WURC

Wood Ultrastructure Research Centre

WURC Evaluation 2001

SLU

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WURC
Wood Ultrastructure Research Centre

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Cover: Multi-aggregate structure of the S2 cell wall layer of a spruce Kraft pulp fibre

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Executive Summary

The Wood Ultrastructure Research Centre (WURC)(*http://www-wurc.slu.se*) at the Swedish University of Agricultural Sciences was established July 1st 1996. The partners in the framework of WURC are the Swedish Pulp and Paper Research Institute (STFI), the Royal Institute of Technology (KTH) and Chalmers University of Technology (CTH) together with eight forest related industries: Stora Enso, SCA, Korsnäs, M-real, Holmen, Södra Cell, AssiDomän and EKA Chemicals. The number of Universities involved in WURC's activities has expanded during phase 2 and members from the Department of Biochemistry, Uppsala University now actively participate in the Centre's activities. The companies involved in WURC's activities have been strongly affected by the dynamic changes currently occurring within the pulp and paper industry.

WURC's mission is to significantly increase the basic knowledge on wood and wood fibres regarding their morphological ultrastructure, chemical structure and physical properties and to determine how these properties change after different chemical, mechanical and enzymatic treatments. The research conducted is primarily fundamental in character and is based on cooperation between universities, industrial research institutes and the R & D centres of forest industry related industries. The establishment of WURC has, despite its slightly dispersed geographical nature, provided the opportunity for specialists from a number of widely different disciplines to cooperate and build a united body to carry out research on wood fibre structure primarily on the nanoscale; a research area which was at the start of WURC insufficiently developed in Sweden in comparison to the economic importance of the industry benefitting from WURC.

During its five year existence, WURC has attained a high level of competence in the area of wood fibre ultrastructure and become internationally recognized (e.g. by annual conferences, involvement in COST actions, exchange of guest researchers) as a major *Centre of Excellence* interacting with the Swedish pulp and paper industry. By nature of its research, competence and critical mass, WURC is currently quite unique in the world. During the last five years, WURC scientists have so far been involved in approximately one hundred scientific papers and symposia presentations as well as produced four Ph.D and five licentiate graduates and organized five international and numerous industry/ academia interactive seminars.

WURC has a working model whereby interactions occur between industry and academia at all levels. WURC's board is comprised of representatives from both the supporting industries, SLU and STFI. The director has alternated from industry and academia. WURC's Industrial Advisory Group is comprised of representatives from all the industries and together with WURC's management group vets all new projects for both academic and interesting industrial possibilities. This Group also monitors the progress within WURC projects.

The major added benefits of the WURC Competence Centre has been the creation and development of interdisciplinary interactions between the Swedish pulp and paper industry and WURC scientists in a research area of common interest. The industry as a whole has shown great interest in the establishment and development of WURC's program and has among other things produced specialised fibre materials for WURC's scientists and accepted WURC Ph.D students for extended periods of industrial practice.

The First Evaluation

The first evaluation of WURC took place in June 1998. It was very appreciated by WURC's management and board. The board analysed the evaluation report carefully and developed comments which were sent to NUTEK. This introduction serves to point at the major suggestions made by the evaluators and how they have been treated. References to the evaluation are also made at various points in this report.

Co-operation within WURC

WURC had operations in four places during phase 1. The evaluators remarked that besides between STFI and KTH there dit not seem to be very much of inter-institutional co-operation. The board agreed to this remark and is of the opinion that co-operation has improved during phase 2 – although more can still be done. An integrated research program is considered the best vehicle for co-operation.

Management

The evaluators pointed out the importance of continued support from SLU. The board feels that SLU has lived up to expectations.

The evaluators also felt that the Director needs to spend some 50 % of full time on the management of WURC. This has been implemented with Geoff Daniel as Director. Still, it remains important to support Geoff Daniel in his management role so that he can also develop his research which is very important for WURC. The association of Prof. Lars Ödberg, AssiDomän on a 20 % basis to support WURCs management as from spring 2001 is considered very valuable in this respect.

The evaluators questioned if the management structure of WURC was "top heavy". Is it necessary with a board as well as an Industrial Advisory Group and is it necessary with a management group as well as a research collegium? WURC's board feels that his arrangement is adequate for WURC. The Industrial Advisory Group is very instrumental for WURC's interaction with the research in industry.

International contacts

In-line with WURC's own thinking, the evaluators suggested an International Advisory Group. This was implemented in the beginning of phase 2.

Number of industrial partners

The evaluators meant it would be valuable for WURC to increase the number of industrial partners. The board is of the opinion that new members should have something to add to WURC and points out that WURC already has a very strong industrial base. This base has in fact been widened internationally through the structural changes discussed in Section 1.2.1.

