WISSENSCHAFTSRAT

Stellungnahme zu zwei Großgeräten der naturwissenschaftlichen Grundlagenforschung: Freie-Elektronen-Laser für weiche Röntgenstrahlung (BESSY FEL) und eisbrechendes Forschungsbohrschiff (AURORA BOREALIS)

GESCHÄFTSSTELLE

Drs. 7269/06
Nürnberg, 19.5.2006

Stellungnahme zu zwei Großgeräten der naturwissenschaftlichen Grundlagenforschung: Freie-Elektronen-Laser für weiche Röntgenstrahlung (BESSY FEL) und eisbrechendes Forschungsbohrschiff (AURORA BOREALIS)

Inhalt | Seite

Vorbemerkung

Das Bundesministerium für Bildung und Forschung (BMBF) hatte den Wissenschaftsrat im Jahr 2000 gebeten, zur Fortentwicklung und künftigen Struktur der Großgeräte der naturwissenschaftlichen Grundlagenforschung Stellung zu nehmen. Der Wissenschaftsrat hat am 12. Juli 2002 zu neun Großgeräten Empfehlungen ausgesprochen und diese mit weitergehenden Empfehlungen am 15. November 2002 verabschiedet.

Das Land Berlin hat mit Schreiben vom 7. Juli 2004 den Wissenschaftsrat gebeten, das Projekt eines Freie–Elektronen-Lasers für weiche Röntgenstrahlung (Soft X-ray FEL) der BESSY (Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung mbH) in Berlin erneut zu begutachten. Das Land Bremen hat eine entsprechende Bitte am 14. Januar 2005 bezüglich der Planungen des Alfred-Wegener-Instituts (AWI) für ein eisbrechendes Forschungsbohrschiff AURORA BOREALIS an den Wissenschaftsrat gerichtet. Da in beiden Fällen die Voraussetzungen für die Wiederaufnahme des Verfahrens gegeben sind[1], hat der Wissenschaftsrat die Arbeitsgruppe „Großgeräte der naturwissenschaftlichen Grundlagenforschung“ erneut mit dieser Aufgabe betraut.

Die Arbeitsgruppe hat im Januar 2005 ihre Arbeit wieder aufgenommen. Ihr gehören Wissenschaftler aus Universitäten und außeruniversitären Einrichtungen aus Deutschland und den Vereinigten Staaten sowie Angehörige und Vertreter der nationalen Wissenschaftsverwaltung an. Die Arbeitsgruppe hat die fachliche Einzelbegutachtung der Großgeräteinitiativen an international besetzte Unterarbeitsgruppen delegiert, an denen 15 externe Sachverständige teilnahmen.[2] Die Unterarbeitsgruppen haben im Juli 2005 die Einrichtungen besucht. Auf der Grundlage der fachlichen Einzelbegutachtung hat die Arbeitsgruppe die wissenschaftspolitische Bewertung vorbereitet (Näheres zum Verfahren vgl. A.I.).

Die Stellungnahme ist in vier Teile gegliedert. In einer Kurzfassung werden zunächst die Ergebnisse des Begutachtungsprozesses zusammengefasst. In der dann folgenden Ausgangslage (Teil A) werden die methodischen und inhaltlichen Grundlagen des zweistufigen Bewertungsprozesses sowie die fachlichen Zusammenhänge der bewerteten Großgeräte erläutert. In Teil B formuliert der Wissenschaftsrat ein abschließendes wis-

---

1 Beide Institutionen konnten ein ausgearbeitetes Forschungsprogramm sowie eine technische Machbarkeitsstudie vorlegen, die auf einer belastbaren Kostenschätzung beruht.

2 Von den 15 externen Sachverständigen, die nicht Mitglied des Wissenschaftsrates sind, kamen fünf aus Großbritannien, vier aus den Vereinigten Staaten von Amerika, drei aus Schweden sowie jeweils ein Gutachter aus Frankreich, der Schweiz und den Niederlanden.

senschaftspolitisches Votum zu beiden Initiativen sowie Empfehlungen zu weiteren Begutachtungsverfahren von Großgeräten. Teil C enthält die unveränderten fachwissenschaftlichen Bewertungsberichte der Unterarbeitsgruppen zu den einzelnen Großgeräten. Sie werden in der von den Unterarbeitsgruppen verabschiedeten englischen Originalfassung veröffentlicht.

Den Mitgliedern der Arbeitsgruppe und der Unterarbeitsgruppen, die nicht Mitglieder des Wissenschaftsrates sind, ist der Wissenschaftsrat zu besonderem Dank verpflichtet. Dank gilt auch den federführenden und kooperierenden Institutionen, welche die Planungen für die beiden Initiativen sowie das umfangreiche Material für die Begutachtung vorbereitet haben. Zugleich möchte der Wissenschaftsrat der BESSY und dem Alfred-Wegener-Institut für die freundliche Aufnahme sowie für die konstruktiven Gespräche während des Besuchs und im Anschluss daran danken.

Der Wissenschaftsrat hat die Stellungnahme am 19. Mai 2006 verabschiedet.

Kurzfassung

In einem zweistufigen Verfahren hat der Wissenschaftsrat das Projekt eines Freie-Elektronen-Lasers für weiche Röntgenstrahlung der BESSY in Berlin sowie das Vorhaben eines eisbrechenden Forschungsbohrschiff AURORA BOREALIS vom Alfred-Wegener-Institut in Bremerhaven auf Bitten der jeweiligen Sitzländer begutachtet. Zunächst haben international zusammengesetzte Unterarbeitsgruppen die Projekte unter fachwissenschaftlichen Kriterien bewertet. Aufbauend auf den im Bewertungsbericht zusammengefassten Ergebnissen wurde eine wissenschaftspolitische Stellungnahme formuliert.

Bei seiner abschließenden Empfehlung hat der Wissenschaftsrat auf die in seiner „Stellungnahme zu neun Großgeräten der naturwissenschaftlichen Grundlagenforschung“ [3] erarbeiteten drei Empfehlungskategorien zurückgegriffen:

1. Großgeräte, die ohne Auflagen zur Förderung empfohlen werden.
2. Großgeräte, die mit Auflagen zur Förderung empfohlen werden.
3. Großgeräte, zu denen der Wissenschaftsrat auf Basis der vorhandenen Projektvorschläge keine Förderempfehlungen aussprechen kann.

Sowohl das Projekt eines Freie-Elektronen-Lasers der BESSY als auch das eines eisbrechenden Forschungsbohrschiffs AURORA BOREALIS wurden 2002 im ersten Begutachtungsverfahren in die Empfehlungskategorie III eingeordnet. [4] Für Großgeräte dieser Kategorie wurde die Möglichkeit eröffnet, dass der Wissenschaftsrat unter der Voraussetzung, dass ein ausgearbeitetes Forschungsprogramm (scientific programme) und ein ausgereifter technischer Projektvorschlag (technical design report) mit einer belastbaren Kostenschätzung vorliegen, erneut Stellung nimmt. Das Ergebnis dieser erneuten Prüfung ist, dass der Wissenschaftsrat beide Projekte der Empfehlungskategorie II zuordnet. In beiden Fällen sind noch Fragen offen, deren Klärung der Wissenschaftsrat zur Auflage einer uneingeschränkten Förderempfehlung macht.

Im Einzelnen empfiehlt der Wissenschaftsrat für den Freie-Elektronen-Laser der BESSY die Förderung einer neu ausgerichteten Forschungs- und Entwicklungsphase. Erst im Anschluss an diese mehrjährige FuE-Phase, fokussiert auf die Entwicklung des innova-

[3] Vgl. Wissenschaftsrat: Stellungnahmen zu neun Großgeräten der naturwissenschaftlichen Grundlagenforschung und zur Weiterentwicklung der Investitionsplanungen von Großgeräten, Köln 2003.
[4] Vgl. die tabellarische Übersicht in Anhang 2.

tiven HGHG-Prinzips, kann über die mögliche Realisierung eines solchen Lasers und über die Standortfrage abschließend beraten werden. Der Wissenschaftsrat bietet an, diesen Prozess weiter zu begleiten.

Für das AURORA BOREALIS-Projekt empfiehlt der Wissenschaftsrat, die zur Klärung der offenen technischen Fragen (insbesondere zum dynamischen Positionierungssystem) erforderlichen 6 Mio. Euro an FuE-Kosten sofort bereit zu stellen. Anschließend sollte das BMBF seine Bereitschaft zur mindestens 30%igen Übernahme der Baukosten erklären, um in europäische und internationale Verhandlungen über eine angemessene Beteiligung anderer Länder an den Bau- und an den Betriebskosten des eisbrechenden Forschungsbohrschiffes einzutreten. Nach Klärung dieser offenen Fragen empfiehlt der Wissenschaftsrat den Bau von AURORA BOREALIS unter deutscher Federführung.

Abschließend unterstreicht der Wissenschaftsrat die Notwendigkeit, die Schaffung neuer Forschungsinfrastrukturen, den Ausbau und die Weiterführung solcher Strukturen aus einer übergeordneten wissenschaftspolitischen Perspektive zu begutachten. Er betont, dass es sich dabei nicht länger allein um Großgeräte der naturwissenschaftlichen Grundlagenforschung handelt. Es sollten vielmehr alle Disziplinen, auch die Sozial- und Geisteswissenschaften, in Zukunft berücksichtigt werden (z.B. beim Aufbau von Wissensressourcen wie Datensammlungen und Archiven). Daher sollte der Begriff des Großgeräts durch den umfassenderen der Forschungsinfrastruktur ersetzt werden. Forschungsinfrastrukturprojekte, deren Investition die begutachtungsrelevante Schwelle von in der Regel 50 Mio. Euro überschreiten, sollten in einem zweistufigen Verfahren fachwissenschaftlich und wissenschaftspolitisch begutachtet werden.

Der Wissenschaftsrat unterstützt die strategische Investitionsplanung auf europäischer Ebene und spricht sich für eine aktive Beteiligung Deutschlands an diesem Prozess der Gestaltung des Europäischen Forschungsraums aus. Bei der Vertretung der Interessen Deutschlands auf europäischer Ebene muss die notwendige wissenschaftliche Kompetenz einbezogen werden.

A. Ausgangslage

Die vorliegende Stellungnahme beruht auf den Grundsätzen zum Verfahren und zur inhaltlichen Bewertung, die der Wissenschaftsrat in seinen „Stellungnahmen zu neun Großgeräten der naturwissenschaftlichen Grundlagenforschung und zur Weiterentwicklung der Investitionsplanung von Großgeräten“ aus dem Jahr 2002 erarbeitet hat.

A.I. Zum Verfahren der fachlichen Begutachtung und wissenschaftspolitischen Bewertung von Großgeräten

Die Begutachtung von Großgeräteinvestitionen seitens des Wissenschaftsrates beruht auf drei Säulen:

1. auf den allgemeinen Leitlinien, die der Wissenschaftsrat in 10 „Thesen zur Bedeutung von Großgeräten für die naturwissenschaftliche Grundlagenforschung“ formuliert hat;[5]
2. auf einer fachwissenschaftlichen Bewertung (in englischer Sprache) durch eine international zusammengesetzte Expertengruppe (Unterarbeitsgruppe) sowie
3. auf einer wissenschaftspolitischen Stellungnahme, die von der Arbeitsgruppe des Wissenschaftsrates vorbereitet wird und die – neben den oben genannten 10 Thesen – den Stand des Forschungsgebietes, dessen nationale und internationale Förderung im Rahmen von Großgeräteinvestitionen sowie die Frage der Implementierung berücksichtigt.

In einem ersten Schritt begutachten international zusammengesetzte Unterarbeitsgruppen das Großgeräteprojekt unter folgenden fachwissenschaftlichen Kriterien:

- „der Wahrscheinlichkeit fundamental neuer Erkenntnisse bzw. den Möglichkeiten entscheidender, nur mit dem Großgerät erreichbarer wissenschaftlicher Fortschritte,
- der technischen Realisierbarkeit und dem technischen Innovationsgrad des Großgerätes,

[5] Vgl. ebd. S. 23ff.

- der wissenschaftlich-technischen Kompetenz der beteiligten Institutionen,
- der bereits vorhandenen oder zu erwartenden Akzeptanz der potenziellen Nutzer aus den betroffenen und angrenzenden Fachgebieten sowie
- der Erfüllung verschiedener für die Forschung bedeutsamer Ziele (Transfer, internationale Perspektiven, Nachwuchsförderung)". [6]

Das Ergebnis der wissenschaftlichen Begutachtung wird als ein eigenes Votum, das von der Arbeitsgruppe nicht mehr verändert werden kann, festgehalten und publiziert (*Bewertungsbericht*). Mehrere Mitglieder der Unterarbeitsgruppe sind auch Mitglieder der Arbeitsgruppe. Diese personelle Verknüpfung unterstützt den Informationsfluss zwischen beiden Ebenen. Aufbauend auf den Bewertungsberichten bereitet die Arbeitsgruppe eine *wissenschaftspolitische Stellungnahme* vor. Folgende Kriterien liegen der wissenschaftspolitischen Stellungnahme zugrunde: [7]

1. *das wissenschaftliche Potenzial des Forschungsprogramms* (insbesondere die Langfristigkeit seiner Entwicklungsperspektiven, das Potenzial an Themenoffenheit beim Einsatz des Gerätes sowie die wissenschaftliche und technische Kompetenz der Einrichtungen einschließlich der möglichen Profilschärfung mit dem Betreiben eines Großgerätes),
2. *die Perspektive und Bedeutung der betroffenen Forschungsgebiete* sowie die Bedeutung der Forschungsinfrastruktur für die jeweiligen Gebiete,
3. *der Vergleich mit* bereits bestehenden oder in Planung befindlichen ähnlichen bzw. *konkurrierenden Initiativen*,
4. *der Reifegrad* des technischen Konzeptes und damit verbunden die mögliche zeitliche Realisierung der einzelnen Großgeräte bzw. die Dringlichkeit ihrer Realisierung,
5. *die Erfüllung von wissenschafts- und technologiepolitischen Zielen*, wie sie der Wissenschaftsrat in zehn Thesen formuliert hat.

In den 10 Thesen zur Bedeutung von Großgeräten[8] hat der Wissenschaftsrat die Bedeutung des Einsatzes von Großgeräten für die wissenschaftliche und technische

[6] Wissenschaftsrat: Stellungnahmen zu neun Großgeräten, S. 26f.
[7] A.a.O., S. 27ff und S. 76f.
[8] A.a.o., S. 23 ff.

Entwicklung von Wirtschaft und Gesellschaft unterstrichen. Großgeräte der hier betrachteten Dimension müssen mit langfristigen wissenschaftlichen Visionen verknüpft sein und Voraussetzungen für technische Innovationen bieten. Ihr Einsatz erschließt vielfach erst ganz neue Forschungsgebiete. Daher hat der Wissenschaftsrat sich dafür ausgesprochen, dass Deutschland – über die bestehenden Fälle hinaus – Standort multinationaler europäischer oder internationaler Großgeräte wird und zumindest bei einigen von ihnen auch die wissenschaftliche Federführung übernimmt. Großgeräte dieser Dimension müssen einen Kristallisationskern von nationalen und internationalen Forschungskollaborationen und Wissenschaftsnetzwerken darstellen. Aufgrund ihrer Dimension sollten sie in europäischer und internationaler Trägerschaft angelegt sein und zugleich einer breiten europäischen und internationalen Nutzerschaft offen stehen. Duplizierungen auf nationaler und auch europäischer Ebene sollten verhindert werden, um eine effektive Nutzerauslastung des Großgerätes sicher zu stellen. Auch wenn Universitäten in der Regel aufgrund des intensiven, immer auch serviceintensiven, und langfristigen Personal- und Mitteleinsatzes nicht Träger von Großgeräten sein können, muss die Zusammenarbeit mit Hochschulen eine Selbstverständlichkeit darstellen. Dabei muss die Ausbildung des wissenschaftlichen Nachwuchses eine wesentliche Aufgabe der Betreiber eines Großgerätes darstellen.

Im Folgenden werden zunächst der Stand und die Perspektiven der betroffenen Forschungsgebiete (A.II.1.) sowie die bestehende Struktur und Finanzierung von Großgeräten in den jeweiligen Forschungsgebieten als Voraussetzung für die wissenschaftspolitische Stellungnahme der Großgeräteinitiativen dargelegt (A.II.2.).

A.II. Stand und Perspektiven der einschlägigen Forschungsgebiete sowie deren Förderung

II.1. Allgemeiner Stand der Forschungsgebiete

a) Forschungen zur Struktur und Funktion von Materie

Der BESSY Soft X-ray Free Electron Laser unterstützt die Forschung auf den Gebieten Physik der kondensierten Materie, Nanotechnologie, Physik und Chemie von Oberflächen, Materialwissenschaften (materials science) sowie Biochemie und Lebenswissenschaften. Die Physik der kondensierten Materie befasst sich mit der Struktur und Dynamik von Festkörpern und deren Oberflächen, ihren elektronischen und magnetischen Eigenschaften sowie dem Aufbau und Verhalten von Makromolekülen. Die Großgeräte spezifischen Untersuchungsverfahren werden im Wesentlichen mit Synchrotronstrahlung, Neutronen und Ionen durchgeführt. Bedeutende anwendungsorientierte Fragestellungen werden aus den Festkörper- und Materialwissenschaften sowie aus Bereichen der Katalyse und der Lebenswissenschaften aufgenommen.

Die Festkörper- und Materialwissenschaften beschäftigen sich mit hochentwickelten Materialien, die eine wesentliche Voraussetzung für den heute erreichten technischen Stand unserer Zivilisation sind und zentrale Bedeutung beispielsweise für die Information und Kommunikation, den Transport und Verkehr, die Energieversorgung oder das Gesundheitswesen besitzen. Entsprechend dieser zentralen Bedeutung ist die Entwicklung zukunftsorientierter Technologien ohne eine leistungsfähige Materialforschung nicht denkbar. Der heutige Kenntnisstand ermöglicht die maßgeschneiderte Herstellung oder Verbesserung von Materialien für spezifische Anforderungen. Dabei unterscheidet man Strukturwerkstoffe, die durch gewünschte mechanische Eigenschaften wie Festigkeit, Steifigkeit, Duktilität, hohem Verschleißwiderstand sowie Beständigkeit gegenüber Umwelteinflüssen gekennzeichnet sind, von Funktionswerkstoffen, die sich durch ihre elektrischen, magnetischen, akustischen, optischen und biologischen Eigenschaften auszeichnen. Typisch für die meisten Materialklassen ist, dass sie im Allgemeinen sowohl als Struktur- als auch als Funktionswerkstoffe eingesetzt werden können.

Die Zusammenhänge zwischen dem mikroskopischem Aufbau der Werkstoffe und den daraus resultierenden Eigenschaften sind weltweit Gegenstand intensiver Forschung. Sie sind bislang nur in Teilbereichen hinreichend verstanden. Zum Stand des Wissens hat die Forschung mit Synchrotronstrahlung, mit Neutronen und Ionen entscheidende Beiträge geliefert. Die Entwicklung neuer Materialien stellt nach wie vor eine große Herausforderung dar. Hochtechnologiewerkstoffe erfordern die genaue Kontrolle ihrer Struktur über weite Längen- und Zeitskalen, von Nanometern bis zu makroskopischen Dimensionen, von Pikosekunden bis zu Stunden oder sogar Jahren und Jahrzehnten. Dieser weite Skalenbereich sowie die Verschiedenheit der interessierenden Eigenschaften erfordern auf der Seite der Analytik den Einsatz mehrerer aufeinander abgestimmter leistungsfähiger Messverfahren, die sich gegenseitig ergänzen. Zuverlässige Messdaten und immer leistungsfähigere Rechner bilden die Basis für die ständig wachsende Bedeutung der Computersimulation. Komplexe Probleme realer Materialien werden deshalb zunehmend auch mit Höchstleistungsrechnern bearbeitet.

Generell verlangt die Herstellung neuer Materialien im Nanometer-Bereich neue Strategien zur Verbindung von Selbstorganisation und der Fähigkeit zur Bildung hierarchischer Strukturen. Hier ist ein besonders hohes Maß von Interdisziplinarität gefragt, um Ansätze aus der Physik, Chemie, Biologie und den Ingenieurwissenschaften zu verbinden.

Für die Materialcharakterisierung und für die dazu nötigen Großgeräte der nächsten Generation ergeben sich daraus zahlreiche Herausforderungen, insbesondere die Notwendigkeit, immer geringere Substanzmengen handhaben zu können, bis hinunter zu einzelnen Molekülen oder sogar einzelnen Atomen. Beispielsweise erreichen die einzelnen Elemente in elektronischen und magnetischen Speichermedien Strukturgrößen, für die neue Konzepte und Technologien erforderlich sind. Eine Perspektive besteht darin, die Elemente nicht durch die weitere Verkleinerung makroskopischer Festkörper (top down), sondern durch das gezielte Zusammenfügen weniger Atome (bottom up) aufzubauen. Dies erfordert immer leistungsfähigere Methoden und Messgeräte. Insbesondere ist neben einer hohen Ortsauflösung auch eine hohe Zeitauflösung gefordert, um die Eigenschaften von Molekülen, die Dynamik der Festkörper, der kondensierten Materie oder der chemischen Reaktionen bei der Katalyse an Oberflächen zu verstehen. Hier liegt der Schwerpunkt des BESSY FEL-Projekts. Der vorgeschlagene Freie-Elektronen-Laser soll die Untersuchung ultraschneller dynamischer Prozesse ermöglichen. Viele Materialien sind nicht kristallin im gewohnten Sinne, so dass ihre Strukturen den klassischen Verfahren wie Röntgen- und Neutronenstreuung nicht unmittelbar zugänglich sind. Dies erfordert neue Ansätze in der Strukturforschung und eine enge Abstimmung des Einsatzes von Großgeräten mit den sich ständig weiterentwickelnden Labormethoden in Bereichen wie Mikroskopie, Spektroskopie, Rastersensormethoden und Computersimulation. Die sich abzeichnenden Synergien lassen bereits jetzt Chancen zu einer neuen Qualität der Nutzung von Synchrotronstrahlung und der Strahlung von Freie-Elektronen-Lasern in diesem Bereich erkennen.

In diesem Jahrhundert wird den Lebenswissenschaften (life sciences) eine ähnlich prägende Rolle wie im vergangenen Jahrhundert der Mikroelektronik zukommen. Die Gründe für die sprunghafte Entwicklung dieser Wissenschaft sind vielfältig: Durch eine Aufklärung der biophysikalischen und biochemischen Primärprozesse wurde eine neue Dimension des allgemeinen Verständnisses biologischer Materie und ihrer Funktionsprinzipien erzielt. Meilensteine in der jüngsten Vergangenheit waren unter anderen die Aufklärung der Grundmechanismen der Photosynthese und die Entschlüsselung des menschlichen Genoms. Für Themen der Gesundheit und der Lebensqualität ist das Interesse in einem großen Teil der Bevölkerung stark angestiegen.

Als entscheidender Schritt auf dem Wege der wissenschaftlichen Aufklärung biologischer Prozesse kann die Strukturaufklärung durch Röntgenstrahlen angesehen werden. Hierbei wurde nicht nur die Struktur der DNA-Doppelhelix, sondern beispielsweise auch die Struktur von Ribosomen und des photosynthetischen Reaktionszentrums aufgeklärt. In beiden Fällen leisteten Röntgen-Strukturdaten neuer Qualität zum jeweiligen Zeitpunkt den entscheidenden Erkenntnisschritt. Mit der Aufklärung biologischer Grundstrukturen ist jedoch erst ein Anfang gemacht. Die lebenserhaltenden Prozesse in allen Organismen werden nach heutiger Erkenntnis durch dynamische Vorgänge gesteuert, die durch Proteine vermittelt werden. Es gilt deshalb, sehr komplexe, dynamische Molekülstrukturen aufzuklären, die aus teilweise mehr als 1.000 Aminosäuren aufgebaut sind. Diesen biologischen Makromolekülen liegen Primärstrukturen in Form von Aminosäureketten zugrunde, die teilweise recht gut verstanden sind. Durch Faltung dieser Aminosäureketten entstehen jedoch sehr komplexe sekundäre und tertiäre Strukturen, deren Aufbau und Funktion im lebenden Organismus erst noch erfasst werden müssen. Die Kenntnis der dynamischen Wechselwirkung großer Proteine mit pharmakologisch wirksamen Molekülen ist für die Entwicklung neuer Arzneimittel interessant. Zur Aufklärung der Wechselwirkung werden heute eine Vielzahl von Methoden wie die Röntgenkristallographie, die NMR (nuclear magnetic resonance) sowie die Spektroskopie mit Infrarotlicht eingesetzt. Ein Nachteil der Röntgenkristallographie ist die Notwendigkeit, die Proteine kristallisieren zu müssen. Sehr viele Proteine, an denen die pharmakologisch wirksamen Moleküle angreifen, lassen sich jedoch nicht kristallisieren.

In Zukunft werden Fortschritte in der Strukturaufklärung von Proteinen und anderen Biomolekülen durch den Einsatz von Röntgenlasern mit extrem hoher Intensität erwartet. Ziel ist es, die Struktur einzelner Biomoleküle über Experimente mit einem Puls zu bestimmen, ohne diese kristallisieren zu müssen. Dabei wird das Molekül durch hohen Energieeintrag zerstört, die Strukturdaten werden jedoch instantan registriert und könnten eine Rekonstruktion der komplexen Molekülform erlauben. Erste viel versprechende Ergebnisse liegen vor. Die volle Leistungsfähigkeit dieser noch zu entwickelnden Methoden muss noch gezeigt werden.

Parallel zu den experimentellen Techniken wird derzeit der Einsatz der Computersimulation auch unter Einsatz von Höchstleistungsrechnern vorangetrieben. Aus bekannten Nukleotid-Sequenzen werden zunächst Aminosäuresequenzen abgeleitet, die dann über Faltungs-Algorithmen zu dreidimensionalen Proteinstrukturen führen sollen. Die prinzipielle Eignung der derzeitig verfügbaren Algorithmen ist jedoch noch Gegenstand wissenschaftlicher Debatten.

Da die rein auf theoretische Erkenntnis gestützten Methoden, Biomoleküle zu verstehen und Pharmaka zu entwickeln, relativ langsam sind und da der Marktdruck, erfolgreiche Präparate zu entwickeln, sehr groß ist, werden derzeit viele empirische Testmethoden entwickelt. Bekannte Chemikalien werden im Rahmen von kombinatorischen Testprogrammen und mittels meist optischer Testmethoden in einer großen Vielzahl charakterisiert (high rapid throughput screening). Mit diesen Methoden ist es möglich, mehr als 1.000 Testsubstanzen pro Tag zu untersuchen. Dies hat in der Vergangenheit oft dazu geführt, dass mit rein empirischen Methoden Pharmaka entwickelt wurden, deren Funktion molekular erst später aufgeklärt wurde. Die Teilinformationen über Strukturen aus Streudaten, Spektroskopie und Computersimulation müssten systematisch zusammengeführt werden. Hierzu ist eine Stärkung der Zusammenarbeit zwischen den entsprechenden Disziplinen erforderlich.

Wissenschaftliche Fortschritte sind in den Lebenswissenschaften in der Vergangenheit eher durch vergleichsweise kleine experimentelle Aufbauten in einzelnen Laboren als durch die Forschung mit Großgeräten erzielt worden. Hier liegt ein grundlegender Unterschied beispielsweise zur Elementarteilchenphysik mit großen Beschleunigern. Großgeräte wie Röntgenlaser oder Neutronen- und Ionenquellen, die von vielen verschiedenen wissenschaftlichen Fachdisziplinen wie Physik und Materialwissenschaften, Ingenieurwissenschaften, Biophysik, Molekularbiologie und Chemie gegebenenfalls auch parallel genutzt werden können, werden in Zukunft für die Weiterentwicklung der Lebenswissenschaften mit von Bedeutung sein.

In jüngster Zeit entwickelt sich eine neue biologische Fachrichtung, die das zelluläre Geschehen in seiner Gesamtheit analysiert. Hierbei handelt es sich um „Systembiologie", die sehr oft auf Genom- und Postgenomdaten aufbaut. Die neuen Ansätze in der Systembiologie beziehen eine Modellierung und eine mathematische Beschreibung der Modelle mit ein. Damit können anhand der Modelle Voraussagen über das zelluläre Geschehen erzielt werden. Auf die Wirkung von Pharmaka bezogen besteht zum Beispiel die berechtigte Hoffnung, in Zukunft ihre Wirkungen besser vorhersagen zu können. Die Systembiologie benötigt verlässliche Daten von Enzymen und Proteinen. Jedoch erfolgt zurzeit eine Verschiebung von Forschungsschwerpunkten, die andere Aspekte als den atomaren Aufbau von Enzymen und Proteinen in den Vordergrund rücken lassen.

b) Forschungen zum Erdsystem

Ziel der Umwelt- und Geoforschung ist es, die Erde als ein Gesamtsystem zu verstehen, das auf externe und interne Veränderungen dynamisch reagiert. Die komplexen Beziehungen zwischen der festen Erde, dem Ozean und der Atmosphäre, die durch Ursache-Wirkungs-Ketten miteinander verknüpft sind, sowie die Auswirkungen der menschlichen Aktivitäten müssen von der Erdsystemforschung erfasst werden. Zentrale Beweggründe für diese Forschung sind die langfristige Erhaltung der Lebensgrundlagen für die Gesellschaft sowie die nachhaltige Nutzung der natürlichen Ressourcen. Neben der notwendigen Grundlagenforschung ist die Analyse des Globalen Wandels, der in Ansätzen schon erkannt wird und der das Erdsystem zunehmend stärker beeinflussen wird, eine besondere Herausforderung. Die bisher am wenigsten bekannten, großen Komponenten des Erdsystems sind die Tiefsee, die permanent mit Eis bedeckten Gebiete und die tiefe Biosphäre in Sedimenten der Ozeane.

Das Erdsystem zeichnet sich auf allen Zeit- und Raumskalen durch Veränderungen aus, die durch interne Dynamik der Einzelkomponenten und durch Wechselwirkungen und Rückkopplungen zwischen ihnen zustande kommen. Diese Veränderungen sind oft nicht linear sondern zeichnen sich durch Sprünge von einem stabilen Zustand in einen anderen Zustand aus. Dabei ist der anthropogene Wandel neben den natürlichen Variabilitäten oft schwer zu identifizieren. Für eine wissenschaftlich robuste und nutzbare Vorhersage des Erdsystems ist die Entwicklung von adäquaten Beobachtungssystemen, Analysemethoden für ein verbessertes Prozessverständnis und die Entwicklung von Modellen unterschiedlicher Hierarchie von grundlegender Bedeutung. Es wird zunehmend Aufgabe der Umwelt- und Geoforschung, kritische Prozesse und Umschlagspunkte im Verhalten des Erdsystems zu erkennen und zu analysieren. Hierzu ist auch der Blick in die Erdvergangenheit von besonderer Bedeutung, da hier die Hinweise auf andere Zustände im Erdsystem, auf Rückkopplungen und Umschlagspunkte zu finden sind, die nicht direkt beobachtet werden können sondern nur aus der Beobachtung der Prozesse der Vergangenheit rekonstruiert werden können.

Aufgrund des breiten Aufgabengebietes sind die Themen in der Umwelt- und Geoforschung sehr vielfältig, jedoch gibt es eine Reihe von besonderen Schwerpunkten.

Änderungen in der Zusammensetzung und der Dynamik der Atmosphäre sind ein wichtiges Forschungsgebiet, um globale Änderungen im Klima analysieren und prognostizieren zu können. Hier steht insbesondere die Zunahme von CO_2 und anderen klimaaktiven Gasen im Zentrum der Aufmerksamkeit. Prognosen aus Modellergebnissen zur globalen Erwärmung werden zunehmend durch direkte Messungen bestätigt. In den letzten Jahrzehnten wurde eine Abnahme in der Eisbedeckung (Rückgang von Gletschern und Meereis) beobachtet sowie ein erhöhter Anstieg des Meeresspiegels. Weiterhin wird erwartet, dass sich der Wasserkreislauf ändern wird, was vielfältige Auswirkungen z. B. auf die Landvegetation, Albedo (Rückstreuung der Strahlung in der Atmosphäre), Gletscherbildung und Ozeanzirkulation haben kann. Hier sind große Forschungsanstrengungen notwendig, um sowohl die Veränderungen zu beobachten und Vorhersagen zu treffen, als auch die Auswirkungen auf das polare Ökosystem und das Erdsystem als Ganzes zu verstehen.

Die großen Zerstörungen, die vor kurzem durch Erdbeben und Tsunami hervorgerufen wurden, zeigen die Notwendigkeit der Erkennung und Bewertung von Bewegungsprozessen im Erdinneren, die diese Georisiken hervorrufen. Dies erfordert auch die Erforschung bisher unzugänglicher geologischer Formationen, wie zum

Beispiel in eisbedeckten Gebieten, die aufgrund technischer Schwierigkeiten bisher nur sehr unzureichend und lückenhaft untersucht werden konnten.

Der Wandel in der Biosphäre ist vor allem durch die intensive Landnutzung, Zersiedelung und die Nutzung der Küstenräume schon weit fortgeschritten. Damit ändern sich auch die funktionellen Prozesse, durch die das Gleichgewicht im Erdsystem aufrechterhalten wird. Dies betrifft vor allem biologisch kontrollierte Stoffflüsse, wie Austausch zwischen Biosphäre und Atmosphäre, Wasserkreislauf, Kohlenstoffkreislauf, Verwitterung, Erosion und Bodendegradation. Neben diesen auf den globalen Wandel bezogenen Themen stehen aber auch ganz grundlegende Erforschungen unserer Biosphäre an, wie das Leben in der tiefen Biosphäre im Meeresboden, in extrem heißen Hydrothermalquellen und an anderen extremen Standorten.

Als einer der zentralen Stoffkreisläufe, der durch die Energiegewinnung stark gestört ist, steht der globale Kohlenstoffkreislauf im Zentrum vieler Forschungsaktivitäten. Insbesondere die Aufnahme von CO_2 im Ozean und die Speicherkapazität an Land werden untersucht, um die zukünftige Entwicklung der CO_2 Konzentrationen in der Atmosphäre prognostizieren zu können. Weiterhin haben die Methanhydrate, die in Permafrostböden und in den Kontinentalrändern in großen Mengen gespeichert sind, eine potenzielle Auswirkung auf das Klima, da sie durch Erwärmung destabilisiert werden können und in der Atmosphäre eine vielfach höhere Treibhauswirkung als CO_2 entfalten. Eine große Unbekannte ist hierbei, wie sich die Abnahme der Eisbedeckung und der Permafrostböden auf den Fluss dieser Gase zwischen Ozean, Land und Atmosphäre auswirken wird.

Weiterhin sind die natürlichen Ressourcen und ihre mögliche Nutzung ein wichtiges Forschungsgebiet. Dies umfasst Rohstoffe, erneuerbare Energien, Wasser, Nahrung und andere biologische Ressourcen. Neue Aspekte in diesem Feld sind vor allem die erneuerbaren Energien und eine breite Palette von Naturprodukten.

Großgeräte in der Umwelt- und Geoforschung werden für die Beprobung und Beobachtung benötigt (Forschungsschiffe, Forschungsflugzeuge, Tauchboote und ferngesteuerte Roboter (ROV), autonome Meßsysteme (AUVs, Glider), Meeresbodenobservatorien, Bohrplattformen). Langfristige und großräumige Beobachtung ist notwendig, um niederfrequente und globale Prozesse erfassen zu können (Satelliten, Flux Tower, bodengestützte oder verankerte Beobachtungssysteme). Insbesondere die Langzeitbeobachtung bietet Einblicke in die Variabilität der natürlichen Prozesse sowie ihrer anthropogenen Beeinflussung und sie gibt Möglichkeiten zur Warnung vor Naturgefahren. Hierbei ist zu beachten, dass insbesondere die Beprobung und Beobachtung von schwer zugänglichen Lebensräumen (Tiefseeboden, Hydrothermalquellen, tiefe Biosphäre usw.) eine besondere Herausforderung darstellt, die neue Großgeräte erfordert. Das Projekt eines eisbrechenden Forschungsbohrschiffes würde den ganzjährigen Zugang in die bisher kaum erforschte Arktis erlauben. Der Einsatz vom Schiff aus von autonomen Meßsystemen und Meeresbodenobservatorien, die längere Messungen oder direkte Untersuchungen am Tiefseeboden ermöglichen, stellt einen großen Fortschritt für die Untersuchung der polaren Meeresgebiete dar. Damit könnte dieser schwer zugängliche Lebensraum, der besonders sensibel auf Klimaveränderungen reagiert, systematisch und langfristig erforscht werden.

Ein weiterer Schwerpunkt ist die Umweltanalytik, die in den letzten Jahren auf vielen Gebieten große Fortschritte durch die Entwicklung entsprechender analytischer Geräte gemacht hat. Sie dient vor allem der Analyse spezieller Komponenten für die Naturstoffforschung, der Analyse von Indikatoren aus der Erdvergangenheit (Proxies) und der Verfolgung von Schadstoffen in der Umwelt. Auch die Erforschung der Diversität von Organismen und ihres genetischen Potenzials in bestimmten Lebensräumen mit Hilfe molekularbiologischer Methoden ist ein rasch expandierendes Forschungsfeld mit teilweise hohem Geräteaufwand. Zum Teil müssen diese analytischen Methoden schon an Bord von Forschungsschiffen durchgeführt werden, da nicht alle Messungen an gelagerten Proben durchgeführt werden können. Dies erfordert Flexibilität in der Ausstattung der Schiffe, da die technologische Entwicklung der Analytik rasch voranschreitet.

Zunehmende Bedeutung für die Erdsystemforschung erreichen Großrechner für Klimamodelle und für die Analyse des Verhaltens des Erdsystems durch gekoppelte Modelle. In diesem Forschungsgebiet sind die Fortschritte eng an die Leistungsfähigkeit der Großrechner gekoppelt und an die Verfügbarkeit von relevanten Beobachtungsdaten. In dieser Beziehung würde das geplante eisbrechende Forschungsbohrschiff die Erschließung neuer Daten mit hoher Aussagekraft aus der Arktis und langfristig auch der Antarktis ermöglichen.

II.2. Zu Struktur und Finanzierung von Großgeräten

a) Ausgaben des Bundes für Großgeräte der naturwissenschaftlichen Grundlagenforschung

Im Jahr 2004 beliefen sich die FuE-Ausgaben des BMBF für Großgeräte der Grundlagenforschung auf 636,2 Mio. Euro (Ist 2004). Dies entspricht einem Anteil von gut 10 % der FuE-Ausgaben des BMBF.[9] Davon werden in erster Linie Großgeräte in Institutionen der Großforschung gefördert, insbesondere in den 15 Einrichtungen der Helmholtz-Gemeinschaft Deutscher Forschungszentren (HGF). Seltener verfügen Institutionen der Leibniz-Gemeinschaft (WGL) wie etwa BESSY über Großgeräte. Zudem fließt ein Teil der Gelder in europäische Forschungseinrichtungen. So wird beispielsweise der 25,5-%-ige Anteil an den Ausgaben der Europäischen Synchrotron-Strahlungsquelle (ESRF) in Grenoble über den Großgeräteetat finanziert. Knapp ein Zehntel der Mittel für Großgeräte der Grundlagenforschung stehen für die Projektförderung bereit, die vornehmlich Hochschulgruppen in Anspruch nehmen, die an Großgeräten arbeiten.

