from one species into another, or how they behave when subject to extreme conditions of pressure, temperature, density, deformation, rotation, etc.

The fundamental challenges of nuclear physics are the following:

- *What are the constituents of matter, how do they interact, and how do they form nuclei?* At the most fundamental level, modern physics describes matter through a theoretical framework called the "Standard Model", which incorporates two basic forces: strong and electroweak. The strong force binds together the fundamental constituents of nuclei -- quarks and gluons. Composite structures of quarks and gluons are called hadrons (for example, protons and neutrons). Electron and hadron beams are used as complementary probes (see Sections 7.2 and 7.3) to unravel the interaction among the constituents and to determine their properties. Although the Standard Model is remarkably successful, it is incomplete, and its application at the nuclear level is extremely difficult. For instance, we do not know how to derive the properties of hadrons from those of quarks and gluons, nor can we solve the nuclear many-body problem and predict the properties of large nuclei, e.g. their shapes and collective motion, from the known interaction of protons and neutrons. These are formidable theoretical problems that may become tractable using high power computers and experimental results from new generations of electron and hadron beam facilities.

- *What are the limits of nuclear stability?* The evolution of the Universe since the first moments of its history has been determined by the aggregation of quarks and gluons to form hadrons and nuclei, and the synthesis of heavier elements through nuclear reactions. The stability of nuclei arises from a delicate balance between the nuclear, electromagnetic and weak forces in the nuclear medium. Some very neutron-rich nuclei have recently been found to have extended distributions of dilute, nearly pure neutron matter which are of much theoretical interest and thus a subject of intense investigation. Direct investigation of nuclear structure far from stability will be made possible through the production of intense beams of rare and short-lived isotopes ("radioactive beams"). There is world-wide interest in the construction of advanced radioactive beam facilities (see Section 7.1).

- *What happens to matter at extreme pressures and temperatures?* Nuclei can be compared to liquid drops of nuclear matter. In the collision between two nuclei at high energy, the pressure and the temperature of nuclear matter is increased. Is there a transition in the nature of nuclear matter? Is there formation of a plasma of elementary constituents in ultra high-energy collisions of heavy nuclei? The manifestation of these phase transitions in strongly interacting systems formed in heavy ion collision experiments will be a subject of intense experimental and theoretical work during the next decade. The liquid-gas phase transition is studied at existing medium-energy facilities. The "deconfinement" transition to a quark-gluon plasma will be investigated at RHIC and LHC (see Section 7.4). The early Universe presumably underwent this phase transition within the first few millionths of a second following the Big Bang. Such critical phenomena might have a bearing on important aspects of cosmology, such as nucleosynthesis, the existence of dark matter and the large-scale structure of the Universe. In astrophysics, the dynamics of supernova explosions and the stability of neutron stars depend on the compressibility and therefore the equation of state of nuclear matter.

- *What is the origin of the chemical elements in the cosmos?* Many elements are formed in explosive stellar environments with reaction paths proceeding via very neutron-rich or, under different circumstances, very proton-rich nuclei. The properties of both pathways are largely unknown. While the approximate paths of element formation inside stars can be outlined by extrapolating theoretical model calculations to unknown nuclear species, there is a critical need for experimental data which could either provide benchmark tests for these theoretical predictions, or which could provide empirical input to numerical reaction simulations. At this time, scientists do not have a clear understanding of the sequence of events which led to the cataclysmic stellar explosions (supernovae) in which most of the chemical elements on Earth were formed.

6. BENEFITS OF NUCLEAR PHYSICS FOR SOCIETY

Nuclear methods are widely used in materials research and manufacturing. Some examples from a long list are: non-destructive testing via computerised tomography or neutron radiography, the production of densely packed microchips by ion implantation, and the sterilisation of heat-sensitive materials by ionising radiation. Materials analysis using nuclear reactions and Rutherford scattering is a major research tool for surface analysis, catalysis, semiconductor manufacturing, archeology, etc. Particle beams from research accelerators are used to analyse the damage to micro-electronic circuits caused by cosmic radiation or natural radioactivity – an issue of increasing importance for further miniaturisation of electronics. The ultra-sensitive technique of accelerator mass spectrometry (AMS) plays an increasing role for environmental research, providing data for the study of climatic change, global air and water circulation patterns, stratospheric ozone depletion, and monitoring of air and water quality. Nuclear technology is indispensable for monitoring existing radioactive waste repositories.