Strategic planning

The evaluators stressed the importance of a strategic plan for phase 2 with concrete goals in terms of publications and graduated. The board feels that this has been fulfilled although quantitative goals for the number of publications were not set.

1. Basic Facts

1.1 WURC's Research Groups

The following research groups are participating in WURC: SLU, STFI, KTH and CTH. STFI, KTH and CTH are from the beginning contracted partners to SLU, and provide necessary complimentary competence and equipment not available at SLU. SLU Umeå and UU became involved during WURC phase 2 and are expected to become contracted partners in phase 3.

1.1.1a Department of Wood Science, SLU, Uppsala

WURC's main activities are localized at the Department of Wood Science, SLU, Uppsala, where the field of ultrastructural research has expanded. The research work at the department is primarily directed towards studies on the morphological ultrastructure of wood, and pulp fibres including cell wall modelling. Currently four of WURC's projects (fibre models, fibre surfaces, fibre deformations, studies on fibres using enzymes) and part of a further project on wood cell-wall biosynthesis are localized at the department. The department has extensive microscopic and ancillary equipment for research on wood fibre ultrastructure as well as excellent facilities for biology/microbiological studies on wood degrading fungi and bacteria, and in addition possesses a culture collection of wood degrading microorganisms. Engaged in WURC activities at the end of phase 2 are: three senior and two post doctoral scientists, four Ph.D students, two technical/secretary staff members and two administrative persons from the rectors office and Forest Falculty dealing with WURC's economy and other matters. The engagement in WURC has been successively upgraded during phase 2 and the Centre currently forms *ca* 50 % of the Departments staff. Experimental facilities include ESEM, FE-SEM and TEM electron microscopes and ancillary preparative equipment. The ESEM equipment has been financed through WURC.

Key participants: *Profs: Geoffrey Daniel, Thomas Nilsson; Ass. Prof. Paul Ander; Post Docs. Stig Bardage, Jonas Hafrén; Ph.D students: Jonas Brändström, Isabelle Duchesne, Karolina Nyholm, Lars Hildén, Miyuki Takeuchi (guest Ph.D student, Kyoto univ.).*

1.1.1b Department of Forest Genetics and Plant Physiology, SLU Umeå, and Department of Biochemistry and Biotechnology, KTH

Scientists from the Department of Forest Genetics and Plant Physiology together with Professor Teeri from KTH became involved in WURC during its second phase and provide important complimentary expertise to elucidate the mechanisms and enzymes responsible for the physico-chemical properties of wood fibres during biosynthesis. This biotechnological approach complements the more traditional ultrastructural approach based at SLU, Uppsala and opens prospects for identifying and determining the *in-situ* involvement of novel enzymes during wood formation. This in turn opens possibilities for the development of new biotechnological applications in fibre modification. The Department at Umeå possesses excellent facilities for tissue culture, and possesses a laboratory for the macro- (e.g. X-ray microdensitometry, Kajaani-fiber laboratory) and microstructural (e.g. light, fluorescent and confocal microscopy) characterization of wood fibres. The laboratory at KTH is currently a world leader in the application of molecular biology techniques (e.g. geonomics) for the study and characterization of novel proteins expressed in developing wood tissues.

Key participants: *Profs. Björn Sundberg, Tuula Teeri; Post Doc. Ewa Mellerowicz.*

1.1.2 STFI, Swedish Pulp and Paper Research Institute AB

STFI is a joint resource for the Swedish pulp and paper industry and its allied industries and has currently fourteen member companies including, with the exception of SCA, also those supporting WURC. STFI has approximately 230 employees of which about 100 are university graduates. STFI has excellent competence for studies on natural polymers, wood polymer physics and chemistry, surface chemistry, wood mechanics, measurement of fibre properties, pulping chemistry and functional demands on fibres. STFI is an important link between university research and industry. All from the start of WURC, STFI has by industry been considered as an important user of WURC's results and a link to their industrial use. At the end of WURC phase 2, four senior scientists and two Ph.D-students (one partly supported by WURC) were engaged in WURC projects. Experimental facilities relevant to WURC include advanced equipment for chemical and microscopical analyses including: *CP/MAS ^{13}C NMR, 2D-FTIR,* atomic force and confocal microscopy and ESEM.

Key participants: *Prof. Tommy Iversen; Ass. Profs. Lennart Salmén, Tomas Larsson, Mikael Lindström; Ph.D students: Jesper Fahlén, Margaretha Åkerholm.*

1.1.3 Royal Institute of Technology (KTH), Department of Pulp and Paper Chemistry and Technology

This department specializes in research and education on wood chemistry, pulping and bleaching, and papermaking technology. The department is also recognized as a leading body for the analyses of chemicals from wood and biomass. At the end of WURC phase 2, two senior scientists and two Ph.D-students (one partly supported by WURC) were engaged in WURC-projects. Experimental facilities relevant to WURC include Mass Spectrometry, FTIR + Raman and equipment for laboratory pulping and bleaching.