Bezogen auf das Gesamtbudget des BMBF stellt sich die Verteilung der Aufwendungen für die Forschung an Großgeräten wie folgt dar:

Tabelle 1: Ausgaben des BMBF für Großgeräte im Jahr 2004 (Ist)

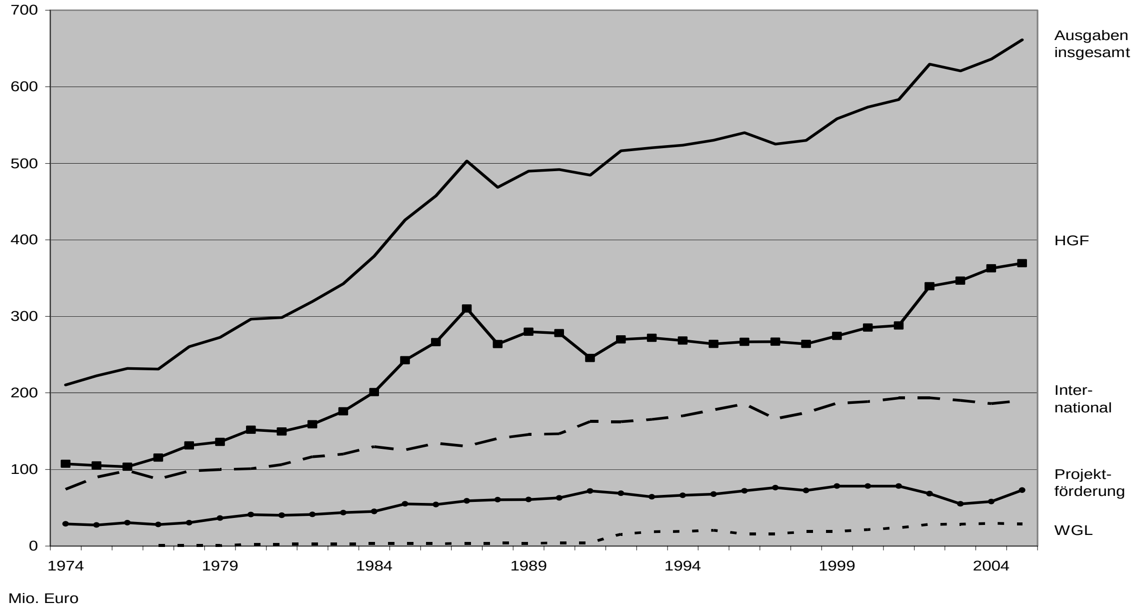
Förderform	in Mio. Euro (% Anteil an der Großgeräteförderung)	in % des Gesamtbudgets des BMBF (in % der reinen FuE-Ausgaben)
Institutionelle Förderung	392,2 (62 %)	5,7 (6,6)
Beteiligung an Europäischen Forschungseinrichtungen (CERN, ESO, ESRF, ILL, ETW)	186,0 (29 %)	2,7 (3,1)
Projektförderung	58 (9 %)	0,8 (1,0)
Gesamtförderung	636,2 (reine FuE-Angaben)	9,2 (10,7)

Quelle: BMBF

[9] Alle Angaben beziehen sich auf den Bereich „Großgeräte der Grundlagenforschung" des BMBF. Förderungen von Großgeräten seitens der DFG oder auf dem Wege des HBFG werden hier nicht berücksichtigt. Außerdem sind Investitionen für Großgeräte aus dem Bereich „Erde und Umwelt" des BMBF nicht in dieser Summe enthalten (z. B. für Forschungsschiffe, Forschungsflugzeuge, Klimarechner etc.). Hier stehen ca. 35 Mio. Euro pro Jahr an Investitonsmitteln zur Verfügung.

Im Laufe der letzten 30 Jahre sind die Ausgaben des BMBF für Großgeräte stetig gestiegen. Die folgende Graphik gibt einen Überblick auf die Entwicklung der Ist-Ausgaben des BMBF seit 1974.

Übersicht 1: Ist-Ausgaben des BMBF für den Förderbereich Großgeräte der Grundlagenforschung nach Förderarten in Mio. Euro von 1974 bis 2005 (Soll)



Quelle: BMBF

b) Ausgaben des Bundes für Großgeräte in der Forschung zur Struktur und Funktion der Materie

In Deutschland liegt ein thematischer Schwerpunkt der Förderung von Großgeräten in jenem Bereich der Physik, der sich mit grundlegenden Fragen von Struktur und Eigenschaften der Materie beschäftigt. An unterschiedlichen Neutronen-, Ionen- und Synchrotronstrahlungsquellen in Deutschland erfolgen Forschungen zu Aufbau und Dynamik kondensierter Materie. Die folgende Tabelle gibt einen Überblick über bereits bestehende Synchrotronstrahlungsquellen, d. h. über das engere Feld an Großgeräten im Bereich der Struktur- und Funktionsanalyse von Materie. Aufgenommen wurde auch der in der Vorbereitungsphase befindliche European XFEL mit einer geplanten Investitionssumme von mindestens 940 Mio. Euro. In dieses Feld ist das auch die BESSY-Initiative eines Soft X-ray FEL einzuordnen.

Tabelle 2: Vom BMBF geförderte oder mit geförderte Großgeräte im Bereich der Synchrotronstrahlung (einschließlich Freie-Elektronen-Laser)

Gerät	Standort	Ungefähre Investitionskosten in Mio. Euro[10]	Betriebskosten pro Jahr in Mio. Euro	Finanzierungsmodell	Ergänzende Angaben
BESSY II	BESSY Berlin Adlershof	118 (1993–1999)	18	Bau: 50:50 Bund/Berlin Betrieb: 50:50 Bund/Länder	Nutzerbetrieb seit 1998
DORIS III	DESY Hamburg	75 (1970-1991)	13,8	90:10 Bund/Hamburg	Nutzerbetrieb seit 1974
PETRA II		3,0 (1993-1995)	0,5	90:10 Bund/Hamburg	nur partielle Nutzung, Nutzungsbetrieb seit 1995
PETRA III		225 [11] (2004–2010)	31,2 [12]	90:10 Bund/Hamburg	Nutzerbetrieb ab 2009
VUV-FEL		117 [13] (1993-2005)	16,6	90:10 Bund/Hamburg	Nutzerbetrieb seit Aug. 2005
European XFEL		939 (2004–2013)	82	Bau [14]: Bund/Länder bis 60 %, Partnerländer mind. 40 %	Vorbereitungsphase bis 2006, geplante Bauphase 2006–2013/14[15]
ANKA	FZ Karlsruhe	35 [16] (1997–2001)	8	Bau: 45:55 Bund/Baden-Württemberg Betrieb: 65:35	Nutzerbetrieb seit 2003
DELTA	Universität Dortmund	20[17] (1994–2000)	1,1	Land Nordrhein-Westfalen	Nutzer vorwiegend aus Universitäten; Betriebsstunden 2000 p.a.; Nutzerbetrieb seit 2000
ELBE-FEL	FZ Rossendorf	26,4 [18] (1998–2005)	1,3	Bau: 50:50 Bund/Sachsen, Betrieb: 50:50 Bund/Länder	Nutzerbetrieb seit 2005
ESRF	Grenoble	466 (1988–1998)	77,8	BMBF-Anteile Bau: 23,0 % Betrieb: 25,5 %	Gesellschaft nach franz. Privatrecht, dt. Gesellschafter DESY

Quelle: BMBF

Als zu Synchrotronquellen komplementäre Instrumente der Strukturforschung sind die Neutronenquellen zu nennen. Mit dem Berliner Forschungsreaktor (BER II) am Hahn-Meitner-Institut (HMI) in Berlin, dem Forschungsreaktor (FRG 1) am GKSS in Geesthacht sowie der Forschungsneutronenquelle Hans Maier-Leibnitz (FRM II) an

---

[10] Die in Klammern geschriebenen Jahreszahlen geben den Investitionszeitraum wieder.
[11] Zusätzlicher Beitrag externer Institutionen in Höhe von 25 Mio. Euro zum Aufbau von Strahlführungen.
[12] Zusätzlicher Beitrag von 8,8 Mio. Euro zum Betrieb durch externe Institutionen.
[13] Errichtung auf Basis der TESLA Test Facility TTF 2; Beitrag ausländischer TESLA-Partner 10 %.
[14] Betriebskostenanteile bisher nicht vereinbart.
[15] Für die Einrichtung des European XFEL wurde 2004 ein International XFEL Steering Committee (ISC) eingesetzt. Dreizehn Länder (Dänemark, Frankreich, Deutschland, Ungarn, Griechenland, Italien, Polen, Russland, Spanien, Schweden, Schweiz, Großbritannien und China) haben ein Memorandum of Understanding (MoU) über gemeinsame Arbeiten in der Vorbereitungsphase des Projektes unterzeichnet. Die Niederlande, Österreich und die Slowakei nehmen als Beobachter teil.
[16] Geplanter Ausbau 2006–2009 18,3 Mio. Euro.
[17] Darunter 4,5 Mio Euro für Instrumentierungen seitens des BMBF.
[18] Darunter 2 Mio. Euro für die Messplätze Bremsstrahlung und Channelingstrahlung.

der Technischen Universität München (TU München) verfügt Deutschland auch in diesem Feld über eine leistungsfähige Infrastruktur. Hinzu kommen deutsche Beteiligungen am Höchstflussreaktor des Instituts Max von Laue – Paul Langevin (ILL) in Grenoble sowie am Impulsreaktor IBR-2 des Vereinigten Instituts für Kernforschung (VIK) in Dubna (bei Moskau).

Im Bereich der Ionenstrahlung plant die Gesellschaft für Schwerionenforschung (GSI) in Darmstadt ein neues Beschleunigerzentrum (FAIR – Facility for Antiproton and Ion Research) mit einem Investitionsvolumen von ca. 990 Mio. Euro, das vom Wissenschaftsrat bereits mit Auflagen als förderungswürdig begutachtet wurde[19] und für das eine prinzipielle Finanzierungszusage durch das BMBF vorliegt.

c) Ausgaben des Bundes für Großgeräte in der Erdsystem-Forschung

In der Erdsystem-Forschung nimmt das Alfred-Wegener-Institut eine zentrale Stellung ein, weil es über eine ausgebaute Infrastruktur in der Polar- und Meeresforschung verfügt. Darüber hinaus sind an unterschiedlichen Orten Großgeräte für diesen Forschungsbereich verankert. Die folgende Tabelle gibt einen Überblick über die bestehende Infrastruktur in der Polar- und Meeresforschung.

[19] Vgl. Wissenschaftsrat: Stellungnahmen, S. 267 ff. und vgl. Anhang 2.

Tabelle 3: Vom Bund geförderte oder mit geförderte Großgeräte im Bereich der Polar- und Meeresforschung[20]

Gerät	Standort	Ungefähre Investitions-kosten in Mio. Euro*	Betriebs-kosten pro Jahr in Mio. Euro	Finanzie-rungsmodell (für die Investition)	Erläuterung zum Einsatz-gebiet
Forschungs-eisbrecher POLARSTERN	AWI	97,34 (1982)	13,00	national (Bund: 100%)	Antarktis und Arktis
permanent be-mannte Station NEUMAYER		17,01 (1982)	3,50	national (Bund: 97,5 %, Länder: 2,5%)	Antarktis (Kosten inkl. Fahrzeugpark)
Mittleres For-schungsschiff HEINCKE**		16,4 (1990)	1,9	national (Bund: 100%)	Atlantik, Nord- und Ostsee
Mittleres For-schungsschiff METEOR**	Leitstelle FS-Meteor am Institut für Meeresforschung der Universität Hamburg (Eigentümer: Bund)	50,6 (1986)	8,9	national (Bund: 100%)	weltweit
Forschungsschiff SONNE	Projektträger Jülich am FZ Jülich (Eigentümer: Reedereigemeinschaft Forschungsschiff GmbH (RF))	28,0*** (1991)	8,9	national (RF: 77,4%, Bund: 22,6%)	Weltweit
Mittleres For-schungsschiff ALKOR**	IFM GEOMAR in Kiel (Eigentümer: SH)	16,9 (1990)	1,9	national (Bund: 90%, SH: 10%)	Ostsee, Nordsee
Mittleres For-schungsschiff MERIAN**	Institut für Ostseefor-schung (IOW) in Rostock-Warnemünde (Eigentümer: MV)	56,2 (2006)	5,4	national (Bund: 75 %, MV: 12,5 %, HB: 2,5 %, HH: 5,0 %, SH: 5,0 %)	weltweit, eis-randständig (ab 2006 einsatzfähig)

* Die in Klammern geschriebenen Jahreszahlen geben den Investitionszeitpunkt wieder.
** Zum Pool der mittelgroßen Forschungsschiffe gehörig; koordiniert von der Leitstelle FS-METEOR.
*** FS Sonne wurde 1969 als Heckfang- und Fabrikschiff gebaut. Erst beim Umbau des Schiffes 1991 wurden öffentliche Mittel in Höhe von 28 Mio. Euro eingesetzt.

Quelle: BMBF

Für den Bereich der Umwelt-, genauer der Atmosphärenforschung stehen bzw. stehen in Zukunft zwei Forschungsflugzeuge, FALCON und HALO[21], des Deutschen Zentrums für Luft- und Raumfahrt (DLR) in Oberpfaffenhofen zur Verfügung. Deutschland beteiligt sich zudem an dem europäischen Umweltsatelliten ENVISAT

[20] Investitionen kleiner als 15 Miillionen Euro sind nicht berücksichtigt.
[21] Im Anschluss an die positive Empfehlung des Wissenschaftsrates ist die Finanzierung von HALO (Forschungsflugzeug für Atmosphärenforschung und Fernerkundung) inzwischen geklärt. 47,5 Mio. Euro der reduzierten Investitionskosten (ehemals 67 Mio. Euro), d. h. 70 %, übernimmt der Bund.

und an dem geplanten Forschungssatelliten CRYOSAT der ESA (European Space Agency).

A.III. Darstellung der Großgeräteinitiativen und ihre fachlichen Begutachtung

III.1. BESSY Soft X-ray Free Electron Laser (Freie-Elektronen-Laser für weiche Röntgenstrahlung)

a) Kurzdarstellung des Großgerätes[22]

BESSY hat einen Freie-Elektronen-Laser für weiche Röntgenstrahlung konzipiert, der den Photonenenergiebereich von 24 eV bis 1000 eV abdeckt. Im Gegensatz zu dem SASE-Prinzip, das in verschiedenen Labors erfolgreich erprobt und bereits eingesetzt wird, soll der neue Freie-Elektronen-Laser der BESSY nach dem HGHG-Prinzip (High Gain Harmonic Generation) arbeiten.[23]

Bei diesem Prinzip werden die Röntgenpulse eingangs durch Femtosekundenlaser definiert („geformt"). Dies ist derzeit die einzige Methode, ultrakurze Pulse im Röntgenbereich mit hoher Leistung in einem kontrollierten Prozess reproduzierbar und synchronisiert zu generieren. Das neue Großgerät, das auf den bisher am BESSY vertretenen Spektralbereich (Vakuum-Ultraviolett und weiche Röntgenstrahlung) abgestimmt ist, verspricht durch die wesentlich höhere Leuchtstärke (Brillanz) der Strahlung sowie durch seine extrem kurzen Lichtpulse (weniger als 20 Femtosekunden) den hohen Anforderungen der Nutzer gerecht zu werden. Der BESSY FEL würde BESSY II nicht ersetzen, sondern aufgrund seiner ultrakurzen Pulse von höherer Brillianz neue, bisher unerreichbare Experimentiermethoden eröffnen und damit die wissenschaftlichen Ziele ergänzen und erweitern.

Mit dem neuen FEL können ultraschnelle dynamische Prozesse in unterschiedlichen Wissenschaftsgebieten untersucht werden. In enger Zusammenarbeit mit den potenziellen Nutzern des Großgerätes wurde ein wissenschaftliches Forschungsprogramm erarbeitet. Demnach soll der Laser in der Chemie (z. B. Chemie der Radikale), der Physik (z. B. Magnetisierungsdynamik von Nanostrukturen), in den Lebens- und Um-

[22] Siehe ausführlicher Teil C.I. der Stellungnahme.

[23] Das SASE-Prinzip (Self Amplified Spontaneous Emission) ist in der LEUTL (Low Undulator Test Line) am Argonne National Laboratory in Illinois sowie in der TTF 1 in Hamburg realisiert worden. Der VUV-FEL bei DESY – derzeit schon im Nutzerbetrieb – basiert ebenfalls auf dem SASE-Prinzip. Das HGHG-Prinzip konnte erfolgreich im Brookhaven National Laboratory (BNL) auf Long Island, Upton, New York demonstriert werden.

weltwissenschaften (z. B. Dynamik biologischer Systeme), in den Materialwissenschaften (z. B. Nanofabrikation von Materialien) sowie in der Spektroskopie (z. B. Zeitauflösung bis in den Attosekundenbereich) eingesetzt werden.

Das detaillierte Forschungsprogramm liegt bereits seit 2001 vor. Der Technische Projektvorschlag wurde 2004 fertig gestellt. Demnach belaufen sich die Investitionskosten auf 222 Mio. Euro. Darin sind Kosten für unmittelbar anstehende Forschungs- und Entwicklungsarbeiten in Höhe von 11,5 Mio. Euro (einschließlich der Kosten für die Vorbereitung des Baus) enthalten. Die jährlichen Betriebskosten, welche die Personalkosten mit umfassen, werden mit 12,4 Mio. Euro angesetzt. Nach einer zweijährigen Vorbereitungsphase für die noch anstehenden FuE-Arbeiten sind weitere fünf bis sechs Jahre für den Bau des Gerätes erforderlich. Der geplante Standort ist BESSY in Berlin-Adlershof.

b) Kurzdarstellung der Begutachtungsergebnisse der Unterarbeitsgruppe[24]

Wahrscheinlichkeit fundamental neuer Erkenntnisse

Schon im Laufe der ersten Begutachtung wurde die Exzellenz des erarbeiteten Forschungsprogramms hervorgehoben. Das neu zu entwickelnde HGHG-System wird neue Experimentiermöglichkeiten eröffnen und damit das geplante Forschungsprogramm erheblich erweitern. Ein Schwerpunkt der Forschungen wird auf der Untersuchung dynamischer Prozesse von chemischen Bindungen und biologischen Systemen liegen. Auch in der Magnetisierungsdynamik werden neue Erkenntnisse erwartet. Der BESSY-FEL wird zudem zur Analyse von Radikalen und Spurenelementen beitragen, um nur die wichtigsten Forschungsfelder zu benennen. Diese Forschungen werden auf der Möglichkeit basieren, eine reproduzierbare Pulsstruktur zu generieren, eine hohe Zeitauflösung zu erzielen, voll kohärente Strahlung zu erzeugen sowie zeitlich gleich verteilte Pulse hoher Frequenz (bis zu 25 kHz) zu erreichen.

Technische Realisierbarkeit und Innovationsgrad

Das technische Konzept des BESSY-FEL verbindet mehrere innovative Technologien, deren Machbarkeit schon für die supraleitende Beschleunigertechnologie, die Hochfrequenztechnik sowie die Undulatortechnologie gezeigt werden konnte. Ent-

[24] Siehe ausführlicher Bewertungsbericht im Teil C.I. der Stellungnahme.

scheidend für die Leistungsfähigkeit des BESSY FEL wird es sein, wie sich die supraleitende Technologie für den Photoinjektor und insbesondere das HGHG-Prinzip realisieren lassen. Für beide Elemente sind weitere FuE-Arbeiten erforderlich, um diese Technologien bis zur vollen Reife zu entwickeln. Das BESSY Design ist optimal auf pump-probe-Experimente, Experimente mit kohärentem Licht und Untersuchungen nicht-linearer Phänomene abgestimmt. Die geplante 180 Grad Krümmung, die auf der Begrenzung des jetzigen BESSY Grundstücks beruht, könnte zu einer Limitierung der Strahlqualität führen. Dies würde einer späteren Verbesserung durch den Injektor oder einem Ausbau des Beschleunigers entgegenstehen.

Die an anderen Orten in Europa geplanten Freie-Elektronen-Laser haben jeweils andere Einsatzschwerpunkte. Der in Bau befindliche FEL in Trieste (FERMI) kann nicht in den Biowissenschaften zur Proteinanalyse eingesetzt werden; der vorgeschlagene FEL am MAX-lab in Lund wird bei einer anderen Elektronenstrahlenergie (2-3 GeV statt 1-2,3 GeV des BESSY FEL) und einer niedrigen Pulsfrequenz arbeiten. Der Einsatz des bestehenden VUV FEL am DESY wird zu Teilen komplementär zu dem geplanten BESSY FEL sein. Der VUV FEL beruht auf dem SASE-Prinzip, wohingegen der BESSY FEL das HGHG-Prinzip nutzen will. Der geplante European XFEL am DESY wird nach der bisherigen Planung mit einer anderen Pulsqualität arbeiten.

Akzeptanz der potenziellen Nutzer

BESSY hat eine starke Tradition im Spektralbereich der weichen Röntgenstrahlung. Die Mehrzahl der Nutzer stammt bisher und wird auch in Zukunft aus Deutschland stammen, davon wiederum ein großer Teil aus dem Berliner Umfeld. Aufgrund von Kooperationen im europäischen Raum werden auch zahlreiche Nutzer – wie auch im Fall von BESSY II – aus nicht-deutschen Arbeitsgruppen den BESSY FEL in Anspruch nehmen. Ungefähr 100 Nutzergruppen haben Interesse an dem neuen Laser bekundet. Gleichwohl sollte BESSY nach Fertigstellung des Lasers neue Nutzer gewinnen, die bisher noch keinen Zugang zur Forschung mit Synchrotronquellen gefunden haben.

Transfer

Mehrere Forschungsgebiete werden von dem neuen FEL profitieren. In den Materialwissenschaften können mit Hilfe der Forschungen zu magnetischen Nanostrukturen die bisher bestehenden Grenzen magnetischer Speichertechnologien ausgeweitet werden. Zeitauflösende Untersuchungen biologischer Proben werden die Erkenntnisse der Zellbiologie vergrößern und könnten damit zur Entwicklung neuer Medikamente beitragen. Der neue Freie-Elektronen-Laser wird auch technische Innovationen nach sich ziehen wie z. B. die angestrebte Entwicklung einer hochfrequenten supraleitenden Elektronenquelle. Der Standort Adlershof würde als Technologiepark von der Ansiedlung des FEL deutlich profitieren können.

Wissenschaftlich-Technische Kompetenz der beteiligten Institutionen

In den letzten 20 Jahren hat BESSY sich zu einer bedeutenden Synchrotronquelle weltweit im VUV- und weichen Röntgenbereich entwickelt. BESSY verfügt über große Kenntnisse und Erfahrungen in der Entwicklung, dem Bau und dem Betrieb von Großgeräten, wie die Realisierung des BESSY II Speicherrings in Adlershof gezeigt hat. Der parallele Betrieb von BESSY II und die Entwicklung des neuen FEL bieten ein einzigartiges Umfeld für exzellente Forschungen mit Freie-Elektronen-Lasern für weiche Röntgenstrahlung. Zudem kooperiert BESSY mit dem MBI und den natur wissenschaftlichen Instituten der Humboldt-Universität im Forschungspark Adlershof.
Ein insgesamt sehr attraktives Forschungsumfeld würde weiter ausgebaut.

Die Zeit- und Kostenplanung ist grundsätzlich realistisch und begründet. Allerdings muss die Realisierung des HGHG-Prinzips über mehr als eine Stufe noch gezeigt werden. Daher erscheint ein schrittweises Vorgehen (staged construction and testing strategy) empfehlenswert, da ein solches Vorgehen nicht allein Tests mit einem auf dem HGHG-Prinzip basierten Laser ermöglicht, sondern zugleich weitere Entwicklungen der FEL-Technologie vorantreiben wird. Das Projekt ist so weit fortgeschritten, dass FuE-Arbeiten gefördert werden sollten (ready for R&D funding).

III.2. Eisbrechendes Forschungsbohrschiff AURORA BOREALIS

a) Kurzdarstellung des Großgerätes[25]

AURORA BOREALIS ist als ein großes eisbrechendes Forschungsbohrschiff konzipiert, das internationale und interdisziplinäre ganzjährige Expeditionen in den zentralen arktischen Ozean ermöglicht. Damit sollen insbesondere die Forschungsbedürfnisse der marinen Polarforschung und der geowissenschaftlichen Forschung bedient

[25] Siehe ausführlicher Teil C.II. der Stellungnahme.

sowie Erkenntnisse zum Verständnis von Phänomenen des Globalen Wandels gewonnen werden.

AURORA BOREALIS würde neue Perspektiven in der Klimaforschung und der biologischen Forschung, den beiden zentralen Bereichen der Polarforschung, eröffnen, da erstmals ganzjährig Daten in fast allen Regionen der Arktis gewonnen werden könnten. Von der Klimaforschung werden Einsichten in den komplexen Zusammenhang von fester Erde, Ozean, Eis und Atmosphäre und damit in die komplexe Dynamik des Globalen Wandels erwartet. Die biologische Forschung liefert, um einen wichtigen Punkt unter vielen zu nennen, Erkenntnisse über Lebenszyklen und Überwinterungsstrategien von Organismen und Populationen in einem weitgehend unerforschten Ökosystem, das derzeit einem rapiden Veränderungsprozess unterworfen ist.

Die Geowissenschaften würden das Forschungsschiff für Tiefseebohrungen in den arktischen Sommermonaten einsetzen. Mit AURORA BOREALIS ließen sich Bohrungen in arktischen Tiefseeböden in permanent mit Eis bedeckten Regionen durchführen. Solche Bohrungen liefern Erkenntnisse über Struktur und Eigenschaften der ozeanischen Kruste sowie über die Geschichte ozeanischer Sedimentschichten. Historische und rezente Klimaentwicklungen können rekonstruiert werden. Zugleich können Einblicke in die Zusammensetzung des Tiefseebodens gewonnen werden, die auch Aufschluss über mögliche Bodenschätze geben.

Zu den technischen Innovationen zählen die modularisierten mobilen Laborsysteme, die eine aufgabenspezifische Auswahl von Forschungslaboratorien erlauben. Das Konzept von zwei Moon Pools auf einem Schiff soll den Einsatz von ferngesteuerten Tiefseefahrzeugen (ROV), autonomen Wasserfahrzeugen (AUV), Meeresbodenobservatorien etc. während des Bohrbetriebs ermöglichen. Eine besondere technische Herausforderung stellt die noch notwendige Fortentwicklung eines Dynamischen Positionierungssystem (DPS) dar. Es soll gewährleisten, dass das Bohrschiff trotz der enormen Kräfte des treibenden Packeises seine Position halten kann. Auch ein mobiler und flexibler Bohrarm muss noch entwickelt werden.

Das AURORA BOREALIS-Projekt wurde ursprünglich vom Alfred-Wegener-Institut initiiert und wird mittlerweile im Rahmen des European Polar Board (EPB) der European Science Foundation (ESF) weiterverfolgt. Das EPB plant, ein Europäisches Polarkonsortium (EPC) einzurichten, das – finanziert von der ESF – Managementstrukturen für dieses multinationale europäische Projekt ausarbeitet. Das Projekt wird mit bestehenden Forschungsprogrammen, insbesondere mit dem Deep Sea Drilling Project (DSDP) und dem Integrated Ocean Drilling Program (IODP), verzahnt. Die Kosten des Projekts belaufen sich derzeit auf 354,6 Mio. Euro; 17,5 Mio. Euro jährliche Betriebskosten sind vorgesehen. Vier bis fünf Jahre müssen für die Ausschreibung und den Bau des Schiffes veranschlagt werden.

b) Kurzdarstellung der Begutachtungsergebnisse der Unterarbeitsgruppe[26]

Wahrscheinlichkeit fundamental neuer Erkenntnisse

AURORA BOREALIS verspricht, Erkenntnisse über eine der letzten bisher unerforschten Regionen der Welt zu liefern. Aufgrund der Geschichte des Projektes standen zunächst die zu erwartenden Fortschritte in den Geowissenschaften im Vordergrund. Der Arktische Ozean ist das einzige Teilbecken der Weltmeere, das bisher – mit Ausnahme der ACEX-Expedition 2004 – durch internationale Forschungsbohrprogramme nicht erschlossen werden konnte. Mit AURORA BOREALIS ließen sich arktische Tiefseeböden systematisch erforschen (bis zu 90% des Arktischen Beckens wären zugänglich), so dass Europa einen zentralen Beitrag zur „Alternate (Mission Specific) Platform“ (aufgabenspezifische Bohrinsel) des IODP liefern würde.

Mindestens gleichrangig zur Bedeutung der Bohraktivitäten ist der Einsatz von AURORA BOREALIS als eisbrechendes Forschungsschiff für die Polarforschung zu werten. Denn erstmals können ganzjährig und regelmäßig Daten in der Arktis gewonnen werden. Von diesen Daten werden Durchbrüche in der Grundlagenforschung zahlreicher Disziplinen wie der Meteorologie, Biologie, Ökologie, Ozeanographie, Physik und Chemie erwartet. Bisher liegen fast ausschließlich Daten aus den Zeiten des arktischen Sommers vor, so dass kaum Aussagen über jahreszeitlich bedingte Veränderungen getroffen werden können.

Die Polarregionen reagieren sensibler und stärker als andere Regionen der Erde auf die Phänomene des Globalen Wandels. Schnee und Eis in der Arktis beeinflussen die globale Wärmeverteilung zum Beispiel über ihre Effekte auf Albedo (Rückstreuung der Strahlung in der Atmosphäre). Zudem sind die Polarmeere die Quelle der kalten und tiefen Wasserströme, die wiederum die thermohaline Wasserzirkulation

[26] Siehe ausführlicher Bewertungsbericht im Teil C.II. der Stellungnahme.

der Ozeane beeinflussen. Der Klimawandel wird hier insbesondere durch die positiven Feedback-Prozesse verstärkt. Daher ist die Arktis ein früher Indikator für die zu erwartenden Veränderungen im Zuge des Globalen Wandels. Die Erkenntnisse, die durch den Einsatz von AURORA BOREALIS gewonnen werden können, werden Gegenstand intensiver umweltwissenschaftlicher und politischer Debatten sein. Da die Arktis derzeit einem starken Temperaturanstieg unterworfen ist, erscheint die Erforschung dieser Region als besonders dringlich.

Technische Realisierbarkeit und Innovationsgrad

AURORA BOREALIS würde zur Klasse der schweren Eisbrecher gehören, vergleichbar den großen russischen Eisbrechern mit mehr als 50 MW Antriebskraft, was einen ganzjährigen Einsatz in fast allen Regionen der Arktis sicherstellen würde. Die Operationstiefe von 4.000 Metern des Bohrgestänges (plus 1.000 m Bohrtiefe im Sediment) ist ausreichend, da nur wenige, wissenschaftlich weniger interessante Teile des Arktischen Ozeans tiefer als 4.000 Meter sind. Das modularisierte Laborsystem erlaubt einen flexiblen Einsatz von AURORA BOREALIS je nach Forschungsauftrag. Spätere wissenschaftliche Entwicklungen können ohne großen Aufwand in das Laborsystem integriert werden. Das innovative Konzept, zwei Moon Pools auf dem Forschungsschiff zu realisieren, ermöglicht auch Datensammlungen für die Polarforschung während der Sommermonate, in denen die Bohraktivitäten im Vordergrund stehen. Ein flexibler Einsatz von AURORA BOREALIS, während des gesamten Jahres ist in jedem Fall wünschenswert, um ganzjährig die Bedürfnisse der Polarforschung bedienen zu können. Dies kann auch über eine Koordinierung mit anderen Forschungsschiffen realisiert werden.

Das Design eines Forschungsschiffes, das zugleich bohren und schweres Eis brechen kann, ist weltweit einmalig und hat überzeugt. Die technische Machbarkeit ist im Rahmen der normalen Risiken, die mit der Entwicklung innovativer Technologien verbunden sind, gegeben. Weitere Modellversuche sind jedoch erforderlich, insbesondere was die Eisbrecherleistung und die Entwicklung des dynamischen Positionierungssystems angeht. Eine solche integrierte Forschungsplattform erweist sich als kostengünstiger im Vergleich zum Einsatz eines konventionellen Bohrschiffes in Begleitung mehrerer Eisbrecher, wie die ACEX-Expedition gezeigt hat.

Akzeptanz potenzieller Nutzer

Das internationale Interesse der Erdsystemforschung an einer systematischen ganzjährigen und alle Regionen umfassenden Untersuchung der bisher unzugänglichen Arktis ist sehr hoch und wird insbesondere in der Polarforschung in den kommenden 20 Jahren anhalten. Das Internationale Polare Jahr (IPY) hat das große Interesse an der Arktisforschung dokumentiert.

Erfüllung für die Forschung bedeutsamer Ziele (Nachwuchsförderung und Transfer)

Die Größe des Schiffes schafft die bauliche Voraussetzung für die Forschung einer kritischen Masse an Wissenschaftlern, so dass im wissenschaftlichen Team interdisziplinär gearbeitet und zugleich mit dem Bohrteam kooperiert werden kann. Daher kann AURORA BOREALIS auch zu Recht als „Floating International Polar University“ bezeichnet werden.

Von AURORA BOREALIS werden wesentliche Erkenntnisse für ein vertieftes Verständnis des Globalen Wandels erwartet, die zu einem fundierten Umgang mit den Klimaveränderungen insgesamt wie zur nachhaltigen Entwicklung der Region beitragen können.

Wissenschaftlich-technische Kompetenz der beteiligten Institutionen

Es ist entscheidend, dass ein Schiff dieser Dimension in der Hand einer Institution mit internationaler Reputation sowie mit einem hohen Maß an Erfahrung liegt. Das AWI hat sich in den 25 Jahren seines Bestehens zu einer exzellenten Forschungseinrichtung sowie zu einer Plattform für große internationale Forschungsprogramme an Bord der POLARSTERN entwickelt. Auch wenn die endgültige Ansiedlung von AURORA BOREALIS noch offen ist, sollte das AWI besondere Verantwortung für die weitere Entwicklung des Schiffes, einschließlich der Auswahl des Heimathafens, tragen. Daher sollte Deutschland zum Pionierinvestor von AURORA BOREALIS werden und mit einer Startfinanzierung in signifikanter Höhe das Projekt auf europäischer und internationaler Ebene weiter vorantreiben.

B. Wissenschaftspolitische Stellungnahme und Ausblick

B.I. Abschließendes wissenschaftspolitisches Votum

I.1. BESSY Soft X-ray Free Electron Laser (Freie-Elektronen-Laser für weiche Röntgenstrahlung)

Wissenschaftliches Potenzial des Forschungsprogramms

Das vorliegende wissenschaftliche Programm der BESSY-Initiative ist exzellent. Der auf dem HGHG-Prinzip basierende Freie-Elektronen-Laser soll eine neue Art von Spektroskopie zur zeitaufgelösten Untersuchung von Festkörpern, Gasen und Flüssigkeiten sowie von bioorganischer Materie ermöglichen. Das wissenschaftliche Potenzial des Forschungsprogramms ist daher für die Untersuchung elektronischer Zustände insbesondere von elektronischen Transferreaktionen sowie für die zeitaufgelöste Röntgenmikroskopie biologischer Zellen und Zellbestandteile besonders hoch. Ein Freie-Elektronen-Laser basierend auf einem supraleitenden Elektronen-Linearbeschleuniger mit Stahlenergien zwischen 1.02 GeV und 2.3 GeV wird Photonen im Energiebereich von 24eV und 1000 eV liefern, was einen Wellenlängenbereich von 52-1,2 nm entspricht. Damit können Schwellenenergien von Sauerstoff, Kohlenstoff, Stickstoff und von Übergangsmetallen abgedeckt werden, so dass biologische Prozesse in lebenden Zellen untersucht werden können.

Perspektive und Bedeutung der betroffenen Forschungsgebiete

In unterschiedlichen Forschungsfeldern besteht ein großes Interesse an dem Einsatz von Freie-Elektronen-Lasern. Die physikalische Chemie interessiert sich vor allem für Prozesse der Moleküldissoziation (Elektronenspektroskopie) und für die Analyse von Übergangszuständen. Die Lebenswissenschaften erwarten, tiefere Einblicke in die Dynamik biologischer Strukturen auf zellulärer und makromolekularer Ebene gewinnen zu können.

Vergleich mit konkurrierenden Initiativen

Derzeit besteht keine FEL-Initiative auf europäische Ebene, die sich bezogen auf die technologischen Rahmenbedingungen und hinsichtlich der wissenschaftlichen Kompetenz des vorschlagenden Teams mit dem BESSY-Projekt vergleichen ließe. An mehreren Orten in Europa werden jedoch Freie-Elektronen-Laser entwickelt, die ebenfalls das neu zu entwickelnde HGHG-Prinzip potenziell nutzen wollen. Dazu zählen die FEL-Initiative am MAX-Lab in Lund und der in Bau befindliche FEL in Triest (FERMI) sowie die beiden auf dem SASE-Prinzip aufbauenden Laser am DESY in Hamburg.

Die an diesen Orten in Europa geplanten bzw. realisierten vier FELs sehen andere Einsatzschwerpunkte und stellen nicht das breit angelegte Spektrum von Photonenstrahlen und die Vielfalt von Experimentierplätzen wie beim BESSY FEL in Aussicht. Die geplante Photonpulsfrequenz wird die parallele Datennahme von mehreren Experimenten erlauben, verbunden mit der Möglichkeit, die Strahlparameter den Bedingungen jedes einzelnen Experiments anzupassen.

Am MAX-Lab ist in einer ersten Phase die Entwicklung und der Bau der MAX IV-Bi-Synchrotron-Anlage geplant, an die sich in einer zweiten Phase ein FEL-Projekt anschließen soll. Die im Bau befindliche FEL Anlage in Trieste ist auf Photonen bis zu 100 eVolt begrenzt und kann damit nicht die für Biowissenschaften wichtigen Energieschwellen von Kohlenstoff, Sauerstoff und Stickstoff nachweisen. Der bestehende VUV-FEL am DESY verfügt gegenwärtig nur über einen Photonenstrahl, der aber durch Spiegel zwischen mehreren Experimenten hin- und hergeschaltet werden kann. Diese Anlage operiert mit dem SASE Konzept. Der Einbau einer HGHG-Photonenquelle ist zurzeit nicht geplant, könnte jedoch grundsätzlich und bei Bedarf nach 2010 realisiert werden. Der geplante European XFEL am DESY soll hauptsächlich im harten Röntgenbereich arbeiten. Während der European XFEL sich auf die Strukturanalyse konzentriert, liegt der Schwerpunkt des BESSY FEL auf der Spektroskopie ultraschneller dynamischer Prozesse. Der Einsatz einer supraleitenden Hochfrequenz-Elektronenquelle ist grundsätzlich gegeben (für Elektronenenergien bis zu etwa 6 GeV). Damit würden Experimente mit längeren Wellenlängen ermöglicht, die allerdings die Zahl an Experimenten mit kürzeren Wellenlängen beschränken, welche den eigentlichen Schwerpunkt des European XFEL ausmachen sollen.

Reifegrad des technischen Konzepts und Dringlichkeit der Realisierung

Das technische Konzept des BESSY FEL, das auf dem HGHG-Prinzip und dem supraleitenden Photoinjektor basiert, ist überzeugend. Die Entwicklung der vorgeschlagenen Technologien ist noch nicht abgeschlossen. Es wird erwartet, dass die erforderlichen FuE-Arbeiten etwa drei bis vier Jahre in Anspruch nehmen werden.

Erfüllung von wissenschafts- und technologiepolitischen Zielen

Deutschland hat eine ausgewiesene Kompetenz auf dem Feld der Spektroskopie und Strukturanalyse von Materie. Es hat in der Vergangenheit einen thematischen Schwerpunkt in der Großgeräteforschung gelegt (vgl. A.II.2. b)). Dementsprechend wurden in den letzten Jahren zahlreiche Investitionen in unterschiedliche Neutronen-, Ionen- und Synchrotronstrahlungsquellen getätigt (vgl. Tabelle 2), um Deutschland auf diesem Feld eine weltweite Führungsrolle zu sichern. Diese Führungsrolle sollte weiter ausgebaut werden.

Der Wissenschaftsrat empfiehlt deshalb, die Forschungs- und Entwicklungsarbeiten für einen auf dem HGHG-Prinzip basierenden Freie-Elektronen-Laser weiter zu führen. Die Wissenschaftler bei BESSY sind für diese Aufgabe hervorragend qualifiziert und sollten sie in kontinuierlicher Abstimmung vor allem mit dem DESY-Team wahrnehmen. Die Kosten der ursprünglichen, auf zwei Jahre angelegten FuE-Phase waren inklusive der standortbedingten Anteile mit 11,5 Mio. Euro kalkuliert worden. Bereinigt um diese Anteile betragen sie 8,8 Mio. Euro. Vor einer endgültigen und begründbaren Bauempfehlung sollte der Nachweis der Realisierbarkeit des HGHG-Prinzips über mehr als eine Stufe gezeigt werden. Daher empfiehlt der Wissenschaftsrat, für eine solche mehrjährige, neu konzipierte FuE-Phase zunächst Mittel im Umfeld dieser Größenordnung auf der Basis eines angepassten FuE-Plans und einer entsprechenden Kostenkalkulation bereitzustellen. Ob weitere Fördermittel erforderlich sind, um die Realisierbarkeit eines mehrstufigen HGHG-Laser zeigen zu können, bedarf einer genauen Prüfung des neu ausgerichteten Forschungs- und Entwicklungsplans. Es kann erwartet werden, dass ein Teil der Kosten der FuE-Phase wie bisher europäisch finanziert wird.[27] Der Wissenschaftsrat bittet den Bund und das Land Berlin, sich ebenfalls an der Finanzierung der erforderlichen FuE-Arbeiten zu beteiligen. Ferner regt der Wissenschaftsrat an, eine künftige Zuordnung von BESSY zur Helmholtz-Gemeinschaft Deutscher Forschungszentren (HGF) zu prüfen.