Nuclear fission reactors currently provide about 17 per cent of the world's electricity, thus reducing the release of CO_2 and other pollutants. Nuclear techniques have an impact on other forms of energy production, including the exploration and utilisation of oil reserves. Neutron techniques are routinely used to monitor the chemical composition of coal at mines, coal preparation plants, and the determination of the sulphur, water, ash, and energy content of coal. In the long run, thermonuclear fusion still holds out the promise of a virtually inexhaustible supply of clean energy, and is an area of very active research and development.*

Nuclear techniques are of special interest in medicine and biology. Radioactive isotopes produced by accelerators or nuclear reactors are widely used for treatment and diagnosis, and in biomedical research.

Training in nuclear physics is of major importance in a significant number of scientific and engineering disciplines, but it is of value to non-scientists as well. An understanding of basic nuclear physics concepts in relation to the world around us helps prepare citizens to participate in critical discussions in areas such as energy policy, environmental protection, and national security.

The Working Group deliberated on applications of nuclear physics and the impact of international collaboration. Most applications are developed by industry and private companies, but the Working Group found that some larger and more far-reaching technologies might benefit from co-ordination of the nuclear physics aspects at the international level. The Working Group focused on three potentially promising topics, as described in Section 8 of this report: accelerator-driven transmutation of nuclear wastes, medical imaging, and cancer therapy.

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* This topic was not part of the Working Group's mandate.

7. FUTURE FACILITIES FOR NUCLEAR PHYSICS

7.1 Radioactive Nuclear Beams (RNB)

Background

To construct the theory of nuclear structure, scientists need to study the properties of a wide variety of nuclei, not just those that exist in stable form in our surroundings (these "ordinary" nuclei constitute only about 10 per cent of all possible nuclei). Exotic nuclei (those with a very large number of nucleons, or an unusual ratio of protons to neutrons) can be created through collisions of energetic beams of ordinary, stable nuclei with other nuclei in a stationary target. The resulting exotic species that are emitted from the target (and which are then studied with a wide range of instruments) are typically unstable and very short-lived (radioactive). In addition to being a tool for the investigation of fundamental nuclear interactions, radioactive nuclear beams provide a way to investigate advanced topics in astrophysics (supernova explosions, novae, x-ray bursters, neutron stars, and perhaps even the spectacular gamma-ray bursters which may be the most violent, energetic phenomena since the Big Bang) and elementary particle physics (where stringent tests can be performed of Standard Model predictions at low energies).

There are two categories of RNB facilities, referred to as "ISOL" *(Isotope Separation On-Line)* and "In-Flight". They differ in the configuration of accelerators, target stations, and the nature of the projectile and target nuclei. The two techniques are complementary: ISOL facilities produce low-energy beams of very high quality, whereas In-Flight facilities are optimal for the study of very short-lived nuclei at higher energies. Both types of installations are operating or under construction in the three regions of the world where nuclear physics is most actively pursued: Europe, Asia/Pacific and North America.

Findings

Many current RNB facilities will reach the limits of their scientific utility in a few years. Several studies of the projected needs of nuclear physics have made a strong science based case for a next generation of facilities. Planning for these is already under way, and some facilities are already approved or under construction. They, and their associated experimental equipment, will be larger, more costly, and their development will present a number of difficult technological challenges. In one important way, however, they will not differ from current facilities: they will be used by a world-wide community of ~2 000 researchers, working as members of medium-sized scientific teams, each performing experiments over a period of weeks or months. Hence, it is appropriate that the facilities be implemented on a regional basis, i.e. the Working Group found that one or two major facilities would not serve the needs of the entire international nuclear physics community.

The Working Group has identified the following crucial technological challenges for next-generation RNB facilities. They should be addressed in a co-ordinated way by the international community.

a) High-power targets and high-intensity ion sources for ISOL facilities. Compared with present targets, the new ones will have to withstand orders-of-magnitude higher power densities.

b) High intensity heavy ion accelerators for the In-Flight production method, also, targets that can withstand high beam power densities, and the development of fast beam cooling and storage techniques.

c) Multi-beam devices that allow an efficient separation and distribution of beams of different isotopes among parallel experiments.

d) High-resolution, high-efficiency detectors of gamma-rays, neutrons and charged particles. High performance traps, spectrographs, and other equipment for storage ring experiments

Recommendations

1. The Working Group recognises the importance of radioactive nuclear beam (RNB) facilities for a broad programme of research in fundamental nuclear physics and astrophysics, as well as applications of nuclear science. A new generation of high-intensity RNB facilities of each of the two basic types, ISOL and In-Flight, should be built on a regional basis. Interested governments are encouraged to undertake the necessary decisions within the next few years, and the facilities themselves should become operational in five to ten years.