Key participants: *Profs. Göran Gellerstedt, Ants Teder (retired 2001); Ass. Prof. Helena Lennholm; Ph.D students: Ulrika Molin, Hans Önnerud.*

1.1.4 Chalmers University of Technology (CTH), Department of Forest Products and Chemical Engineering

Research of particular interest to WURC at this department includes pulping and bleaching and the chemical modification of wood and fibre. During WURC phase 2, two senior scientists and one Ph.D-student were engaged in WURC research. The group collaborates with the Department of Physics, CTH regarding analysis of metal ions in wood, which has made possible the use of the European Synchrotron Radiation Facility (ESRF) in Grenoble, France. Experimental facilities include a pilot plant for chemical modification of wood and fibre and instrumentation for chemical analysis of wood and pulp.

Key participants*: Prof. Rune Simonson; Ass. Prof. Harald Brelid; Ph.D student: Annica Sundén.*

1.1.5 Uppsala University (UU), Department of Biochemistry

The department, which entered WURC during 2001, has wide experience in the biochemistry of novel enzymes (i.e. purification, characterization, kinetics) from fungi and is developing the use of these proteins as markers for targeting specific molecules on wood fibres. More recently their experience in the field of molecular modelling (i.e. Quantum Chemistry) of lignocellulose components and the potential of this technique for characterization of wood cell-wall biosynthesis and delignification during pulp manufacture is being explored. The department has excellent biochemical facilities and access to advanced computer systems for carrying out the above studies. During phase 2, two senior scientists, one post doc. and one Ph.D student were involved in WURCs activities.

Key participants: *Ass. Profs. Leif Eriksson, Gunnar Johansson; Post. Doc. Yan-Ni Wang; Ph.D student Bo Durbeej.*

1.2. WURC's Industrial Partners

1.2.1 Structural Changes

During phase 1, WURC's industrial partners were quite stable with the exception for the "path-breaking" merger between the companies Stora (partner) and Enso (Finland) into Stora Enso. During phase 2 the global restructuring of the pulp and paper industry has been very intense and it has been somewhat difficult for WURC's management to keep up with all changes. These changes have also affected how the companies concerned have been able to address resources to external research, including WURC.

The following changes can be noted:

AssiDomän: During 2001, AssiDomän has started to sell off its pulp and paper operations. A new company Billerud has been created by joining two AssiDomän mills with the Gruvön mill of Stora Enso. The Väja Dynäs mill was sold to Austrian company Frantschack. The Lövholmen mill was sold to the global company Kappa. Remaining still within AssiDomän is the Frövi mill but this mill is also "for sale".

MoDo: During 2000, MoDo was split up into Holmen and MoDo Paper to which latter company was added the fine paper operations in SCA. Soon after, MoDo Paper was bought by the Finnish company Metsä Serla which merged company has recently changed its name to M-real.

SCA: See MoDo Paper above. In addition, SCA has extended its operations by acquistions abroad.

Stora Enso: See AssiDomän above. In addition Stora Enso has extended its operations by acquisitions abroad – particularly in the US.

Södra Cell: During 2000, Södra Cell acquired Tofte mill from Norske Skog.

So, obviosly the situation has been very dynamic. It is hoped that in the preparation for phase 3 it shall be possible to clarify and define WURC's future membership base. Further changes should, however, not come as surprises.

It is obvious that all-in-all, WURC now covers a wider industrial base than when phase 2 started.

1.2.2 AssiDomän

AssiDomän's main operations (as of fall 2001, cf. 1.2.1) are focused on the production of carton-board for packaging (e.g. for liquid packaging), sawn timber and solid wood processing. The company is also one of Europe's largest listed forest-owner companies with 2.4 million hectares of productive forest land. AssiDomän's basic production is located in Sweden, with the company's main market concentrated in Europe. AssiDomän has a number of employees of about 2,200.

1.2.3 EKA Chemicals

EKA Chemicals is part of the worldwide company AKZO NOBEL. The company is one the world's leading manufacturer of bleaching agents sodium chlorate and hydrogen peroxide as well as leading supplier of other papermaking chemicals. EKA Chemicals is a supplier of chemicals and systems for environment compatible pulp bleaching processes as well as chemical systems for the wet section of paper making. EKA Chemicals also markets chemicals for certain industrial and specialty applications as well as engineering, process plants and equipment. EKA Chemicals headquarters and the main process plants are located in Bohus, Sweden. The company has *ca* 3,100 employees located in over 30 countries of which 50 % are located in Sweden.