Ob der Bau eines Freie-Elektronen-Lasers, der auf dem HGHG-Prinzip basiert, möglich ist, hängt vom Verlauf der FuE-Phase ab. Wo ein solcher Laser im Erfolgsfalle

---

[27] Bisher wurden bzw. werden folgende Arbeiten von europäischer Seite gefördert: Resonator für eine Elektronenkanone mit hohem Tastverhältnis (0,1 Mio. Euro), Design und Test eines Lasersystems im sichtbaren und ultravioletten Spektralbereich für Pump-Probe Experimente in Kooperation mit DESY, MBI, LURE, Lund University und der University of Dublin) (1,2 Mio. Euro), Beteiligung an vier Arbeitspaketen der EUROFEL Initiative (1,41 Mio. Euro): Photoinjektoren, „Seeding and Harmonic Generation“, Supraleitende Dauerstrich- und nahe Dauerstrich-Linearbeschleuniger, Technologie-Transfer für Kryo-Module, sowie die Entwicklung eines Charakterisierungssystems für Femtosekunden Pulse im weichen Röntgenbereich (0,3 Mio. Euro).

gebaut werden sollte, kann zum gegenwärtigen Zeitpunkt noch nicht abschließend entschieden werden. Aus heutiger Sicht ist sowohl der Bau eines Freie-Elektronen-Lasers in Berlin-Adlershof (BESSY) als auch der entsprechende Ausbau der Röntgenlaser in Hamburg (European XFEL und/ oder VUV FEL bei DESY) denkbar. Eine Entscheidung wird zudem im Lichte einer sorgfältigen Prüfung und eines Vergleichs der entstehenden Investitions- und der dauerhaft anfallenden Betriebskosten zu treffen sein. Der Wissenschaftsrat bietet dazu seine Hilfe an.[28]

I.2. Eisbrechendes Forschungsbohrschiff AURORA BOREALIS

Wissenschaftliches Potenzial des Forschungsprogramms

Das jetzt vorliegende Forschungsprogramm von AURORA BOREALIS spiegelt den in den letzten Jahren vollzogenen Paradigmenwechsel zu einer integrierten Erdsystemforschung wider (vgl. A.II.1.b.). Erst ein integrierter Forschungsansatz, der unterschiedliche Disziplinen wie die Biologie, Geophysik, Geochemie, Meteorologie etc. zusammenführt, wird der Komplexität des Systems Erde gerecht. Aus der ursprünglichen Idee eines Forschungsbohrschiffes hat sich das Konzept einer einzigartigen multifunktionalen und multidisziplinären Forschungsplattform für den ganzjährigen Einsatz in der Arktis entwickelt. Das wissenschaftliche Potenzial des Forschungsprogramms von AURORA BOREALIS ist daher sowohl für die Grundlagenforschung wie für die Forschung zum Globalen Wandel sehr hoch.

Perspektive und Bedeutung der betroffenen Forschungsgebiete

Die Erforschung schwer zugänglicher Lebensräume wie die Tiefsee oder permanent Schnee bedeckter Regionen verlangt den Einsatz von Großgeräten. Die Arktis lässt sich ganzjährig und in fast allen ihren Teilregionen allein mit Hilfe eines großen Forschungseisbrechers oder eines vergleichbaren Großgeräteeinsatzes erforschen. Die dadurch ermöglichten Fortschritte in der Erdsystemforschung wie in der Forschung für den Globalen Wandel sind auf anderem Weg kaum zu erzielen. Erst die ganzjährige und umfassende Beobachtung dieser sensibel auf Umweltveränderungen reagierenden Region liefert die Grundlage für ein ausgewogenes Urteil zu umweltwissenschaftlichen und -politischen Fragen der globalen Erwärmung.

[28] Vgl. zu diesem Angebot: Wissenschaftsrat: Stellungnahmen zu neun Großgeräten, S. 76.

Mit dem Einsatz von AURORA BOREALIS kann das AWI die POLARSTERN dauerhaft in die Antarktis überführen. Die POLARSTERN verliert nicht länger wertvolle Forschungszeit für den Transfer zwischen den Polarmeeren. Zugleich ist damit zum ersten Mal eine vergleichende Datenerhebung und Erforschung beider polaren Regionen möglich. Wertvolle Erkenntnisse über die Dynamik von Veränderungen im Klima, in der Eisbedeckung, im Gletscherverhalten etc. in beiden Polarmeeren können gewonnen und für die Einschätzung der Prozesse des Globalen Wandels genutzt werden. Daher sollte ein paralleler Einsatz beider Forschungsschiffe gewährleistet werden.

AURORA BOREALIS mit einer geschätzten Lebensdauer von 30 bis 40 Jahren würde langfristig die POLARSTERN ersetzen können. Die POLARSTERN ist nach einem technischen Erneuerungsprogramm in den Jahren 1998-2002 auf den neusten Stand gebracht worden, um weitere 15 bis 20 Jahre für die Forschung eingesetzt zu werden. Das technische Konzept von AURORA BOREALIS sieht vor, dass das Forschungsschiff den Belastungen (z. B. aufgrund extremer Temperaturen und Stürme) während des Transfers durch tropische Meere in die Antarktis standhalten kann. AURORA BOREALIS fügt sich auch langfristig gut in die deutsche Forschungsflotte ein.

Vergleich mit konkurrierenden Initiativen

AURORA BOREALIS ist ein einzigartiges Projekt. Derzeit werden Forschungseisbrecher dieser Größe und Leistungsfähigkeit weder im europäischen noch im internationalen Forschungskontext für einen Einsatz in der Arktis diskutiert. Europa wird sich mit diesem Forschungsbohrschiff an die Spitze der Polar- und Tiefseeforschung setzten können.

Reifegrad des technischen Konzepts und Dringlichkeit der Realisierung

AURORA BOREALIS sollte möglichst schnell realisiert werden, um Daten in der sich rasch verändernden Arktis gewinnen zu können. Gleichwohl sind noch wesentliche Entwicklungsarbeiten und Modellversuche, die das dynamische Positionierungssystem, die Leistungsfähigkeit des Eisbrechers sowie die Realisierung von zwei Moon Pools in einem Schiffsrumpf betreffen, erforderlich. Der Wissenschaftsrat empfiehlt, die Entwicklung und den Reifegrad des dynamischen Positionierungssystems vor der endgültigen Förderentscheidung zum Bau des Schiffes noch einmal in geeigneter Weise ingenieurwissenschaftlich zu prüfen.

Erfüllung von wissenschafts- und technologiepolitischen Zielen

Das AWI spielt bereits heute eine führende Rolle in den Meeres- und Polarwissenschaften. Es hat dieses Projekt initiiert und seine fortschreitende Realisierung auf europäischer Ebene wesentlich mitgetragen. Deutschland sollte das AWI in seiner Rolle als international wahrgenommener Leuchtturm der Meeres- und Polarwissenschaften stärken.

Der Wissenschaftsrat empfiehlt, dass sich Deutschland nach Klärung der ingenieurwissenschaftlichen Frage zum dynamischen Positionierungssystem durch eine mindestens 30%ige Beteiligung Deutschlands an den Investitionskosten die Federführung am Projekt AURORA BOREALIS sichern sollte. Für die weiteren Entwicklungsarbeiten und Modellversuche, die der Klärung der offenen ingenieurwissenschaftlichen Fragen dienen, sollte die vom AWI beantragte Summe von 6 Mio. Euro sofort bereit gestellt werden.

Der Wissenschaftsrat bittet das BMBF, dieses Projekt auf europäischer Ebene aktiv weiter zu verfolgen (im Rahmen von ESFRI wie auch im Kontext des 7. Rahmenprogramms, Näheres vgl. B. II. 3.). Gleichzeitig sollte ein Konzept zur europäischen Finanzierung der Betriebskosten entwickelt werden.

Dass es zu einer europäischen Mitfinanzierung der Baukosten und der laufenden Betriebskosten kommt, ist integraler Bestandteil der positiven Empfehlung des Wissenschaftsrates. Ohne eine europäische und internationale Beteiligung (durch IODP) kann eine vollständige und adäquate Ausnutzung der Kapazitäten des Schiffes nicht gewährleistet werden. Eine substanzielle europäische Mitfinanzierung des Baus und des Betriebs von AURORA BOREALIS ist daher notwendig, um die von Deutschland zu tragenden Kosten in einem angemessenen Verhältnis zu halten und zu keinem Ungleichgewicht in der deutschen Meeres- und Umweltforschung zu führen. Die überragende Bedeutung von AURORA BOREALIS für die Erdsystemforschung als weltweit einmalige Einrichtung ist unbestritten, jedoch ist dieses Großgerät als Infrastruktureinheit nur auf europäischer Ebene sinnvoll. Der Wissenschaftsrat empfiehlt dem BMBF und den Akteuren auf deutscher Seite, in die Aushandlung der europäischen Mitfinanzierung von Beginn an die Sicherung und Verwertung der Rechte an den zu erwartenden Forschungsergebnissen mit einzubeziehen.

I.3. Votum zur Einordnung in Empfehlungskategorien

In seinen „Stellungnahmen zu neun Großgeräten der naturwissenschaftlichen Grundlagenforschung" hat der Wissenschaftsrat drei Empfehlungskategorien entwickelt. Die erste Gruppe beschreibt Großgeräteinitiativen, die ohne Vorbehalt zur Förderung empfohlen werden können. Eine zweite Gruppe wird definiert von Projekten, bei denen – trotz grundsätzlicher Zustimmung – noch Klärungsbedarf in bestimmen Fragen besteht. Kategorie III bezieht sich auf Projekte, zu denen der Wissenschaftsrat spezifische, auf das jeweilige Projekt bezogene Stellungnahmen vorlegt, da zum Zeitpunkt der Begutachtung auf der Basis der vorgelegten Materialien keine Förderempfehlung möglich ist.

Sowohl das Projekt eines Freie-Elektronen-Lasers der BESSY als auch das eines eisbrechenden Forschungsbohrschiffs AURORA BOREALIS wurden im ersten Begutachtungsverfahren in die Empfehlungskategorie III eingeordnet. Für beide Initiativen fehlten zum damaligen Zeitpunkt substantielle Vorarbeiten, um die technische Machbarkeit der Projekte beurteilen zu können. Der Wissenschaftsrat hat in der hier vorgelegten Stellungnahme die in der Zwischenzeit geleistete und dokumentierte Entwicklungsarbeit fachwissenschaftlich und wissenschaftspolitisch bewertet. Der Wissenschaftsrat ordnet beide Projekte der Empfehlungskategorie II zu. Die diese Kategorie konstituierenden offenen Fragen sowie die die Vorhaben betreffenden weiteren Schritte wurden ausführlich formuliert.

Der Wissenschaftsrat empfiehlt die Förderung einer neu ausgerichteten FuE-Phase zur Entwicklung eines auf dem HGHG-Prinzip basierenden Freie-Elektronen-Lasers. Erst im Anschluss an diese mehrjährige FuE-Phase kann über die mögliche Realisierung eines solchen Lasers und über die Standortfrage abschließend beraten werden. Der Wissenschaftsrat bietet an, diesen Prozess weiter zu begleiten.

Für das AURORA BOREALIS-Projekt empfiehlt der Wissenschaftsrat, die zur Klärung der offenen technische Frage erforderlichen 6 Mio. Euro an FuE-Kosten sofort bereit zu stellen. Anschließend sollte das BMBF seine Bereitschaft zur mindestens 30%igen Übernahme der Baukosten erklären, um in europäische und internationale

Verhandlungen über eine angemessene Beteiligung anderer Länder an den Bau- und Betriebskosten des eisbrechenden Forschungsbohrschiffes einzutreten. Nach Klärung dieser offenen Fragen empfiehlt der Wissenschaftsrat den Bau von AURORA BOREALIS unter deutscher Federführung.

B.II. Perspektiven zum zukünftigen Umgang mit Forschungsinfrastrukturinitiativen

II.1. Zum Begriff der Forschungsinfrastruktur

Als sich der Wissenschaftsrat in den Jahren 2000-2002 erstmals systematisch mit der Begutachtung von Großgeräten befasst hat, hatte das BMBF dem Wissenschaftsrat eine Liste von Geräten vorgelegt, die ausschließlich der naturwissenschaftlichen Grundlagenforschung dienten. Schon damals hat der Wissenschaftsrat darauf aufmerksam gemacht, dass diese Liste nicht alle Forschungsgebiete, in denen Großgeräten eine hohe Bedeutung zukommt, abdeckt, so zum Beispiel weder die Astrophysik noch Hochleistungsforschungsinfrastrukturen.[29] Mittlerweile zeichnet sich ab, dass prinzipiell alle Disziplinen – einschließlich der Sozial- und Geisteswissenschaften – jeweils einen spezifischen Bedarf an Forschungsinfrastrukturmaßnahmen entwickelt haben. Diese müssen nicht unbedingt zentral vorgehaltene Geräte sein, sondern können auch dezentral organisiert sein. Daher erscheint es angemessener, den Begriff des Großgerätes durch den umfassenderen Begriff der **Forschungsinfrastruktur** zu ersetzen. Dieser Begriff umfasst

- die ‚klassischen' *Großgeräte* für Forschungszwecke (z. B. Beschleuniger, Teleskope etc.),
- *Wissensressourcen der Forschung* wie Sammlungen, Archive (auch biologische Archive), strukturierte Informationen (z. B. Datensammlungen in den Sozialwissenschaften) oder Datenbanken (z. B. in Genomik), die auch dezentral errichtet werden können, sowie
- *IKT-Infrastrukturen* wie GRID, Hochleistungsrechner, Hochleistungskommunikations- und Rechnergitterverbund-Infrastrukturen (GEANT) sowie Software und Netzverbindungen.[30]

---

[29] Vgl. Wissenschaftsrat: Stellungnahmen zu neun Großgeräten, S. 21.

[30] Vgl. hierzu auch: Europäische Kommission: Vorschlag für eine Entscheidung des Rates über das spezifische Programm „Kapazitäten" zur Durchführung des siebten Rahmenprogramms der Europäischen Gemeinschaft (2007-2013) im Bereich der Forschung, technologischen Entwicklung und Demonstration. KOM (2005) 443 endg.; Ratsdok. 12729/05, S. 25). Als weitere Kategorie wird hier „jegliche sonstige für die wissenschaftliche Forschung genutzte einzigartige Einrichtung" genannt.

Der Wissenschaftsrat schließt sich daher der weiten Definition von Forschungsinfrastrukturen an, die ESFRI (European Strategy Forum on Research Infrastructures)[31] entwickelt hat:

> „Research Infrastructures are facilities, resources or services that are needed by the scientific community for development of leading-edge research, as well as for transmission, exchanges and preservation of knowledge."[32]

Initiativen für Forschungsinfrastrukturen zeichnen sich mittlerweile durch eine zunehmende Komplexität aus. Die Komplexität besteht hinsichtlich:

- der Infrastrukturtypen (u. a. zentral/dezentral),
- der potenziellen Partner für die Finanzierung und den Betrieb der Forschungsinfrastrukturen (sowohl hinsichtlich der beteiligten Länder als auch mit Blick auf potenzielle Partner aus dem privaten Sektor),
- der möglichen Optionen für Investitionsplanungen (Weiterführung, Schließung, Ausbau und Schaffung neuer Strukturmaßnahmen) sowie
- der zunehmenden Zahl an beteiligten Disziplinen, die eine solche Infrastruktur nutzen können, so dass sich letztere zu Serviceeinrichtungen entwickeln müssen, die eine Vielzahl von wissenschaftlichen Bedürfnissen bedienen können.

Angesichts dieser Komplexitätssteigerung betont der Wissenschaftsrat erneut die Notwendigkeit, die Schaffung neuer Infrastrukturen und ihre Ausgestaltung, aber auch den Ausbau, die Weiterführung und die Schließung bestehender Großgeräte aus einer übergeordneten vergleichenden Perspektive zu begutachten (vgl. B.II.3.).

In der Regel sind mit der Einrichtung oder dem Ausbau von Forschungsinfrastrukturen große Investitionen verbunden, die langer Vorlaufzeiten bedürfen und nach ihrer Einrichtung auf längerfristige finanzielle Förderung (in der Regel mit jährlichen Betriebskosten von mehreren Millionen Euro) angewiesen sind. Schon in der vom BMBF an den Wissenschaftsrat zur Begutachtung übermittelten Liste von Großgeräten der naturwissenschaftlichen Grundlagenforschung aus dem Jahre 2000 lagen die

---

[31] Beim Europäischen Strategieforum für Forschungsinfrastrukturen – kurz ESFRI – handelt es sich um ein europäisches Koordinierungsgremium. Mitglieder sind – neben einem Vertreter der EC – Vertreter der 25 Staaten der Europäischen Union und sieben assoziierter Staaten. Die Forschungsministerien der einzelnen Staaten ernennen die Vertreter. Seit Gründung der ESFRI vertritt das BMBF die Interessen Deutschlands in diesem Forum (Näheres zu den Aufgaben vgl. B.II.2.).

[32] Vgl. ESFRI, persönliche Mitteilung.

geplanten Investitionsvolumina je Maßnahme in der Regel über 50 Mio. Euro.[33] Die Grenze von 50 Mio. Euro als im Wissenschaftsrat vereinbarte Schwelle für die Begutachtung von Infrastrukturmaßnahmen, ist im Grundsatz angemessen.[34] Im Folgenden werden sie als **umfangreiche Forschungsinfrastrukturen** bezeichnet. Auch die derzeit im Rahmen der europäischen Union diskutierten Projekte überschreiten fast ausnahmslos die 50-Mio.-Euro-Grenze.[35] Diese begutachtungsrelevante Schwelle kann jedoch unterschritten werden, wenn mit einer solchen Maßnahme für eine Disziplin Struktur bildende oder Struktur verändernde Prozesse einhergehen.

II.2. Zur Förderung von umfangreichen Forschungsinfrastrukturmaßnahmen auf nationaler und europäischer Ebene

Umfangreiche Forschungsinfrastrukturmaßnahmen können in der Regel – schon aufgrund des Investitionsvolumens – nicht länger allein von einem Staat getragen werden. Daher gehört die Frage der Förderung und Begutachtung solcher Maßnahmen in den Kontext der Gestaltung des europäischen Forschungsraumes.

Im Februar 2005 hat die Europäische Kommission (EC) einen Neubeginn für die Strategie von Lissabon vorgeschlagen. Sie hat erkannt, dass, wenn sich der derzeitige Trend fortsetzt, die FuE-Investitionen deutlich unter dem vereinbarten Ziel von 3 % bleiben werden. Im Jahr 2010 werden sie vermutlich erst bei 2,2 % liegen.[36] Daher hat die EC sich auf die „Unterstützung von Wissen und Innovation in Europa“ als eine von acht Schlüsselmaßnahmen geeinigt.[37]

In dieses übergeordnete Ziel fügt sich das 7. Rahmenprogramm (2007-2013) mit vier spezifischen Programmen ein. Neben die Programme „Zusammenarbeit“, „Ideen“

---

33 Vgl. Anhang 2. Eine Ausnahme bildete lediglich das Labor für gepulste, sehr hohe Magnetfelder (HLD) in Dresden mit einem Investitionsvolumen von 24,5 Mio. Euro. Bei 48,5 Mio. Euro lag die Hochfeldmagnetanlage für Strukturuntersuchungen mit Neutronen am HMI in Berlin. Das HMI verfolgt jedoch inzwischen ein alternatives Projekt auf der Basis eines Supraleitermagneten oder einer Magnetanlage in Hybridtechnik.

34 Schon 2002 formulierte der Wissenschaftsrat seine Bereitschaft, in Zukunft Projekte mit einem Investitionsvolumen von mehr als 50 Mio. Euro zu begutachten (vgl. Wissenschaftsrat: Stellungnahmen, S. 76).

35 Vgl. ESFRI: List of opportunities. http://www.cordis.lu/esfri/publications-others.htm. Nur wenige Projekte unterschreiten diese Grenze.

36 Vgl. hierzu u. a. Mitteilungen der Kommission: Die Schaffung des EFR des Wissens für Wachstum, Brüssel, 6.4.2005 (KOM (2005) 118 endgültig: „Derzeit stellt die EU nur 1,96 % ihres BIP für Forschung und Entwicklung bereit, verglichen mit 2,59 % in den USA, 3,12 % in Japan und 2,9 % in Korea. Damit beträgt die Lücke zwischen den USA und der EU etwa 130 Mrd. Euro pro Jahr, die zu 80 % auf Unterschiede in den Forschungs- und Entwicklungsausgaben des Privatsektors zurückzuführen sind“ (ebd. S. 3).

37 Vgl. Mitteilungen der Kommission an den Rat und das Europäische Parlament. Gemeinsame Maßnahmen für Wachstum und Beschäftigung: Das Lissabon-Programm der Gemeinschaft. KOM (2005) 330 endg.; Ratsdok. 11618/05, S. 4. Die übrigen Schlüsselmaßnahmen betreffen vor allem die wirtschaftliche und soziale Entwicklung Europas.

und „Menschen“[38] soll das Programm „Kapazitäten“ treten, das der Stärkung der Forschungs- und Innovationskapazitäten in ganz Europa dienen soll. Ein wesentliches Ziel, auf das ein erheblicher Teil – laut Planung mehr als die Hälfte des Budgets „Kapazitäten“ – entfallen soll, ist die Förderung von Forschungsinfrastrukturen. Die Förderung zielt sowohl auf Verbesserungen bestehender Infrastrukturen, als auch darauf, einen Beitrag zur Schaffung neuer Infrastrukturen zu leisten. Dabei werden die Vorbereitung von Projekten (mit einer möglichen Förderung bis zu 50 %) und wahrscheinlich auch die Errichtung neuer Forschungsinfrastrukturen unterstützt.

Um den Ausbau von Forschungsinfrastrukturen effektiv gestalten zu können, bedarf es einer strategischen Planung von Investitionen in diesem Bereich. Grundlage dieser Planungen und Förderentscheidungen der EC sind derzeit die Arbeiten von ESFRI. Die Gründung von ESFRI im Jahr 2002 beruhte auf der Einsicht in die zunehmende Komplexität von Forschungsinfrastrukturen sowie auf der Überzeugung, dass die Entwicklung von Forschungsinfrastrukturen – auch im Zusammenhang mit dem Aufbau des Europäischen Forschungsraums (EFR/ERA) – eher als Partnerschaftsaufgabe denn als Wettbewerbsfeld zu betrachten ist. Im europäischen Raum bestehen bereits mehrere multinationale europäische Vereinigungen (wie CERN, ESA, ESO, EMBL), die eine partnerschaftliche Zusammenarbeit praktizieren.

Die übergeordnete Aufgabe von ESFRI besteht daher darin, eine kohärente europäische Wissenschaftspolitik für Forschungsinfrastrukturen zu entwickeln. Dazu hat ESFRI sich insbesondere zwei Ziele gesetzt:

(1) ESFRI will eine *Inkubatorfunktion für internationale Verhandlungen* über konkrete Initiativen erfüllen. Für zwei in Deutschland verankerte Projekte, das europäische XFEL-Projekt am DESY in Hamburg und das FAIR-Projekt (Facility for Antiproton and Ion Research) am GSI in Darmstadt, hat ESFRI diese Funktion bereits übernommen. Ende 2004 wurde jeweils ein „Memorandum of Understanding“ unterzeichnet.[39]

---

[38] Das Programm „Zusammenarbeit“, auf das mehr als die Hälfte des RP7-Budgets entfallen wird, fördert transnationale Forschungsaktivitäten, von Verbundprojekten bis zur Koordinierung nationaler Forschungsprogramme. Im neuen Programm „Ideen“, gesteuert durch den Europäischen Forschungsrat (ERC), soll die „Forschung an den Grenzen des Wissens“ d. h. vor allem exzellente Grundlagenforschung gefördert werden. Das Programm „Menschen“ zielt auf die Entwicklung und Stärkung des Humanpotenzials mittels der Förderung von Ausbildung, Mobilität und europäischer Laufbahnentwicklung der Forscher. Ein Beispiel ist das Marie-Curie-Programm. Vgl. hierzu u. a. Mitteilungen der Kommission: Die Schaffung des EFR des Wissens für Wachstum, Brüssel, 6.4.2005 (KOM (2005) 118 endgültig, S. 6ff.

[39] Das Memorandum of Unterstanding (MoU) für das europäische XFEL-Projekt haben 13 Länder unterschrieben (vgl. Fußnote 15). Das MoU für die Errichtung des FAIR-Projekt haben 10 Länder (Finnland, Frankreich, Deutschland, Griechenland, Italien, Polen, Russland, Schweden und Großbritanien) unterzeichnet. China will dem MoU beitreten. Österreich, Ungarn, Indien, Rumänien und die Slowakei nehmen als Beobachter teil.

(2) ESFRI erarbeitet einen europäischen Plan (*European Roadmap*) für neue Infrastrukturen von pan-europäischem Interesse, die in den kommenden 10-20 Jahren vorbereitet bzw. geschaffen werden sollen. Eine erste Roadmap soll im Herbst 2006 vorliegen.

Die European Roadmap soll drei Funktionen übernehmen: Sie wird wichtige neue Infrastrukturmaßnahmen und/oder notwendige Verbesserungen bestehender Anlagen – entsprechend den Bedürfnissen der europäischen Scientific Communities – identifizieren. Gleichzeitig fungiert die Roadmap als Werkzeug für Entscheidungsträger im europäischen Raum, um den Auf- und Ausbau von Anlagen in den unterschiedlichen Forschungsgebieten harmonisieren zu können. Darüber hinaus soll die Roadmap die Grundlage für langfristige Budgetplanungen seitens der Förderinstitutionen liefern. ESFRI selbst trifft jedoch keine Entscheidungen über die Finanzierung oder den Standort einzelner Initiativen. Dazu wird – so die derzeitigen Planungen – die EC einen eigenen Ausschuss bilden, der die Entscheidungen im Programm „Kapazitäten" des 7. Rahmenprogramms der EU vorbereitet sowie die Koordinierung mit dem Programm „Zusammenarbeit" übernehmen wird.

Im März 2005 hat ESFRI dem EU-Kommissar für Wissenschaft und Forschung eine **„List of opportunities"**[40] übergeben. Sie umfasst 23 Infrastrukturprojekte.[41] Sowohl die BESSY FEL-Initiative als auch das AURORA BOREALIS-Projekt sind als Vorhaben in die Liste aufgenommen worden.[42]

Über die finanzielle Ausstattung des 7. Rahmenprogramms wird noch verhandelt. Der Wissenschaftsrat würde es sehr begrüßen, wenn das 7. Rahmenprogramm einen Umfang annähme, der die Entwicklung einer starken und kohärenten europäischen und internationalen Wissenschafts- und Technologiepolitik erlaubt. In der Vergangenheit hat Deutschland durchaus von den Investitionen in Forschungsinfrastrukturen im 6. Rahmenprogramm profitieren können. Unabhängig vom Ausgang der Verhandlungen zum 7. RP erachtet der Wissenschaftsrat es für wichtig, dass sich Deutschland aktiv an der Gestaltung des Europäischen Forschungsraums und in diesem Kontext an der strategischen Planung für Forschungsinfrastrukturmaßnah-

[40] Die Liste dient einerseits der Vorbereitung des 7. Rahmenprogramms der EU. Zugleich richtet sie sich an die Scientific Communities, die in ihren Planungen solcher Infrastrukturmaßnahmen zügig voranschreiten und ESFRI über den Stand der Planungen informieren sollen.

[41] Hinzu kommen fünf globale Projekte wie ITER oder der ILC (International Collilder), an denen sich Europa oder einige europäische Staaten beteiligen.

[42] Der BESSY FEL ist Teil des Projekts „IRUVEX-FELs", einem transeuropäischen Netzwerk von sieben Laboratorien für Freie Elektronen Laser (vom Infrarotbereich bis zu weichen Röntgenstrahlen). Dieses Netzwerk soll eine enge und arbeitsteilige Kooperation auf europäischer Ebene sicherstellen. Die Kooperation bezieht sich auf die Vorbereitung des Baus mehrerer solcher Quellen in Europa sowie auf ihre Nutzung, vor allem der Messstationen am jeweiligen FEL.

men beteiligt. Der Bereich der umfangreichen Forschungsinfrastrukturmaßnahmen stellt ein Feld dar, in dem die regionale und die nationale Forschungsförderung an ihre Grenzen stößt, wie der Wissenschaftsrat zuletzt im Rahmen seiner Empfehlung für die Einrichtung europäischer Höchstleistungsrechner festgestellt hat.[43] Hierbei handelt es sich um ein Feld, das auf Gemeinschaftsebene besser und effektiver zu gestalten ist. Die Europäische Union kann hier den besten Beitrag zur Verbesserung des Forschungspotenzials Europas leisten, wenn sie die Ressourcen bündelt.

Zugleich hat der Wissenschaftsrat die „herausgehobene Bedeutung (von Forschungsinfrastrukturmaßnahmen) für die Weiterentwicklung und den Attraktivitätsgewinn des Wissenschaftsstandorts Deutschland“, unterstrichen.[44] Daher sollte sich Deutschland aktiv an der strategischen Investitionsplanung für umfangreiche Forschungsinfrastrukturen im europäischen Raum beteiligen und dafür Sorge tragen, dass eigene Initiativen in Kooperation mit europäischen Partnern auch in Deutschland realisiert werden.

II.3. Zum zukünftigen Verfahren der Evaluierung von umfangreichen Forschungsinfrastrukturen

Der Wissenschaftsrat hat sich bereits ausführlich zum Verfahren der Begutachtung von Großgeräteinitiativen geäußert. Ein beim Wissenschaftsrat angesiedeltes zweistufiges Verfahren erlaubt es, die Initiativen nach einheitlichen wissenschaftlichen und wissenschaftspolitischen Kriterien – auch vergleichend – zu bewerten sowie die Investitionsplanung in einem transparenten Verfahren aus einer übergreifenden Perspektive zu koordinieren.

Bei der Vorbereitung der European Roadmap wurde deutlich, dass – bis auf Großbritannien und Deutschland[45] – kein Land der Europäischen Union bisher eine systematische und koordinierte Investitionsplanung für Forschungsinfrastrukturmaßnahmen vorbereitet hat. Einer solchen Planung kommt jedoch mit Blick auf Europa besondere Bedeutung zu. Denn nicht die EC selbst ergreift die Initiative für ein Projekt. Vielmehr

---

[43] Der Wissenschaftsrat hat in seiner Empfehlung zur Einrichtung europäischer Höchstleistungsrechner festgestellt: „Die Wettbewerbsfähigkeit im internationalen Rahmen kann auf die Dauer sehr viel effizienter durch eine europäische Finanzierung und den Zusammenschluss nationaler Ressourcen erreicht werden“ (Wissenschaftsrat: Empfehlung zur Einrichtung europäischer Höchstleistungsrechner, in: ders.: Empfehlungen und Stellungnahmen 2004, Bd. III, Köln 2005, S. 528 f). Daher hat er sich für die Einrichtung von Höchstleistungsrechnern der höchsten Leistungsklasse auf europäischer Ebene ausgesprochen.

[44] Vgl. Wissenschaftsrat: Stellungnahmen zu neun Großgeräten, S. 73.

[45] Damit sind die Stellungnahmen des Wissenschaftsrates zu neun Großgeräten gemeint.

muss mindestens ein Staat ein Projekt vorantreiben, um eine Förderung auf europäische Ebene erreichen zu können. Daher ist es entscheidend, welche Projekte national Priorität erhalten.

Aufgrund seiner Organisationsform kann ESFRI keine in seiner Tiefe mit dem Verfahren des Wissenschaftsrates vergleichbare Begutachtung der Projekte leisten. ESFRI hat daher bereits sein großes Interesse an den Ergebnissen des Begutachtungsprozesses seitens des Wissenschaftsrates geäußert.

Vor diesem Hintergrund gewinnen die Empfehlungen des Wissenschaftsrates eine europäische Dimension, die die aktive Rolle Deutschlands bei der Gestaltung des EFR unterstützen. Daher empfiehlt es sich, die nationale Koordinierung und Planung von Forschungsinfrastrukturmaßnahmen aus einer übergreifenden Perspektive heraus fortzusetzen und dabei, wie eingangs erläutert (vgl. B.II.1.), alle umfangreichen Infrastrukturprojekte und alle wissenschaftlichen Disziplinen mit einzubeziehen.[46] Es sollten auch solche Projekte berücksichtigt werden, an denen Deutschland im Ausland eine Beteiligung anstrebt.

Der Wissenschaftsrat bittet Bund und Länder darüber hinaus sicherzustellen, dass seine Empfehlungen zum Bau und zur Finanzierung von umfangreichen Forschungsinfrastrukturen in den europäischen Beratungs- und Entscheidungsgremien zur Geltung gebracht werden. Bei der Vertretung der Interessen Deutschlands auf europäischer Ebene muss die notwendige wissenschaftliche Kompetenz einbezogen werden.

[46] Vgl. Wissenschaftsrat: Stellungnahmen zu neun Großgeräten, S. 76.

C. Bewertungsberichte zu den beiden Großgeräteinitiativen

C.I. Recommendations on the BESSY Soft X-ray Free Electron Laser (BESSY-FEL)

Drs. 7031/05
Cologne, 15 December 2005

Recommendations on the BESSY Soft X-ray Free Electron Laser (BESSY-FEL)

Contents | Page

Note:

This statement given by a sub-panel of the steering committee „Large-scale Facilities for Basic Scientific Research“ of the German Science Council concentrates on the scientific and technical investigation of the project. A separate report evaluates the project from an overall science policy perspective taking into account the results of another sub-panel assessment on the European Drilling Research Icebreaker AURORA BOREALIS.

The report is divided into two parts. The first descriptive part is cleared with BESSY regarding the correct reproduction of the facts. The second evaluating part contains the results of the assessment procedure from an expert point of view.

A. Introduction and Background

A.I. Field of Research

Over the last thirty years remarkable progress has been made in VUV, soft X-ray and hard X-ray science and its applications, largely stimulated by the availability of synchrotron radiation from storage ring facilities. In such storage rings, SR is emitted by relativistic electrons that are radially accelerated in a magnetic field. Modern synchrotron radiation facilities provide important tools for research in a large number of different fields of science, such as physics, chemistry and biology as well as in materials, geo- and environmental sciences. So far, the pace of progress in the various fields of research has been closely tied to the development of synchrotron radiation sources for which the tunability, output power, brilliance and polarization are unmatched by any other short wavelength source.

Synchrotron radiation (SR) has been regarded for a long time as an unwanted by-product of high energy synchrotrons and storage rings and was first time applied for research in the late 1950s at Cornell (USA) and further exploited for research in the late 1960s for instance at TANTALUS (Wisconsin) and at the DESY I synchrotron in Hamburg. In the 1970s, new storage rings became available as much more stable sources at SPEAR I (Stanford) and at DORIS (Hamburg). These facilities were followed by so-called dedicated or 2nd generation synchrotron light sources (among others SRS at Daresbury, BESSY I at Berlin-Wilmersdorf, NSLS at Brookhaven, Photon Factory (Tsukuba), DORIS III at DESY and ANKA at Karlsruhe). These dedicated storage ring facilities of the 2nd generation produced the radiation still predominantly in bending magnets and wigglers, although first UV undulators started operation 1986 at DORIS as well as a first in-vacuum undulator and a crossed field undulator were operated in BESSY I as early as 1987 and 1991. In the 1990s the 3rd generation synchrotron light sources started operation, in which wigglers and especially undulators were inserted into storage rings specially designed for low emittance (for instance ESRF in Grenoble and BESSY II at Berlin-Adlershof). These undulators provide stable and well collimated vacuum-ultraviolet (VUV) and/or X-ray beams and enhance the brilliance of the radiation by several orders of magnitude. The construction of low emittance storage rings has become a proven technology and the innovation at 3rd generation facilities is by now mainly in stable operation and in the design of undulators, beam lines and instrumentation.

The undulator based beams at 3rd generation synchrotron radiation facilities not only deliver high-brilliance beams for new imaging techniques and spectroscopy with nanometer resolution and for structural determinations of very small protein crystals, but also allow for a very flexible control of the polarization properties. The latter is extremely useful in the investigation of specific magnetic properties of matter. Microbeams are also used for interface studies revealing the internal atomic and electronic structure of nanoscale structures, liquid surfaces, catalysts, magnetic layers etc. First real time structural studies are reported down to picosecond resolution.

While the storage ring based sources approach their theoretical performance limit with respect to brilliance, degree of coherence and pulse length, the development of linear accelerators (LINAC), providing low emittance electron bunches of high energy, very short bunch length and high electron charge, has stimulated a world-wide effort to develop LINAC driven synchrotron radiation sources, especially X-ray free electron lasers (X-FEL). In the USA, the LINAC driven LEUTL FEL at the Advanced Photon Source in Argonne was the first device reaching saturation in the SASE (Self Amplified Spontaneous Emission) process at wavelengths down to 385 nm. In this scheme, an electron beam with an extremely high density passes through a long undulator. The interaction with the electric field of the photons that are spontaneously emitted in the undulator causes a spatial modulation of the electron bunch. This in turn results in coherent emission of photons by the electrons in the bunch and thus leads to an amplification of the spontaneous radiation of the undulator by several orders of magnitude. The whole process occurs in a single pass and does not require an optical cavity with mirrors, thus the SASE-principle is well suited for X-rays. In 2000, by using the TESLA Test Facility (TTF) at DESY, laser light was generated for the very first time in the wavelength range from 80 to 180 nm. This proof of principle has stimulated intense activities in the field of short wavelength SASE FELs world-wide.

The following table contains some synchrotron light sources (overall there are about 50 operating world-wide), storage rings and free electron lasers (FEL) that are presently being operated as well as FELs currently being under study. IR-FELs are not included in this list since the have developed into standard facilities world-wide by now.

Table 1: Synchrotron light sources, storage rings and free electron lasers (FEL) presently being operated and under study

Type	**Name**	**Location (Start of operations)**
2nd Generation SR (dedicated sources)	ANKA	Karlsruhe (2000)
	BESSY I	Berlin-Wilmersdorf (1981)
	DORIS III	DESY, Hamburg (1992)
	SPEAR II	SLAC, Stanford, USA (1982)
3rd Generation SR (undulator sources)	ALS	Berkeley, USA (1993)
	APS	ANL, Chicago, USA (1995)
	BESSY II	Berlin-Adlershof (1998)
	ELETTRA	Trieste, Italy (1993)
	ESRF	Grenoble, France (1992)
	MAX II	Lund, Sweden (1997)
	SLS	PSI, Villigen, Switzerland (2000)
	SPEAR III	SLAC, Stanford (2003)
	Spring-8	Harima, Japan (1997)
SASE-FEL	LEUTL	ANL, Chicago, USA (no longer in operation)
	TTF I VUV-FEL (with TTF II linac)	DESY, Hamburg User Facility (2005)
X-ray SASE- FEL (under construction)	LCLS	SLAC, Stanford, USA
	European X-FEL	DESY, Hamburg
HGHG-FEL	DUV-FEL Soft X-ray-FEL	BNL,Brookhaven (2002) BESSY, Berlin

However, storage ring based synchrotron radiation facilities are expected to continue to play a crucial role in many different fields of science and will not at all be replaced by LINAC driven X-ray free electron lasers. The LINAC driven light sources are still in the development phase and it will take several years and a large world-wide effort by accelerator physicists and potential users to develop the LINAC and the appropriate instrumentation before such a device will become a research tool of the reliability appreciated at modern storage-ring facilities. By now many synchrotron radiation facilities base their long term strategy on adding LINAC driven light sources to their existing storage rings and devote substantial R&D efforts to this new technology.

To complete the picture, the successful application of energy recovery (ERL) schemes in a superconducting LINAC of the IR FEL at the Jefferson Laboratory, USA, opens the possibility of energy efficient single-pass operation of undulators with low emittance electron bunches. The same concept is also being studied at Cornell University, USA, and could produce normal undulator radiation of higher quality with a peak brilliance expected to be 3 orders of magnitude higher than at present 3rd generation storage rings. Similar studies are being pursued in Daresbury, UK and at KEK, Japan. These ERL facilities offer a large variety of different options with respect to pulse duration and sequence and degree of coherence of the X-ray beams. At least three ERL prototype facilities have been funded and are presently under construction: at Cornell, Daresbury and the electron cooling R&D ERL at BNL. ERL facilities could become available within the next 10 years and they have the potential to significantly extend the range of applications of X-rays in different fields of science.

German SR research has a long tradition starting with DESY in Hamburg more than 40 years ago, extended by the first German dedicated synchrotron radiation source BESSY I and at the end of the 1990s by BESSY II, the first 3rd generation source in Germany. The German SR community also had a very strong impact on the construction and the usage of the European Synchrotron Radiation Facility (ESRF) in Grenoble, which is currently the most important facility for X-rays in Europe and mostly seen as the world-leading facility. At DESY the transformation of PETRA into a third generation Synchrotron X-ray source will start in 2007. World-wide the next generation of new 3rd generation X-ray Facilities with a smaller radius and lower electron energy is also underway, either just in operation, under construction or close before starting, to service the demand of photons around 1 Angstrom wavelength. These are DIAMOND (Oxfordshire, UK), CLS (Saskatoon, Canada), SOLEIL (Paris, France), ALBA (Barcelona, Spain), SSRF (Shanghai, China), AS (Melbourne, Australia), SLS (Villigen, Switzerland) and NSLS-II (Brookhaven, USA).