2. The Working Group recommends the establishment of a contact group consisting of government appointed programme managers and other scientific and technical experts from countries that are actively involved in planning and implementing new (or upgraded) RNB facilities, to provide a venue for accurate and timely exchange of information regarding decisions, priorities, schedules and progress being made in the three major regions of the world. The deliberations could be instrumental in identifying, at an early stage, attractive opportunities and partnerships for international co-operation, and in facilitating collaboration at the world level on research and development on the crucial technical challenges a) to d) above.

7.2 High-energy Electron Facilities

Background

High-energy electron beams provide a unique probe of nuclear structure and the interactions between nuclear constituents. By varying the energy of the incident electrons (and other experimental parameters) and by analysing the products of the interactions, physicists can study a wide range of properties of the nuclei themselves, of the arrangements of their constituent strongly-interacting subnuclear particles (hadrons) and ultimately, of the elementary quarks and gluons. By studying nuclear matter at high resolution and at different levels of aggregation, electron scattering explores the interface between particle and nuclear physics. The description of nuclear matter in terms of quarks and gluons is successful at very short distances and very high energies, but nuclear scientists want to know how the fundamental constituents combine to form nucleons and nuclei

Findings

A highly active community of more than 1 200 scientists is currently performing electron-nucleus scattering experiments at facilities around the world. By 2005, most of the existing facilities will have completed their experimental programmes, leaving important questions about the structure of matter at short distances unanswered. Scientists have determined the desirable parameters of future facilities and instruments. Such facilities would serve to illuminate the dynamics of quark confinement in nuclear matter. The scientific case for accelerators operating in the 10-30 GeV range has been extensively studied in recent years. A desirable electron beam energy would be such as to probe distances (approximately 1/50 of the nucleon size) where the relevant building blocks are the quarks and gluons. The beam must be continuous (not pulsed) and of high intensity (tens of microamperes), to permit the coincident measurement of particles emitted in reactions that have very small probabilities. A series of workshops and conferences has been conducted in Europe, focusing on a future facility named ELFE (Electron Laboratory for Europe). In the United States, discussions have centred on upgrading the capabilities of the Jefferson Laboratory.

The following ELFE options are currently being studied in detail:

- At the DESY laboratory in Hamburg, the 27 GeV pulsed injector of the proposed linear collider TESLA could be used with the existing HERA ring (operating in a "pulse stretcher" mode) to obtain an extracted continuous electron beam with a maximum intensity of 30μA.

- The existing superconducting radio frequency cavities from CERN's LEP accelerator (which will be removed to make way for the Large Hadron Collider) could be utilised in the construction of a new 3.5 GeV linac which could provide a continuous 150 microampere beam at 25 GeV by means of multiple re-circulations of the electrons through the cavities.

The possibility of injecting heavy ions into HERA has also been discussed as a way to create electron-nucleus collisions at even smaller distances, where the gluon density is expected to strongly increase, leading to an onset of non linear effects which mark the boundary of a completely new regime of strong interaction physics.

In the United States, an evolutionary upgrade of the CEBAF accelerator at the Jefferson Laboratory is being considered, based on the availability of space in the existing linac areas, the advantageous physical layout of its magnetic arcs, and the proven performance of the superconducting radiofrequency cavities. A possible strategy is to increase the nominal beam energy to 12 GeV (from the current 5 GeV) in the first stage, and later to double the energy to 24 GeV. The first step would require relatively minor changes, and is envisaged for the years 2003-2005.

The Working Group found that a consensus exists in the world-wide scientific community of the importance and the fundamental interest of using continuous electron beams as probes of nuclear and hadronic structure at the level of quarks and gluons. During the future evolution of the field, there will be significant new opportunities for international co-operation

Recommendations

1. The proposed evolutionary upgrade of CEBAF at the Jefferson Laboratory to 12 GeV by 2005 would give the scientific community the opportunity to enter the high-intensity, high-energy domain at a reasonable cost, at the right time.