1.2.4 Korsnäs

Korsnäs is one of Sweden's leading forestry companies with operations completely based on renewable forest raw materials. Fifty per cent of the Group's raw material requirements are supplied by its own forests. Using technically advanced processes, Korsnäs manufactures top-quality, environmentally compatible specialist products for customers in more than 60 countries. Korsnäs production mainly concentrates on paperboard and paper products used in the packaging industry, fluff pulp for sanitary products and sawn timber for the joinery and carpentry industries. Korsnäs employs approximately 3,700 (ca 2,200 in Sweden) at its mills and factories in nine European countries.

1.2.5 MoDo (now Holmen and M-real), cf. 1.2.1)

Holmen

The company consists of Holmen Paper, Iggesund Paperboard, Iggesund Timber, Holmen Skog and Holmen Kraft. There are a number of sales offices in Europe and the rest of the world, together about 5300 employees. Products are newsprint and magazine paper, paperboard, wood and sawn timber.

M-real

M-real is Europe's third largest paper merchant (main operation in Finland) and specializes in producing and selling high-quality papers and paperboard grades for demanding end uses. M-real is Europe's leading supplier of printing and office papers as well as magazine papers. M-real has a worldwide network of more than 70 local sales companies and representatives and has about 22000 persons employed.

1.2.6 SCA

SCA is an international group with a worldwide production of absorbent hygiene products, packaging solutions, publication papers and solid-wood products. Their products are marketed wholly or by jointly owned companies in all continents of the world and the company has over 38,000 employees in over 40 countries. Although prominent on both the European and world markets, SCA's main market lies in Europe. SCA Hygiene Products is a leading manfacturer in Europe of feminine hygiene products, baby diapers, incontinence products and consumer/institutional tissues.

1.2.7 Stora Enso

Stora Enso is one of the world's leading forest product companies, with over 45,000 employees working in 40 countries around the globe. The company is an integrated forest products company producing magazine papers, newsprint, fine papers and packaging boards, areas in which the company is a global market leader. Stora Enso also conducts extensive saw-milling operations. Research and development is an integrated part of Stora Enso's business environment.

1.2.8 Södra Cell AB

Södra Cell AB is part of the economic corporation Södra, which is an association owned by 34,000 forest farmers in Southern Sweden. Together, Södra members own *ca* 2 million hectares of forest land and is the largest forest-owner association in Sweden. Last year (2000) Södra reported sales of SEK 12 billion and currently employs 3,000 people. Södra Cell is the world's leading manufacturer of market pulp intended for paper production and has five mills in Norway and Sweden.

It should be emphasized that WURC's participating companies represent the main bodies involved in pulp and paper production as well as forest owners in Sweden. Thus their interests are quite broad and variable. Most of the companies are internationally based and have significant activities, including production, outside Sweden, primarily in Europe. It is also apparent that the companies have relatively few research employees in relation to their annual turn over, a point of significance to be borne in mind with respect to the mobility of personnel from WURC into industry. An earlier enquiry to member companies to specify their main interests (and to some extent expectations) from WURC resulted in the following:

- To obtain a more in-depth knowledge of wood and fibre ultrastructure, which will stimulate and contribute to the further development of their industrial processes and products and lead to the improved utilization of wood fibre. For example a better selectivity in the cooking and bleaching steps of pulp production was given priority by all WURC companies and is reflected in several projects and more recently a proposal from industry for WURC phase 3. Higher selectivity during these processes can be realized only by a better knowledge of wood fibre cell wall ultrastructure and the influence of the different events on this structure;
- To have available a cooperating leading research body within the field of wood ultrastructure which can be both consulted and conduct contract work;
- To improve interaction with academic research and facilitate greater contact between industry and academia;
- To increase the companies own competence by involving its own staff in WURC research and by allowing WURC personnel to work in their industries.

2. *WURC's Management Structure & Staff*

2.1 Organization & Management

WURC is from a management point of view and as regards the core of its research activities located at the Department of Wood Science (since 1999) at SLU, having previously been a relatively independent part of the Department of Forest Products, SLU. Because of WURC's dominating financial and research influence during phase 2, WURC has become a major component in the department. WURC is however responsible for its own economy and all cash money from the companies and VINNOVA is paid into WURC's account at SLU and then distributed to the various consumers within WURC. All the research participants within WURC belong to their respective departments whether at SLU, STFI, KTH, CTH or UU. WURC itself, like all other competence centra, is not an employer and has no legal obligations in this respect.

The current organization of WURC is outlined Figure 1. Essentially, the organization has remained fairly similar to that developed during phase 1 and comprises a board, director, managing group, industrial advisory and senior scientist groups, project leaders and Ph.D students as well as industrial contact persons and the international advisory group. One major change following WURC's first international evaluation is the incorporation of the international advisory group.