At DESY Hamburg - besides the synchrotron radiation source DORIS III - a linac driven FEL facility for the hard X-ray wavelength range is planned as a European institution (European XFEL). At the TESLA Test Facility (TTF I) at DESY an FEL was operated at wavelengths around 100 nm. The DESY VUV-FEL (with TTF II linac) started operation recently as a facility serving users since mid 2005. In order to further improve the performance of the photo-cathode electron gun, a dedicated test station (PITZ) was built by a collaboration of DESY, BESSY, Technical University Darmstadt and the Max-Born-Institute at DESY-Zeuthen. After the shut down of

HERA in 2007, the storage ring PETRA will be reconstructed to become the world's most brilliant synchrotron radiation source in the X-ray range (PETRA III). The "Electron Accelerator of High Brilliance and Low Emittance" (ELBE) with a high power FEL in the infra red, driven by a TESLA type LINAC, has started to operate at the Forschungszentrum Rossendorf (FZR).

Furthermore, important activities towards the construction of LINAC-driven X-FELs are pursued in Italy, mainly by institutions which are members of the TESLA collaboration. At ELETTRA a soft X-ray FEL (FERMI) is under construction. FELs for the VUV spectral range are discussed in Lund, Sweden, and at Daresbury, UK. In addition, the possibility of constructing an ERL source is discussed in the UK, a small scale prototype of this ERL is presently under construction. The Linear Coherent Light Source (LCLS) at Stanford aiming for laser light at 0.15 nm is under construction, so that the first light could be available in 2008/9. In Japan, an X-ray laser for wavelengths down to 3.6 nm is under construction at the Spring-8 site.

Thus, the development and planning of new FEL based facilities is proceeding at several locations around the world: USA (Stanford, Argonne, Cornell), Japan (Spring-8), Russia (Novosibirsk), Italy (ELETTRA, SPARC), England (4GLS), Sweden (MAX-lab), France (Arc en Ciel) and Germany (DESY, BESSY).

A.II The Proposed Facility

II.1. Scientific Objectives and Research Prospects

BESSY proposes to build a Soft X-ray FEL user facility in the photon energy range 24 eV to 1000 eV with reproducible, short (less than 20 fs) pulses in a quality that is – according to BESSY – not available anywhere else today. This FEL project is based on three technological innovations: The SASE (Self-amplified spontaneous emission) process, the HGHG (High-Gain-Harmonic-Generation) scheme of cascaded seeded FEL stages and the development of the superconducting TESLA cavities that allow CW-operation.

The HGHG FEL will be able to fulfill – as BESSY stated – the crucial requirements of the user community concerning pulse length, pulse shape, reproducibility, synchronization, and pulse peak power. The BESSY-FEL will not replace the existing synchrotron light sources as it would be – in the words of BESSY – a powerful "race horse" for its spectral range for world-class research complementing the “work horse” of the conventional source BESSY II.

II.1.1. Research Programme

BESSY has listed the following major scientific applications according to their scientific disciplines:

<u>Chemistry</u>

Femtochemistry: Understanding the dynamics and formation of a chemical bond

On the femtosecond (fs) timescale the nuclei in a molecule or solid are "standing still". Typical vibrational periods are between 20 and several 100 fs. Therefore spectroscopy with fs time resolution allows to observe the effects of the motion of the nuclei on the electronic structure in a molecule, solid, or adsorbate on a surface. In pump-probe experiments the development of the electronic states in a dissociating or desorbing molecule can be followed, yielding insight into the transition states and the nature of barriers determining the pathways for chemical reactions. Thus the dynamics of the complete electronic structure can be observed using photoemission as a tool.

Chemistry of radicals

Understanding the factors and key processes influencing the global change in climate is one of the most important scientific problems of present times. The chemistry of radicals as well as of photophysical reactions on the surfaces of suspended nanoparticles play an important role in understanding the processes and interactions in the upper atmosphere. The FEL, possibly in conjunction with an ion device, would be a new spectroscopic tool to study these processes, reaction pathways, cross sections and the formation of elusive chemical species. Furthermore, the FEL is expected to open fascinating prospects for the study and the simulation of the processes and reactions occurring in interstellar clouds in the presence of intense VUV and X-ray radiation.

New perspectives on catalysis

Spectroscopy of catalysts under ‘real conditions’, i.e. under a gaseous atmosphere or submerged in a liquid is one of the visions to advance research in catalysis from the study of model systems towards real catalysts. Photons are able to penetrate their environment and to carry spectroscopic information. Using sum frequency generation (IR + VUV), for example, a specific vibrational mode can be detected originating at a specific atom selectable via the chemical shift of its core electrons. Resonant inelastic X-ray scattering is another probe that allows to distinguish the electronic structure at atomic centers according to their chemical environment, promising new insights about local electronic interactions at the reaction centers in this complex environment.

Physics

Magnetization dynamics of nanostructures on the femtosecond time scale

Magnetic data storage is continuously increasing in density and speed. In order to explore and expand the limits of this important technology, the BESSY FEL would enable studies of the magnetization dynamics of magnetic nanostructures and clusters on the femtosecond timescale in conjunction with nanometer spatial resolution. Dichroic effects in the soft X-ray regime are an ideal probe to monitor the magnetic moments with elemental specificity in space and time.

Atoms and molecules - New fundamental limits

Novel exotic states of matter can be prepared by Bose condensation of atoms in electrodynamic and optical traps. The BESSY-FEL would offer unique possibilities for spectroscopy and selective preparation or excitation of dilute assemblies and condensates of atoms in various traps. Thus elementary steps for the experimental realization of quantum computers may be explored. Furthermore, linear and non-linear interaction of radiation with atoms and molecules would serve to test very basic theoretical models with the highest possible precision.

The nature of complex solids

To give an example oxidic materials exhibit a wealth of phenomena. In particular, the mechanism of superconductivity in superconducting oxides is still not understood. Apart from the high-temperature superconductivity of the cuprates this includes also the colossal magnetoresistance phenomenon of the manganates. These materials exhibit complex phase diagrams with interesting stationary and dynamic phases. Resonant inelastic soft X-ray scattering, which can also be carried out in the presence of magnetic fields, as well as electron spectroscopy with ultimate energy and momentum resolution hold the promise to furnish decisive data to resolve some of these mysteries of solid state physics. The BESSY Soft X-ray-FEL would enhance the resolution capabilities for electron spectroscopy and soft X-ray scattering by orders of magnitude in the spectral and spatial domains.

Ultra-high resolution spectroscopy

The dramatic increase in brightness of the FEL would open up the possibility to perform investigations of the electronic structure of atoms and molecules, solids and surfaces with an ultra-high resolution comparable to the thermal energy scale (Kelvin). This would allow one to investigate energy gaps in superconductors, phase transitions, Kondo resonances, and other many-body phenomena with unprecedented spectroscopic precision.

<u>Life sciences and environmental sciences</u>

Dynamics in biological systems

The BESSY soft X-ry FEL would open the unique possibility to combine microscopy with a resolution in the nanometer range, spectroscopy with high energy resolution and accordingly high chemical selectivity, and a superb time resolution in the femtosecond range in investigations of biological systems in their natural wet environment. This would open a new route to develop an understanding of functional systems such as ion channels, molecular motors and pumps embedded into cellular membranes. Furthermore, the dynamics of various steps in biological functional cycles in photosynthesis or in enzymatic reactions may be followed and resolved in real time. Radiation damage is a concern, however some of it may be alleviated by the fact that sufficient signal may be recorded within the timeframe of a single FEL pulse, faster than the important fragmentation processes that are occurring.

Environmental chemistry and analysis

Chemical and biological processes occurring at the complex interfaces between organic and inorganic matter, aqueous solutions, and gases control the composition of the environment and determine the migration and toxicity of pollutants in the biosphere. Understanding these processes and their dynamics at the molecular nanometer size scale in their natural environment is a key factor for the development of better models for the spreading of pollutants and to develop better strategies for environmental remediation. Soft X-rays from the FEL would uniquely enable a characterization of these systems and processes in their natural state with nanometer spatial and sub-picosecond time resolution.

Materials science and technology

Clusters as new materials

Clusters of almost any element of the periodic table may be assembled with an exactly defined number of atoms thus paving the way for the development of new materials tailored with unprecedented precision. The fullerenes are presently the best known example of such cluster materials. Upon condensation, the fullerenes form a semiconducting solid, the third modification of carbon apart from graphite and diamond. Because of their low density, mass-resolved clusters can in general only be produced and studied in molecular beams using lasers. Consequently, with a few exceptions, for individual clusters neither the atomic geometry nor the electronic structure has been determined. The FEL with a photon energy in the VUV and soft X-ray range and pulse energy comparable to present day lasers would be a unique tool for the characterization of these exciting new materials.

Materials and processes observed under technologically relevant conditions

Electrochemical reactions, thin film growth, corrosion, and friction are, apart from catalysis, technologically and economically highly relevant processes, where surfaces are in contact with a gas or a liquid. The FEL photons have sufficient intensity to penetrate this liquid or gaseous environment. This would open the field for spectroscopic investigations of these surfaces under process conditions using the methods of resonant inelastic soft X-ray scattering for the investigation of the electronic structure with not only elemental but even chemical specificity.

Characterization of fusion plasmas

The diagnostics of elementary processes in fusion reactors rely on the analysis of the characteristic radiation emerging from the reactor. Important parameters for these diagnostics are absolute cross sections and lifetimes of highly excited states of multiply charged ions, which are currently only partially known. Using the FEL a reliable database may be established in studies of dilute plasmas or on ion beams to provide a better understanding and diagnostics for the development of this future energy source.

Nanofabrication of materials using soft X-rays

Materials with a structural size on the nanometer scale offer unprecedented possibilities for atomic scale engineering of materials which is synonymous for tailoring the electronic, optical, magnetic, chemical or mechanical properties to specific needs. Already today, thin film systems, where one dimension is reduced to the nanometer-size scale, form the basis of the advanced electronics and information industries. Laterally or even 3-D structured materials with controlled features in the nanometer range are still largely a challenge for the future. At the BESSY FEL, feature sizes may be realized that would be - corresponding to a wavelength limit as short as 1.2 nm - much smaller than envisioned for the next step in industrial applications of EUV Lithography (at 13.5 nm). Furthermore, the FEL, where the high power is concentrated in an extremely narrow spectral range, would be an ideal source for nanolithography.

Spectroscopy and imaging

Time resolved spectroscopy – reaching the attosecond range

Intrinsically a SASE FEL has pulses up to about 100 femtoseconds in length. Advanced seeding concepts, which are the basis of the HGHG design of the BESSY

FEL presented here, would be implemented in close collaboration with the Max-Born Institute Berlin (MBI). This design holds the promise to reproducibly reach pulse lengths shorter than 20 femtoseconds. Ultimately for soft X-ray pulses the time resolution could be pushed into the attosecond region, far beyond the limits of lasers at photon energies in the visible optical spectrum.

New frontiers in photon-related spectroscopies and coherence

The FEL offers a fully transversely coherent beam with about 10^9 degenerate photons within the coherence volume. Exploiting the coherence would open the pathway for new imaging techniques, where the individual rather than the statistical properties of the sample could be probed in time resolved single-shot experiments in life sciences, environmental sciences as well as materials and chemical sciences. Furthermore, photons are able to penetrate through solids, liquids, and gases. Thus resonant (inelastic) scattering offers a unique, element and chemical environment selective probe of the electronic structure.

The start of the scientific research programme at the BESSY FEL will possibly be in 2012.

II.1.2 Services

Services at BESSY II include:

- development, construction, and access to highly advanced undulator sources and beamlines providing monochromatized synchrotron radiation and support in using these beamlines;
- development of experimental techniques and instrumentation including support by external user groups;
- fabrication and characterization of optical elements for synchrotron radiation beamlines.

Users have the choice of installing their own experimental stations for their specific experiments or of making use of CRGs (Cooperation Research Groups)[47] or BESSY

---

[47] Collaborating Research Groups (CRGs) may set up beamlines and experimental stations from own funds. Beamtime for own research of the CRGs is up to 70 % of the available time while 30 % must be allocated to general users.

owned and operated end stations equipped with experimental techniques. Recently BESSY has embarked on a project where more and more highly sophisticated sample chambers and environments will be provided by the facility for use of external groups. In addition, BESSY offers scientific advice for preparing experiments and infrastructure support for performing experiments including logistics, housing etc.

Services related to the operation of the Soft X-ray-FEL are planned to be outsourced as widely as possible, such as the operation of the user guest facilities, the servicing of technical infrastructure and possibly the full operation and maintenance of the ryogenic system for the superconducting linear accelerator.

The different user groups of the BESSY FEL will require different sample environments and detector setups. Nevertheless, there would also be quite a number of common features. For example synchronized pump-laser pulses (using commercial technology for the IR to the UV wavelength range) will be provided at each FEL experimental station. Furthermore, a set of generic end-stations would be constructed as part of the original FEL budget. The exact kind of these end-stations will be determined in discussions with the user community following a similar process as was adopted for the construction and implementation of the ESRF beamlines.

Due to the very special properties of the HGHG- FEL, BESSY expects that in a close collaboration with user groups highly sophisticated experimental end-station equipment, such as a microscope facility for wet samples of the life sciences, atom or ion traps, a cluster beam facility and others would be installed for several months at a time or even longer at one of the FEL stations. Additionally, femtosecond-lasers in the IR, visible, and near UV photon energy range would be made available for pump-probe experiments with extensive scientific, technical and engineering support from BESSY.

II.1.3. National/International Networks

On the national level there are different networks into which the facility is to be incorporated. In Berlin there are currently two “Sonderforschungsbereiche” (Collaborative

Research Centres, SFBs)[48] which could benefit from the Soft X-ray FEL. Scientists of the SFBs have contributed to the scientific case of the FEL. Moreover, BESSY also expects that research groups of the Deutsche Forschungsgemeinschaft (German Research Foundation, DFG), which have recently been established or are presently being established in the general field of femtosecond spectroscopy of solids and clusters, would be highly interested in the BESSY Soft X-ray-FEL.

BESSY scientists take part in the DFG Priority Programme 1133 (“Ultraschnelle Magnetisierungsprozesse”) and groups from this programme as well as from the DFG Priority Programme 1128 (“Optical analysis of supramolecular biological complexes”) are carrying out experiments at BESSY. The Soft X-ray-FEL is supposed to be integrated into the “Verbundforschung” of the Bundesministerium für Bildung und Forschung (BMBF). BESSY scientists are already partners in such a project (in co-operation with scientists of DESY, of the University of Münster and of the Freie Universität Berlin).

The Max-Planck Society considers establishing an institute for FEL-based research with about six research groups in three departments which should be located at both FEL sites in Hamburg and in Berlin.

On the European scale, the FEL is planned to be part of the programme “Large Scale Facilities” like BESSY II. Apart from this, BESSY was involved in an EC funded project with the goal of synchronizing an external femtosecond-laser to the VUV-FEL at DESY and to carry out first FEL-pumpe-probe experiments. BESSY recently also received a grant within the Human Frontier Science Programme to develop nanotomography for applications in cell biology together with scientists from the NIH (Bethesda, USA).

BESSY, DESY and institutions from four other European countries are closely cooperating in a number of FEL related projects of the EU-funded EUROFEL design study. BESSY and DESY work together concerning targeting injectors (PITZ), CW-operation of superconducting cavities (HoBiCaT), and the preparation of the indus-

[48] The two SFBs are: SFB 450 „Analysis and Control of Ultrafast Photoinducted Reactions/ Analyse und Steuerung ultraschneller photoinduzierter Reaktionen“ at the Technical University of Berlin and the SFB 546 “Structure, Dynamics and Reacitivity of Aggregates of Transition Metal Oxides/Struktur, Dynamik und Reaktivität von Übergangsmetalloxid-Aggregaten“ at the Humboldt University of Berlin.

trial production of complete cryomodules.[49] Jointly with MAX-lab a test facility for the HGHG FEL will be installed at Lund within the EUROFEL programme.

II.2. Technology

Following the success in reaching full gain at the SASE-FEL at LEUTL, Argonne, and the demonstration of SASE laser action at wavelengths below 100 nm with the TTF I at DESY in the years 2001/2002, now extended to the VUV user facility, the time seemed to be ripe to design and construct a FEL for the VUV and XUV energy range, the traditional spectral range of the BESSY user community. But the performance of SASE-FELs needs to be improved. Especially a shot-to-shot reproducibility of the photon pulses with respect to width and shape and a possibility for synchronization at the level of a few ten femtoseconds were strongly requested by the potential users.

The HGHG scheme pioneered and successfully demonstrated at BNL (Brookhaven National Laboratory) is the only approach which offers the possibility of generating photon pulses of variable femtosecond duration, gigawatt peak power, full shot-to-shot pulse reproducibility as well as full transverse and longitudinal coherence. Hence this promising alternative single-pass FEL approach has been chosen for the BESSY-FEL. The HGHG-FEL would offer inherent synchronization at the femtosecond level for pump-probe experiments, since the timing of the FEL pulse is determined by the optical seed pulse and not by the timing of the electron bunch in the linear accelerator. A shot-to-shot reproducibility of shape and pulse width is given.

To synchronize FEL-pulses with external lasers on the femtoseconds time scale is the major challenge at all current projects. The seeded HGHG-FELs have the inherent advantage of using the same optical laser pulse to produce the X-rays and to pump the sample. According to BESSY they therefore present the superior technology to obtain synchronization values below 50 fs in the near future.

The superconducting CW-linac will produce flexible pulse patterns of monoenergetic soft X-ray pulses of variable femtosecond duration at extremely high peak brightness as well as full transverse and longitudinal coherence. The use of an external seed in

[49] Main contributions from BESSY's side on the Photoinjector Test Stand at Zeuthen (PITZ) and at the VUV-FEL are a fast (ps) photon beam diagnostics, a time correlation photon beam setup, the design of the monochromator installed at the VUV-FEL as well as beamline components, electron intensity and pulse shape diagnostics, software modules of data analysis, magnets, and power supplies.

this cascaded HGHG-FEL provides full control on the output photon pulse in terms of pulse duration and pulse shape. Only minor modifications are required to adapt the (pulsed) TESLA technology for CW operation. In comparison to the photon beam characteristics of SASE - FELs there are significant advantages in output-power stability, negligible power fluctuations during the pulse, and a shot-to-shot reproducible non-spiky spectral power distribution.

To exploit the full flexibility of a CW-linac, a superconducting photoinjector is needed. Following the successful pioneering works at FZR (Forschungszentrum Rossendorf), an initiative of BESSY, DESY, FZR, and MBI has been formed to develop a superconducting photoinjector for ELBE (Electron Accelerator of High Brilliance and Low Emittance) at the FZR and the BESSY Soft X-ray FEL. As stated by BESSY, such an injector will be feasible at the time of the construction start.

In the first phase of the project the scientific potential of the BESSY Soft X-ray FEL will be developed as follows:

- Constructing and commissioning the basic facility with a normal conducting photoinjector and three HGHG-FEL lines with nine experimental stations.
- Due to the rapid progress worldwide in the development of superconducting CW photoinjectors since the publication of the TDR in early 2004 the implementation of such a photoinjector that exploits the full flexibility of the CW linac will be possible already in the first phase. Variable pulse repetition frequencies can then be chosen according to the experiment’s requirements.

In a second phase of the project a number of extensions and performance improvements are possible that can be realized without any major change on the available building site. These are:

- Increasing the number of FEL lines from three to five with a corresponding increase in the number of experimental stations from nine to 15.
- Adding spent beam undulators and corresponding beamlines, as well as experiments.

Thus the unique push from utilizing the enormous brilliance output of the FEL can be further expanded to deliver highly flexible, low-energy-spread femtosecond pulses with photon energies reaching far into the X-ray range.

BESSY does, however, not regard a mere enlargement of the site as a necessity for future expansions, but clearly sees that the facility will benefit from new developments such as photoinjectors with even lower emittance or from the expected progress of seed lasers e. g. HHG lasers.

II.3. Transfer of Research Results

Even though it is quite difficult to extrapolate from present day sources to the performance levels of the FEL (an improvement in brilliance by almost ten orders of magnitude), a diverse scientific programme ranging from physics, chemistry, materials science to biology, life and environmental sciences has been envisioned and documented (cf. A. II.1.1). Most of the scientific goals are oriented to basic research, but in some areas technological impact is predictable. BESSY states three examples:

- Research on the magnetization dynamics of magnetic nanostructures would help to expand the limits of magnetic data storage technology.
- Time-resolved microscopy of biological samples in a wet environment would increase our knowledge in cell biology and could lead to the development of new drugs.
- The study of reaction dynamics of radicals would improve our knowledge of atmospheric processes contributing to the mechanism of global change in the climate.

As in the case of BESSY II, the development of high technology will probably produce an enormous impact for the technology park at Adlershof (WISTA, a supportive environment of small startup companies) as well as in the general area of X-ray optics, precision mechanics, the technique of extreme vacuum, and microsystem technology. BESSY also expects a large impact on optical technology. Optical technology – similar to the electronic development in the 20th century – seems to represent the technology of the 21st century. BESSY and the MBI are both members of the OpTecBB[50] network, which is designed to market new optical components.

The fields mentioned are fields of development for small and medium size industrial companies. Consulting relationships and licensing agreements have been imple-

[50] Optec-Berlin-Brandenburg (OpTecBB) e.V. is an initiative formed by companies and research institutions in Berlin and Brandenburg to promote R&D and usage of optical technologies.

mented with several small companies in and outside Adlershof. BESSY states 13 companies cooperating with BESSY and marketing products under license agreements for a world-wide market. Due to a successful collaboration with BESSY one of these companies working in the field of precision mechanism and vacuum systems has developed to a world-wide leading company in this field.

The realization of the Soft X-ray FEL by itself will have an impact, largely concerning superconducting accelerator techniques, including the construction and operation of a large cryogenic facility, and optical components for high power loads of soft X-rays, which will be very useful for the EUV lithography applications based on plasma sources.

Furthermore BESSY expects that – after startup – the science at the FEL will have an impact on many fields such as information technology, including magnetic and holographic data storage, chemistry and catalysis, the health sector via time resolved imaging of processes in cell biology, and also the energy sector in connection with both solar cells and fusion research.

A.III Institutions Participating in the Project

The Soft X-ray FEL-project is mainly developed in a "cooperation triangle" between BESSY, DESY and the MBI.

(1) BESSY, Berlin[51]

BESSY as the institution in charge of the project has gained for more than 20 years experience in developing, constructing, and operating synchrotron radiation facilities starting with the first German dedicated synchrotron light source BESSY I in Berlin-Wilmersdorf and continuing with BESSY II in Berlin-Adlershof. The BESSY GmbH was for the first time evaluated by the German Science Council in 1994. It certified that BESSY is a service institution with high national and international reputation as

[51] BESSY is a shareholder company. The shares are held by the Max Planck Society (25.8 %), the Hahn Meitner Institute (24.2 %), the Deutsche Elektronen-Synchrotron (DESY, 16.7 %), the Forschungszentrum Jülich (FZJ, 16.7 %), and the Forschungszentrum Karlsruhe (FZK, 16.7 %). In 2002 BESSY became a member of the Wissenschaftsgemeinschaft (Association) Gottfried Wilhelm Leibniz (WGL).

well as high scientific potential.[52] It has an international reputation for designing, developing, constructing, and operating state-of-the-art synchrotron radiation facilities. This includes accelerator and storage ring components, undulators and beamlines, experimental end-stations and culminates in the creation of the BESSY II facility.

In 1998 BESSY joined the TESLA collaboration – now TESLA Technology collaboration – and has a representative in the XFEL "Science and Technology Issues" (STI) Working Group.[53]

In the past years, the in-house research at BESSY has been expanded. The additional new activities of the in-house research programme are centered in the following key areas:

- cluster and cluster based materials,
- magnetic thin films and nanostructures,
- development of soft X-ray elastic and inelastic scattering methods for the investigation of novel materials and processes,
- X-ray microscopy and holography.

BESSY has strategically chosen these areas of the scientific programme to match the capabilities of the existing BESSY II facility and also because they belong to areas of science which would clearly benefit from the planned BESSY Soft X-ray FEL. BESSY points out that femtosecond pump-probe experiments are already carried out using visible and UV lasers as well as using the femtosecond slicing experiment at the BESSY II storage ring.

(2) DESY, Hamburg

For more than 40 years DESY has gained experience in building and operating synchrotron radiation user facilities. Presently DESY is operating the HASYLAB synchrotron radiation sources, i.e. the DORIS and PETRA storage rings. In addition, the first

---

[52] Wissenschaftsrat: Stellungnahme zur Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung (BESSY), in: Empfehlungen und Stellungnahmen 1994, Cologne 1994, vol. II, pp. 125-160: „BESSY II bietet (...) günstige Rahmenbedingungen sowie ein leistungsfähiges Umfeld für Nutzergruppen aus dem gesamten Bundesgebiet, stellt aber auch einen spezifischen Beitrag zur internationalen Weiterentwicklung der Forschung mit Synchrotronstrahlung dar. (...) Die Hauptaufgabe der BESSY GmbH liegt in der Bereitstellung eines anspruchsvollen Angebots an Serviceleistungen für externe Nutzergruppen und deren Experimente" (p. 158).

[53] STI is a sub-panel of the Steering Committee (SC) for the European projects FAIR and XFEL.

VUV FEL world-wide is currently operating at DESY. A self-seeding project for the VUV FEL user facility is realized by DESY and the GKSS in collaboration with Århus University. An EU-network including researchers from Dublin City University, Research Center Jülich, Lund-Laser-Centre, LURE, MAX-lab, MBI, BESSY and DESY is currently developing a local facility for pump-probe techniques with optical lasers which will be implemented at the VUV-FEL at DESY. This facility is expected to allow the study of ultra-fast processes initiated by a high power optical laser beam.

The close relationship between BESSY and DESY dates back to the early days of the institution of BESSY, when DESY joined the BESSY GmbH as a shareholder in 1979. In November 1998 a cooperation agreement between BESSY and DESY was signed defining subjects of common interest in the field of R&D of FELs such as cooperation on the further development of FELs with TTF I and TTF II linacs, as well as on the establishment of the necessary know-how to construct an FEL user facility in Berlin-Adlershof.

The DESY-BESSY cooperation is by now a very intensive one. BESSY extensively relies on DESY’s competence in the development of superconducting accelerator modules and on its expertise in FEL technology. In 2004 a second agreement was signed between the DESY and BESSY directors as well as a BMBF representative, where the realization of two FEL facilities, the European XFEL at DESY in Hamburg and the BESSY Soft X-ray FEL in Berlin-Adlershof were defined as a common goal to suit the anticipated user community best.

(3) Max Born Institute (MBI)

The MBI focuses on basic research on and with short-pulse lasers and pursues applications in emerging key technologies. Its competence and experience in the field of high-power, ultra-short pulse lasers for photoinjectors and seeding techniques at FELs is essential for the BESSY Soft X-ray-FEL project as well as for the VUV-FEL and the European XFEL at DESY. The design of all laser systems was performed by the MBI who will also take over the responsibility of constructing these lasers.

All three institutions are cooperating within EUROFEL and were partners in an earlier EU project with the goal to construct and test a synchronized visible laser at the VUV-FEL for pump-probe experiments.

Furthermore, the “Institut für Energiemaschinen und Maschinenlabor, Lehrstuhl für Kälte- und Kryotechnik” of the Technische Universität Dresden acts as a subcontractor cooperating with BESSY in the field of cryogenics for the superconducting accelerator. This institute has influenced the cryotechnique layout of HERA and of the TESLA linearcollider project at DESY.

University scientists as well as scientists from extra-university institutes have been involved in the planning of the Soft X-ray-FEL, especially in defining the scientific case.

A.IV. Users of the Research Facility

The potential users are expected to come from the present BESSY user and laser community. In several workshops with international participation (especially two workshops in July 2000 in Blankensee and in January 2001 in Holzhau) BESSY and its user community have identified areas in science where only the extreme brilliance combined with femtosecond pulses provided by the BESSY Soft X-ray FEL would enable new classes of experiments (cf. A.II.1.1). Following workshops at the annual BESSY user meeting as well as workshops emphasizing certain applications have rounded off the scientific case (applications such as coherence: Motzen in 2002; as magnetization dynamics: at BESSY in 2003 and 2004; as femtosecond spectroscopy: Montreux in 2003 and Zeuthen in 2005 in cooperation with the SLS (Swiss Light Source) and SOLEIL (Soleil Synchrotron, Saint-Aubin in France)).

The BESSY Soft X-ray FEL would generate a unique possibility for scientists to explore and resolve ultra-fast dynamical processes using soft X-rays. The pulse duration of the BESSY FEL is intrinsically about 20 fs full-width half maximum (FWHM), reflecting the duration of the external seed-laser pulse. This opens up the possibilities for studies on structural and electron dynamics of systems including the femtosecond-chemistry field. Due to the fact that the time structure is determined by the seed pulse it would be possible to synchronize the FEL pulse with high precision to pulses from external lasers to perform pump-probe experiments involving soft X-rays.

After an initial test phase and commissioning the FEL (schedule cf. A.V.5), the steady-state schedule of the FEL will closely resemble the present schedule of the BESSY II facility. BESSY plans to operate the facility 5000 user-operation hours per year on a 7-day-per-week, 3-shift-per-day schedule. Remaining time will be reserved for shutdowns to maintain infrastructure and time-consuming upgrades of the accelerator and/or beamlines.

Expansion of the number of FEL-lines from 3 to 5 is planned. Thus up to 15 user beamlines – using switching toroidal mirrors to serve the three beamlines at each FEL – would be available in phase II. Implementation and commissioning of the upgrade are expected to be realized in two shutdown periods in two consecutive years.

Access to the facility will be organized according to the guidelines followed by BESSY II and other international synchrotron radiation research facilities. BESSY will call for research proposals semi-annually. All proposals would be treated equally regardless of origin of the applicants or the funding source (including the ones for the in-house research). In a first step, BESSY scientists will check the technical feasibility of all submitted proposals, given the available beamlines and instrumentation. At the next stage all feasible proposals will be sent to the external selection panel for evaluation of scientific merit. Each proposal will be reviewed in detail by several panel members and based on the ranking and the recommendations of the panel beam time will be scheduled.[54]

As the FEL experiments are very complex, they require substantial support. The plans call for six experimental stations (plus three white light ports) at three independent FELs. The experiments at the three independent FELs would run simultaneously, whereas the time on the individual stations at each FEL would be shared on a shift basis. For each experimental station one scientist and two post-docs as well as the equivalent of two engineers/technicians are required. In sum six scientists, twelve postdocs and twelve engineers/technicians are the necessary user support for the planned six experimental stations (white light ports excluded).

Upgrades and/or additional experimental stations have to be provided for by separate funding.

According to BESSY, the institute has a long-standing tradition in supporting technological activities close to applications by providing XUV radiation for lithographic and

[54] The independent expert panel: BESSY's Beam Time Committee meets twice a year in person at BESSY to discuss the scientific merit as well as to evaluate and rank the proposals.

analytical purposes. An application center for microengineering has been established at BESSY II and is operated jointly with the TU Berlin. This center houses all the auxiliary equipment necessary for a full production line for micromechanical structures and systems generated by the exposure to the synchrotron radiation in the LIGA process. This center is also ideally suited to follow up on the possibilities generated by the interference-based lithography using the coherent FEL beam.

Presently BESSY has industrial contracts with Hitachi Global Storage Technologies concerning research on magnetic recording media and with Sumitomo Industries on investigations of catalysts under process conditions. Both could also be potential candidates for FEL applications. Another potential industrial user could be AMD with a project investigating defect formation and electromigration processes in microprocessor chips.

IV.1. Scientific Education

Many of the experiments are usually carried out by graduate students and postdocs who are trained by BESSY scientists "on the job". Seminars on the currently performed scientific experiments as well as visits and talks by external scientists are scheduled regularly. The high standard of the instrumentation and the stimulating international research atmosphere contribute to the future career of the graduate and postdoc students.

In the past, more than 1,000 scientists and engineers have been educated and trained at BESSY (up to the end of 2004 468 diploma theses, 519 PhD theses, and 43 habilitation treatises). The majority of these young scientists have joined high-tech companies in the field of information technology (semiconductor technology, software), chemical industry, automobile industry, optics suppliers as well as small and medium-sized enterprises and consulting agencies. In addition, a substantial number of scientists and engineers have pursued academic careers. More than 40 faculty positions have been awarded to scientists who performed their research predominantly at BESSY.

IV.2. Public Relations

Groups from publicly funded institutions, universities, industrial companies and school classes regularly visit BESSY (in 2004 110 groups i.e. 2,000 people visited BESSY). BESSY has established collaborations with Berlin schools giving lectures by BESSY scientists, accepting students for practical training and donating a prize for physics. In order to further inform the general public, BESSY regularly arranges open house events. On these occasions, BESSY presents its activities in exhibitions and lectures and organizes tours of the facilities (e. g. “Lange Nacht der Wissenschaften” (5,500 visitors in 2004), “Physik zum Frühstück”).

Furthermore BESSY presented the Soft X-ray-FEL project at parliamentary events, conferences, and lectures. Industry and government leaders visited BESSY on the occasion of the meeting of the initiative “Partners for Innovation” (December 2004).

A.V. Project Management, Location, Costs and Schedules

V.1. Project Management

BESSY plans to follow the same concept that has been applied during the BESSY II construction phase between 1993 and 1998 up to the design of the Metrological Light Source (MLS) of the PTB (Physikalisch-Technische Bundesanstalt, National Metrology Institute for Scientific and Technical Services). There will be three major divisions:

M – Maschine (machine): accelerator and buildings;

E – Experimente (experiments): undulators, beamlines, and experimental equipment; and scientific planning

V – Verwaltung (administration): project administration and controlling.

Each division will be headed by a member of the BESSY directorate who will take responsibility for the budgetary plan and the allocations by the funding agency. There will be internal oversight by the BESSY control group and external reviews by the departments of funding agencies.

The BESSY directorate is transferring the relevant tasks for permanent operation of facilities to the heads of the machine operation and the experimental service groups and will act likewise when the FEL will be operational.

Scientific and technical activities of BESSY are regularly evaluated by a Scientific Advisory Committee (SAC) that meets at least twice a year. It has dealt several times with the Soft X-ray FEL plans. The status of the FEL project is also presented to the Supervisory Board (Aufsichtsrat). The SAC plans to form a Machine Advisory Subcommittee (MAC) and a Programme Advisory Subcommittee (PAC) in order to provide specific guidance during the construction phase of the project.

Since BESSY is a member of the WGL, the Institute is evaluated in intervals of seven years according to the evaluation system of the WGL. In 2004 the evaluation committee visited BESSY. Due to the evaluation outcome BESSY did already register five of 15 recommended positions for beamline scientists for the fiscal year 2006.

V.2. Location

The Soft X-ray-FEL is planned to be built on the BESSY-site in Berlin-Adlershof, the City of Science, Technology and Media (WISTA) next to the 3rd generation synchrotron source BESSY II. The MBI as the major collaborator and the Natural Sciences Campus of the Humboldt-Universität zu Berlin are located within walking distance. Furthermore at WISTA there are several small and medium-sized companies (FMB, RÖNTEC, BESTEC) which supply accelerator and beamline (optics) technology across the world.

BESSY is owner of free-of-charge long-term building rights for the site (an almost 500 m long area parallel to the Teltow canal). In eastward direction a 350 m extension of the site would be possible (presently in possession of the Federal Republic of Germany).

V.3. Costs

V.3.1. Cost estimates for Soft X-ray-FEL development (R&D) and Construction

The total cost for the BESSY FEL is estimated to be 222.32 million Euro according to FY 2003 pricing (assumed accuracy of 10 %). This estimate has been based on the final costs of BESSY II as well as on up-to-date cost information obtained from the TESLA and the MLS/PTB projects. The figure includes costs accruing during the two year preparatory lead phase and the construction phase. It summarizes costs for further R&D, hardware, building construction, infrastructure, operating costs during the construction phase as well as 155 person years (FTEs)[55] of the group to be built up during the project group preparatory and the construction phase. No contingency has been included in the cost estimate. BESSY does however see the possibilities to realize cost savings from industrial mass production if e. g. the superconducting cavities could be produced in coordination with the European XFEL. In this sense, from BESSY's point of view, the estimated cost saving of 20 million Euro could be regarded as a contingency.

Future possible extensions (phase II cf. A.II.2) are not included in the figure given (222.32 million Euro). A phase II of the project foresees extensions and further improvements by two additional FEL lines, spent beam undulators, six additional beamlines and end-stations as well as three additional linac modules for fast energy ramping and an office- and laboratory-building. The cost of this phase II is estimated to 60 million Euro. A possible time schedule for this extension has to be worked out later and depends on the experience gained with the proposed project. Up to now, the costs for preliminary R&D work add up to about 12 million Euro. The following table sums up the remaining costs for development and construction of the BESSY Soft X-ray FEL.

[55] FTE = full time equivalent one man per year.

Table 2: Estimated remaining costs for development and construction

	BESSY Staff (FTE)	Project Staff (FTE)	Total Staff (FTE)	Staff Costs (million Euro)	Other Costs (million Euro)	Total Costs (million Euro)
Costs for R&D						
Preparatory Phase		25	**25**	**1.05**	**10.45**	**11.50**
Construction Phase	300	130	**430**	12.60 5.43 **18.03**	**192.79**	**210.82**
Total* R&D + Construction	**300**	**155****	**455**	**19.08**	**203.24**	**222.32**

* During the project phase plus a two year preparatory lead phase
** In build up during preparatory phase and construction phase

V.3.2. Cost estimates for Soft X-ray-FEL construction[56]

The personnel required for R&D, for the specification, procurement, testing, assembly, and commissioning of components requires an increasing number of staff, up to 50 positions, taking into account a realistic growth of personnel during the project phase of six years.

[56] Cost estimates are based on FY 2003 pricing.

Table 3: Detailed Cost Estimates (R&D and construction)

	Total Staff (FTE)	**Other Costs (million Euro)**	**Staff Costs (million Euro)**	**Total Costs incl. Staff (million Euro)**
Preparatory Phase				
Prep. Building		2.70		2.70
Prep. Experiments	11	3.14	0.46	3.60
Prep. Machine	14	4.61	0.59	5.20
Prep. Phase Total	**25**	**10.45**	**1.05**	**11.50**
Construction				
Civil Construction (Building)	_	**62.00**	_	
Core FEL-Facility: - Injector - Linac modules and RF System - Beam transport - Undulators and seed lasers		**110.04** 3.15 46.58 12.83 20.59		
- Additional infrastructure	130	26.89	5.43	
Beamlines/Experiments: - Beamlines - Experiments	_	**20.75** 10.85 9.90	_	
BESSY Staff	300		12.60	
Construction Total	**430**	**192.79**	**18.03**	**210.82**
FEL Project Total	**455**	**203.24**	**19.08**	**222.32**

An initial set of experiment stations is included:

- high resolution photoemission,
- photoemission microscopy,
- soft X-ray microscopy and holography,
- resonant inelastic photon scattering,
- experiments on clusters, gas jets, and dilute species.

Beyond the initial complement additional funding of user experiments will be required. BESSY intends to encourage the formation of user consortia (e. g. within the framework of the BMBF Verbundforschung or the initiative on FEL research by the Max Planck Society).

European and other vendors for the high-cost components (cryosystems, superconducting cavities, undulators etc.) are well known by BESSY due to their BESSY II project experience and to the MLS/PTB projects. In particular, BESSY and DESY are cooperating with industrial vendors within the EUROFEL project on the realization of industrial production of superconducting cavities and within the BMBF funded project on quality improvement for the fabrications of permanent magnets.

The engineering and the design for the new facility (including the accelerator, the undulators, beamlines, and experimental stations) would be carried out by the BESSY staff and the additional staff. The laser systems would be built by the MBI which has already supplied the lasers for the VUV-FEL project at DESY and for PITZ in Zeuthen. The cryrogenic systems would be designed by the Technische Universität Dresden. The conventional construction would be handled by the construction department of the Max-Planck Society (Bauabteilung der Max-Planck-Gesellschaft).

V.3.3. Cost estimates for Soft X-ray-FEL operation

The annual operating costs of the BESSY-FEL have been evaluated on the basis of a 5,000-hours-per-year operation schedule and amount to 12.4 million Euro.

Table 4: Cost estimates for annual operation

Operation	**Total Staff (FTE)**	**Other Costs (million Euro)**	**Staff Costs (million Euro)**	**Total Cost incl. Staff (million Euro)**
Staff[57]			2.1	
Electricity		3.3		
Regular replacement or refurbishing		2.9		
Maintenance		4.1		
Operation Total/a	50	10.3	2.1	12.4

57 50 persons in addition to the present staff of BESSY II are required for the operation of the Soft X-ray FEL.

50 FTE staff at BESSY would be necessary for the operation of the new facility. This additional staff would be recruited during the six years of project phase reaching a level of 50 FTEs by the end of the project phase. Later they would take on the operation of the new facility.[58]

Although much of the know-how from the present operation crew of the BESSY light source would also be available for the Soft X-ray-FEL and expertise in the field of superconducting RF will have developed around the HoBiCaT project, further personnel for laser and cryosystem operation and sophisticated diagnostic methods would be needed for operation. Therefore, besides having “supervisors” on call for these additional fields, one additional operator would have to be on duty. Altogether 20 operators and supervisors would have to be recruited from the project personnel to ensure an effective operation of the FEL.