2. Regarding possibilities for a 25-30 GeV facility, the Working Group recommends that discussions in the scientific community continue, accompanied, as needed, by consultations with national/regional planning and funding bodies. At the appropriate time, consultations should occur to encourage co-ordination and, if appropriate, collaboration to take maximum advantage of international opportunities and resources

7.3 MULTI-purpose Hadron Facilities

Background

A rich and varied part of the nuclear physics scientific programme is best carried out with particle beams at multi-purpose hadron accelerator facilities which produce high quality, high-intensity secondary beams of kaons, pions, muons, neutrinos, neutrons and antiprotons. A broad range of topics can be addressed at these facilities, including fundamental symmetries, nuclear and particle spectroscopy, quantum chromodynamic (QCD) studies in the perturbative and non-perturbative regimes, as well as studies of the role of confinement and that of chiral symmetries. The availability of this large variety of secondary beams also provides unique opportunities for the development of applications such as materials science and energy research.

Findings

Vigorous research programmes using hadron beams are being pursued in several laboratories around the world. As existing programmes come to an end, the world-wide scientific community will shift its activities to a major new facility: the Japan Hadron Facility (JHF) which will be built in Japan on the initiative of the KEK laboratory in Tsukuba, producing intense high-quality beams based on a new high-intensity 50 GeV proton synchrotron. However, the Working Group found that the termination of operations of the existing hadron facilities (most notably, the AGS at the Brookhaven National Laboratory, which, at this time, features the most intense beams of kaons and other particles) prior to the beginning of operations at JHF, will have a negative impact on nuclear physics research.

Among the specific research topics that currently generate very high levels of interest among nuclear physicists are: a) hyperon-nucleon interactions and hypernuclear physics, b) hadron properties and interactions in nuclear matter, c) antiproton physics, d) light and heavy quark spectroscopy, e) kaon decays and other processes to measure CP parameters, f) flavour mixing and other topics beyond the Standard Model, g) accelerator-based neutrino oscillation experiments, h) other topics in hadron physics (hadron spectroscopy, physics with polarised protons, physics with heavy ion beams, etc.), and i) other specific experiments in fundamental symmetries (neutron dipole moment, g-2, etc.).

The JHF will become the premier facility of its type, and will attract nuclear physicists from all over the world. At a recent JHF Workshop (co sponsored by the Working Group) at KEK in Japan with over 400 attendants, the subatomic physics community established that the physics with secondary beams is of paramount importance for a continued advance in understanding the fundamental interactions in nuclear and particle physics.

Recommendations

1. The Working Group recognises and emphasises the scientific importance of the Japan Hadron Facility (JHF) proposed by the KEK laboratory. This facility would attract the scientific community active in the above fields world wide. Interested agencies and laboratories are encouraged to consider forming partnerships for developing instrumentation and detectors to take advantage of the facility.

2. The Working Group welcomes the initiative by the JHF proponents to open it to the international user community and to stimulate the formation of collaborations for its experimental exploitation in accordance with accepted and applied policies for access to large nuclear physics facilities world-wide.

7.4 *High-energy Heavy Ion Collisions*

Background

A very powerful technique in nuclear physics involves generating head-on collisions of nuclei that have been accelerated to very high energies. Detailed analysis of the products of the collisions provides unique insights into the behaviour of strongly interacting matter (that is, nucleons and mesons and, eventually, their constituent quarks and gluons) at extreme energy densities. Of particular interest is the prediction of quantum chromodynamics (QCD) that, under these conditions, nuclear matter should undergo a phase transition to an entirely new state, the "quark-gluon plasma", in which the recognisable components are not the familiar nucleons and mesons, but the elementary quarks and gluons themselves. Most physicists believe that all of the matter in the entire Universe existed in a similar high-temperature, high-density state a few microseconds after the Big Bang. The Universe's subsequent transition to a cooler, less-dense state is thought to be the last of a sequence of fundamental transitions involving the most elementary natural forces, creating the matter that we observe today. Thus, the study of the behaviour of quarks and gluons under these primordial conditions is sure to provide exciting new insights into the structure and history of the Universe.

Creating nuclear collisions is highly challenging technologically, since it involves the concentration, focusing and steering of beams of ionised atoms (i.e. essentially, nuclei) as they circulate in large, high-power accelerators at nearly the speed of light. Historically, this field has involved large-scale experiments at some of the world's major accelerator laboratories. A long tradition of world-wide co-operation has been of paramount importance, through collaborative experiments at the Berkeley Bevalac, Brookhaven AGS, and CERN SPS. Over the past twenty years, the international community of scientists in this field has grown to ~2 500 members, representing over thirty countries.