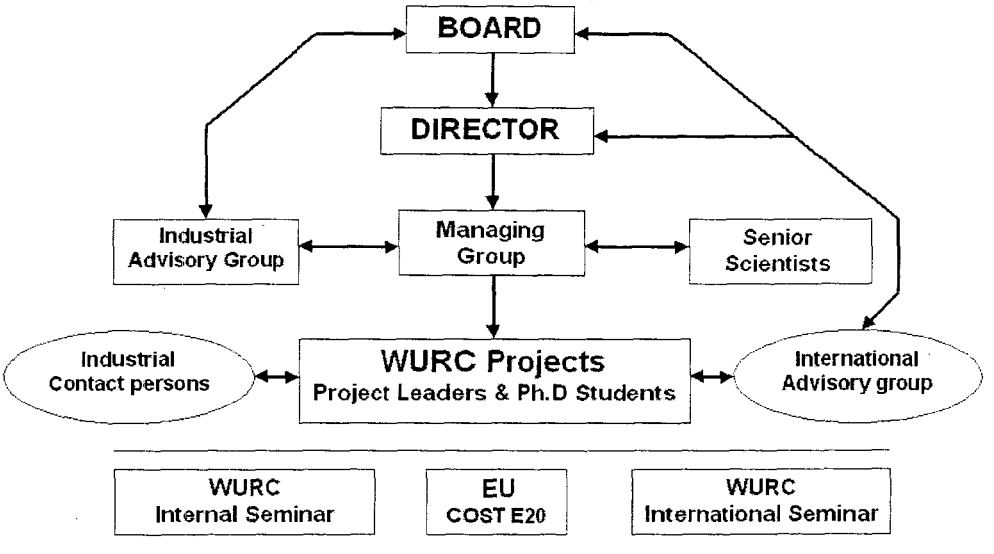

Figure 1. WURC's current working organization

The board consists of representatives from the companies and SLU and is formally established by the rector of SLU. It is currently chaired by Lennart Eriksson (STFI) as proposed to this position by the industrial partners. The board met six times during phase 2. The board is ultimately responsible for WURCs research direction as well as its economy and administration. The organizational structure, rules for procedure and responsibilities within WURC established by the board in 1996 were updated in 2000. The board conveys important information to and from their mandators and delivers directives to WURC from member companies or organizations. The chairman of the board meets frequently with WURC's director and has contact with WURC's management group. Board meetings have variously taken place at the Centre, SLU, industrial sites and for convenience, Stockholm airport. The chairman of the Industrial Advisory Group is normally invited to the board meetings.

Two companies, Korsnäs and Södra Cell have changed their board representation during phase 2. In the fall of 2000 a joint strategy meeting with the board and the Industrial Advisory Group was organized as a start-up of the planning for phase 3.

Table 4. WURC's board of directors (Year 2001)

Vice Director Lennart Eriksson, **STFI, Chairman**
Research Director Anders Brolin, **StoraEnso**
Research and Development Director Inger Eriksson, **SCA Graphic Research**
Professor Thomas Nilsson, **SLU**
Dr. Torsten Nilsson, **Korsnäs**
Professor Sune Linder, **SLU**
Professor Lars Ödberg, **AssiDomän**
Research Director Sune Wännström, **M-real**
Tech. Dir. Karin Emilsson, **Södra Cell**

The daily running of WURC is carried out by the management group lead by the director Prof. Geoffrey Daniel. The group meets frequently and has regular contact with the Chairman, the industrial advisory group, project leaders and Ph.D students. The group is responsible for following up WURC's economy, research projects, proposing new research areas, organizing meetings and recruiting scientists and Ph.D students. At the beginning of WURC phase 2, Geoffrey Daniel (SLU) took over as director from Brita Swan (Stora Enso), and the directorship increased to 50 % as was also recommended by WURC's first evaluation in 1998. During 2001, Prof. Lars Ödberg (AssiDomän) strengthened WURC's management group on a part-time basis and the Centre also engaged Fredrik Gunnarsson from SLU's Forest Falculty in order to help administrate WURC's economy following changes in SLU routines.

WURC also has an Industrial Advisory Group comprised of company representatives. This group has been very active during WURC phases 1, 2 (*ca* 6-8 meetings per year) and has organized for example the production and extensive characterization of special pulp fibres (unbleached and bleached kraft pulps) in two large industrial cooperative projects to be utilized in WURC's projects. In addition, the group has been active in organizing industrial practice (periods up to 2 months) for WURC Ph.D students, seminars for discussion of WURC projects out in industry, as well as industrial study trips for Ph.D students. The group has also been active during WURC's internal meetings with seminars. The main role of the Group is, however, to review the research direction of WURC and to prioritize project proposals. In this role the Group also serves as an expert panel to the board.