The experiments at the FEL would be at a level of sophistication that exceeds present-day experiments at synchrotron radiation sources. Apart from the FEL beamlines the high complexity of experimental end-stations with sample environments ranging from high to low temperatures, ultra-high vacuum (UHV) to high pressures, magnetic fields, aqueous environments for living cells, or ion beams and atom traps and synchronization of seed and pump-probe lasers require support to the users. Based on the personnel that supports experiments at 3rd generation light sources BESSY expects that for operation of the FEL one scientist and two post-docs for each experimental station would be needed as well as a technical engineering staff pool of twelve skilled engineers and/or technicians covering tasks as UHV, electronics, mechanical design, optics, computing/data acquisition, and femtosecond-laser maintenance.

V.4 Funding

BESSY regards the new FEL as a national facility with international participation as far as the user community is concerned. Accordingly BESSY will apply to the Bundesministerium für Bildung und Forschung (BMBF) and the Senatsverwaltung für Wissenschaft, Forschung und Kultur of the Land Berlin (SenWFK) for financing in the framework of the “Großgeräte der Naturwissenschaftlichen Grundlagenforschung”.

---

[58] 20 operators and supervisors are required to ensure the effective operation of the FEL facility. For operation of the FEL beamlines and experiments 30 FTE are needed, in total 50 FTE (cf. A.IV).

BESSY expects that funds would be shared in the ratio of 90 % (BMBF) to 10 % (SenWFK).

BESSY deems it necessary, that for the activities in the two year preparatory phase (cf. V.5) a continuation of the R&D funding (until 2005 by the Zukunftsfonds) must be secured. The institute has filed a corresponding application for 11.5 million Euro to the state of Berlin. The Berlin Standing Committee for Science and Technology has according to BESSY favorably discussed this application at its meeting in June 2004 at BESSY.

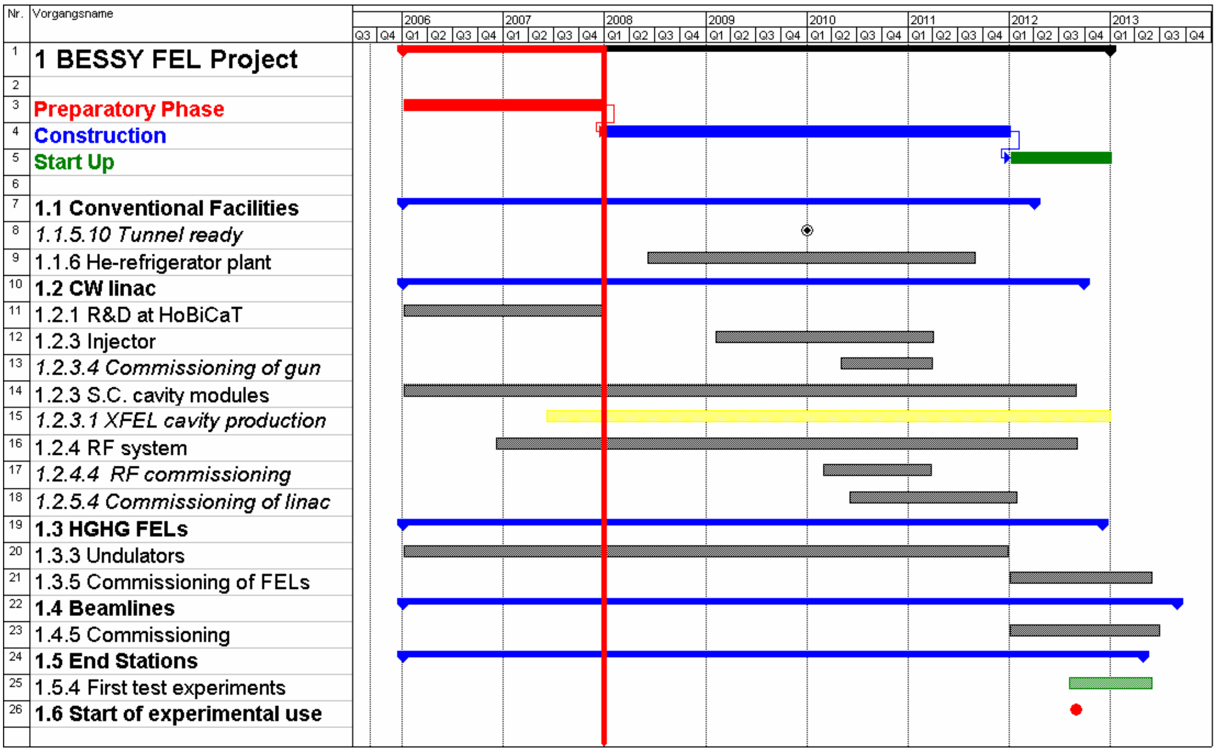
Currently BESSY receives funding at the level of about 6.4 million Euro for access and development projects of the storage ring and FEL applications within FP6. BESSY expects that this level of support increases when the BESSY FEL is constructed.

The long-range perspective of one large European XFEL facility in addition to several smaller complementary national FEL facilities for the VUV and Soft X-ray range was adopted by the European Strategy Forum for Research Infrastructures (ESFRI). In March 2005 ESFRI has presented a "List of Opportunities" to the European Commission including a project of a Trans-European Network of complementary Infrared to Soft X-ray Free Electron Laser Laboratories for NanoScience and Technology (as one of 23 projects in the list of opportunities).

V.5. Schedule

The schedule for the BESSY Soft X-ray FEL user facility is based on established and proven technologies available today, allowing for a fast start after approval of the project. Total construction time for the facility is six years, starting with a preparatory R&D phase of two years for finalizing decisions concerning the system layout and further detailing of the design. The schedule for the implementation of the facility is determined by two important activities, the construction of the buildings and their earliest availability, and the procurement of the superconducting accelerator modules. The detailed planning of all civil engineering and the infrastructure of the facility has been done by the construction department of the Max Planck Society. The important milestone "tunnel clear for implementation of the FEL" is set for the 5th year after the project start.

Table 5: Schedule



The most critical milestone determining all planning is the proper synchronization of production of TESLA accelerator modules by DESY and BESSY to take advantage of production of a larger quantity and synergies with the European XFEL project at DESY. As of today, DESY's planning aims for preparation of industrial production of modules in 2007, starting series production in 2009 and installing the last modules in 2012.

All other procurements are independent from third-party timing. The most time-consuming item of those will be the manufacturing of 115 m of undulators, 2 ½ year industrial production is assumed.

Procurement of the cryo-plant will take 30 months, while installation in the technical infrastructure building is scheduled for six months after earliest availability of the building.

Injector and photocathode laser will be available within 16 months after order. Delivery times for conventional magnets, power supplies and vacuum components are within 18 months.

It is realistic to start the experimental programme six years after approval of the project.

The total period of operation of the facility would be at least 15-20 years.

B. Statement and Recommendations

B.I Field of Research

The world-wide interest in synchrotron radiation (SR) based research has been strongly increasing during the last decades. The constant improvement of the quality of SR sources has opened up new fields of research. However, traditional spectroscopic techniques at present synchrotron storage rings face their limits of applicability. With regard to time resolution, brilliance and degree of coherence the development of soft X-ray free electron lasers (FEL) will definitely enlarge current SR opportunities and furthermore open new experimental methods and fields of research. Nevertheless, FEL facilities will not replace present-day SR storage rings but rather complement them in multiple ways.

X-ray lasers are expected to play an important role in time resolved studies as well as in structural and functional analysis of large molecular complexes, which are crucial to the functioning of cells, but which are extremely difficult to crystallize and thus cannot be studied with present-day SR techniques. There is no doubt that FEL facilities will be able to provide radiation of the appropriate wavelength and time structure so that materials and the changes of their properties can be portrayed at atomic level in both space and time. The further development of the FEL concept will make possible an extension of existing techniques to ultra-short time resolution for structural studies. Furthermore it will open up new domains in coherent radiation, time resolution, wavelengths, and intensity.

FEL facilities are likely to revolutionize experimentation in many areas of research. Fundamentally new insights are in particular expected in the following most important areas:

- dynamics and formation of chemical bonds,
- magnetization dynamics,
- diagnostics in nanostructures,
- dynamics in biological systems,
- single-shot microscopy for materials science and biology,
- environmental chemistry of radicals,
- trace element analysis e.g. in environmental science.

Decisive scientific advances in these fields are highly probable and will allow broad interdisciplinary research.

B.II. The Proposed Facility

II.1. Scientific Programme

In the previous evaluation the scientific case received excellent marks.[59] It was appraised as “extremely strong and well defined”. The programme is at the forefront of international research and will have a strong impact on basic as well as applied science. The enhanced technical approach with the seeding scheme (HGHG) will further strengthen and broaden the scientific programme in significant areas. The specific characteristics of the BESSY-FEL will allow gaining insight in particular by making use of the

- reproducible pulse structure and peak intensity,
- high time resolution,
- complete transverse and longitudinal coherence (transform limited pulses),
- energy tunability by changing the seeding pulse and/or undulator gap,
- synchronized pump-and -probe experiments,
- high repetition rate (CW-operation).

These techniques are partly unique and have complementary characteristics compared to other existing and planned sources as to the VUV-FEL and to the soft X-ray beamline of the European X-FEL at DESY in Hamburg as well as the planned FEL in Trieste and the expansion of the SR facility to a FEL at MAX-lab in Lund (for further details cf. B.II.2).

II.2. Technology

The BESSY FEL is a challenging project. The feasibility of several aspects, such as the superconducting RF linac technology, the low-level RF controls as well as the undulator technology, has already been successfully demonstrated. But some aspects, in particular, the Superconducting RF (SRF) gun technology and the HGHG principle, need more research and development to ensure that they will work in the

---

[59] Cf. Wissenschaftsrat: Stellungnahmen zu neun Großgeräten der naturwissenschaftlichen Grundlagenforschung und zur Weiterentwicklung der Investitionsplanung von Großgeräten. Statement on Nine Large-scale Facilities for Basic Scientific Research and on the Development of Investment Planning for Large-scale Facilities, Cologne 2003, p. 310.

expected way. This R&D work will be crucial in ensuring feasibility of the entire project.

The technology choices in terms of the kHz repetition rate of the gun (up to 25 kHz) and the superconducting RF linac appear to be well matched with the requirements of the soft X-ray FEL and the demands of future experiments.

The choice of the superconducting RF system parameters appears optimal and definitely not stretching the state of the art in CW SRF technology. Higher gradients, up to 20 MV/m, at similar external Q-factors are envisioned for other CW SRF applications, such as the CEBAF 12 GeV Upgrade project and future ERL light sources. To date, there is no experience with acceleration of nC-charge bunches in CW SRF cavities, however no particular issues are foreseen, especially in combination with the relatively low average current. The HoBiCat facility is expected to play a crucial role in the BESSY Soft X-ray FEL project, while it is already playing an important role in the CW SRF development program in Europe in general. At the present time, the HoBiCat facility is used to test and qualify cavities and ancillary equipment produced and assembled by industry. In the context of the EUROFEL collaboration, the HoBiCat facility is used to access the TESLA technology and its suitability for CW operation. Input couplers, transmitters, low-level RF control, microphonics, CW cryogenics are some of the aspects being evaluated with respect to modifications required for CW operation.

During the cavity production phase of the BESSY Soft X-ray FEL project, the HoBiCat facility is envisioned to be used for quality control and testing. Finally, this facility is an invaluable training ground for scientists and engineers in the field of superconducting RF, where the BESSY Laboratory historically did not have expertise. The sub-panel commends the project team for taking the initiative to establish this SRF test facility at BESSY and finds that their plans for using the facility are detailed and advanced, as well as prepared and thought out. Training of BESSY personnel in SRF technology is necessary and should proceed timely.

The photoinjector for the BESSY Soft X-ray FEL is a critical system required for the generation of high intensity and high brightness electron bunches. The superconducting RF gun is the ideal choice for CW operation, and the only technology that could work at a repetition rate of 25 kHz. Further, it allows operation with flexible bunch patterns, a likely user requirement. The SRF gun technology, however, is at the present time the least mature photoinjector gun technology, compared to DC and RF photoinjectors. Substantial development is required on both the engineering and the accelerator physics fronts before SRF guns can be used reliably for routine operation. The two SRF gun experiments that are going on now at Rossendorf and at BNL are important milestones. It is critical that the existing collaboration between BESSY and Rossendorf continues, and lead to the experimental demonstration of the beam parameters required for the BESSY FEL. Furthermore, establishing an SRF injector test stand would allow experimental measurements of the gun performance and experimental verification of simulations. In the next two years, experimental and theoretical R&D on the SRF gun and injector must be pursued with highest priority.

On the other hand, the normal conducting RF photoinjector development - PITZ - provides a safety net for the first phase of the BESSY FEL project (repetition rates up to 1 kHz) as the required injector parameters of the BESSY FEL are within factors of approximately two from experimentally demonstrated parameters from the PITZ gun. The extrapolation appears safe as it is based on simulations that have already been benchmarked against experimental data.

Sophisticated diagnostics capable of quantifying the beam quality in the 6-dimensional phase space is an important and challenging aspect of the injector development program and continuous effort in this area is required.

Some sensitivity studies have been included in the TDR, in which the beam quality and its effects on the FEL performance are evaluated as a function of parameter variation around design values. It is suggested that sensitivity analysis continues with more detailed studies and over a wider and more realistic parameter range, as it will shed light on the operational robustness of the entire system, and may also point towards a global optimization of the design.

It is recommended that the progress of the project development should be assessed regularly by an external committee of experts.

HGHG is a unique approach of achieving control of pulse width, longitudinal coherence, synchronization with the laser and shot to shot reproducibility of the intensity. The technology is explicitly designed following user demands which were worked out in different workshops with international participation (cf. A. IV). Following these demands the SASE technology does not seem to be an alternative as its performance is not comparable to the performance of the HGHG technology.

However, at the present time, only a single stage of HGHG has been demonstrated. This demonstration only reached down to 100 nm. Cascading and operation at shorter wavelengths has yet to be demonstrated experimentally. The thorough work of simulating cascading HGHG and overall analysis of the operation is commendable. Given the state of HGHG development, it is essential to develop an R&D programme in order to experimentally verify at least the second stage of cascading. At the moment, we can not see alternative technologies that would deliver comparable performance to the HGHG scheme.

An upgrade path for adding more beamlines has been identified. However, the ability to take advantage of gun developments is limited by the 180 degree arc, and the future upgrade potential would certainly benefit from a straight linac. The sub-panel perceives the 180 degree bend construction in the present design as a potential obstacle to further developments of the FEL facility and an operational liability of this construction. Therefore, a thorough study of a straight-ahead option should be carried out, as it may lead to an improved performance and to more flexibility. The sub-panel recommends obtaining development rights for the neighbouring parcel in order to allow a straight linac and to preserve the future upgrade potential.

The development and planning of new FEL based facilities is – as mentioned in the introduction (cf. A.I) – proceeding at several locations around the world. In Germany the BESSY FEL must be seen in the context of the VUV FEL Facility, now in operation at DESY, and the proposed European X-FEL also at DESY (with 60 % German funding committed)*. The focus of the European X-FEL will lie on the hard X-rays but it will also hold soft X-ray capabilities. In principal, the VUV FEL Facility and the BESSY FEL are based on different technologies, the most important ramification being that certain classes of experiments are better optimized on one source or the other. For instance, the BESSY FEL with basically transformed limited pulses with perfect synchronization is superior for pump-probe experiments, coherent control ex-

---

* Corrigendum: Following the actual state of negotiations the Federal Republic of Germany agreed on funding the European X-FEL at an amount of 55.5 up to 60 % of the costs; the States of Hamburg and Schleswig-Holstein accepted to contribute 5.5% to the costs.

periments and studies of non-linear phenomena. The following table compares the radiation characteristics of the BESSY-FEL to the other FEL facilities at DESY.

Table 6: Comparison of BESSY-FEL with other FEL facilities at DESY

Parameter/Type	**VUVFEL** SASE	**VUVFEL self seeding**	SASE3 **XFEL** SASE	**BESSY-FEL** HGHG
Electron beam energy [GeV]	0.3 - 1.0	0.3 - 1	10 - 17.5	1 - 2.3
Photon tuning range [keV]	0.02 - 0.2	0.02 - 0.2	0.2 - 3	0.024 - 1
[nm]	60 - 6	60 - 6	6.4 - 0.4	52 - 1.2
Energy tuning by	electron beam energy	electron beam energy	Undulator gap	Undulator gap/ seed frequency
Undulator gap	fix	fix	variable	variable
Pulse duration [fs]	20	400	100	20 (variable)
Seeding	no	yes	not specified	yes
Intensity fluctuations/ stability	of the order 10 - 20%	5%	of the order 10 - 20%	< 1%
CW operation	no	no	no	yes
Repetition rate [Hz]	1 - 10	1 - 10	10	variable < 25000
Pulse pattern [bunches per train]	1 - 7200	1 - 7200	1 - 3250	variable
Polarization	linear (horizontal)	linear (horizontal)	circular/ linear variable	circular/ linear variable
Synchronization	yes < 100fs	yes < 100fs	yes < 100fs	intrinsic by seed
Peak power [GW]	0.3 - 2.8	2	80 - 130	1.5 - 14
Brilliance [10E30 ph/s/mm2/mrad2/ 0.1%bw]	0.2 - 2.4	< 80	500 - 2000	0.6 - 13
Source	TESLA-FEL 2002-01, DESY	J. Feldhaus et al., Optics Comm. **140**, 341 (1997); E.L. Saldin et al., NIM A **445**, 178 (2000).	Report DESY 2002-167; STI report, January 2005; Note ' Base-line XFEL Para-meter ', June 2005.	BESSY-TDR

The baseline layout of the European XFEL Facility gives room for further developing and incorporating schemes other than Self-Amplified-Spontaneous-Emission (SASE) such as seeding and High Gain Harmonic Generation (HGHG).[60] The present layout has ample possibilities to include laser seeding for the soft X-ray FELs. Both space and electron parameters cover the required parameters space. To be reviewed is the possibility to use the filling of the bunch train to reach high average brilliance. Experiments requiring exact knowledge of temporal and spectral distributions, e.g. smooth profiles, will be challenging for FEL sources due to the single pulse character of the radiation. The development of HGHG and SASE sources will show their respective limitations. The design difference, therewith the different orientation of the scientific and the user profile, remains.

The focus of the planned FEL in Trieste will also be different as it is limited to photon energies below 100 electron Volt (eV), not covering the important carbon, nitrogen and oxygen edges, and the transition metal 2p-edges. The proposed MAX-lab FEL will be operating at 2-3 GeV energy. It will be based on the warm linac technology and will hence operate at lower repetition frequencies (200 Hz to start with).

In the whole, the proposed BESSY soft X-ray FEL is internationally very competitive and fits very well into the European net of FEL facilities that are planned or that are already under construction (FERMI in Trieste) as well as in operation (VUV FEL at DESY).

II.3. Transfer of Research Results

The sub-panel expects an impact of the BESSY FEL on scientific and technological developments, in particular on science relying on high time resolution. Femtosecond-chemistry and biology will profit from the new source due to the dynamics and catalysis studies. Furthermore, magnetic recording, fast photon pulse diagnostics, as well as detection schemes will be possible.

Even several spin-offs are expected concerning surface treatment as well as precision-optics and –mechanics. In the fields of X-ray optics, vacuum-technology and cryogenics technology progress is highly probable.

---

[60] Cf. Interim Report of the Scientific and Technical Issues (XFEL-STI) Working Group on a European XFEL Facility in Hamburg, January 11, 2005, p. 10 (cf. also *http://xfel.desy.de/e169/e1736/Interim_Report_STI-XFEL_050111_eng.pdf*).

B.III. Participation of Institutes in the Project and Collaboration

BESSY has established different significant collaborations on the technical and the scientific side. First of all, the FEL project is very well embedded in Berlin's science area, in particular with the proximity to the Max Born Institute and the Humboldt University in Adlershof. The existing collaboration with the MBI will be of special importance to the proposed Soft X-ray FEL since the MBI contributes a unique expertise in laser development and laser applications.

The location in Berlin-Adlershof is perfect for realizing such an ambitious project. The interaction with the other research institutes on site as well as the universities, such as the Free University Berlin and the Technical University Berlin, should be further strengthened and placed on a more formal basis early on in the project. Furthermore, a closer involvement of local universities will boost education and could channel young scientists into the project (cf. B.IV).

There are further significant co-operations with different national research institutes and universities, in particular with the Forschungszentrum Rossendorf, the Dresden University of Technology and the Technical University of Darmstadt. These collaborations have been very fruitful. A well established collaboration also exists between DESY and BESSY who both are members in the international TESLA collaboration. They have defined subjects of common interest in the field of R&D of FELs such as the collaboration on the further development of superconducting RF-technology, as well as on the establishment of the necessary know-how to construct the FEL user facility in Berlin-Adlershof. This fruitful collaboration should be improved to avoid a negative interference with the construction of the European XFEL. This closer involvement of DESY is in particular necessary as a very good and adjusted collaboration with DESY opens significant possibilities for cost savings (cf. V.2.).

B.IV. Users of the Facility

The proposal is embedded in the international community. The user community will be significantly extended and comprised of traditional synchrotron radiation user communities and researchers from the laser science community.[61] The user demand has been studied and identified on the European level. This was confirmed by the ESFRI Steering Group.[62] Although the BESSY FEL will be a national facility, it will offer excellent opportunities for European and other international collaborations concerning science with radiation from synchrotrons and lasers. The BESSY FEL will be a national source with international participation on the user side.

The BESSY expectation that a total of about 100 user groups will be interested in the BESSY-FEL is a realistic one. National university groups, groups of different SFBs and SPP as well as groups coming from the MPG, HGF, WGL (e.g. FZR) etc. will make use of the new facility. A significant amount of the user groups stems from the Berlin area. In this early stage of the project the involvement of industry will be limited.

BESSY has a long and excellent track record in accommodating a large and diverse user community. But careful attention should be paid to the required user support of the BESSY FEL as the institute has suffered from scientific and technical understaffing in support of users on the beamlines. Adequate scientific and technical support for users is necessary, in particular as the BESSY FEL facility will initially be a R&D facility. At a R&D facility the emphasise lies on the development of new methods in close collaboration between the users and the in-house scientists.

A continuing build-up of the user support at BESSY is strongly recommended. This means that strengthening of the user support of BESSY II continues and, at the same time, an adequate user support has to be implemented on the FEL. Otherwise, the

---

[61] For comparison the numbers concerning the beamtime of BESSY II: At the moment, 8.7 % of the beamtime at the BESSY II Bending Magnet Beamlines is occupied by non-German universities, 7.0 % by the EU-I3-Programme, and 5.2 % by BESSY in-house research. At the BESSY II Insertion Device Beamlines 0.7 % of the beamtime is used by participants from non-German universities, 8.7 % by participants of the EU-I3-Programme and 7.2 by BESSY in-house researcher (Source: BESSY).

[62] The European Strategy Forum on Research Infrastructures (ESFRI) was launched in April 2002 to support a coherent approach of policy-making on Research Infrastructures in Europe. The Forum brings together representatives, nominated by Research Ministers, of the 25 EU Member States and of 7 European countries associated with the Framework Programme, and a representative of the European Commission. As part of the development of a European Roadmap for new, large-scale Research Infrastructures ESFRI established three Steering Groups to provide advice on the following fields: Physical Sciences and Engineering; Biological and Medical Sciences; Social Sciences and Humanities. In March 2005 ESFRI presented a “List of Opportunities” to the EC. BESSY is included in this list as part of the IRUVX-FELs (Trans European Network of complementary Infrared to Soft-X-ray Free Electron Laser Laboratories for Nanoscience and Technology) (cf. A.V.4).

competition for resources, in particular expert personnel, between BESSY II and the BESSY-FEL will cause severe problems that will no longer be manageable for the BESSY directorate. Typically a group of 3-5 persons (scientists/technicians) per beamline is the standard at international sources.

The existing user fee is an obstacle and is against the common practise at national as well as at international user facilities. Access to the facility should be based on the excellence of the scientific proposals.

BESSY has well-established procedures how to schedule and support users on beamlines. On the FEL similar procedures should be implemented.

Each user group will consist of a senior scientist and many students. Due to the accessibility of the BESSY facility to external users there is a great impact on the training of future generations. According to BESSY more than 1000 scientists and engineers have been educated and trained at BESSY (up to 2004 486 diploma theses, 519 PhD theses, and 43 habilitation treatises). Nevertheless, BESSY has to strengthen the training of the future generation (in-house activities) as for the moment only 16 PhD-students (seven working on the FEL) as well as 10 postdocs (seven working on the FEL) are supervised by BESSY scientists in their function as a university professor or a “Privatdozent” (lecturer). Training and education should be intensified in the future.

With the opening of the new facility BESSY has to think about new forms of stimulating and facilitating access to BESSY for user groups not yet involved in research with synchrotron radiation (summer schools, additional training programmes etc.).

B.V. Project Management, Location, Costs, Schedule

V.1. Project Management and Location

Over the last 20 years BESSY has become one of the major synchrotron radiation sources world-wide in the VUV and soft X-ray domain. It is experienced in developing, constructing and operating large scale facilities like BESSY I and II. The BESSY laboratory has established an excellent track record, developing BESSY II into a powerful synchrotron light source with 45 experimental stations. Recently, BESSY has successfully implemented a femtosecond slicing scheme as well as pump-probe spectroscopy. This in-house expertise forms a solid base for the development of the FEL science programme.

The parallel operation of BESSY II and the development of the FEL are viewed as a unique opportunity for an excellent programme at the frontier of the science with soft X-ray FELs. The location in the Adlershof Research Park, next to the MBI and the science institutes of the Humboldt-University, is extremely attractive (cf. B.III).

V.2. Costs, Funding and Schedule

The planning and management as well as the on-schedule and on-budget realization of the BESSY II construction is recognized as a major achievement. The present schedule and project cost estimation for the soft-x-ray FEL facility are based on past experience, current developments and knowledge with large scale projects as well as the recent experience with the DESY TTFII and VUV FEL. The principal cost drivers are the civil construction, the linac modules and the RF system. The civil construction, primarily the building housing the accelerator and experimental facilities, was planned in collaboration with the Bauabteilung of the MPG. Cost estimates for the accelerator and FEL components were obtained with reference to industrial sources and with experts from DESY. In the actual cost estimate (cf. A.V.3 table 2 and 3), BESSY has not taken into account expected cost savings from large scale production of the major cost items, the superconducting cavities and RF as well as the undulators. About 20 million Euro cost savings could probably be realized.[63]

Although the level of detail provided on the cost estimate and on the schedule was not in all aspects sufficient to allow for an thorough evaluation, the basis of estimate, the past experience as well as the track record of the management give the planning a high degree of credibility. Thus, the cost and the manpower estimates for the project are judged to be reasonable.

The total project extends over six years, starting with two years for continuation of the preparatory R&D in order to finalize the detailed implementation and specification for fabrication. These first two years foreseen in the schedule for extensive R&D are considered to be an important and prudent feature of the presented schedule. The

[63] Cost savings from large scale production concerning cavities and RF as well as undulators are estimated as follows: BESSY will need 144 pieces of these cavities and RFs that would cost 156 kEuro instead of 323 kEuro per piece. An undulator produced in a large production series would cost 60 kEuro/m instead of 134 kEuro/m. BESSY needs 115 meters of undulators.

realization of the HGHG scheme as the heart of this proposal is very important and should be demonstrated as soon as possible. As stated above, the proof of principle for the HGHG requires additional time and may lead to a stretched-out construction and procurement, potentially also a staged implementation. A staged construction and testing strategy could be beneficial not only for allowing tests on lasing with HGHG but also for developing other options for lasing in case the HGHG technology turns out to be more difficult than expected. BESSY is encouraged to consider and work out in some detail credible fall-back options.

In the opinion of the sub-panel the project is ready for R&D funding. Continued funding is imperative to ensure that the project team does not lose momentum and is able to proceed with the R&D on the key components.

C. Conclusion

The BESSY Laboratory has developed into a research facility with a large and active user community sited in a scientific environment with a strong tradition in soft X-ray science. The BESSY team is recognized for its outstanding expertise and accomplishments in this field. Over the years BESSY has developed an excellent scientific and technical staff. The FEL proposal is a natural, very promising and challenging extension of the current research programme. It represents a valid option for a continued successful development of the whole institution. Therefore the process of developing the FEL should not be interrupted.

Up to now, Germany holds a very good international position in the science with synchrotron radiation. The BESSY-FEL as a project with a demanding future technology is in excellent position to further define and strengthen the leading role of Germany in FEL-based research.

Annex 1: List of Abbreviations

ALBA	Synchrotron Light Facility, Barcelona
ALS	Advanced Light Source, Berkeley
ANKA	Angströmquelle Karlsruhe GmbH
APPLE	Advanced Polarized Photon Light Emitter
APS	Advanced Photon Source, Argonne
AZM	Anwendungszentrum Mikrosystemtechnik/ Application Center for Micro Engineering
BAM	Bundesanstalt für Materialforschung und –prüfung/Federal Institute for Materials Research and Testing
BESSY	Berlinger Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung/ Berlin electron storage ring company for synchrotron radiation
BMBF	Bundesministerium für Bildung und Forschung/Federal Ministry of Education and Research
BNL	Brookhaven National Laboratory
BTC	Beam Time Committee
CLS	Canadian Light Source, Saskatoon, Saskatchewan
CEBAF	Continous Electron Beam Accelerator Facility
CNRS	French National Center for Scientific Research, Paris
COFIN	Italian Grant Review Committee
CRG	Cooperating Research Group
CW	Continuous Wave
DAAD	Deutscher Akademischer Austauschdienst/German Academic Exchange Service
DELTA	Dortmunder Elektronen Speicherring Anlage/Dortmund Electron Accelerator Facility
DESY	Deutsches Elektronen Synchrotron/German Electron Synchrotron, Hamburg
DFG	Deutsche Forschungsgemeinschaft/German Research Foundation
DIAMOND	Diamond Light Source, Didcot, UK
DOE	US-Department of Energy
DORIS	Storage ring for synchrotron radiation of DESY, Hamburg
DUV FEL	Deep Ultraviolet Free Electron Laser
ERDF	European Regional Development Fund
ELBE	Electron Accelerator of High Brilliance and Low Emittance, Forschungszentrum Rossendorf
ELETTRA	Synchrotron Light Laboratory, Trieste
ELSA	Electron Stretcher Accelerator, Bonn University
ERL	Energy recovery
ESFRI	European Strategy Forum for Research Infrastructures
ESRF	European Synchrotron Radiation Facility, Grenoble
EUV	Extreme Ultraviolet
eV	Electron Volt (energy unit)
FEL	Free Electron Laser
FERMI (Fermilab)	U.S. National Accelerator Laboratory
FHI	Fritz-Haber-Institute of the Max-Planck-Society
fs	Femtosecond
FTE	Full Time Equivalent (one man per year)
FU	Free University Berlin
FWHM	Full width at half maximum (linewidth)
FY	Financial Year
FZJ	Forschungszentrum Jülich/Research Center Jülich
FZK	Forschungszentrum Karlsruhe/Research Center Karlsruhe
FZR	Forschungszentrum Rossendorf
GeV	Giga electron Volt
GKSS	Gesellschaft in Kernenergieverwertung für Schiffbau und Schifffahrt
GW	Giga Watt
HASYLAB	Hamburger Synchrotron Strahlungslabor at DESY, Hamburg
HERA	Hadron-Elektron-Ring-Anlage (Particle accelerator) at DESY, Hamburg

HGF	Helmholtz-Gemeinschaft Deutscher Forschungszentren/Helmholtz Association of German Research Centers
HGHG	High Gain Harmonic Generation
HMI	Hahn-Meitner-Institute
HoBiCaT	Superconducting Cavity Test Facility at BESSY (horicontal bi cavity test facility)
HOM	High Order Modes
HU	Humboldt University, Berlin
IFW	Institute for Solid State and Materials Research, Dresden
IR	Infrared
keV	kilo electron Volt
LEUTL	Low energy undulator test line
LIGA	Liga Technique, a micro-fabrication method developed in Karlsruhe (deep X-ray lithography, electroforming and moulding)
LURE	Laboratoire pour l'Utilisation du Rayonnement Electronmagnétique, Orsay, Fance
LINAC	Linear accelerators
MAX-lab	National Electron Accelerator Laboratory for Nuclearphysics and Synchrotronradiation Research, Lund University, Sweden
MAC	Machine Advisory Subcommittee
MBI	Max-Born-Institute
MeV	Mega electron Volt
MLS	Metrological Light source
MPG	Max-Planck-Gesellschaft/Max-Planck-Society
nC	nanoCoulomb
NIH	National Institute of Health, USA
NSF	National Science Foundation, USA
NSLS II	National Synchrotron Light Source, Brookhaven, New York
NSRRC	National Synchrotron Radiation Research Center, Taiwan
OpTecBB	Optec-Berlin-Brandenburg e.V.
PAC	Programme Advisory Subcommittee
PITZ	Photo Injector Test Facility, DESY (Zeuthen)
PSF	Protein Structure Factory
PSI	Paul-Scherrer-Institute, Villigen, Switzerland
PTB	Physikalisch Technische Bundesanstalt/National Metrology Institute for Scientific and Technical Services
R&D	Research and Development
rf	radio frequency
RÖNTEC	Firma Röntec AG Adlershof, Berlin
SAC	Scientific Advisory Committee
SASE	Self Amplified Spontaneous Emmission
SenWFK	Senatsverwaltung für Wissenschaft, Forschung und Kultur of the Land Berlin
SFB	DFG-Sonderforschungsbereich/Collaborative Research Center (funded by DFG)
SLAC	Stanford Linear Accelerator Center
SLS	Swiss Light Source, Villigen, Switzerland
SOLEIL	Soleil Synchrotron, Saint-Aubin, France
SPEAR	Stanford position electron accelerator ring
SPP	Schwerpunktprogramm/Priority Programme (funded by DFG)
Spring-8	Super Photon ring-8 GeV, Nishi-Horima, Japan (Japanese 3rd generation synchrotron radiation facility)
SR	Synchrotron Radiation
SRF	Superconducting Radio Frequency
SRI	International Conference on Synchrotron Radiation Instrumentation
SRS	Synchrotron Radiation Source, Daresbury, U.K.
SSRL	Stanford Synchrotron Radiation Laboratory, Menlo Park, California – division of Stanford Linear Accelerator Center
STI	Science and Technology Issues
Tc	Superconducting transition temperature
TANTALUS	Synchrotron at the University of Wisconsin, USA

TESLA	Tera Electron Volt Energy Superconducting Linear Accelerator
TFR	Forschungsrat für technische Wissenschaften, Schweden/ Research Council on Technical Sciences, Sweden
THz	Terahertz
TTF	TESLA Test Facility
TU	Technical University Berlin
UC	User Committee
UV	Ultraviolet
VUV	Vacuum Ultraviolet
WISTA	City of Science, Technology and Media in Berlin-Adlershof
WGL	Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz
WR	Wissenschaftsrat/ German Science Council
XUV	Extreme Ultraviolet

C.II. Recommendations on the European Drilling Research Icebreaker “AURORA BOREALIS”

Drs. 7080/06
Cologne, 11 January 2006

Recommendations on the European Drilling Research Icebreaker "AURORA BOREALIS"

Contents | Page

Note:

This statement by a sub-panel of the steering committee „Large-scale Facilities for Basic Scientific Research“ of the German Science Council concentrates on the scientific and technical review of the project. A separate report evaluates the project from an overall science policy perspective taking into account the results of the BESSY Soft X-ray Free Electron Laser assessment by a separate sub-panel.

The report is divided into two parts. The first (descriptive) part has been cleared with the Alfred Wegener Institute for Polar and Marine Research (AWI) with respect to the correct representation of the facts. The second (evaluating) part contains the results of the assessment procedure from an expert point of view.

A. Introduction and Background

A.I. Field of Research

The AURORA BOREALIS project addresses two scientific communities, which in part overlap and in part have divergent interests. The first community is the general *polar science* community, which requires a ship for conducting year-round work and pursues a wide spectrum of scientific disciplines. The second is the *deep-sea drilling community*, which would use the ship mainly during the summer months to study the structure and properties of oceanic crust and the history of the oceanic depositional environments that can be deduced from the oceanic sediment cover. Deep-sea drilling was only accomplished once in the permanently ice-covered waters of the Arctic during the ACEX expedition in 2004 and required the deployment of three icebreakers. On the other hand, substantial progress has been achieved around Antarctica by using the drilling platforms of the Deep Sea Drilling Project (DSDP) and the Ocean Drilling Program (ODP) during the ice-free seasons and by deploying a small drill rig from the land fast sea-ice very close to shore (ANDRILL: ANtarctic DRILLing Cape-Roberts-Project).

Polar research and in particular the properties of northern and southern high latitude oceans are currently subject of intense scientific and environmental debate because they are (at the present time) and have been (over historic and geologic time scales) subject to rapid and dramatic change. Many parts of the polar regions respond to global changes more strongly than other regions of the Earth. Repeated news concerning the shrinking of the Arctic sea-ice-cover potentially leading to an opening of sea routes to the north of North America and Eurasia as well as about the calving of giant table icebergs from the ice shelves of Antarctica, are the latest examples for these modern changes which are subject of a global debate world-wide. Up to now, most data from polar seas have been collected during summer seasons but in order to understand the complex dynamics of the Arctic System the other seasons of the year should be investigated in considerable detail too. There are several major themes that are relevant to the project:

(1) Large and medium-scale circulation of ocean and atmosphere

It is thought that the polar oceans, via their interaction with atmosphere and sea-ice significantly influence variations in the global ocean circulation and hence in global climate. To evaluate this hypothesis, it will be necessary to carry out experiments with a variety of ocean models, using satellite data (e.g. form the ENVISAT and CRYOSAT missions)[64], analyses of the atmospheric circulation, and time series of hydrographic measurements. These studies have to be accompanied by detailed investigations of water mass transformation in polar regions and of the related contributions of new deep and bottom waters to the global thermohaline circulation. From the northwestern European perspective the circulation in the Arctic Ocean and its changes are particularly important and data critical to understanding its hydrography and circulation will have to be collected year-round. Additionally studies of the decadal variability of the atmospheric circulation and its interaction with the ocean have to be conducted. The processes controlling the renewal of the world ocean's bottom waters from Arctic and Antarctic deep and bottom watersources have to be investigated by long-term observational programmes and high-resolution regional models. The goal is to describe the nature, impact, and future development of these processes and their variability in numerical simulations that are as close to reality as possible. Such simulations have to take into account processes controlling energy and momentum exchange between the partly ice-covered ocean and the atmosphere as well as the spatial and temporal variability of the sea-ice cover.

(2) Interactions between the pelagic ecosystems and the biogeochemical state of the water masses of the open ocean and as well as of shelf seas, with particular emphasis on flux and natural material studies

Evolution of biota living in the oceanic water column and in the sea-ice as well as related material fluxes to a large degree depend, on the physical conditions and on the availability of nutrients and trace elements and compounds. Composition and evolution of pelagic communities in various Arctic and Antarctic Ocean regions would have to be determined to clarify the complex interactions between the biosphere and the ocean physics including ocean currents and modifications of water masses. It will be

[64] The initial field phase of the CRYOSAT mission failed as the satellite crashed into the polar sea during the first attempted launch on 9 October 2005.

necessary to study the biological properties of these communities, their phylogenetic relations, nature and structure of their natural materials, their dominant species as well as their energy balances. Intensive bentho-pelagic coupling has been detected in the open ocean, which is even more pronounced in the shelf regions. There is a close coupling between the oceanic segmentation of the biosphere with turbulent current systems. Long time series should not only be established for the German Bight of the North Sea, but also for Arctic (Svalbard) and Antarctic (Antarctic Peninsula) regions in order to survey and describe composition and standing stocks of living assemblages in extreme habitats. The aim is to develop models to predict the Potential consequences of future environmental change on the ecosystems.

(3) Physiology and population dynamics of benthic assemblages in the deep-sea and in coastal shelf seas in polar and mid as well as in intermediate latitudes

The properties of benthic habitats depend upon vertical and horizontal advection of food from the pelagic realm and from the sea-floor. In addition to water depth and local environmental conditions they control the biogeography and population densities on the seafloor. Rates of adaptability of benthic organisms to changing environmental conditions can be deduced from diversity, distribution patterns and composition of benthic assemblages. Such studies allow determinations of reaction times of benthic organisms to natural and anthropogenic perturbation These studies will frequently be intertwined with studies of processes controlling the dynamics and fluxes of carbon in marine plants and animals, which can also be investigated by means of laboratory studies and numerical modelling. However, the past decades have seen remarkable changes in key Arctic variables. We do not know in all cases whether these represent temporary perturbations as consequences of human impact, natural long-term trends, or new equilibria. Because Arctic ecosystems are adapted to extreme environmental conditions with large seasonal forcing the increasingly rapid rate of recent climate change poses new challenges to the resilience of Arctic life. The entire system is likely to be severely stressed by changing ice and water conditions, varying primary production and food availability to faunal communities, an increase in contaminants, and possibly increased UV radiance. As the actual changes proceed at a rate beyond evolutionary time scales the adaptive capacity of a number of Arctic populations and ecosystems is certainly not strong enough to withstand the sum of these factors which might lead to a collapse of subsystems.