Findings

The next round of experiments will be carried out at two facilities. In 1999, the experimental programme at the new RHIC accelerator at Brookhaven will begin, dedicated entirely to heavy ion collisons using four detectors. Beginning in 2005, part of the experimental programme of the CERN Large Hadron Collider (LHC) will be devoted to the study of nuclear collisions in the special-purpose ALICE detector, at energies some thirty times higher than RHIC. (Most of LHC operations will involve proton/proton collisions.)

The scale of these new collider experiments in cost, manpower, and the time required for design and execution is significantly bigger than has been experienced previously in the heavy ion community, or, for that matter anywhere in nuclear physics. While all of these experiments involve large international collaborations, it has been found that the degree of collaboration between the RHIC and ALICE communities has not reached levels achieved in the past, and may be insufficient to take full advantage, on a global level, of the opportunities offered by the new facilities.

Given the many common challenges in detector technology facing the builders of the RHIC and ALICE experiments, and the pre-eminent importance of the two collider programmes in the pursuit of the ultimate quark matter physics goals, significant benefits would be realised from an enhanced level of collaboration among the two communities.

Recent discussions under the aegis of the OECD Working Group resulted in a better mutual understanding of the planning processes in the different regions, and the identification of specific opportunities for scientific and technological co-operation between the US and CERN programmes. Each collaboration outlined areas where stronger co-operation could be useful for enhancing the capability and future performance of the RHIC detectors, and for optimising the ALICE detector by utilising experience gained at Brookhaven. Co-operation in the development of new detector technologies of mutual interest for the two collider facilities was also explored. Following these discussions, a number of European initiatives for collaboration at RHIC have made significant advances, and US and Japanese groups have identified opportunities and expressed a general interest in future participation in ALICE.

Recommendation

The Working Group recommends that scientific and technical groups, in co-ordination with the relevant funding agencies, maintain the productive contacts that began under the aegis of the Working Group. Enhanced co-ordination and collaboration will strengthen the world-wide effort in this field, and, in particular, the collaboration between the RHIC and ALICE communities.

8. SELECTED APPLICATIONS OF NUCLEAR PHYSICS

The Working Group considered a number of applications of nuclear physics, based on their importance to society. The following three topics were selected for detailed discussion. The Group believes that they deserve the special attention of policy makers who will be deciding on nuclear physics priorities and investments for the next 10-20 years.

Progress in these fields requires the existence of a dynamic nuclear physics community whose primary mission is basic research. Nuclear science continues to make important contributions to society via the development of important applications and spin-offs

8.1 Accelerator-Driven Systems (ADS) for Nuclear Waste Transmutation

In recent years, the accelerator-driven transmutation of nuclear wastes has emerged as a potentially complementary technology for radioactive waste handling, by transmuting the longest-lived radioactive isotopes into short-lived or stable ones. This technology could have a significant synergy with other megascience-scale projects like neutron sources and high-intensity accelerators.

Findings

A distinguishing feature of ADS is the strong coupling between scientific/technological issues and public policy regarding nuclear power, nuclear waste management, environmental safety, national security, and related concerns in which public opinion also plays a major role. Accordingly, science policy decisions in this area are particularly sensitive and difficult. The diversity of the political and social environments in OECD countries is reflected in the varying degrees of financial support for R&D in this area. In some countries, formal government-sponsored programmes are under way, whereas in others the work is pursued at a much more modest level, based on the discretionary authority of laboratory managers and individual academic researchers. Despite this diversity, there is considerable agreement on the short- and medium-term goals of the research. This is in itself remarkable, since the study of ADS is inherently multidisciplinary, involving for the nuclear physics community elements of basic and applied research in the following areas:

- The fundamental nuclear physics of transmutation
- The spallation process for neutron production, including high-power target technology
- The design and operation of high intensity, high reliability accelerators.

The Working Group found that, if called upon, nuclear scientists are willing to contribute to the development of this potential solution to an important problem in many OECD Member countries.

International co-operation and consultations are proven tools for advancing scientific and technological understanding of ADS, and contacts are frequent at the scientist-to-scientist level. Several conferences and workshops have already been held. There are also mechanisms for exchange of experimental results and compilation of data in international bodies such as the OECD Nuclear Energy Agency (NEA) and the UN International Atomic Energy Agency (IAEA). Formal agreements exist among several research institutions in Europe, North America and Asia.

It is the consensus view of the participants to the ADS sub group that the full potential of international co-operation and co-ordination has not yet been achieved among those countries that are interested in this technology.