WURC also has a senior scientist group which has an annual meeting to discuss cooperative research possibilities.

The detailed planning of individual projects is carried out by the respective project leaders who are also responsible for conducting the research and administrating economy. WURC financially supported fourteeen projects during year 2001 and twelve Ph.D students. Both Ph.D students and senior scientists (i.e. professors, post docs) are actively involved in research activities and some projects do not involve students.

WURC has industrial contact persons associated with individual projects. These persons function to give advice on possible industrial relevance of the research project and are responsible for individual contacts between students and the companies thereby providing a direct channel of contact. WURC previously had industrial mentors to advise Ph.D students on their work. For some students, this approach worked well but in other cases was not successful.

An International Advisory Group has been established during Phase 2. This group is further described in Section 4.3.

2.2 Staff

The main persons that were involved in WURC's activities during year 2000 are outlined in Tables 1-3. The senior scientists, administrative and technical staff are outlined in Table 1, the Ph.D students in Table 2, and scientists and specialists from industry in Table 3. In the Tables, the affiliations and the percentage of activities for academical staff in WURC activities are approximated. It should be emphasized that the Tables only provide details for year 2000, and it should be recognized that *numerous* other persons have also been involved during WURCs five year existence and have contributed significantly to WURCs activities and development.

Tables 1-3 can be seen as representative also for 2001.

Table 1. Senior scientists, administrative and technical staff

Name	Univ./Institute	Position	%
Geoffrey Daniel SLU		Prof.	100
Göran Gellerstedt	KTH	Prof.	10
Tommy Iversen	STFI	Prof.	35
Thomas Nilsson	SLU	Prof.	50
Rune Simonson	CTH	Prof.	10
Björn Sundberg	SLU	Prof.	30
Ants Teder	KTH	Prof.	10
Tuula Teeri	KTH	Prof.	10
Paul Ander	SLU	Assoc. Prof.	90
Harald Brelid	CTH	Assoc. Prof.	100
Tomas Larsson	STFI	Assoc. Prof.	80
Lennart Salmén	STFI	Assoc. Prof.	30
Helena Lennholm	KTH	Assoc. Prof.	10
Leif Eriksson	UU	Assoc. Prof.	30
Gunnar Johannsson	UU	Assoc. Prof.	30
Stig Bardage	SLU	Post. Doc	90
Ewa Mellerowicz	SLU	Post. Doc	90
Jonas Hafrén	SLU	Post. Doc	90
Yan Ni Wang	UU	Post. Doc	20
Per Jennische	SLU	Admin/econ.	10
Fredrik Gunnarsson	SLU	Economy	10
Brita Swan		Management	20
Gabriella Danielsson	SLU	Secretary	50
Ann-Sofie Hansén	SLU	Technician	100

Table 2. WURC Ph.D students

Name	Univ./Institute	Position	%
Annica Sundén (Berglund)*	CTH	Ph.D Student	80
Jonas Brändström	SLU	Ph.D Student	100
Isabelle Duchesne**	SLU	Ph.D Student	100
Jesper Fahlén	STFI/KTH	Ph.D Student	100
Eva-Lena Hult**	STFI/KTH	Ph.D Student	100
Ulrika Molin**	KTH	Ph.D Student	100
Karolina Nyholm	SLU	Ph.D Student	100
Margaretha Åkerholm***	STFI/KTH	Ph.D Student	100
Hans Önnerud***	KTH	Ph.D Student	100
Bo Durbeej	UU	Ph.D Student	50
Lars Hildén	SLU/UU	Ph.D Student	100
K. Wickholm**	STFI	Ph.D Student	50

* Unpayed leave of absence; ** Ph.D completed 2001;
*** Ph.D students financed by SJFR with renumeration from WURC

Further senior scientists from universities/research institutions active in a supervisory capacity of WURC Ph.D students and involved in WURC projects include: Tord Eriksson, Gunnar Henriksson, KTH; Fredrik Thuvander, Karlstad Univ; Jerry Ståhlberg, UU; Bert Pettersson, Ulla-Britt Mohlin and Sören Östlund, STFI; Anders Rindby, CTH.