(4) Reconstructions of past climate systems from deposits in marine and periglacial environments including modelling of their properties and variability

Deposits from the ocean floor contain some of the best archives of past global climate changes, depending on sedimentation rates for short and long time spans ranging from years to millions of years. Impressive progress has been achieved over the past decade, but the high latitude ocean basins in both the northern and southern hemispheres are still poorly known in comparison to the mid- and low-latitude regions. Despite the patchy record it is clear, however, that these regions represent one of the driving forces for climate change during the entire later part of the Cenozoic. Correlation of marine palaeoclimate records to terrestrial and limnic records, as well as to the ice core archive would provide further insights into the interaction between the atmospheric and oceanic circulation and thus contribute to our understanding of the mechanisms of climate change, indeed one of the major challenges for mankind in the coming years. Promising first steps have recently been taken through drilling the sediment on top of Lomonosov Ridge, close to the North Pole and obtaining cores that reach far back in time.

(5) Structure and kinematics of the lithosphere and the polar ice caps

The structure and properties of the lithosphere and its tectonics can be investigated by seismic, gravimetric and magnetic measurements at sea, on land and by means of airborne systems and satellites. Last but not least such data will be collected in large quantities because, in the near future, the regulations of the law of the sea require states with continental margins in the Arctic Ocean to support their claims by means of geophysical data. The Arctic and Antarctic oceans are poorly known in this respect, and many open questions exist when trying to reconstruct their plate tectonic evolution. Such detailed reconstructions, however, are baseline data for deciphering the tectonic history of the polar regions, for evaluating their Potential for non-living resources and for understanding the palaeoclimatic history of the earth over the past 100 million years. Reconstructions will remain subject of study for many years to come. Probably the worldwide largest uncertainties exist in the Arctic Ocean.

(6) Origin and evolution of the Arctic lithosphere

The Arctic basin is underlain by a lithosphere that is among the least understood in the world. For most of the Arctic Ocean the lithospheric history is either only barely understood or completely unknown. Of particular note is the Gakkel Ridge, the world's slowest spreading ridge, which was recently studied during an expedition by scientists on the icebreakers POLARSTERN (Germany) and HEALY (US). In particular, this mid-ocean ridge provides a unique key to understanding both the formation of oceanic crust at very slowly spreading rates and, more generally, of basaltic magmas. This is because low-degree partial melts developed in the Gakkel-Ridge system can be studied in relative isolation from extensive magmatic plumbing systems and from the effects of mixing with melts of higher melting degrees. Since low-degree partial melts are difficult at best to produce experimentally in laboratory settings, the Gakkel Ridge is a globally unique key area for understanding the processes of the formation of basaltic magmas.

Other parts of the Arctic basin are even less well studied. The Lomonosov Ridge is apparently a thin slice of Eurasian continental crust split from the continent by the Gakkel-Ridge, and the age and origin of the basement in the Makarov Basin and at the Alpha Ridge are at present largely a matter of speculation. Lithospheric evolution is also important to the study of the origin of the continental shelf and slope (with their significant mineral resources). Thus, target areas for studies of the lithosphere via drilling will include the Yermak Plateau and similar structures. Of these regions, only the sediment-free western end of the Gakkel-Ridge is amenable to investigation without the use of an icebreaking drill ship. AURORA BOREALIS will enable studies of the basement evolution of these basins for the first time.

(7) Ocean history and basement structure

DSDP and ODP have always faced special problems when attempting to drill deep-sea basins in very high latitudes. Because of the special geography of the polar regions progress has been greater in the Southern Ocean around Antarctica than in the Arctic. The latter has remained largely undrilled, and obtaining stratigraphic sections through the upper Mesozoic and Cenozoic sediment cover of the Arctic Ocean currently has a high priority for proposed future drilling activities. This has been discussed for decades, and the scientific aspects of the problem are well documented in the science plans of the international “Nansen Arctic Drilling Program” (NAD), as well as of the “Arctic Program Planning Group” (APPG) of ODP/IODP. The execution of deep drilling in the Arctic Ocean has yet to be accomplished – the delay being mainly due to the unresolved problems related to deep-sea drilling in sea-ice covered oceans. Arctic deep-sea drilling indeed will be a scientific challenge for the next 10 - 20 years; it would produce a data set indispensable for understanding the evolution of the earth’s climate and, through samples of basement rocks, it would contribute to solving the unresolved puzzle of northern hemisphere plate tectonic and palaeo-geographic evolution. Important progress was made during the exploratory ACEX expedition of summer 2004, when a drill ship escorted by two powerful icebreakers sampled Tertiary and Quaternary sediments from the Lomonosov Ridge.

Despite the important progress that has been achieved off Antarctica, many drilling targets with a very high scientific potential remain in the Southern Ocean. Although the scientific case for AURORA BOREALIS is at present primarily framed from an Arctic perspective, it is important to note that this novel ship could also play a valuable role in the Antarctic realm.

The AURORA BOREALIS project requires the formation of an international consortium of interested countries. Polar research, over the past years, has fostered many international contacts and projects. The type of cooperation which has developed over the past decades will grow in the future and from AWI’s point of view it is a logical step in this evolution to propose the first European research ice-breaker also be a European contribution to the 3rd leg ("Alternate Platforms") of IODP that began in 2003. Consequently, the project AURORA BOREALIS is currently being planned by the European Polar Board (EPB) of the European Science Foundation (ESF) and by the European Consortium for Ocean Research Drilling (ESCOD).

In the international context Germany belongs to the Ivy League in polar research since it decided to join the Antarctic Treaty and established the Alfred Wegener Institute for Polar and Marine Research (AWI) in 1980 which later became the “Stiftung Alfred-Wegener-Institut für Polar- und Meeresforschung in der Helmholtz-Gemeinschaft”. The heavy emphasis of the German polar research programme on marine disciplines, as well as the decision to work in both polar regions are defining features of the scientific directions which are pursued by AWI and its partners.

The AURORA BOREALIS project would have considerable impact on the use of the research and supply icebreaker POLARSTERN which originally had been built as a dual purpose ship: a reinforced supply vessel for work on the Antarctic continent (NEUMAYER base and traverses, that set out from there to explore terrestrial scientific targets) and as a large, modern and sophisticated research vessel which allows to support substantial, international, multidisciplinary expeditions to the remote ocean basins of high latitudes. While presently being obliged to employ POLARSTERN for logistics and science in the Southern Ocean as well as in the Arctic, with expensive and long annual transits between the polar regions of both hemispheres, AWI is now planning to move POLARSTERN permanently to the southern base in Capetown. This 23-year-old ship will be available as a research vessel for approximately 15 more years. It has recently gone through its “mid-life refit” (2002-2004) bringing it up to state-of the art technology. POLARSTERN is stable enough to withstand very rough weather as it occurs during the unfavourable seasons of the year in the Southern Ocean as well as for investigating new regions around Antarctica. For the first time there will be a capable vessel available to collect the long demanded data from fall, spring and winter expeditions. The additional ship time will allow broadening its field of operations to the entire circum-Antarctic ocean, opening new scientific opportunities with new international partners. Considering the presence of the French research vessel MARION DUFRESNE and of the British JAMES CLARK ROSS for extended periods in high southern latitudes it also seems to offer an excellent opportunity to establish a decade-long substantial Southern Ocean research programme where a number of European nations could play a leading role. The European Polar Board (EPB) and the European Polar Consortium (EPC) provide a forum for developing such strategies. The upcoming International Polar Year (IPY) will permit the implementation and coordination of such long-term programmes.

There are currently two dedicated research icebreakers available for investigations in the deep Arctic Ocean, namely the new US Coast Guard Cutter HEALY and POLARSTERN. In addition there are research opportunities through a number of other icebreakers such as the Swedish ODEN, the Russian KAPITAN DRANITSYN and several others, but they are not dedicated research icebreakers. Moving POLAR-

STERN permanently to the southern hemisphere will mean a considerable reduction of the European capability to conduct research in the central Arctic and AURORA BOREALIS is meant to fill this void. In addition it will provide part of the 3rd leg of IODP. Contributions to IODP and research in the central Arctic Ocean have a high scientific priority in a number of European countries. In the view of the AWI, it is therefore a "natural step" to try to make AURORA BOREALIS a European initiative based on joint finances and, consequently, joint use by a core group of interested European countries.

There will be no substantial overlap with investment plans for similar platforms of potential partner institutions for the AURORA BOREALIS. If AURORA BOREALIS is not realized, there will be no other research icebreaker to conduct deep-sea drilling and year round research in the deep Arctic Ocean.

A.II. The Proposed Facility

II.1. Scientific Objectives and Research Prospects

II.1.2 Research Programme

A detailed science plan for Arctic marine research for the next 1-2 decades, defining the needs for a large research icebreaker that can operate in ice-covered waters for most of the year has been produced by a working group of EPB (published in 2004). The working group consisted of representatives from the institutions in most EPB member countries covering a diverse set of scientific disciplines and scientific communities as well as institutions and companies with qualification in the design of icebreakers.

AURORA BOREALIS would fulfil the scientific demands of two major scientific communities: classical marine polar research community and the deep ocean drilling community. New perspectives would open for almost all disciplines of marine polar research if a ship would be operated most of the year in the Arctic Ocean. The new perspectives are illustrated by examples from climate research, biological research and geological research.

(1) Climate Research

The Arctic Ocean is an important part of the global climate system and a unique environment that is currently undergoing well-documented, rapid changes. These changes can be observed in the physical domain including, for example, the distribution of weather systems, sea-ice, and ocean water temperature, and already have observable effects on life in the Arctic. The changes are well documented in the evolution of the atmospheric circulation, since relatively long time series from atmospheric variables based on instrumental records are available. The Arctic circulation is subjected to the so-called Arctic Oscillation, which involves a periodic displacement and weakening of the Arctic high-pressure system above the Beaufort Sea. Presently it is not yet clear to which extent these profound changes on pan-Arctic scales are natural variability or caused by human activity. Thus research has been focused on the understanding of the observed change in order to project its further evolution. Since the changes are phenomena occurring over time scales of decades, long time series data describing atmospheric and oceanic conditions are required for their understanding and projection of their future evolution. Although such understanding requires the investigation of the coupled ocean-sea-ice-atmosphere system the different components of that system are addressed separately in the following paragraphs:

Physical Oceanography

The modification of water masses in the Arctic Ocean and the export of sea-ice are key elements in the global oceanic circulation. Due to the freshwater input of the Arctic rivers into the Arctic Ocean it plays a key role in the global fresh water budget, which has direct impact on the stability of the water column in the North Atlantic and hence on the global circulation.

The physics of the Arctic Ocean is determined to a large extent by the interactions of the coupled system ice-ocean-atmosphere. The quantitative connections between these system components are almost unknown over longer time periods, which are governed by sensitive feedback mechanisms. This means that the importance of temporal variations cannot be assessed if measurements in all parts of the system are not performed simultaneously.

The goal of future Arctic research will be to quantify the decadal variability in the coupled system ice-ocean-atmosphere and to understand the processes that are causing these changes in order to distinguish between natural fluctuations and the influence of human activity. A special emphasis will be placed on the fresh water budget.

For oceanographic field research to be meaningful, hydrographical transects must be measured at least once every five years. Since the observed fluctuations are quite fast, these large-scale measurements must be supplemented by continuous measurements from moored of instrument arrays at defined sites and by vertically profiling floats drifting under the sea ice, as well as platforms with tethered instruments on the ice. The AURORA BOREALIS would enable measurements that would provide essential contributions to understanding regional phenomena such as Arctic change as well as the global climate system.

Sea-ice research

Increase or decline of ice volume in the Arctic is a central problem in studies of the changing Arctic. To address this problem, large-scale observations of sea-ice thickness as well as of ice motion and properties are required. The observations will be extrapolated and interpreted by model calculations. Even if, in future decades, remote sensing techniques are developed for this work, in situ calibration and validation will still be essential (e. g. the validation of sea ice heterogeneity for the European CRYOSAT mission which failed during the first launch-attempt on October 8, 2005). Autonomous underwater vehicles would be able to provide *in-situ* data, but they will need platforms from which they are deployed, recovered and serviced.

Studies of sea ice albedo and other physical properties that contribute to the understanding of the energy budget are central for evaluating the role of Arctic sea-ice in the global climate system. *In-situ* studies during all seasons are necessary, including sampling of sea-ice and measurements of surface properties (partially by satellites).

Meteorology

Future polar meteorological research will be aimed at providing better understanding of the role of the atmosphere in the polar climate system. The main focus will be on identification and quantitative description of the central feedback mechanisms in the polar atmosphere as well as in the system atmosphere-hydrosphere-cryosphere. This requires the combination of modelling and observation programmes as well as theoretical studies. An essential part of this research programme, to which ship based measurements will provide an essential contribution, is the investigation of the energy budget of the polar atmosphere.

(2) Biological Research

Up to now, marine-biological studies in the Arctic are concentrated mainly on areas of east Greenland, Fram Strait and the Eurasian shelf seas (ice margin areas). The central Arctic Ocean with its deep basins remains largely unexplored. Furthermore the few existing investigations have been conducted almost exclusively during the summer. Current models, e.g. of annual primary and secondary production, are lacking spatial and temporal high resolution data. Due to sea-ice cover, remote sensing techniques can only be applied in a restricted manner in studies of the Arctic Ocean and large-scale *in-situ* measurements become essential. The availability of a research platform such as AURORA BOREALIS would open the possibility of investigating the marine biota in the major part of the Arctic Ocean that is still unstudied. The recent joint expedition of POLARSTERN and HEALY has revealed indications of widespread and unexpected hydrothermal venting along the Gakkel Ridge; after POLARSTERN found fossil remains of vent-related faunas on the Laptev Sea continental slope (intersection of the Gakkel-Ridge spreading centre with the continental crust) it can be expected that a substantial number of sites with living vent faunas exist along the rift valley of Gakkel-Ridge. Time series of life cycles and winter-over strategies of key organisms and populations will be investigated. These basic investigations become more important considering the background of predicted changes in Arctic ice regime, since ice is a defining factor for Arctic ecosystems.

About 10 % of the freshwater input into the global oceans is delivered to the Arctic Ocean. Besides the relevance for sea-ice formation, ocean circulation, and surface productivity, this freshwater input is of great importance for the sediment budget. Rivers are transporting large amounts of suspended material into the Arctic Ocean. The material is subject to various biological and geochemical transformation and degradation processes. AURORA BOREALIS would open the possibility to investigate the amount of suspended material that is transported into the Arctic Ocean, its fate and its importance for pelagic and benthic communities in different regions (shelf, slope, deepbasins) during different seasons.

The deployment of Remotely Operated Vehicles (ROVs) through a moon pool at sites completely covered by ice would open new perspectives concerning targeted sampling and manipulative studies at the sea floor of the Arctic Ocean. This would be especially important for studies of complex but heterogeneously distributed communities e. g. at methane hydrate sites.

The deployment and servicing of instrumentation at deep-sea sites in the central Arctic Ocean for collecting long-term physico-chemical data, for describing material fluxes to the bottom and its turnover, and for investigating deep-sea communities is not yet possible, since a platform with the required facilities is missing. AURORA BOREALIS would be the platform to serve such deep-sea stations and observatories including the deployment, maintenance and retrieval of instruments and data.

The awareness concerning the necessity of long-term records in the deep-sea and the Arctic Ocean is growing. A recent study of the US Polar Research Board calls for terrestrial, atmospheric and marine observatories. The European Seafloor Observatory Network (ESONET) initiative is a proposed sub-sea component of the European program GMES (Global Monitoring for Environment and Security) to provide strategic long-term monitoring capability in geophysics, geotechnics, chemistry, biochemistry, oceanography, biology and fisheries. Within the ESONET project, the AWI long-term observatory “Hausgarten” is envisaged to become the northernmost node within a network of ten regional deep-sea observatories in contrasting oceanographic regions covering the entire European coastline from the Arctic into the Mediterranean and Black Sea. One aim of ESONET is to connect seafloor observatories via cable to land stations to enable unlimited transfer of energy to the various subsystems and to allow on-line data retrieval. The composition, activity, and phylogenetic diversity of microbial communities in deep sediment layers is one of the fundamental scientific questions of scientific deep-sea drilling projects. The new research icebreaker would enable investigations of microbial communities in the extreme and still unknown habitats of the Arctic Ocean floor.

(3) Geoscientific Research

To a large extent, the new research icebreaker is supposed to conduct geoscientific research on the Arctic deep-sea floor. The demands of the geoscience research community are explained in the context of deep-sea drilling in permanently ice-covered ocean areas.

The technique of deep-sea drilling to investigate geological features of the ocean floor has been used since the 1960s and has revolutionized our understanding of the Earth System. The ships of the Deep Sea Drilling Project (DSDP) and Ocean Drilling Programme (ODP), namely the GLOMAR CHALLENGER and the JOIDES RESOLUTION, were not built to operate in ice and never visited ice-covered areas, although the latter ventured into the ice-free area north of Svalbard. Deep-sea drilling technologies will be further employed (the submitter is involved) to promote scientific perspectives in the context of IODP under the theme “Earth, Ocean and Life”. IODP envisions the application of an entire fleet of drilling platforms. Japan provides a large drill ship, CHIKYU, which, being equipped with a riser, will be able to drill risky geological structures in deep-sea basins and on continental margins. The USA will provide a new drill ship with similar technical facilities to those of the JOIDES RESOLUTION but with modernised technology. Both Japan and the USA have decided to build their drill ships and are thereby ahead of the Europeans to whom it remains to develop scientific perspectives within the context of the so-called “Alternate (or Mission Specific) Platforms”. One of these initiatives could comprise the construction of the new research icebreaker AURORA BOREALIS with a deep-sea drilling capability in ice-covered areas, and this would allow the European members of IODP to gain lead agency status.

The scientific preparations for these drilling plans have been made for several years in the scope of international working groups. The Nansen Arctic Drilling Program (NAD) published its scientific concept and its science plan in 1992. Some of the consequences of this science plan were that JOIDES RESOLUTION was deployed to sample a small area just north of Spitsbergen (during ODP leg 151, to examine the northernmost branch of the North Atlantic Current system of which the submitter was cruise leader) and that shallow drillings off North Siberia, a permafrost region, could be realized (from KIMBERLIT, a small Russian geotechnical drill ship). However, the technical challenge of deep-sea drilling in permanently ice-covered areas of the Arctic Ocean were only recently realized during the ACEX expedition of late summer 2004, when the supply vessel VIDAR VIKING (re-equipped to drill), escorted by the ODEN and SOVJETSKY SOJUS, carried out successful drilling operations on the crest of the Lomonosov Ridge. ACEX proved that drilling operations are possible in ice-covered waters. At the end of January 2001, a working group under the joint auspices of IODP and the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) passed a science plan that encourages the conception and construction of a platform for deep-sea drilling in the Arctic. The report is entitled “The High Arctic Drilling Challenge”. The AWI was a member of the working group responsible for this report.

Some of the scientific objectives of a long-term Arctic-drilling programme are:

- The Arctic and global climate (e.g. extreme climate in earth history, rapid climate change),
- evolution of polar biota,
- Arctic gateway and basin evolution, and
- Gas hydrates in the Arctic.

Shallow water drilling targets in the circum-Arctic shelf seas can also be addressed by means of small geotechnical drilling vessels such as the Russian KIMBERLIT from Murmansk which in fall 2000 was used to conduct the first drilling into the submarine permafrost of the Laptev Sea.

For defining accurate and well accepted sites for drilling in the high Arctic, continuous site surveying is necessary. The site surveys will either cover new regions or will refine and look for new targets based on the drilling results obtained by the AURORA BOREALIS. Currently only two-ship experiments allow to gather seismic data with sufficient quality to compete with other regions. Seismic surveys in the last decade were limited to four cruises at all, as it is extremely difficult to coordinate the available ships with the national science programmes. The new research platform, therefore, must have the capability to carry out geophysical investigations in most parts of the Arctic to ensure the scientific quality of the drilling programme. The vessel has to be equipped with the state-of-the-art geo-physical instruments (seismic, magnetic, gravity, bathymetry system, sediment echosounder) in order to efficiently gather such critical data. For conducting seismic investigations in the heavy pack ice of the Arctic the experience of more than one decade of geophysical research in ice covered regions must be included.

In the long run, drilling platforms such as AURORA BOREALIS are also required in the Southern Ocean. Drilling programmes in ice-covered circum-Antarctic areas were only realized within the Cape-Roberts-Project, which allowed drilling conducted from a platform deployed on stationary sea-ice. DSDP/ODP drilling delivered good data concerning the history of the Southern Ocean, and new objectives and strategies for shallow drilling of the Antarctic margin and nearby regions are developed in the “Antarctic Offshore Stratigraphy Project” (ANTOSTRAT), but there is still need for drilling directly in the sea-ice covered areas.

a) Services

AURORA BOREALIS would have to enable meteorological, biological, oceanographic, glaciological, geological, and geophysical investigations and would have to satisfy the technical needs for remote sensing, ocean technology, sub sea-floor engineering and deep-sea drilling. From this platform all necessary sampling and data acquisition could be carried out within the air and the water column down to the sea bottom with cranes and winches and with (semi-) automatic sampling devices such as ROVs, AUVs as well as from helicopters and balloons. The platform would be equipped to provide all necessary environmental data as well as the logistic support for data handling and processing. The ship would also serve as a laboratory to analyse and store all kind of samples in dry and wet laboratories as well as in a system of modularized laboratories that allows expedition-specific laboratory complexes to be set up (e.g. isotope-containers, clean containers, low-temperature containers, etc.). The two moon pools and a dynamic positioning system would enable deployment and collection of scientific equipment (moorings, nets, box- and multicorers, CTD, AUV, ROV etc.) in 100 % ice-covered areas where, up to now, such work has not been possible with any research or commercial icebreaker.

To date, the only existing modern research vessels that can reach the central Arctic Ocean are the German research icebreaker POLARSTERN, the new US American Coast Guard Cutter HEALY and, to a certain degree, the Swedish ODEN and the Russian KAPITAN DRANITSYN. However, none of the ships has the characteristic features of the proposed AURORA BOREALIS:

- a deep drilling capability,
- a capability to operate year-round in the central Arctic and to keep position against drifting sea-ice,
- a dynamic positioning system, and
- moon pools for deep drilling and sampling in completely ice-covered areas.

b) National and International Networks

The implementation of an Arctic drilling vessel has been discussed by different working groups e.g. of the Joint European Ocean Drilling Initiative (JEODI), now ECORD, and IODP. It is conceived as an "Alternate Platform" for the 3rd leg of IODP. The USA and Japan will each build a new research drill ship, and Europe is engaged in developing mission-specific platforms for drill sites that are not accessible for the new IODP drilling vessels. If realized, AURORA BOREALIS would be committed about four months per year to IODP as a mission-specific platform for drilling in the central Arctic Ocean, where no drilling will be possible with the planned drilling platforms.

The rest of the year it would be deployed as a European (or international) polar research platform that is integrated into the polar research programmes of the participating countries. During that time, it would perform polar marine science in almost all disciplines of polar research. Running a project as challenging as the AURORA BOREALIS, would require that the participating countries would co-ordinate their polar research programmes on a high level. On an international level, European Arctic research supported by AURORA BOREALIS would contribute to large research projects such as CLIVAR (Climate Variability and Predictability), and Arctic Climate System Study (CLIC, previously: ACSYS). In the framework of the Global Ocean Observing System GOOS/EuroGOOS it was outlined that powerful research icebreakers are essential for the implementation of an Arctic component. Close co-operations would be established with international organizations such as the International Arctic Science Committee (IASC), the Arctic Ocean Sciences Board (AOSB), among others.

At the global level, many nations engaged in polar research in both hemispheres are presently defining their national and international research programmes under the auspices of the ICSU/WHO efforts towards a new international Polar Year (the 125th Anniversary of the first IPY occurs between 2007 and 2009). As the available ship capacity for research in ice-covered Arctic and the Antarctic waters is by far insufficient to execute the envisaged research programmes, a platform such as AURORA BOREALIS is therefore urgently needed, and a timely decision could ensure the ship's involvement towards the end of the upcoming IPY. The proposal has the broad support of most of the relevant national and international organisations.

II.2. Technology

The planned icebreaker will be able to solve all tasks as an icebreaking research vessel (with a drilling capability) for the central Artic, and it could be deployed worldwide as a multipurpose research vessel. In 2000, AWI commissioned a preliminary technical study conducted by the Hamburger Schiffbau-Versuchsanstalt (HSVA). The study revealed that a research icebreaker with the demanded capabilities for deep-sea drilling and dynamical positioning in the central Arctic Ocean is, in principle, feasible. The feasibility study is based on a comprehensive description of the regions where the ship will operate and takes into account drilling as well as sampling operations. The detailed study includes five fundamental points (more details cf. annex 2):

(1) General layout of the vessel

The relative weight of the hull of an Arctic icebreaker is necessarily very high. Additionally, extensive and heavy machinery has to be installed as well as the drilling equipment, scientific equipment, spare parts, accommodation, fule, lube oils, water, provisions etc. Taking these general conditions into account leads to a calculated minimum size of the vessel that exceeds the dimensions of the first draft.

(2) Icebreaking capability

In order to conduct drilling operations as planned, positioning of the vessel must be performed automatically. In open water, the technology to enable this is state of the art, but in drifting Arctic pack ice, different problems may occur. Invaluable data were gained during the development of other icebreakers, most recently during the ACEX expedition of IODP. The theoretical studies showed the high ice breaking capacity of AURORA BOREALIS and its world wide unique performance in dynamic positioning in drifting ice.

(3) Propulsion

Diesel-electric systems are state of the art, and specialised German enterprises play a leading role in their construction and realization besides other European countries. For the dynamic positioning in drifting Arctic ice, electric azimuth propulsion systems are the up to date propulsors used in several new icebreakers and vessels operating in ice covered water. Such azimuth propulsors must be further optimised for the high power and high ice class necessary for AURORA BOREALIS.

(4) Drilling equipment

The Drilling equipment is a point concerning several fields of engineering sciences. In particular, the maximum drilling depths must be defined and new solutions for the realization of a mobile and flexible derrick must be found.

(5) Mission specific laboratory systems

A modularised laboratory system, based on exchangeable containers, has to be deployed in order to operate the new ship with the equipment most suitable for its various missions. Several European countries have developed such systems and have gained valuable experience.

Alterations to the ship (enlargement or reduction in size) or technical refits (as well as equipment with design engines, coolings, air conditioning etc. for tropical temperatures in case that AURORA BOREALIS needs to cross tropical areas to reach the Antarctic) are possible with relative ease due to the hull form, with its long longitudinal segment midships, and the placement of the deckhouse towards the bow. If the area of operation will be extended to the Antarctic, it will be necessary to cross tropical areas.

AURORA BOREALIS has an expected time of operation of 30 to 35 years with a significant mid-life refurbishment and conversion after approximately 15-20 years. New technology developed during this time will not require an enlargement but a modification of the installed equipment.

II.3. Transfer of Research Results

AWI expects an impact of AURORA BOREALIS in different fields:

(1) Impact on the science system

In the view of AWI, AURORA BOREALIS as the world’s first internationally run drilling and research icebreaker will further the international advantage that European research has in the polar areas. The year-round availability of a dedicated research icebreaker will facilitate implementation and maintenance of a sustained Arctic observing system that would cover a wide range of parameters of non-living and living components. This will encourage further development, implementation and refinement of the observing system and provide the basis for ongoing *in-situ* monitoring of the various components of the Arctic system. As the central Arctic Ocean is a key area for understanding the history of the Earth System the construction of the facility would increase our understanding of the Arctic system's role in past and present global climate. It is expected that an increase in understanding these processes will allow us to predict the future development of the Earth System. Knowledge of the future evolution of the Arctic system would provide the foundation for designing options to protect this extremely fragile region in the face of its rapidly changing environment.

Although these insights will, at least as a primary goal, not be put to commercial use, they will be of general importance for agriculture, the insurance industry, energy companies (in particular those involved in hydrocarbon exploration), tourism, and coastal engineering and management.

(2) Impact on the economy (esp. ship construction and ancillary industry)

The construction of AURORA BOREALIS requires several new technical solutions and will provide an extended technical potential and knowledge for marine technologies and the ship building industry. The AWI expects that the following business sectors and key technologies will benefit from the projects various innovations:

- Weather and ice-condition forecast authorities in polar regions,
- Shipbuilders, regarding the hull form that is suitable for drilling in ice-covered areas as well as for navigating in open waters,
- Producers of ship propulsion systems, regarding the powerful ice-going and extendible Azimuth propulsion system as well as pump-jets,
- Deep-sea drilling technologies, regarding the development of a mobile derrick and the technology of deep-sea drilling in ice-covered areas,
- Shipyards in general for developing an environmentally sound ship (Blue Angel Concept),
- Information and computer technology, regarding the development of an advanced fibre network for data acquisition, processing and monitoring tasks,
- Producers of new laboratory systems, regarding the flexible, modularized laboratory container system,

- The shipping industry in general, if trans-Arctic sea-routes are developed, and
- The AURORA BOREALIS would also be able to assist in Arctic emergencies.

The design and construction of AURORA BOREALIS would lead to spin-offs in the mentioned business sectors and key technologies but at this time their volume cannot be estimated accurately. Measures to support expected spin-offs will be developed in the course of further planning. Most importantly, AWI envisages that the ship will be run by a private company. Altogether, the research vessel would document the qualifications of the European maritime industry and it would explore potential new markets of energy resources for the commercial and scientific fields.

(3) Impact on socio-economical development

AURORA BOREALIS will operate in an area that may become ever more economically promising, because of its large unexploited reserves of living and non-living resources and because of growing traffic and transport demands. As predictions indicate the central Arctic ice cover will be reduced substantially in coming decades, opening up new sea routes to the north of Eurasia and North America. Hence, the project may have substantial economical consequences in preparation of new commercial routes to the Far East.

In contrast to many polar research programmes the AURORA BOREALIS project has a socio-economic element insofar as the exploration of the central Arctic Ocean would provide data that will help indigenous and non-indigenous inhabitants of the high northern latitudes prepare for the environmental changes to come.

A.III. Institutions Participating in the Project

AURORA BOREALIS is presently conceived as a European project and can only be realized in a European consortium. Several institutions participate in the AURORA BOREALIS project.

(1) Alfred Wegener Institute for Polar and Marine Research (AWI) of the Helmholtz Association

AWI was founded in 1980 to conduct its own scientific research in the polar regions and to support German polar research by providing the necessary logistics. The headquarter of the AWI is located in Bremerhaven. The institute has branches in Potsdam, Helgoland and Sylt. It possesses a substantial research infrastructure: besides the research icebreaker POLARSTERN, permanently manned stations in the Antarctic (NEUMAYER) and in the Arctic (KOLDEWEY jointly with France), a research laboratory at the Antarctic Peninsula (DALLMANN), several smaller ships, and two research aeroplanes. This infrastructure is available to the scientific staff of AWI as well as to all other German research institutions engaged in polar research. Through a wide international network of cooperation this infrastructure is also involved in many international projects and programmes so that a considerable number of users comes from scientific institutions outside Germany. Besides operating these large-scale facilities for German polar research, AWI has a leading role in large national and international research projects, e. g. in EPICA (European Polar Ice Coring in Antarctica).

(2) European Polar Board (EPB)

The member institutions of the EPB[65] have nominated members for the science perspective working group representing a wide range of disciplines covering polar sciences in general. The working group established a science plan for AURORA BOREALIS which was presented to the various national funding agencies late in 2004. The ocean drilling community nominated its members through ECORD. The working group was further strengthened by the nomination of specialists in icebreaker technology.[66]

---

65 The director of the AWI is vice-chair of the EPB, and the scientific secretary of the EPB is co-ordinating the activities related to the AURORA BOREALIS project.

66 *Polar Sciences (nominations via the EPB)*: Geological Survey of Denmark (GEUS), Finnish Institute of Marine Research (FIMR: Its special competence is to be found in atmosphere-ocean interaction, sea-ice and global change studies as well as Arctic hydrography and circulation and oceanography. It will contribute to the planning of the overall strategy and the logistics), University of Bordeaux, The Department of Geology and Oceanography (DGO), France; Alfred Wegener Institute for Polar and Marine Research (AWI), University of Oslo, Department of Geosciences, Norway, All-Russian Research Institute for Geology and Mineral Resources of the World Ocean. *Ocean Drilling (nomination via ECORD)*: French Research Institute for Exploitation of the Sea (IFREMER), France; French Institute for Polar Research and Technology (IFRTP), France; Institute Nazionale di Ozeanographia e di Geophysika Sperimentale Trieste, Italy; Research Centre for Marine Geoscience at Kiel University (GEOMAR), Germany; University of Bergen, Norway; British Antarctic Survey (BAS), United Kingdom; *Icebreaker Technology and Ship Design*: Kvaerner Masa Yards Inc. Finland; HSVA Hamburg, Germany.
The listed institutions are the core of a scientific working group that has set up a science plan for AURORA BOREALIS for the next 1 - 2 decades. This working group represented universities, polar research institutions and industry, and it has formally been established under the umbrella of the ESF, and by ESCOD, which is combining the European contribution to ODP, now IODP.

(3) University of Applied Sciences (Department of Naval Architecture, Ocean Engineering and Applied Sciences), Bremen

The Department of Naval Architecture and Ocean Engineering is 110 years old, created as a shipbuilding school in 1895. The members of the department have substantial experience in building large scale ships for cutting edge activities. The projects were carried out in different shipyards and marine companies (Bremer Vulkan AG, Fr. Lürssen Werft etc.). Through current research projects on determination and measurement of the ice loads of POLARSTERN and participation in the Refit-programme for POLARSTERN, appropriate experiences was gained for work related to icebreaking research ships. The Department carried out the feasibility study and is specifically responsible for:

- Management and coordination of the construction of the ship,
- Ship design, general arrangement, weight calculation, intact and damage stability,
- Structural design,
- Accomodation and equipment,
- Propulsion systems,
- Estimation of new building costs.

(4) Hamburg Ship Model Basin - Hamburger Schiffbau-Versuchsanstalt (HSVA)

The HSVA is a company with scientific knowledge of ice breaking techniques and the natural properties of the Northern Sea route of the Arctic Ocean. It has been operating ice research and ice model testing facilities since more than 50 years. Its present major facility is the 78 m long, 10 m wide and 2.5 m deep ice model tank, one of the largest in the world and unique in the European Community. Hence, HSVA has the technical capability to develop concepts and plans for icebreakers and to evaluate their performance in model experiments. The HSVA has great experience in the development, construction and testing of research icebreakers (POLARSTERN), ice drill platforms (KULUK) and other ships for work in ice-covered regions (NEUWERK). It has tested all new ice going vessels built for German authorities on the model scale and some at full scale in open and ice-covered waters, as well as more than 100 icebreaking vessels for other countries (e. g., the US Coast Guard icebreaker HEALY). It is responsible for:

- Hull lines,
- Icebreaking technology,
- Manoeuvring capabilities,
- Energy production,
- Propulsion systems.

(5) Det Norske Veritas

This Norwegian classification society is responsible for:

- Safety requirements and regulations.

(6) National Oilwell

This Norwegian company that specializes in drilling technologies is responsible for

- Drilling technology and drilling concept.

(7) Reederei F. Laeisz (Bremerhaven) GmbH

This Shipping Company has more than twenty years of experience in running the world’s most efficient research icebreaker and is responsible for:

- Design of ship operation technology and propulsion systems in cooperation with MAN B& W Diesel AG, Augsburg MTU Friedrichshafen GmbH, Hamburg; Siemens AG, Hamburg.
- Tank capacities,
- Crew strength.
- Ship operation concept, service and handling.

A.IV. Users of the Research Facility

AURORA BOREALIS would provide the only platform operable year-round world-wide for environmental research in the Arctic Ocean. In particular, the project AURORA BOREALIS would open new perspectives for almost all disciplines of marine polar research. The icebreaker would have to satisfy the demands of meteorological, biological, oceanographic, glaciological, geological, and geophysical research and to satisfy the technical needs for remote sensing and ocean technology. Studies in these disciplines have been conducted using POLARSTERN for almost 20 years but due to her limited possibilities, only during summer and mostly not in the central Arctic Ocean. Polar marine research (biology, geology, geophysics, glaciology, meteorology, oceanography, etc.) would henceforth be dominating on AURORA BOREALIS during fall, winter and spring expeditions to collect data during these presently under- investigated seasons.

The drilling phase would be in summer for about four months when the conditions are most favourable for dynamic positioning in drifting sea-ice or continuous seismic reflection profiling. To enable a maximum use of the ship, it is proposed to run AURORA BOREALIS for eleven months of the year.

Although it is foreseen to use AURORA BOREALIS mainly as a drilling platform during summer and to relocate POLARSTERN to the Southern Ocean, classical Arctic marine research will still be possible during summer. Various European research vessels are able to operate at the ice margins (e. g. the Norwegian LANCE and JAN MAYEN and the new German MARIA S. MERIAN). Furthermore, the Swedish icebreaker ODEN and various Russian icebreakers are able to penetrate into the central Arctic Ocean. None of these ships could fully replace POLARSTERN or AURORA BOREALIS, but they can support the continuity and expansion of a European central Arctic research programme.

The different European polar research programmes contribute to almost all large international research programmes in the Arctic and AURORA BOREALIS could be the central platform for realization, sustaining and expanding the European contribution to these programmes. This would require the coordination of the European research activities in the Arctic and would allow the European nations to continue to carry out cutting edge Arctic research in cooperation with their international partners. The AWI expects that implementation of AURORA BOREALIS would give the European polar research programmes the much-needed continuity that never existed before, and would provide for a major input into the final year of the IPY and – especially – to post IPY planning.

AURORA BOREALIS would be committed for about four months as a mission-specific platform to IODP and the use of the vessel would be under charge of IODP during that time. IODP published an initial science plan for 2003-2013 and developed appropriate structures to organize the access of users to IODP platforms. There are two key elements of this structure: (1) IODP will be a programme driven by proponents who develop scientific drilling proposals which will be peer-reviewed and ranked by the international community, and (2) the advisory structure will review all proposals and, with expert technical advice, determine the most appropriate drilling platform to use in addressing the scientific objectives.

The access of users from the classical polar marine research community during the rest of the year would be organized in a similar way. There would be a user board, consisting of representatives from all participating countries. Proposals from Potential users would be reviewed and ranked according to their scientific quality. The allocation of ship time to users of the participating countries would also depend on their contribution to the construction and operating costs of the ship, following many of the principles developed by IODP and ECORD. Details of user access still have to be defined during the coming planning process.

Users from universities and other external users would have equal possibilities to submit proposals to IODP or the user board of AURORA BOREALIS.

The call for proposals for the International Polar Year (about 900 submissions) demonstrates the huge amount of work awaiting Arctic scientists. In addition, AWI tries to engage the USA and Russia, both countries with large research communities but limited logistical access to the Arctic Ocean. The Arctic science community has been gathering proposals at the ICARP II (International Conference on Arctic Research Planning) in November in Copenhagen (DK). The proposers are members of the organizing committee.

IV.1. Scientific Education

The AURORA BOREALIS research facility will give young scientists the possibility to receive training and to conduct research on the world's most advanced research platform. The implementation of a world-class scientific programme will permit an education of students allowing them to become the future generation of scientists. The AWI envisions the AURORA BOREALIS to fulfil functions of a "floating international polar university".

As AURORA BOREALIS would be a research platform for fundamental scientific studies most of the students trained on the platform would be employed as research scientists in the fields of the major disciplines addressed in polar science i. e. meteorology, biology, oceanography, glaciology, geology, geophysics, and remote sensing. Further qualification could be mediated in the fields of ocean technology, sub sea-floor engineering and deep-sea drilling.

Students engaging in the latter, more technical fields of research would have a great potential for employment in the private-sector fields of ocean exploitation and technology transfer.

IV.2. Public Relations

Most of the involved research centres have well functioning press and public relation offices that are experienced in mediating projects, expeditions and scientific results of polar research to journalists, other scientists, government representatives and the general public. Public affairs activities would include promotional activities, news conferences and open ship events where the public can tour the ship and learn about the research of AURORA BOREALIS. The public affairs programme would also include developing materials, such as descriptive brochures and booklets, fact sheets, and designing and updating an AURORA BOREALIS web site dedicated to outreach. The web site might contain, for example, a virtual ship tour, scientist profiles, a daily log of ship activities, scientific highlights and links to world-wide activities of polar research and IODP. The legacy of global change and polar research will also be communicated to schools by inviting selected teachers and students to join ship expeditions.