Recommendation

As research progresses, there is an increasing possibility that important avenues of investigation will remain unexplored, or that unnecessary duplication will occur. To make optimum use of available intellectual and financial resources, it may be necessary to strengthen existing co-operative mechanisms, or to create new ones. In particular, the Working Group recognised that the OECD Nuclear Energy Agency (NEA) is an existing structure that could be broadened and adapted to play a larger role in co-ordinating international activities. While recognising the diversity of national policies in the area of nuclear waste management, the Working Group encourages interested countries to co ordinate their efforts.

8.2 Cancer Therapy with Nuclear Beams

Background

The goal of radiation therapy is to maximise the tumour dose without harming surrounding healthy tissues. The use of heavy particles in radiotherapy is motivated by a superior accuracy in the spacial dose distribution in the human body for deep-seated tumours compared to photons and electrons, and an inverse dose profile depositing the highest dose at the end of the particle range in the tumour volume.

Ions have a well-defined range in tissue with a small lateral scattering and a maximum dose deposition at the end of the track. By varying the energy during the irradiation in a well-controlled manner, one can exactly cover the volume to be treated. To allow full flexibility in patient treatment, the accelerator should be coupled to an isocentric beam delivery system called a "gantry". At present, proton therapy centres are located in the United States, Russia, Europe, Japan and South Africa.

Findings

Most of the clinical experience has been obtained at nuclear physics institutions that have devoted part of the accelerator time – mainly cyclotrons – to medical use. In the next ten years, more hospital based facilities are needed, as exemplified by the creation of Loma Linda (USA), Chiba (Japan), NPTC (USA) centres and the new projects in Austria, France, Germany, Italy, and Japan. In these centres, the main accelerators are cyclotrons, delivering proton beams of 70 to 230 MeV and synchrotrons, accelerating other light ions (carbon, in particular), up to 400 MeV/u. For proton therapy, the needed accelerators are, at present, industrial products, while optimised medical synchrotrons for light ion therapy have recently been designed by CERN and GSI. Because all therapy facilities in operation use passive beam shaping methods (with both absorbers and apertures), the optimal dose profiles are not transferred into clinical routine. To improve these systems, active beam delivery systems using magnetic beam deflection and energy variation by the accelerator have recently been developed, and have been put into operation at PSI (Switzerland) for protons, and at GSI (Germany) for carbon beams.

Fast position monitors developed in the course of basic nuclear research are now routinely used as control systems in hadron therapy. Recently, GSI researchers have shown that, using positron emission tomography (PET), the small amounts of positron-emitting isotopes created by the carbon beam can be used to determine the exact beam location inside the patient's body.

The new techniques of more accurate beam delivery and precise control permit the treatment of tumours in critical locations such as the brain, or the vicinity of the spinal cord.

8.3 *Medical Imaging*

Standard nuclear medicine instruments such as gamma cameras, Single Photon Emission Computed Tomography (SPECT) scanners, PET, and MRI provide basic tools for detection, diagnosis and post-treatment follow-up of cancer. While providing powerful diagnostic adjunct tools to X-ray radiography or Computed Tomography (CT) scans, these large and heavy instruments are not well adapted to such important tasks as detection of breast and prostate cancers, or to assist surgeons directly in the operation room in cancer removal operations.

Significant progress can be expected in the next few years in the domain of medical imaging in terms of spatial resolution and sensitivity. Novel detection techniques involving new crystal scintillators and photodetectors and new solid-state sensors, originally developed for applications in nuclear and particle physics experiments, can now be adapted to medical imaging. Compact and powerful dedicated digital dual-modality imagers can be envisaged, directly combining (co-registering) structural information (such as is offered by digital mammography) with metabolic functional information (such as obtained from scintimammography or Position Emission Mammography PEM) to provide a unique diagnostic tool to the radiologist.

Large international instrumentation conferences organised by the scientific community show ever-growing interest of the instrumentation community in the medical application effort. However, this effort is still fragmented and lacks co-operation at the international level. Examples of activities that can immediately profit from research co-ordination at a global level are breast imaging (digital mammography and gamma imaging - scintimammography and dedicated PET instruments for breast imaging), improved intra-operative gamma and beta (positron) probes, and functional small animal imaging (single gamma and PET) for cancer research on small animals.

The medical imaging field is an example of a unique situation where a relatively small investment by the nuclear physics community can potentially produce an immense result in the form of improved cancer diagnostics and so be of great value to all society.

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