Table 3. Industrial Advisory Group members, scientists and coworkers actively involved in WURC's research during 2000. (Industrial advisory group members given in italics)

Jiri Basta, Van Kees Leerdam, Lena Heuts, Ann-Sofie Holm, ***EKA Chemicals***
Ann Marklund, plus co-workers (technicians), ***M-real***
Karin Emilsson, Ulla Jansson and co-workers, ***Södra Cell***
Stefan Högman, Torsten Nilsson and co-workers, ***Korsnäs***
Mikael Lindström, ***STFI***
Ove Rehnberg, Monica Edsborg and co-workers, ***AssiDomän***
Peter Sandström, Inger Eriksson, Lars Wågberg* and co-workers (technicians), ***SCA***
Gunilla Söderstam, Anders Brolin, Catrin Gustavsson, Anders Moberg, Magnus Lestelius, Bofeng Mao and co-workers, ***Stora Enso***

*from 2001 with Mid Sweden University

Additional members of the Industrial Advisory Group

Geoffrey Daniel, Stig Bardage, ***SLU***
Brita Swan, ***Säffle*** (previously director of WURC)

Contact (mentors) persons from industry active within the projects

Jiri Basta, ***EKA Chemicals***
Inger Eriksson, Peter Sandström, Lars Wågberg, ***SCA***
Stefan Högman, Torsten Nilsson, ***Korsnäs***
Ulla Jansson, Per Larsson, Martin Waubert-de Puiseau, ***Södra Cell***
Ann Marklund, ***M-real***
Gunilla Söderstam, Anders Brolin, ***Stora Enso***
Lars Wågberg, ***SCA/Mid Sweden University***

3. *WURC's Aims & Long-Term Strategies*

The highly complex structure of wood fibres, the industrial need for new knowledge, and the infrastructure of research on wood fibres in Sweden constitutes the basis for the long-term aims and strategies of WURC. Thus, the major long-term objective of WURC is to enhance the industrial utilization of wood fibres by significantly improving the understanding of their morphological and chemical ultrastructure including the interactions between the constituting wood components.

WURC's mission is to conduct focused *basic research* of both immediate and long term relevance. In addition WURC performs non-competitive research that its industrial partners cannot, or do not find feasible to conduct themselves.

WURC's research should serve as a basis for further R & D by its industrial partners and by research organizations that carry out more applied research "downstream" the process chain. Ultimately the knowledge created by WURC should support the development of resource-efficient and ecobalanced products fulfilling market demands. This includes – in addition to improvements in existing industrial processes and products – ultimately the development of new industrial processes, new fibre

based materials and new consumer products. The improved knowledge of wood fibre ultrastructure is also linked to research on the biology of cell wall formation (i.e. wood biosynthesis) and thus should promote the understanding of how wood is formed in nature.

The original objectives of WURC as a Competence Centre were defined as:

- Provide an inventive and stimulating environment for high quality research and post graduate education. WURC is not however equivalent to a research school for Ph.D students;
- Create a research environment where companies within the forest industry sector are actively participating;
- Become an internationally recognized research unit which attracts foreign researchers;
- Promote interdisciplinary research and strong cooperation between the rather few, and geographically scattered scientists in Sweden working on aspects of wood fibre ultrastructure;
- Develope a competence profile and research program which gives WURC a clear identity within the Swedish research infrastructure.

Before WURC was established, research on wood fibre ultrastructure was carried out by a number of diverse specialists geographically located across Sweden. WURC has provided the first true opportunity for these specialists to work together and unify, and above all strengthen, the research topic in Sweden.

The aims of WURC which to some extent were fulfilled by the end of phase 1 have been realised and further developed at the end of phase 2. WURC has developed a clear research profile and industry has been actively in engaged in its program of activities at all levels. WURC as a centre is now well known nationally and internationally by way of its research activities and achievements. In addition, WURC's Ph.D and Licentiate students are now graduating and taking up positions in research.

4. *WURC's Competence Profile, Aims & Networks*

4.1 Research Aims

The Wood Ultrastructure Research Centre carries out research aimed at:

- Increasing our knowledge on the morphological, chemical and physical ultrastructure of wood fibres. WURC's main focus is on the ultra- and nanostructure of wood fibres from *ca* 500 nm to less than 1 nm;
- Determining the effects of chemical, physical and enzymatic treatments on the ultrastructure and the influence of such effects on wood fibre properties.

Research work is carried out on relevant fibre and wood materials and results obtained interpreted from both the academic and industrial point of view.

WURC's main research encompass the following areas:

- Ultrastructural morphology of wood and fibres i.e. fibre cell wall organization and nanostructure;
- Surface ultrastructural morphology and chemistry of wood and pulp fibres;
- Chemistry of wood polymers at supermolecular levels;
- Metals and extractives in wood – their location, nature and extractability;
- Ultrastructure and related physical properties of pulp fibres;

- Biotechnological, molecular and ultrastructural aspects of wood fibre biosynthesis;
- Molecular modelling of wood fibre formation and delignification.