A.V. Project Management, Location, Costs, Funding and Schedule

V.1. Project Management

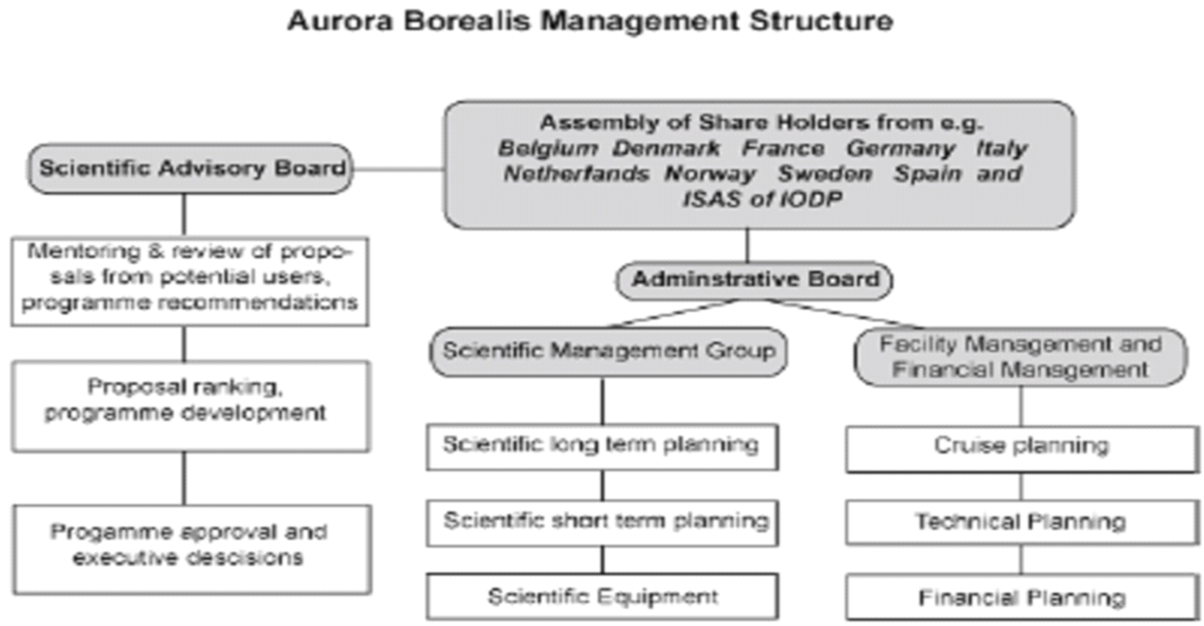
AURORA BOREALIS would be a European contribution to the alternate platforms of IODP. The idea of deep-sea drilling in the Arctic has been developing in the scientific community for many years. With an increasing understanding of the Arctic Ocean's role in past and modern climate, as well as the fundamental new insights of the deep-sea drilling programmes DSDP and ODP, it became clear that the Arctic Ocean is one of the primary targets for new deep-sea drilling. Scientific working groups developed programmes such as the Nansen Arctic Drilling Program (NAD) that defined the need for deep-sea drilling in the Arctic. But the implementation of most of these programmes failed due to the absence of a suitable drilling platform. The idea of the project AURORA BOREALIS was originally brought up by AWI to overcome the obvious lack of urgently needed research platforms, and is now promoted by the EPB of ESF.

The next two steps in project planning are:

- to establish an implementation working group for realisation of the AURORA BOREALIS project, and
- to prepare for tendering for shipbuilding, once a consortium for AURORA BOREALIS has been formed.

The implementation consortium will be tasked to generate management structures, a business plan and structures for establishing the scientific programmes. A scientific advisory board as well as an administrative board have to be set up, which should oversee the management of the facility in close coordination with the EPB and also IODP. A preliminary concept of the AURORA BOREALIS management structure is shown in Fig. 1.

Fig. 1: Preliminary management concept of AURORA BOREALIS



AWI does not intend to secure AURORA BOREALIS for management by AWI, but considers instead defining a new management structure through the EPC.

The budget responsibility will be organized in the AURORA BOREALIS management structure through an administrative board (Fig. 1).

An advisory board for AURORA BOREALIS would be established but its exact structure is not yet defined. The functions of the scientific advisory structure will include:

- Mentoring and review of proposals from Potential users, programme recommendations,
- Proposal ranking, programme development, and
- Programme approval and executive decisions.

Recently, the EU funded a major proposal, submitted by the European Polar Board, to establish a European Polar Consortium (EPC) (funding is guaranteed for four years) whose aim is to define and establish many of the necessary steering and management bodies needed for operation of facilities such as AURORA BOREALIS. This will necessitate a major integration of European polar research programmes, which could only be defined in detail once a decision on AURORA BOREALIS has been reached.

Depending on the composition of the consortium to be formed, responsibility for maintaining permanent operation of the facility might either be entrusted to an institute with long experience in running polar research ships, or to a consortium of participating research institutions, or it may lead to the formation of a new international institution.

V.2. Location

The port of registry for the new Arctic research icebreaker is not yet settled. The AURORA BOREALIS will have to be attached to a home port with suitable facilities, as close to the area of investigations as possible and as the contributing countries agree. If Bremerhaven or another European harbour (e. g. Tromsø) is the most efficient port of registry for the new ship remains to be investigated.

Bremerhaven fulfils favourable requirements for operating a large and sophisticated research icebreaker. It is the port of registry of POLARSTERN, therefore the know-how and experience in operating large research icebreakers is present. Shipyards and suppliers for technical service and scientific installations, which have been used for many years for service of research vessels of different kind for years, are present in the region.

V.3. Costs

Only preliminary estimates have been made of the total development and construction costs for the new research icebreaker AURORA BOREALIS. A reliable estimate can be given after the scientific requirements of the design have been defined. Firm calculations will only be established through the international tendering process. The emerging costs are listed in the following (see Table 1):

Table 1: Estimated remaining Development and Construction Costs (million Euro)[67]

	Total Staff (FTE)	Staff Costs	Other Costs	Total Costs
Costs for remaining experiments, development and optimisation	35	5.5	0.5	6.0
Costs for construction	759	103.5	245.1	348.6
Total (R&D + Construction)	**794**	**109**	**245.6**	**354.6**

The following cost estimate is for a ready-to-use research ship based on the design of AURORA BOREALIS that can be employed for the planned tasks. The scientific infrastructure and equipment are not included in the estimate in view of the various permutations possible with a multipurpose research ship. [68]

The estimate of a ready-for service ship includes:

1. The ship will be completed as a research ship that is ready for service, with the ship's own infrastructure and machinery necessary for its planned role, with cranes, winches, logistical machinery, and helicopter pad and hangar. Foundations and utilities connections for the planned scientific infrastructure are installed and ready to use.
2. The propulsion and ancillary machinery for drilling operations and multipurpose scientific use are prepared.
3. All Scientific spaces, such as laboratories, working rooms and IT-rooms, are fully equipped with computer network connections and utilities connections.
4. The complete drilling system, its components, derrick, and utilities are installed and ready to use.
5. The ship is fully equipped with consumables for its first operation.

The building costs do not include the following:

1. Laboratory- and freight containers.

[67] Cost estimates are based on FY 2005.
[68] The costs for further scientific technical equipments amount to about 21 million Euro. For details cf. Annex 3. Partly, the equipment is already available at the AWI.

2. Equipment for scientific infrastructure (e. g. contents of laboratories, working rooms and IT rooms).
3. Structural elements of the ship and its machinery necessary for scientific service, such as special deployed machinery, deep-sea winches, sliding beams, sondes, sonar equipment, and so on.
4. Helicopters.
5. Drill pipe joints.
6. Model experiments in tow tanks and ice-filled tanks.
7. Financing and further development costs for this ship.

The estimate of construction costs is based on material and labour costs for 2004/2005. For later work, inflation at 3 % per year should be taken for granted. A construction time of 24 months is assumed, with a lead-time of around one year depending on the delivery schedule for large components. The estimate is based on the costs of already-built ships, on current and comparable material and labour costs in Europe, and on manufacturers' statements. The costs will be spread over four years in the following way:

Table 2: Estimate of total costs for R&D and construction (including staff costs) by year in million Euro

	2005	**2006**	**2007**	**2008**	**2009**	**Total Costs**
Civil construction		43.6	70	155	80	348.6
Remaining experiments and development		6				6
Total		**49.6**	**70**	**155**	**80**	**354.6**

The annual operation costs are estimated – based on those of POLARSTERN – at 17.5 Million Euro. For crew manning and ship's management, an external shipping company is needed. This will cost about 7 million Euro/year. The costs for fuel and lubricants amount to about 7.5 million/year. The costs for maintenance, development and upgrades of facility are estimated as about 3 million Euro/year. Additionally, at least 3 persons at the institute are needed to organize the scientific missions: A Scientific coordinator, a technical coordinator and a mission operator.

Table 3: Operation Costs (Million Euro)

	Total Staff (FTE)	Staff Costs	Other Costs	Total Costs
Estimated annual operation costs	46	7.0	10.5	17.5

The Institute will need user support for the operation costs and the organisation of scientific cruises.

Uncertainties in the operational costs are the increasing fuel prices. Until now, we have not identified potential shipyards, which are able to build the ship. The foreseen budgetary reserves are about 5 % of the total costs.

V.4. Funding

At the present state of planning the AWI assumes that a core group of European nations with interests in Arctic research will bear the construction and operating costs of AURORA BOREALIS. So far, no negotiations about spreading the costs have been taken place between interested partners. The AWI expects that France, the Netherlands, Spain, Italy, the Scandinavian countries, and Germany belong to the core group. They have indicated interests in the AURORA BOREALIS science perspective. Only the United Kingdom has declined to participate in an implementation working group. Partners in the USA, Canada and Russia are informed about the project but up to now have not yet decided to participate.

The AWI developed a concept under which the costs, both for the ship's construction and running expenses, are subdivided into about 20-25 shares. Individual countries or a core group of countries can "buy" these shares and – according to the distribution of the shares – could claim person-days per year. Potential funding mechanisms through the European Investment Bank (EIB) and the EU have been explored. The EIB loan for comparable projects is usually up to 50 % of the initial investment. The payback period for the loan could be over 10-15 years.

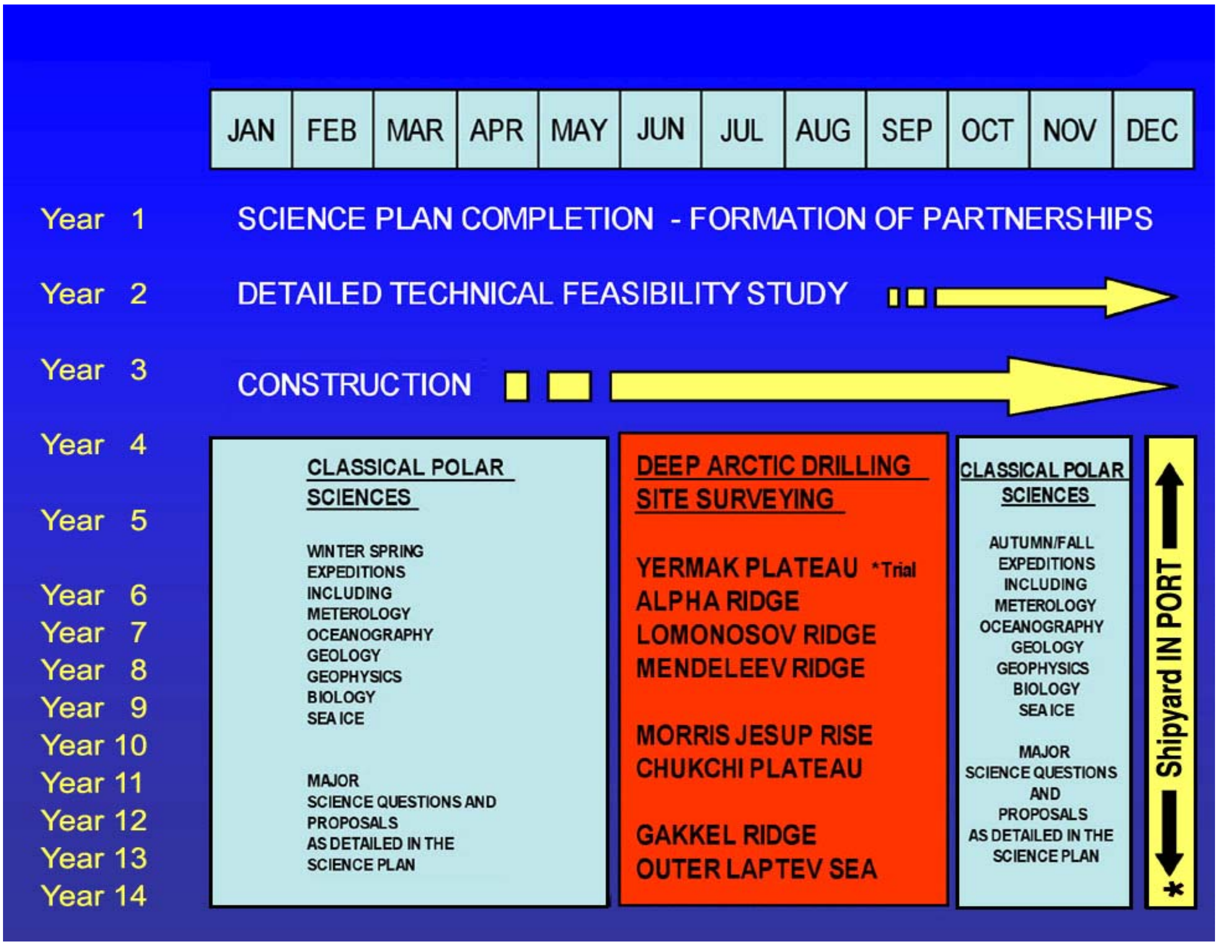
AWI expects research with AURORA BOREALIS to be funded through the national funding agencies and sources such as the EU or the National Science Foundation. The EU has historically been quite restrictive in its funding of Arctic research, but this has changed since the establishment of large networks and coordinating efforts, such as CARE, DAMOCLES and the EPC. AWI expects to secure the necessary funding to support the planned research in the central Arctic Ocean. This expectation is based not only on the proven success of European polar research institutions to acquire the funds to run their scientific and logistical programmes, but also on the observation that large numbers of young researchers have been, and continue to be, interested in this extreme region of the planet.

V.5. Schedule

Planning of AURORA BOREALIS is currently promoted in national and international working groups. An intensive co-operation exists with IOPD (replaced ODP in 2003), of which Germany and several other European nations are members. The European Polar Board (EPB) and an appointed working group documented the European interests in the presence and operation of AURORA BOREALIS. This working group has developed a science plan for the next 1-2 decades and defined the technical requirements for the ship.

Table 4: Draft Implementation & Decadal Utilisation Plan for AURORA BOREALIS[69]

The yearly sojourn of Aurora Borealis in the shipyard will be handled flexible depending on scientific objectives of the participating countries and weather conditions.



Operation of AURORA BOREALIS is planned for up to eleven months per year, where in a typical year about six months will be devoted to advanced fundamental research in all polar disciplines (biology, chemistry, physics etc.) that benefit from a platform in the Central Arctic Ocean, and about four months (in general June to September) devoted to deep drilling activity. Whether and to what degree the Antarctic drilling will be considered is a task of the consortium of participating countries.

Service and maintenance of the ship as well as modernization of the scientific equipment to keep up with newest developments would be performed during one month per year. Under these conditions AURORA BOREALIS would be an out-

69 Cf. European Polar Board. An ESF Expert Committee: AURORA BOREALIS: A Long-Term European Science Perspective for Deep Arctic Ocean Research 2006-2016, June 2004, p. 65 (slightly modified by the AWI). The draft schedule for planning, construction, and operation was originally conceived beginning in 2003. Presently, it is already a year behind.

standing research platform in AWI’s opinion for at least 15–20 years before it would have to be seriously refitted for an additional time span of 15–20 years of operation.

B. Statement and Recommendations

B.I. Field of Research

In the context of global warming and global climate and environmental change, research in the polar regions holds a prominent position. Of all regions on Earth, the polar regions are the most sensitive to climatic and environmental change. While some historical changes in climate have resulted from natural variability, the amplitude and patterns of the recently observed changes reflect the consequences of the increased emissions of carbon dioxide and other greenhouse gases[70]. In fact, they show that mankind has inadvertently started “the biggest experiment” ever by modifying the biosphere of the planet.

The emission of carbon dioxide due to fossil fuel burning has caused a major increase of CO_2 in the atmosphere, likely causing a general global warming. State of the art climate models predict the warming effect to be strongest towards the poles. The Arctic region most likely will experience the strongest rise in temperature in the coming century. It provides an early indication of the environmental and societal significance of global climate changes as it is considered an important amplifier of climate change, through positive, most likely nonlinear feedback processes. The recent Arctic Climate Impact Assessment[71] already reports major changes taking place in the physical, biological, chemical and human domains of the Arctic region, and predicts further and larger changes in coming decades to centuries. Habitats of all biota from single cell algae to polar bears or caribou will change, and this will also affect the lives and cultures of northern peoples in Scandinavia, Siberia and Canada.

Moreover, the world-wide emissions of halogenated molecules (chlorine, fluorine) are adding to the climate and environmental changes. Some molecules (CFCs), via reactions with natural ozone in the troposphere, are affecting the ultraviolet part of the sunlight reaching the Arctic as well as Antarctic regions. Other toxic halogen molecules are, by a global distillation process, eventually accumulating in the cold polar regions and there affecting all levels of the food chain. Also, the increasing CO_2 is

---

[70] Apart from carbon dioxide, the concentration of other heat-trapping gases in the atmosphere (e.g. methane) has increased. They are called “greenhouse” gases as they contribute to the observed global warming processes. Most of these processes are attributable to human activities (cf. Artic Climate Impact Assessment (ACIA): Impact of a Warming Arctic, Cambridge 2004).

[71] Artic Climate Impact Assessment, ibid.

causing a general acidification of the oceans[72] where again, for complicated bio-chemical reasons, the cold polar marine ecosystems are most at risk.

Given these imminent changes in the Arctic due to activity by mankind, the international community has a strong interest or even an obligation to monitor, investigate, and understand these changes in coming decades. Despite the central importance of the Arctic to climate research, there is a remarkable dearth of long-term observations. In addition, there is a nearly complete absence of data on climate history on any time scale. As a matter of fact the remote and harsh environment of the Arctic remains a last frontier in science, where we still need to understand how the Arctic system is functioning to obtain baseline description against which future observations can be compared for accurate evaluations of Arctic change.

Below, the most important areas of research where new insights are expected by the deployment of AURORA BOREALIS are presented:

Climate Change

Water mass transformation, as well as fresh water production, in the Arctic Ocean and northern seas is an important component of the global climate system. Climate change is expected to have particularly large effects in the Arctic, especially where it leads to changes in sea-ice thickness or extent. There is evidence that the sea-ice is decreasing in volume with important consequences for arctic ecosystems, human access and exploitation, as well as the global climate. However this evidence needs further study because the available observations are sparse. Given the potential effects on life in northern countries, and Europe in particular, it is vital that we have a means to detect and understand these fundamental changes occurring in the Arctic.

The AURORA BOREALIS will provide a unique platform from which observations of the water column structure may be measured throughout the year using instruments lowered or deployed through the scientific moon pool. For the first time it will be possible to build a spatial and temporal picture of the signature of climate change within the waters of the Arctic and to monitor the changes taking place. The AURORA BOREALIS will also provide a platform for process studies of the impact of the ocean on

[72] Cf. The Royal Society: Ocean acidification due to increasing atmospheric carbon dioxide, London 2005.

the atmosphere. The characteristics of sea ice and the structure of the leads are very different in winter compared to summer but we know little about how this affects the near surface atmosphere. Using flux probes suspended from helicopters, ice masts, and balloons, the AURORA BOREALIS will allow these processes to be investigated.

There is almost total lack of comprehensive mean meteorological measurements in the winter Arctic (other than the restricted but valuable data from ice buoys). The AURORA BOREALIS will provide a unique opportunity to obtain that data, albeit from a single, moving site, and over the years, will provide a time record of changes in weather conditions.

Biology and Ecology

The majority of past expeditions to the Arctic were carried out during the summer season. Hence, only for this period a sound database on the biology and ecology of the organisms inhabiting the sea ice, the water column and the seafloor is available. AURORA BOREALIS would allow a year-round study of the biology and ecology of these organisms.

By now, most of the studies are carried out on the marginal Arctic Ocean and its surrounding shelf sea. This research on the margins of the Arctic Ocean is of great socio-economic importance as these regions are amongst the most productive fisheries in the world, in particular the Barents Sea Cod. AURORA BOREALIS would allow intensifying the research on the margins. Furthermore, the deployment of a research icebreaker opens access to the central Arctic Ocean, a fairly unknown part of the Arctic. Apart from the research in the central Arctic Ocean and its margins, rare environments such as vents and seeps could be studied.

AURORA BOREALIS would allow revealing the biological production in the surface layers as well as the life under the ice including the study of fishes and plankton. The year-round deployment of the vessel would open up the opportunity to study the seasonal reproductive cycles. Research on the by now unknown abyssal life could be started.

In contrast to the Antarctic, the north polar region is surrounded by land masses. Hence, intense interactions between continents and the ocean are observed. Freshwater discharge has significant relevance for the role of the Artic Ocean in the global climate system as the river runoff influences the sea-ice formation, the primary production and the water mass distribution. Amounts of sediments, nutrients and pollutants are transported into the shelf seas and the deep basins. The year-round deployment of AURORA BOREALIS would allow studying the transport of these materials across the ocean from artic river effluents into the shelf seas and open oceans, as well as consequences for the biological life in the Arctic Ocean.

Geology

The deployment of a drilling ship with the capabilities of AURORA BOREALIS will contribute to the understanding of various major problems in Geology, in particular to the understanding of the slowest spreading ridge of the world, the oceanic ridge, as well as of the long term climate evolution and variability in the polar region (over the last hundred million of years). Furthermore, the drilling will allow for studying the evolution of the polar biota and defining the amount and distribution of gas hydrates.

With socio-economical development in mind, the studies from the research vessel provide the opportunity of reconstructing the development of the artic ocean and the gateways to other oceans, as well as the discovery of further carbon energy sources (e. g. hydrocarbon exploration). Resource exploitation and navigation will probably increase as sea-ice cover retreats. It is important to understand the environment and the ecosystems so that we can assess the impact of such developments and design mitigation plans to minimize them.

Oceanology – History of Sea Ice

The climatic development of the Arctic and sub-Arctic has been characterized by changes in sea-ice cover, ice sheet dimensions and thermohaline ocean circulation. These three system variables influence different processes in the Artic, for example the albedo. Lack of suitable material from the central Arctic prevents documentation of the long-term history of the Arctic sea ice cover. Many studies have implicated a strong positive feedback from the sea-ice cover as the key mechanism whereby small changes in the solar insulation related to orbital parameters lead to high amplitude climate responses. Hence, studying the temporal and spatial variability of in sea-ice, the extent and thickness of the sea-ice cover, as well as the motion of sea-ice and its properties, would contribute not only to a deeper understanding of the history of sea-ice, but also to a deeper understanding of the mostly unknown feedback processes amplifying the climate change.

B.II. The Proposed Facility

II.1. Scientific Programme

The scientific case is extremely strong promising unique scientific discoveries with great impact on a large set of research fields. AURORA BOREALIS is the ultimate platform the international community is waiting for as it provides a very large range of capabilities (from drilling to meteorology) that no other ship can offer.

According to the history of the facility project, the scientific drilling programme was clearly worked out. However, the marine part of the scientific case is even as important as the drilling activities, and gains increasing attention due to the rapidly developing pictures of ongoing change in the Arctic system, at least in part caused by human activity. The major scientific insights due to drilling activities are expected over the forthcoming five years. The polar and marine research will in all likelihood continue to increase beyond the first five years of the AURORA BOREALIS deployment. The importance of this area of research cannot be overestimated as year-round changes of many key variables required for understanding the Arctic system and its variability and change can be observed. These observations will allow breakthroughs in many disciplinary fields. Future presentations of the scientific case should draw a more balanced picture of the research opportunities offered by AURORA BOREALIS for both the deep-sea drilling community, and the polar science community at large.

The innovative concept of AURORA BOREALIS provides for two ice-free moon pools. One of the moon pools, the “clean” one, will be the facility for launch and recovery of sophisticated underwater instrumentation such as ROVs or AOVs as well as sampling equipment and observatories. The other moon pool, the “dirty” one, is dedicated to drilling activities that may be performed at the same time.

The Arctic is an important region to be studied (cf. B.I.) AURORA BOREALIS offers the only way to achieve the overall and year-round study of this region. As this widely unstudied region is subjected to the transition into a “greenhouse world”, the realization of such a project deserves major support. The innovative project operates on high technical standards and will address the following major themes seen as outstanding from a global perspective:

- environmental global change,
- historical evolution of the climate system and its variability and changes,
- knowledge of the deep sea (morphology, biology etc.), as well as
- polar gateways as a global issue.

Moreover, by having AURORA BOREALIS year-round in the Arctic, the Alfred Wegener Institute will be able to dedicate the existing ice breaker POLARSTERN to year-round research in the Antarctic region. Similarly, this will allow far improved capability to study the existing Antarctic system, its physics, biology and chemistry, also with an eye on early detection of global change affecting the Antarctic region.

II.2. Technology

The technical design of the vessel is well thought-out (including the conception of a fixed derrick) and enables access to most of the areas in the Arctic. The principal design of the platform is based on proven concepts and technology. The technology required for combination of strong icebreaking and drilling capability has been worked out. AURORA BOREALIS will operate in regions with up to about 4,000 meter of water depth plus 1,000 meter of drilling depth. This operation depth seems to be sufficient; in particular as the water depth exceeds 4,000 meter only in few, scientifically less interesting, parts of the Artic Ocean.

The remaining small inaccessible parts of the Arctic could be reached by deploying other platforms.

AURORA BOREALIS will be a unique icebreaker being able to conduct year-round research in the high Arctic, as well as Arctic deep-sea drilling during the summer season. Existing research icebreakers are limited in their performance or their operation regions.

A comparison of the operational capabilities of existing polar icebreakers and of ice strengthened ships shows that AURORA BOREALIS will be the only European

“Heavy Polar Icebreaker” according to the US Cost Guard definition. At present only the USA and Russia have ships in this class (cf. Table 5). Although AURORA BOREALIS will be slightly smaller than the largest Russian icebreakers in this class it will be much larger than comparable US icebreakers. The total installed power available for propulsion (50 MW) will be modest compared with other ships. The following table compares the AURORA BOREALIS to existing icebreakers of other nations.

Table 5: Comparison of operation and working capabilities of Heavy and some Medium Icebreakers

Name	Country	Displacement (Ton)	Length (m)	Propulsion Plant (HP)	Power for Propulsion (MW)
Heavy Icebreaker					
AURORA BOREALIS**	Europe (Germany)	44300	196	75000	50,00
Arktika	Russia	23460	148	75000	55,95
Rossiya	Russia	23625	148		55,95
Sovietskiy Soyuz	Russia	23460	148	75000	55,95
Ural	Russia	25800	148	75000	55,95
Yamal	Russia	23460	150	75000	55,95
Polar Sea*	USA	13334	122	60000	44,76
Polar Star*	USA	13334	122	60000	44,76
Medium Icebreaker					
Healy**	USA	16165	128	30000	22,38
Oden*	Sweden	9438	108	23200	18,00
Polarstern**	Germany	17300	118	20000	15,00

* Research icebreaker with limited research capabilities
** Research icebreaker

AURORA BOREALIS will be a unique ship with sufficient size and power for a research icebreaker in the Arctic. For the summer period when AURORA BOREALIS frequently will not be available for year-round programmes due to its drilling activities a coordination with other vessels is highly desirable. The year-round observations should be realized without interruption.

A major strength of the facility will be the inclusion of a number of highly innovative elements such as the Dynamic Positioning System (DPS). DPS is a system for keeping a ship on station and a system for gearing precise satellite measurements of position to small shifts in the power supply to the propellers and thrusters. In the case of AURORA BOREALIS DPS includes the capability to break ice sideways over the total length of the ship with the help of sharply inclined frames in the waterline area. During dynamic positioning in ice, the vessel is operating backwards which enables it to operate more easily against the drifting ice. To overcome an ice ridge obstacle the propellers are used for crushing ice; the propeller jet stream washes the ice slightly aside, which reduces the ice contact of the drilling rig. AURORA BOREALIS will probably be capable to access over 90 % of the Arctic Ocean in summer and in winter.

Further model tests are needed to lead to more accurate data concerning the capability of icebreaking as well as other technical innovations (e. g. the existence of two moon pools in the context of the structural integrity of the hull). These tests are highly recommended as the technique is unique and extremely sophisticated.

Additional major strengths of the project are the capability of drilling in ice-covered regions as well as the conception of two moon pools, one “clean” moon pool for underwater research instrumentation and the other “dirty” one for drilling activities. The installation of a second “clean” moon pool for deployment of underwater vehicles and instrumentation (e. g., ROVs, AUVs, seafloor observatories), constitutes an innovation even relevant for other vessels. The size, engine power, and propulsion of the vessel are optimized to accommodate the requirements posed by drilling, extended cruises and heavy ice breaking. The strength in icebreaking allows year-round access to most regions in the central Arctic Ocean. The vessel is capable of deploying a large variety of complex scientific equipment including, for example, the Calypso Piston Corer.

It must be recognised that it is difficult to obtain reliable meteorological observations from a ship of the size and configuration of the AURORA BOREALIS. Careful positioning of the meteorological sensors will be required in the implementation phase to fulfil the important potential measurements.

The modular approach to laboratory design allows easy accommodation of future requirements of new scientific applications. The ship will undergo a major refit after about 15 years with the possibility of a major equipment upgrade, and regular IT upgrades.

Altogether, the reasonability and feasibility of the project has been demonstrated within the normal risks that have to be expected from a project with a large number of new developments and innovations. State of the art measures to minimize pollution have been implemented in the design of the vessel. The risks involved in the proper performance of the DPS are acceptable given the innovative nature of the application in sea ice.

The concept of one platform integrating strong icebreaking and drilling capability is superior to the utilization of multiple platforms in terms of cost and integration of science and drilling teams on one vessel (for details concerning the cost of alternatives cf. B.V.2.). A considerable advantage of the AURORA BOREALIS is that the vessel offers a design that allows work of groups from several disciplines thereby fostering scientific exchange and interdisciplinary work (cf. B.IV.1.).

II.3. Transfer of Research Results

An impact of the research results attained by the deployment of AURORA BOREALIS can be expected on the scientific, the technical as well as the socio-economic level.

In general, the activity of the drilling research icebreaker will further global earth system science. The main impact will be understanding global climate change in the most sensitive region of the earth and exploring an area that is changing fast. These studies are of major importance as they reveal the growth and decay of the Arctic ice sheet (on both geological and contemporary time scales).

On the technical level, the inclusion of a number of highly innovative elements such as the Dynamic Positioning System, which will be able to break ice sideways, will probably lead to spin-offs. The novel propulsion systems may be of wider application than in the Arctic sea.

The research made possible by AURORA BOREALIS will lay down the scientific basis for the future sustainable development of the Artic region as well as for the conservation of bio-diversity. Already now, the new and unexpected findings of the only partly successful ACEX expedition in 2004 reveal the potential of a routine, reliable Arctic drilling activity that can be implemented with AURORA BOREALIS. The data collected will probably help to study and conserve so far largely unknown organism as well as endangered species (e. g. the polar bear).

B.III. Participation of Institutes in the Project and Collaboration

AWI has attained a leading role in the international marine community. It has an excellent track record in operating the German research icebreaker POLARSTERN (cf. B.V.1.) and other research facilities in the Arctic and Antarctic (e. g. permanently manned stations like NEUMAYER).

During the preparation phase the institute has played a major role in promoting the AURORA BOREALIS project. It has established good cooperation with the most experienced partners in ship construction, drilling technology and safety requirements. Furthermore, the AWI plays a major role in national and international research projects.

Although the facility has an order of magnitude that demands participation on the European and even on the global level the AWI should keep the leadership in realizing the project, at least for the initial years. It is very important that the project is promoted and realized by an institution with international reputation and a great amount of experience. There are doubts whether the European Polar Consortium (EPC) has enough experience to realize the project and to gain commitments of the international co-operation partners.

B.IV. Users of the Facility

The International Polar Year (IPY) has demonstrated the great demand for research facilities in Polar Regions. By now, the call for papers resulted in a total of over 1,000 international submissions, one third concerning the Artic. There is no doubt that the national and international interest in AURORA BOREALIS will be high and will last over the following two decades. The Konsortium Deutsche Meeresforschung (KDM)[73]

[73] The Konsortium Deutsche Meeresforschung (KDM) was founded in 2004 in order to promote science and research in the field of marine research. The KDM consists of ten member institutions: Alfred-Wegener-Institut für Polar- und Meeresforschung (AWI), GKSS Forschungszentrum Geesthacht, Institut für Chemie und Biologie des Meeres, Universität Oldenburg (ICBM), Leibniz-Institut für Meereswissenschaften (IFM-GEOMAR), Institut für Ostseeforschung Warnemünde (IOW), International University of Bremen (IUB), Max-Planck-Institut für Marine Mikrobiologie (MPI Bremen), Universität Bremen, Zentrum für Meeres- und Klimaforschung, Institut für Meereskunde, Hamburg (ZMK), Zentrum für Marine Tropenökologie (ZMT) (as on 18 March 2005).

regards the project as very well embedded in the national community. On the international level, the project would meet existing needs and expectations which have long been the consensus of the marine science community as a whole.

Potentially, 500 scientists per year will have access to the facility. Online access to data collected on the vessel will increase the potential impact of the facility. Furthermore, the station in the Arctic allows for an easy exchange of scientists.

In the case of the existing German research and supply icebreaker POLARSTERN operated by AWI, about four fifth of the users (79 %) account for German institutions, one fifth for foreign institutions (21 %).[74] The most important part of the non-German contributers comes from the EU (53 % compared to 15 % for the US). In the case of AURORA BOREALIS the participation of the European, as well as the international community, will probably increase. Research institutions of the 25 European countries as well as from Norway, Russia and the United States of America will be interested in participating in the AURORA BOREALIS project.

As a general rule, the research of foreign users on POLARSTERN is funded by their own institutions or projects. A user fee is not charged. However, in numerous cases a use of other foreign research infrastructure free of charge could be achieved in exchange for the POLARSTERN ship-time. The Ocean Facilities Exchange Group (OFEG)[75] arranges the exchange of ship-time among several European countries (Germany, Great Britain, France, the Netherlands and Spain). The use of different European research ships (e.g. POLARSTERN) as well as the use of research facilities (e. g. the French ROV “Victor 6000”) is organized with the help of a credit point system. The credit point system is very cost effective but it is based on optimisation of programmes of equivalent vessels (positioned in different geographical areas) and on limitation of passage time. As AURORA BOREALIS will be unique, either in terms of position or of missions, the objectives mentioned above may not be achieved. Pre-

---

[74] 37 % of the users come from the AWI, 27 % from other German research institutions. As the port of registry of POLARSTERN is Bremerhaven, the technical, logistical (14 %) and public relation activities (1 %) also are counted among the national use of the vessel. The remaining 21 % of the POLARSTERN users are scientists from foreign institutions.

[75] In February 1996, a Tripartite Agreement was signed between NERC (Natural Environment Research Council), IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer) and BMBF (Bundesministerium für Bildung und Forschung) for the mutual cooperation of marine scientific interests and activities. Under the aegis of this agreement a Marine Facilities Tripartite Group (MFTG) was established which comprises the managers and planners of the respective fleets of scientific research ships and major marine facilities. This group has been meeting since 1996 with the primary objective of bartering ship-time and exchanging major marine equipment without the need to charter or exchange money. In November 2002, the NIOZ (Royal Netherlands Institute for Sea Research) became a full member and in April 2003 a Spanish representative was invited to attend meetings as an observer. In light of the fact that the Group then had more than three members the MFTG was re-named the Ocean Facilities Exchange Group (OFEG). Full particulars cf.: *http://www.nerc.ac.uk/funding/marineplan/tripartite.shtml*.

sumably, a new system has to be invented. A priority for European proposals should be guaranteed in case the EU supports a great part of the investment costs. During the non-drilling part of its activity AURORA BOREALIS should operate as other research ships in terms of free-of-charge at least for young scientists and engineers. Thus, AURORA BOREALIS could oscillate between IODP and research ship type of funding. However, final details have yet to be decided.

Concerning the organization of the access to the facility, drilling and non-drilling activities of the icebreaker have to be distinguished. For about four months of the year AURORA BOREALIS will be committed to the Integrated Ocean Drilling Programme (IODP) as a mission-specific platform. During this period the IODP and its advisory structures will control the use of the vessel. For the rest of the year the access to the ship for users from the classical marine research community will be organised by a user board consisting of representatives from all participating countries. Proposals will be reviewed and ranked according to their scientific quality. But the allocation of ship time will also depend on the contribution of the participating countries to the construction and operating costs of the ship (cf. B.V. 2).

There are well established ways of controlling access to drill ships and polar research facilities. In its "Statement on Nine Large Scale Facilities", of 2003 the German Science Council has preferred the installation of one steering committee:

> "Access to the facility should be controlled by a steering committee consisting of a science group (polar research community and drilling community), a logistic group, and a technical advisory group on the basis of research proposals. The proposals would have to go through a confidential review process (peer-review according to DFG standards). Successful proposals would be transferred to the logistic group for cruise planning. It is important to have an open system which makes access of the facility transparent for Potential users. It should be aimed at a forward planning of 3 – 5 years with a certain degree of flexibility for short-notice projects. A performance evaluation (quality control) should be based on a rigorous assessment of publications resulting from the individual projects."[76]

In general, the option of one steering committee seems to be better. But, as AURORA BOREALIS will be part of the EU's contribution to IODP for about four

[76] Cf. Wissenschaftsrat: European Drilling Research Icebreaker (Aurora Borealis), in: Wissenschaftsrat: Statement on Nine Large-scale Facilities for Basic Scientific Research and on the Development of Investing Planning for Large-scale Facilities, Cologne 2003, p. 371-401, here p. 399

months per year, the costs will be covered by ECORD for the period. The steering committee will therefore operate for the remaining period of the year and should interact with ECORD.

IV.1. Scientific Education

The idea of a “Floating international polar university” is very convincing. AURORA BOREALIS will offer three thousand student-days per year. The potential of AURORA BOREALIS as a state-of-the-art research laboratory for the training and education of young scientists with multiple skills was already appreciated by the Science Council in the first statement on this project.[77] The large size of the vessel will offer the opportunity to students to fully participate in the research on board in an international working environment. Due to the size it will also be easy to include seminar facilities.

The size of the ship allows pursuing different research projects on the same ship at the same time and allows working on one theme from different disciplinary viewpoints. AURORA BOREALIS will be an innovative platform for multidisciplinary research under application of the most modern technology.

It is important to stress that the vessel offers high safety for students and personnel even under worst weather conditions.

IV.2. Public Relations

Public affairs activities are necessary and important to communicate the relevance of research to a greater public, in particular in the case of such a cost-intensive facility. AURORA BOREALIS has a significant Potential for the promotion of science in society and, vice versa, for revealing the societal relevance of science. Hence, the participation of the media in AURORA BOREALIS should be organized in an easily accessible way. On POLARSTERN 1 % of the users come from the field of the media. Furthermore, a participation of NGO (non-governmental organizations) members should be discussed.

[77] Ibid., p. 399.

B.V. Project Management, Location, Costs, Schedule

V.1. Project Management and Location

Over its 25 years of existence the Alfred Wegener Institute has proven to be an excellent catalyst and host for large international programs aboard the POLARSTERN. Moreover AWI has shown to be a most reliable and safe operator of one of the largest research vessels in the world in a very hostile environment of heavy storms, dense sea-ice and huge icebergs. This track record also warrants safe and reliable operation of AURORA BOREALIS.

There are several viable options for the operation of the vessel. The final location will depend on the makeup of the consortium of nations contributing to the vessel, as well as scientific needs and costs of operation. At least initially, AWI should have major responsibility for operating the vessel, including selection of the home port.

V.2. Costs, Funding and Schedule

The cost estimate for the construction of the platform seems realistic. The increase in cost from the first projection is related to the increased size of the refined design. No further major changes in the design are expected. The estimates of the costs for construction and operating of the vessel seem to be in line with those of comparable platforms. Inherent uncertainties in the cost estimates are related to the price of fuel and possibly steel. Due to the instability of the fuel price the running costs will depend on the world’s economic cycles with augmentations of 30 % and more. The additional costs related to scientific research conducted on the vessel will mainly be shared by the nations contributing to AURORA BOREALIS (for an overview of these costs cf. Annex 3).

AURORA BOREALIS will be the only vessel able to drill the Arctic without aid of additional icebreakers. As the ACEX expedition has shown, the deployment of three additional ice breakers will make a research expedition very cost intensive. For a period of three weeks of drilling 15 million dollars had to be expended (science costs not included). Furthermore, the drilling ship and the icebreakers deployed during the ACEX expedition do not seem to be adequately equipped and prepared for scientific goals. Neither the dynamic positioning nor the deployment of Advanced Piston Coring (APS) could be realized during the expedition as the two systems failed shortly after their first deployment. The construction and operation of a drilling research icebreaker is – in the long run – more cost effective. Furthermore, the scientific output is expected to be superior.

An amount of 6 million Euro should be provided for immediate funding in order to complete the design work. From a scientific and technological point of view, the project is ready to move on to the funding phase.

Although the size and scope of the project requires international contributions to the overall costs of the project, Germany must initiate the implementation of the project by providing the initial funding at a significant level and by securing participation of other nations and the EU.

The estimate of 4 to 5 years for tendering and construction of the vessel is realistic.

C. Conclusion

In the context of global warming, research in the polar regions occupies a prominent position, because these regions are the most sensitive to climate and environmental change of all regions in the world. Despite the central importance of the Arctic, in particular, to climate and environmental research there is a remarkable dearth of long-term observations and of data on climate evolution and change on all time scales. The remote and harsh environment of the Arctic remains one of the last frontiers in science that has to be studied just in order to be able to deal with the expected changes.

AURORA BOREALIS will provide a unique international platform for year-around study of the natural Arctic and its changes in the coming 30-40 years of its operation. For thirty years, this platform will provide continuous long-term observations and research throughout all seasons, a time scale that is sufficient to resolve contributions from decadal cycles and long-term trends to the overall signal. Moreover, its additional and very advanced deep seabed drilling capacity will allow study of the sediment record of past climate change in the Arctic for the first time, thus providing the baseline data that are essential for understanding future Arctic change. By having AURORA BOREALIS year-round in the Arctic, the Alfred Wegener Institute will be able to dedicate the existing ice-breaker POLARSTERN to year-around research in the Antarctic region.

Germany should strengthen the Alfred Wegener Institute as it already plays a leading role in the international context of marine science and has gained international reputation in this field (“Leuchtturm als Leitidee”). Although AURORA BOREALIS should be realized as an international project aggregated around the AWI, Germany – as pioneer investor – should initiate the implementation of the project by providing the initial funding at a significant level and by securing the participation of other nations and the European Community and other international partners.

Annex 1: List of Abbreviations

AARI	Arctic – Antarctic Research Institute, St. Petersburg, Russia
ACEX	Artic Coring Expedition
ACSYS/CLIC	Arctic Climate System Study
ANDRILL	ANtArctic DRILLing
ANTOSTRAT	Antarctic Offshore Stratigraphy Project
AOSB	Arctic Ocean Sciences Board
APPG	Arctic Proramme Planning Group of ODP/IODP
AUV	Autonomous Underwater Vehicle
AWI	Alfred Wegener Institute for Polar and Marine Research
BAS	British Antarctic Survey
CLIVAR	Climate Variability and Predictability
CRYOSAT	Name of ESA Cryosphere Satellite
CTD	Conductivity-Temperature-Depth
DGO	Department of Geology and Oceanography (University of Bordeaux)
DSDP	Deep Sea Drilling Project
ECORD	European Consortium for Ocean Research Drilling
EIB	European Investment Bank
ENVISAT	European Environmental Satellite
EPB	European Polar Board
EPC	European Polar Consortium
EPICA	European Polar Ice Coring in Antarctica
ESCOD	European Scientific Committee for Ocean Drilling
ESF	European Science Foundation
ESONET	European Seafloor Observatory Network
EU	European Union
FIMR	Finnish Institute of Marine Research
GEOMAR	Zentrum für marine Geowissenschaften an der Universität Kiel
GEUS	Geological Survey of Denmark
GMES	Global Monitoring for Environment and Security
GOOS	Global Ocean Observing System
HGF	Helmholtz-Gemeinschaft Deutscher Forschungszentren eV (Helmholtz Association of National Research Centres)
HSVA	Hamburger Schiffbau-Versuchsanstalt
IASC	International Arctic Science Committee
ICARP	International Conference on Arctic Research Planning
ICSU	International Council of Scientific Unions
IFREMER	Institut Français de Recherche pour L'Exploitation de la Mer
IFRTP	Institut Français pour la Recherche et la Technologie Polaire (now called IPEV)
IODP	Integrated Ocean Drilling Program (replaced ODP in 2003)
IPY	International Polar Year (2007/2008)
JEODI	Joint European Ocean Drilling Initiative (now: ECORD)
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
KDM	Konsortium Deutsche Meeresforschung KDM
NAD	Nansen Arctic Drilling Program

NOAA	National Ocean and Atmospheric Administration (USA)
ODP	Ocean Drilling Project
OFEG	Ocean Facilities Exchange Group
ROV	Remotely Operated Vehicle
SME	Small and medium sized enterprise
WG	Working Group
WR	Wissenschaftsrat (German Science Council)

Annex 2: Main Particulars of the Icebreaking Research Vessel with a Drilling Capability[78]

Main Particulars of the Icebreaking Research Vessel with a Drilling Capability

Main Dimensions

Length between perpendiculars Lpp	132 m
Beam (main deck)	40 m
Beam CWL	36 m
Draft CWL	8.5 m
Depth to main deck	13.5 m
Max. Displacement approx.	23000 t

Classification (estimated): Drilling Vessel, DRILL, DYNPOS, HELD, CRANE

Ice Class (estimated):	Russian Register:	LL3
	DNV	Polar 10, Ice 15
	CASPPR	CAC 3
IMO Polar Code		

Installed Engine Power

Diesel Generators	6 x 5 MW
Diesel Generators	4 x 2.5 MW
Total installed Power	40 MW

Propulsion

Azimuthal propulsion at the stern	2 x 12.5 MW
Retractable azimuthal thrusters in bow area	3 x 3 MW
Total installed propulsion and thruster power	35 MW
Dynamic positioning DP Class 3	
Endurance at ½ of total installed power	60 days
Fuel Capacity approx.	6000 to

Icebreaking Performance

Ahead and astern icebreaking performance in level winter ice with snow cover at about 1 knot	>2.0 m
Dynamic positioning in ice (conditions to be determined)	

Drilling

Core Drilling
Automatic pipe rack
Automatic pipe lift

[78] Alfred Wegener Institute: Technical feasibility study „AURORA BOREALIS“, November 2004, p. E 302/00 A.2.0-21 to A 2.0.-23.

Pipe store capacity approx.	9,000 m
Height of derrick approx.	62 m
Moonpool (drilling)	7 x 7 m
Moonpool (vehicle)	5 x 5 m
Remote Operated Vehicle (ROV)	
2 cranes on deck, range 30 m, 25 t	
Workshop and spare parts area	

Research

Laboratory and electronic area approx.	2,300 m^2
Containers (laboratory or storage)	30
Storage for cores	
Helideck and hangar	
Helicopter + research equipment	

Living Quarters

Cabins	64
Conference room	
Mess	
Cafeteria	
Pantry and galley	
Hospital	
Sauna, pool and gym	

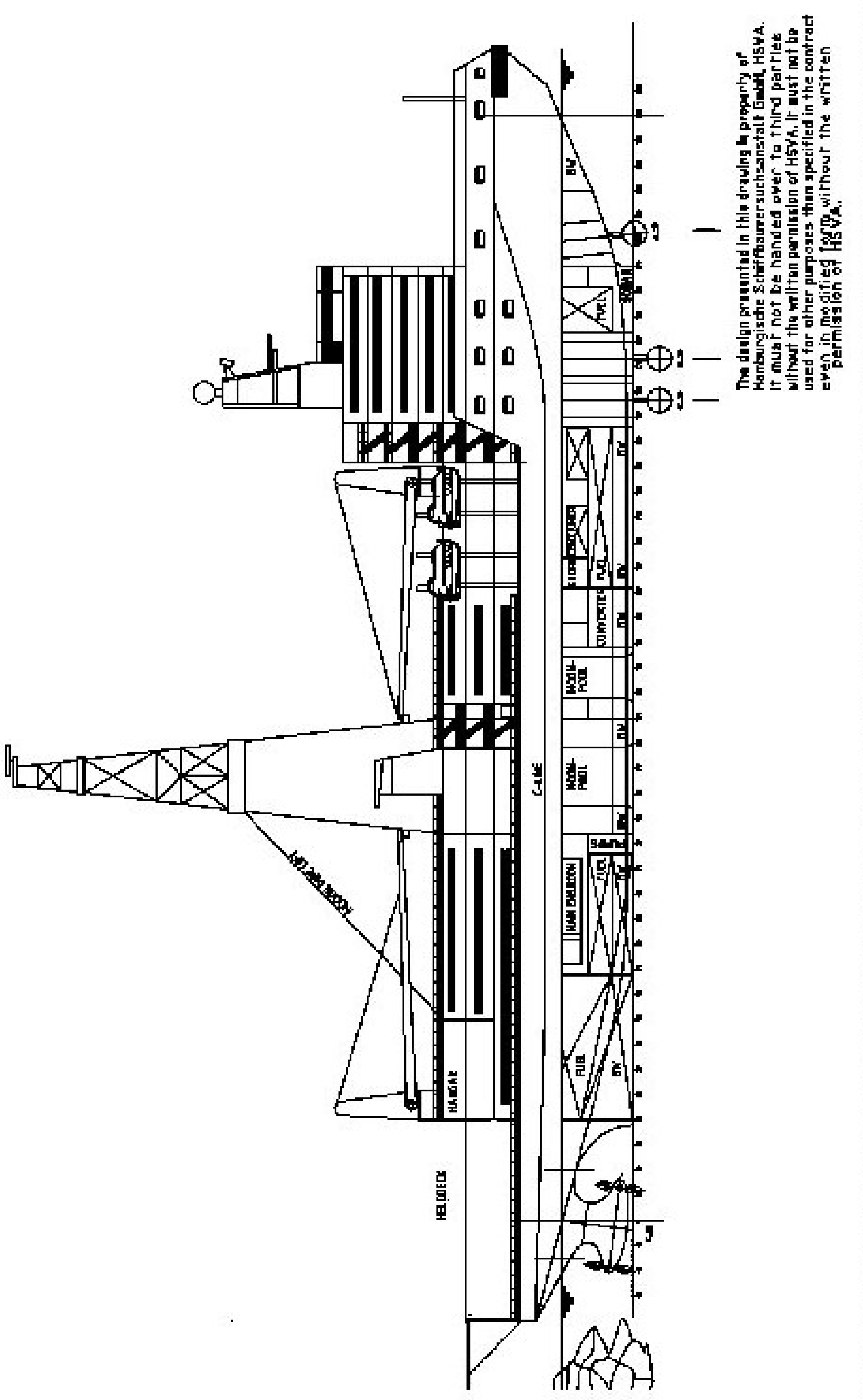
Safety

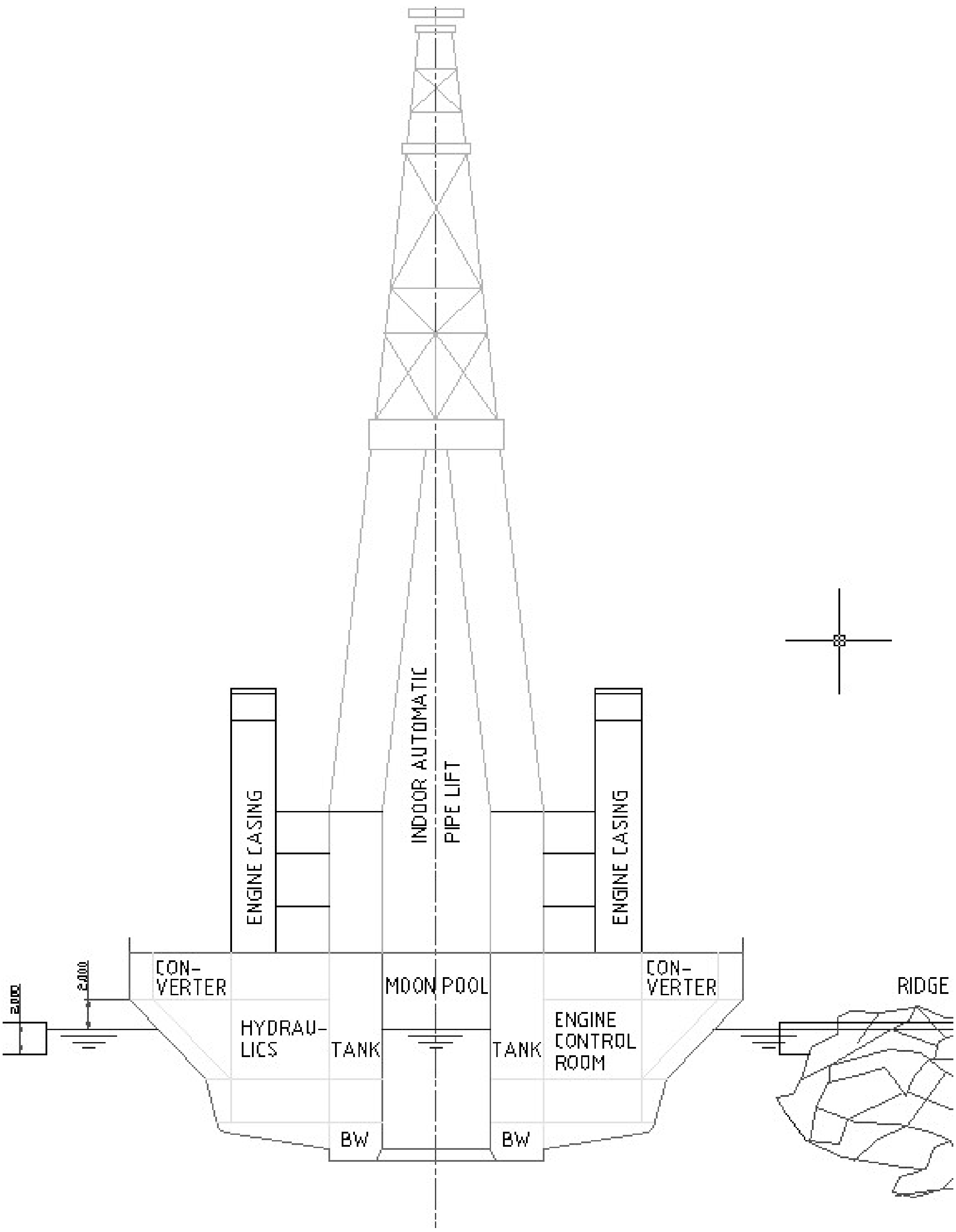
4 x 50 person lifeboats, closed, ice resistant
Inflatable life rafts

2 radars
GPS/Glonass
Sonar
speed log
clinometers
gyro and necessary nautical instruments

Communication system (cranes, drilling, total crew and researchers)
Monitoring system (engine rooms, working area)

Sketches of the General Arrangement Plan




INDOOR AUTOMATIC
PIPE LIFT
ENGINE CASING
ENGINE CASING
CON-
VERTER
MOON POOL
CON-
VERTER
RIDGE
HYDRAU-
LICS
TANK
TANK
ENGINE
CONTROL
ROOM
BW
BW

Annex 3: Required Scientific Technical Equipments for AURORA BOREALIS

The following equipment was not included in the last price calculation for the Drilling Icebreaker "Aurora Borealis".

1. General Infrastructure for Scientific Laboratories, Working Areas and Laboratory Containers

Equipment	**Description**	**Estimated Costs in Thousand Euro**
General infrastructures for laboratories	Furniture, Water Supply Installation, Electricity, Compressed air, etc.	1000
Sea Water Supply Systems For laboratory use	Teflon Coated Stain Less Steel Pipes System (V4A) for Biological and Chemical use, operated with a Membrane Pump (1 – 4 m³/h) and a Centrifugal Pump (4 m³/h). The Second System is a Pure Stain Less Steel Pipes (V4A), Operated with Centrifugal Pump (25 m³/h) for general use	1500
Computer Network System	Fiber Optics Network, 1000 Optical Fiber Pairs to all cabins, Laboratories and Working area. 300 TP-Connection (4 Ports HUB), Totally 1200 RJ45-Connections (TCP/IP), 10 Gbits/s, 6 CISCO Router	500
Computer System	Main Computer, Mass Storage System, Server, Info System, user PC, Printers, etc.	600
Software and Licences	For Data Acquisition System, E-Mail and Application Software	200
Data Communication Systems	Permanent Satellite Link 28 kBit/s	300
2 X UPS Systems for Adequate Power Supply	MERLIN GERIN, 2 x 120 kW, 20 Minutes	200
Total Infrastructure		**4300**

2. Hydro Acoustics

Equipment	**Description**	**Estimated Costs in Thousand Euro**
Multi Beam Sonar	Deep Sea Multi Beam Sonar up to (10.000 m) 12 to 15,5 kHz, 90° & 120°, 60 Hard Beams, 256 Soft Beams, Side-Scan-Function	1200
Sediment Parametric Echo Sounder PARASOUND-DS III	Deep Sea Parametric Sonar, Atlas Hydrographic Type PARASOUND-DS III, 18 – 23 kHz, up to 10.000 m Water Depth , up to 150 m Penetration in Sediment.	800
Deep Water Sounder (DWS)	Hydrographical Deep Sea Echo Sounder, SIMRAD, Type EA 500, 13 kHz, up to 12.000 m Water Depth , Bottom Slope Detection	600
Fishery Echo Sounder EK 60	SIMRAD, EK60, 4 Split-Beam-Transducer, 38, 70, 120 und 200 kHz, for Fish & Krill	400
Acoustic Doppler Current Profiler (ADCP)	Hydro Acoustical Current Profiler RDI, Type OS II, ADCP, 150 kHz	80
Short Base Under Water Navigation System POSIDONIA 6000	IXSea, POSIDONIA 6000, 16 kHz, Tow Mobile Transponder	300
Fishery Net Sonde	SCANMAR, Cable Less hydro acoustical Fishery-Sonde, System 400, Depth Sensor HC4-D12, Height Sensor HC4-CT180, Mobile Hydrophones in Moon Pool	50
Total Hydro Acoustics		**3430**

3. Scientific Winches

Equipment	**Description**	**Estimated Costs in Thousand Euro**
Winch Data Logging and Control System	SAM, 2 PC, Software, SPS, Control , Data Collection, Acquisition and Data Display.	200
2 X Cable Winch for 11 mm Coax cable	Winches for Oceanography 7000 m, 11 mm-Coax Cable, Connector SEACON RMG-2 FS (Female), max. Working Load 4 to	600
2 X Storage Winches for 18 mm Wire	Winches for Geology 10.000 m, 18 mm Wire max. Working Load 20 to	1000
1 X Storage Winches for 18 mm Coax Cable	8.000 m 18,2 mm-Coax Cable, Connector GISMA BR 10 Size 2 (3 Pin Female) , Slipper Ring RAMERT with FOCAL Mono Mode Fiber Optic Slipper Ring (SRV 2.182.2T3), max. Workings Load 5 to including the Cable	500
2 X Storage Winches for Fishery	Fishery Winches, 3000 m, Wire 30 mm in Diameter, max. Working Load 30 to	500
2 X Friction Winches	Alternative for 30 mm und 18 mm Wires and Cables	1000
1 X Horizontal Capstan for Mooring	Special Horizontal Capstan with a Stor-age Winches, for Mooring Works, Workings Load 5 to.	200
Total Winches		**4000**

4. Scientific Cranes and Lifting Gears

Equipment	**Description**	**Estimated Costs in Thousand Euro**
1 X Main Beam (20 to) Starboard	**20 to SWL, Working Height 4.30 m, Working Length 7 m, max. 3 m over the Ship's Edge, Hydraulic Thorn for Gravity Corer, 5 to**	500
1 X Main Beam (5 to) Starboard	**5 to SWL, Working Height 4.30 m, Working Length 7 m, max. 3 m over the Ship's Edge**	300
1 X A-Frame Crane , Aft	**30/10 to, Rope Tensions , for Fishery Purposes**	1000
1 X Travelling Crane for CTD	**3,5 to, for CTD and Rosettes**	200
Total Cranes		**2000**

5. Other Scientific Equipments

Equipment	**Description**	**Estimated Costs in Thousand Euro**
2 X Thermo Salino Graphes	SEABIRD SBE 21 with External Thermometer SBE 38, for Keel and Bow, installation	200
X Salinometer	Guildline Type 8400B	50
1 X CTD and Rosette	SEABIRD SBE 911 Plus with Deck Unit SBE 11 Plus and 24 X 12 l Bottles Rosette	150
1 X Sea Gravimeter	BODENSEEWERKE, KSS31	50
XBT- Launching Device (Expandable Bathythermograph, XBT)	Sippican & Nautilus, for XBT-Launching	30
1 X High Pressure Compressor Plant for Marine Seismic	LEOBERSDORFER MASCHINENFABRIK LMF, with Pulser Station and Compressed Air Battery, 210 bar, 32 l/s, 600kW	3000
1 X Sea Ice Thickness Detector	Sea Ice Thickness Detector (SIMS), Mobile and Operated at the Bow Crane, For Monitoring the Sea Ice Thickness	50
5 X Laboratory Containers	For mobile use	1000
1 X Isotopes Container	For use of radio active materials	500
ROV-System	For general use and assistance by drill operations	1000
Weather Station	Complete Weather Station including Satellite image Systems, Sensors, Radio Sounding System and data Acquisition System	1200
Total Other Scientific Equipment		**7230**

		Estimated Total Costs in Thousand Euro
Total Costs for Scientific Equipments According items 1 to 5		**20960**

D. Anhänge

Anhang 1 Abkürzungsverzeichnis der Gesamtstellungnahme

AARI	Arctic – Antarctic Research Institute, St. Petersburg, Russia
ACEX	Artic Coring Expedition
ACSYS/CLIC	Arctic Climate System Study
ALBA	Synchrotron Light Facility, Barcelona
ALS	Advanced Light Source, Berkeley
ANDRILL	ANtArctic DRILLing
ANKA	Angströmquelle Karlsruhe GmbH
ANTOSTRAT	Antarctic Offshore Stratigraphy Project
AOSB	Arctic Ocean Sciences Board
APPG	Arctic Programme Planning Group of ODP/IODP
APPLE	Advanced Polarized Photon Light Emitter
APS	Advanced Photon Source, Argonne
AUV	Autonomous Underwater Vehicle
AWI	Alfred Wegener Institute for Polar and Marine Research
AZM	Anwendungszentrum Mikrosystemtechnik/ Application Center for Micro Engineering
BAM	Bundesanstalt für Materialforschung und –prüfung/ Federal Institute for Materials Research and Testing
BAS	British Antarctic Survey
BER	Berliner Forschungsreaktor
BESSY	Berlinger Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung/ Berlin electron storage ring company for synchrotron radiation
BIP	Bruttoinlandsprodukt
BMBF	Bundesministerium für Bildung und Forschung/Federal Ministry for Education and Research
BNL	Brookhaven National Laboratory
BTC	Beam Time Committee
CEBAF	Continous Electron Beam Accelerator Facility
CERN	European Organization for Nuclear Research
CLIVAR	Climate Variability and Predictability
CLS	Canadian Light Source, Saskatoon, Saskatchewan
CNRS	French National Center for Scientific Research, Paris
COFIN	Italian Grant Review Committee
CRG	Cooperating Research Group
CRYOSAT	Name of ESA Cryosphere Satellite
CTD	Conductivity-Temperature-Depth
CW	Continuous Wave
DAAD	Deutscher Akademischer Austauschdienst/ German Academic Exchange Service
DELTA	Dortmunder Elektronen Speicherring Anlage/ Dortmund Electron Accelerator Facility
DESY	Deutsches Elektronen Synchrotron/ German Electron Synchrotron, Hamburg
DFG	Deutsche Forschungsgemeinschaft/ German Research Foundation
DGO	Department of Geology and Oceanography (University of Bordeaux)
DIAMOND	Diamond Light Source, Didcot, UK
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DOE	US-Department of Energy
DORIS	Storage ring for synchrotron radiation of DESY, Hamburg
DSDP	Deep Sea Drilling Project
DUV FEL	Deep Ultraviolet Free Electron Laser
ECORD	European Consortium for Ocean Research Drilling
EC	Europäische Kommission/ European Commission
EFR	Europäischer Forschungsraum
EIB	European Investment Bank
ELBE	Electron Accelerator of High Brilliance and Low Emittance, Forschungszentrum Rossendorf

ELETTRA	Synchrotron Light Laboratory, Trieste
ELSA	Electron Stretcher Accelerator, Bonn University
ENVISAT	European Environmental Satellite
EPB	European Polar Board
EPC	European Polar Consortium
EPICA	European Polar Ice Coring in Antarctica
ERC	European Research Council
ERDF	European Regional Development Fund
ERL	Energy recovery
ESA	European Space Agency
ESCOD	European Scientific Committee for Ocean Drilling
ESF	European Science Foundation
ESFRI	European Strategy Forum for Research Infrastructures
ESO	European Southern Observatory
ESONET	European Seafloor Observatory Network
ESRF	European Synchrotron Radiation Facility, Grenoble
ESS	European Spallation Source
ETW	European Transonic Windtunnel
EU	European Union/ Europäische Union
EUV	Extreme Ultraviolet
eV	Electron Volt (energy unit)
FEL	Free Electron Laser
FERMI (Fermilab)	U.S. National Accelerator Laboratory
FHI	Fritz-Haber-Institute of the Max-Planck-Society
FIMR	Finnish Institute of Marine Research
fs	Femtosecond
FTE	Full Time Equivalent (one man per year)
FU	Free University Berlin
FWHM	Full width at half maximum (linewidth)
FY	Financial Year
FZJ	Forschungszentrum Jülich/ Research Center Jülich
FZK	Forschungszentrum Karlsruhe/ Research Center Karlsruhe
FZR	Forschungszentrum Rossendorf
GEOMAR	Zentrum für marine Geowissenschaften an der Universität Kiel
GEUS	Geological Survey of Denmark
GeV	Giga electron Volt
GG	Großgeräte
GKSS	Gesellschaft in Kernenergieverwertung für Schiffbau und Schifffahrt
GLF	Grundlagenforschung
GMES	Global Monitoring for Environment and Security
GOOS	Global Ocean Observing System
GRID	Engl.: Versorgungsnetz. Gemeint ist ein System für die system-, orts- und organisationsübergreifend bereitgestellten Daten-, Informations- und Rechnerdiensten
GW	Giga Watt
HASYLAB	Hamburger Synchrotron Strahlungslabor at DESY, Hamburg
HBFG	Hochschulbauförderungsgesetz
HERA	Hadron-Elektron-Ring-Anlage (Particle accelerator) at DESY, Hamburg
HGF	Helmholtz-Gemeinschaft Deutscher Forschungszentren eV (Helmholtz Association of National Research Centres)
HGHG	High Gain Harmonic Generation
HMI	Hahn-Meitner-Institute
HoBiCaT	Superconducting Cavity Test Facility at BESSY (horicontal bi cavity test facility)
HOM	High Order Modes

HSVA	Hamburger Schiffbau- und Versuchsanstalt
HU	Humboldt University, Berlin
IASC	International Arctic Science Committee
ICARP	International Conference on Arctic Research Planning
ICSU	International Council of Scientific Unions
IFREMER	Institut Français de Recherche pour L'Exploitation de la Mer
IFRTP	Institut Français pour la Recherche et la Technologie Polaire (now called IPEV)
IFW	Institute for Solid State and Materials Research, Dresden
IKT	Informations- und Kommunikationstechnologie
ILC	International Linear Collider
ILL	Institut Max van Laue – Paul Langevin
IODP	Integrated Ocean Drilling Program (replaced ODP in 2003)
IPY	International Polar Year (2007/2008)
IR	Infrared
ITER	International Thermonuclear Experimental Reactor/ Internationaler Thermonuklearer Experimenteller Reaktor (bzw. lateinisch: der Weg) in Cadarache, Frankreich
JEODI	Joint European Ocean Drilling Initiative (now: ECORD)
JOIDES	Joint Oceanographic Institutions for Deep Earth Sampling
KDM	Konsortium Deutsche Meeresforschung KDM
keV	kilo electron Volt
LEUTL	Low energy undulator test line
LIGA	Liga Technique, a micro-fabrication method developed in Karlsruhe (deep X-ray lithography, electroforming and moulding)
LINAC	Linear accelerators
LURE	Laboratoire pour l'Utilisation du Rayonnement Electronmagnétique, Orsay, Frankreich
MAC	Machine Advisory Subsommittee
MAX-lab	National Electron Accelerator Laboratory for Nuclearphysics and Synchrotronradiation Research, Lund University, Sweden
MBI	Max-Born-Institute
MeV	Mega electron Volt
MLS	Metrological Light source
MPG	Max-Planck-Gesellschaft/ Max-Planck-Society
MV	Mecklenburg-Vorpommern
NAD	Nansen Arctic Drilling Program
nC	nanoCoulomb
NIH	National Institute of Health, USA
NMR-Gerät	Nuclear magnetic resonance-Gerät/Kernspinresonanzgerät
NOAA	National Ocean and Atmospheric Administration, USA
NSF	National Science Foundation, USA
NSLS II	National Synchrotron Light Source, Brookhaven, New York
NSRRC	National Synchrotron Radiation Research Center, Taiwan
ODP	Ocean Drilling Project
OFEG	Ocean Facilities Exchange Group
OpTecBB	Optec-Berlin-Brandenburg e.V.
PAC	Programme Advisory Subcommittee
PETRA	Positron-Elektron-Tandem-Ring-Anlage
PITZ	Photo Injector Test Facility, DESY (Zeuthen)
PSF	Protein Structure Factory
PSI	Paul-Scherrer-Institute, Villigen, Switzerland
PTB	Physikalisch Technische Bundesanstalt/ National Metrology Institute for Scientific and Technical Services
R&D	Research and Development
rf	radio frequency
RÖNTEC	Firma Röntec AG Adlershof, Berlin
ROV	Remotely Operated Vehicle

RP7	7. Rahmenprogramm der EU
SAC	Scientific Advisory Committee
SASE	Self Amplified Spontaneous Emmission
SenWFK	Senatsverwaltung für Wissenschaft, Forschung und Kultur of the Land Berlin
SFB	DFG-Sonderforschungsbereich/ Collaborative Research Center (funded by DFG)
SLAC	Stanford Linear Accelerator Center
SLS	Swiss Light Source, Villigen, Switzerland
SH	Schleswig-Holstein
SME	Small and medium sized enterprise
Soft Y-ray FEL	Freier Elektronen Laser für weiche Röntgenstrahlung
SOLEIL	Soleil Synchrotron, Saint-Aubin, France
SPEAR	Stanford position electron accelerator ring
SPP	Schwerpunktprogramm/Priorty Programme (funded by DFG)
Spring-8	Super Photon ring-8 GeV, Nishi-Horima, Japan (Japanese 3rd generation synchrotron radiation facility)
SR	Synchrotron Radiation
SRF	Superconducting Radio Frequency
SRI	International Conference on Synchrotron Radiation Instrumentation
SRS	Synchrotron Radiation Source, Daresbury, U.K.
SSRL	Stanford Synchrotron Radiation Laboratory, Menlo Park, California – division of Stanford Linear Accelerator Center
STI	Science and Technology Issues
TANTALUS	Synchrotron at the University of Wisconsin, USA
Tc	Superconducting transition temperature
TESLA	Tera Electron Volt Energy Superconducting Linear Accelerator
TFR	Forschungsrat für technische Wissenschaften, Schweden/ Research Council on Technical Sciences, Sweden
THz	Terahertz
TTF	TESLA Test Facility
TU	Technical University Berlin
UC	User Committee
UV	Ultraviolet
VUV	Vacuum Ultraviolet
WG	Working Group
WGL	Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz
WISTA	City of Science, Technology and Media in Berlin-Adlershof
WR	Wissenschaftsrat (German Science Council)
XUV	Extreme Ultraviolet

Anhang 2 Vom Wissenschaftsrat im Auftrag des BMBF begutachtete Großgeräte (aktualisierte Übersicht)

Gerät	Standort	Investitionskosten	Betriebskosten pro Jahr in Mio. Euro	Finanzierungsmodelle	Realisierungsstand
Gruppe 1					
HLD	FZ Rossendorf/ IFW (Dresden)	24,5	3,7	national (Bund: 50%)	Im Bau
HALO	DLR (Oberpfaffenhofen)	69,0	3,8	national (Bund: 70%, Rest HFG u. MPG)	z.Z. in wissenschaftlicher Umrüstung
Gruppe 2					
TESLA	DESY (Hamburg)	3450,0	135,0	international	v.Bund D nicht als Standort vorgeschlagen
European XFEL (früher: TESLAX-FEL)		908,0	90,0	europäisch (Bund: 50%)	Bau ab 2006
FAIR	GSI (Darmstadt)	990,0	120,0	Europäisch (Bund: 65%, Hessen: 10%, Rest: europäisch)	MoU über gemeinsame Vorbereitung
Gruppe 3					
Soft X-Ray FEL	BESSY (Berlin)	222,3	12,4	national	2. Begutachtung im WR
AURORA BOREALIS	AWI (Bremerhaven)	354,6	17,5	europäisch/ international	2. Begutachtung im WR
ESS	FZ Jülich oder Halle/Leipzig	1387,0	144,0	europäisch	Bund unterstützt derzeit keinen dt. Vorschlag.
Supraleitermagnet oder Magnet in Hybridtechnik	HMI	48,5	4,3	national	früher: Hochfeldmagnetanlage

Quelle: Einrichtungen und BMBF

Anhang 3 Questionnaire

Der im Folgenden wiedergegebene Fragebogen wurde an BESSY geschickt. Bis auf wenige spezifische Fragen, die auf das AURORA BOREALIS Projekt zugeschnitten waren, hat das Alfred-Wegener-Institut den gleichen Fragebogen erhalten. Aufgrund der internationalen Zusammensetzung der Unterarbeitsgruppen wurde der Fragebogen in Englisch entworfen und allein in dieser Form den betroffenen Institutionen übermittelt.

Foreword

The purpose of this questionnaire is to provide the sub-committee of the Science Council working group on large-scale facilities for basic scientific research with key information on the proposed large-scale facility. Supplementary information or documents in addition to the answers to the questionnaire and the requested documents may be provided. Please keep the responses brief and concise.

The reporting period covers the last five years (2000 up to and including 2004); all facts and figures provided should be those that were current on 1 January 2005. All financial data should be given in Euros (Euro).

Any further questions, particularly those concerning the technology and operation of the large-scale facilities, will be dealt with in more detail during a visit by the sub-working group to the premises.

NB

Throughout this questionnaire, the term “field of research” refers to the field of research or fields of research in which the large-scale facility is or will be used.

Please send 40 printed copies of your responses and additional documents, each in a file, to the Secretariat of the Science Council by **3 June 2005**. If possible, please also send your responses and additional documents in electronic form (barkhaus@ wissenschaftsrat.de).

A Executive summary

Please provide a brief summary of the facility project (scientific vision, strategic importance, scientific objectives, max. two pages).

B Field of research and technology

B.1 How has the field/have the fields of research developed over the last ten years, nationally and internationally? Which changes do you expect until the facility could become fully operational? (approx. 3-4 pages)

B.2 How do you assess Germany's position in this field of research? Are there any specific qualitative or structural strengths or deficits relevant to Germany's competitiveness?

B.3 Which technological innovations is the project based on? Are there major R&D tasks that remain to be completed before the facility can be realised? Do these include potential obstacles to its successful realisation?

B.4 Which different technologies exist for obtaining analogous, related, or supplementary information? How have these developed over the past few years, nationally and internationally? How will they develop until the facility could become fully operational? (If more than one field of research is involved, please answer these sub-questions separately for each field.)

B.5 Please discuss to what extent different technologies are alternative, complementary, and/or mutually dependent. Will the success and the strategic importance of the proposed facility be influenced, positively or negatively, by expected or possible developments in other technologies?

C The facility

C.1 Scientific objectives, services, and technology of the facility

C.1.1 Please outline the research programme for the facility.
C.1.2 What range of services is the facility meant to offer to scientists? How do these services differ from those of existing or projected other facilities?
C.1.3 What are the facility's main strengths and weaknesses? From a scientific or technological point of view, what does it leave to be desired?
C.1.4 Explain the feasibility of the facility. To what stage has the planning of the facility proceeded?
C.1.5 What options are there for enlarging / upgrading the facility at some later date? Do these imply specific requirements at the present stage?

C.2 Impact of the facility on the science system and on the economy

C.2.1 What impact will the expected research results have on scientific, technological and social developments?

C.2.2 In what way is implementation of the facility likely to benefit Germany / to benefit the EU as a centre of scientific activity and excellence? Please outline alternative infrastructure options (plans for new facilities or expansion / upgrading of existing facilities) should the facility not be implemented.

C.2.3 Are there analogous projects (in Germany/in the EU/overseas)? If so, are these mutually exclusive or additional? How do you assess overlaps? What is the specific contribution of BESSY in this context? Please explain especially the scientific and technical co-operation with DESY and the question of the link-up with the TESLA-FEL fabrication.

C.2.4 If the project is implemented, how will it affect the structure and priorities of extra-university research?

C.2.5 Which business sectors and which key technologies could particularly benefit from the results and the development of the facility? Are appropriate transfer mechanisms projected for this purpose?

C.2.6 Are spin-offs expected to arise from this project, and if so, how will they be supported?

C.2.7 According to your estimates, to what extent will regional, national and international businesses participate in the project by way of contracts awarded for planning and construction services as well as for services relating to further operation of the facility?

D Institutions participating in the project

D.1 Please list the institutions participating in the project and outline their contribution and specific competence.

D.2 What experience do the institutions in charge have in planning and operating large-scale facilities?

D.3 Please describe the national and international networks and programmes into which the facility is to be incorporated.

D.4 Describe the research results of the past years achieved either a) at the proposing institutions, b) at one of the collaborating institutions or c) worldwide which were most important for implementation of the facility.

D.5 How many members of staff will be required for the appropriate use and operation of the facility (please differentiate by levels of qualification)?

D.6 What costs have been incurred so far for preliminary development work etc. for the facility, and how have these been financed? How much external funding (not including budgetary funds) has been obtained for this purpose by the proposing institutions (or their co-operation partners) in the last five years (broken down into funding from the Federal Government, state government, the DFG, the EU, business and industry, and other sources)? Please specify the fields in which this funding was used.

E Users

E.1 Which disciplines stand to benefit from or are dependent on use of the facility for research purposes, and to what extent (main interested parties)? How can the different needs of diverse user groups be reconciled?

E.2 What is the expected extent of external use (numbers and origin of users, duration and extent of use)? How have potential users been taken into account in the planning for the facility? (Please document user meetings.)

E.3 How will access to the facility be organised for external scientists?

E.4 What role will the facility play in training and furthering the future generation of scientists (both guided and independent scientific work, seminars, postgraduate studies, etc.)?

E.5 In which fields of work and research can future scientists be employed following successful qualification?

E.6 How will the plans for the facility and the future research results be presented to the general public?

E.7 To what extent do you expect the facility to be used by private-sector companies?

F Project management, location, costs and schedules

F.1 Project management

F.1.1 How is the project's progress planned and managed? Please describe your quality assurance procedures.
F.1.2 How is budget responsibility organised structurally and in terms of personnel?
F.1.3 Has an advisory board been established, or are there plans to do so? If so, please specify its functions and name its members.
F.1.4 What evaluations of the facility (assessment of concepts, preliminary work, etc.) have been carried out by external assessors in the last five years? What were the results and what was the impact? How and by whom were the evaluation groups named? (see also G.3)

F.1.5 Who will have organisational responsibility for maintaining permanent operation of the facility?

F.2 Location

F.2.1 Which are the specific requirements for a potential location for the facility? What possibilities have been envisaged for a) a national location, b) a location elsewhere in Europe c) a location overseas?

F.2.2 What would be the consequences for a) the research institutions currently involved in the project and b) for the national research institutions working in your field of research if the facility (or a similar facility) was implemented elsewhere in the EU/overseas?

F.3 Costs

F.3.1 Please detail the expected R&D, construction, and total cost, and the expected annual operation costs, each broken down into personnel and other costs (table 1, cf. Appendix). Which of these components are the most expensive ones? How do you assess the long-term cost impact, and on what criteria is your assessment based?

F.3.2 How do you rate the status of the table of costs and how up-to-date is it?

F.3.3 Please give estimates of total costs for R&D and construction by year if the project proceeds as intended (table 2). Differentiate by costs for civil engineering, core facility, and experiments.

F.3.4 How is the overall cost for the facility meant to be financed? Are there plans to involve foreign partners in the financing, and to what extent would this be realistic? What mechanism is used for apportioning overall costs (or parts thereof) to any foreign partners involved? Are there plans to involve industry? If so, what will be the modalities, and what kind of services will be provided?

F.3.5 What financial consequences do you expect if the project were to fall behind schedule?

F.4 Schedule

F.4.1 What is the schedule for implementation of the facility? What are the critical milestones of the schedule? Please provide the necessary details concerning planning, construction, time of commissioning, and periods of use.

F.4.2 Specify the annual period of use for the facility and the total period of operation including/without any expansions to the facility.

G Additional information

The institutions involved are requested to provide, if applicable, the following additional documents in triplicate:

G.1 Proposal for the facility (if any);

G.2 List of publications (publications in refereed scientific journals, collections, monographs, textbooks) of the leading scientists involved in the project;

G.3 Documentation of the evaluations carried out with regard to the facility (assessment of concepts, preliminary work, etc.) by external experts in the last five years.