4.2 Competence Profile

In terms of competence profile, WURC's research is centred around the following disciplines involving both subject and technical expertise: plant and wood anatomy, polymer chemistry, material and polymer physics, microbiology, molecular biology and wood chemistry, spectroscopy and electron microscopy. During phase 2, molecular biology, biochemistry and quantum chemistry were introduced into WURC's competence portfolio with the introduction of projects on wood biosynthesis, enzymes and molecular modelling. Thus, WURC now comprises a broad spectrum of competences allowing a multidisciplinary approach to the understanding of the wood ultra structure.

4.3 International and National Networks

Research in WURC's competence area is carried out by scientifically recognized groups in Finland, Canada, USA, France, Japan and New Zealand. Scientists from several of these groups have been invited speakers at the five international seminars held by WURC. However, it is apparent that the activities in these countries like previously in Sweden are very specialist orientated and research of critical mass does not currently exist outside of WURC. However, plans are being made for the establishment of Competence Centres on plant fibres in other European countries (e.g. France) providing for the oportunity of a European network of Centres in the future. International networks and contacts are essential for WURC's successful development. One reason for arranging the International seminars outlined above was to develop and strengthen the international network. In addition to these seminars a number of other steps have been taken to increase the international scientific input into WURC.

WURC has endeavoured to progressively develope its national and international reputation in number of ways including: *i*) annual international conferences; *ii*) acting as the initiator and driving force for the development of the European COST Action E20 "*Wood Fibre Cell Wall Structure*" involving many countries; *iii*) attracting guest researchers to the Centre for various periods of time; *iv*) by WURC scientists presenting research work at international symposia and publishing in refereed scientific journals; and *v*) setting up an international advisory group comprised of experts in the wood fibre field to advise on project developments. WURC scientists also actively participate in international projects particularly within EU.

It is worth noting that practically all industrial partners in WURC have very significant international operations – particularly throughout Europe. So, from this point of view, WURC automatically has an international penetration.

WURC has so far arranged five "*open*" international symposia held at the centre, SLU in Uppsala. Each year in April a new theme (e.g. "*Lignin and cell wall ultrastructure*", "*Influence of structure on fibre properties*") has been adopted and 3 - 4 international experts (e.g. from USA, Canada, Japan, France, New Zealand, Finland) have been invited to give extended lectures and interact with WURC's own scientists. These invited lectures have been mixed with lectures given by WURC's own scientists from projects in the same field. On average these meetings have attracted over 110 persons from both academia and the industry allowing for dissemination of WURC's results and further developing its international reputation (*Appendix 2*).

In autumn 1997, WURC took the initiative to propose the COST Action: "*Wood Fibre Cell Wall Structure*". A European working group chaired by WURC (P. Ander) developed a proposal which was successsfully accepted and now seventeen countries are actively participating in the action. An important aspect of this *Action*, besides creating a European network on *Wood fibre ultrastructure*, was to link expertise from research on non-wood cell walls. Final approval of the *Action* was taken within COST February 1999 and the action will run for four years ending September 2003. The action involves at least one-two meetings (symposia/workshops) per year. During April 2001, an extensive Action Workshop was arranged connected to WURC's international symposium and similarly attracted over 100 persons from countries throughout Europe as well as USA, Japan and New Zealand. The Action is divided into three Working Groups: *WG1* Biosynthesis and Modelling; *WG2* Characterization and Ultrastructure; and *WG3* Cell Wall Structure and Properties; all areas of importance to WURC. The development of the COST Action is seen as an initiation point for a future grant application on *Wood fibre ultrastructure* to the EU commission.

Since WURC's establishment, several guest scientists including Professors (*K. Takabe, N. Terashima, Japan*), senior scientists (e.g. *Drs. Lloyd Donaldson, Adya Singh, NZ)* and several Ph.D students have been working at the Centre for periods ranging from several weeks or months up to one year. This has been advantageous from the point of view of learning and developing new techniques within the Centre. In addition, two Ph.D students within WURC have carried out parts of their industrial practice abroad (Germany and Holland) and two students have spent periods ranging from 4 - 6 months learning and applying new techniques in their projects at Universities in Japan. In all cases the interactions have resulted in scientific publications. New international channels have also been developed through utilization of the European Synchrotron Radiation Facility in Grenoble where studies on the ultrastructural distribution of metal ions in wood have been carried out.

In line with the recommendation of WURC's first international evaluation, the Centre set up a panel of three experts from USA, France, Japan (Profs. M. Brown, B. Monties, K. Takabe) to advise WURC's management and board on the development and direction of its research program. The members of the panel have attended WURC's annual international and internal meetings held in April since year 2000. Reports from the above persons are included in *Appendix 4.*

WURC has a national contact network, which has progressively developed through phases 1 and 2. In addition to STFI, KTH, CTH and UU which participate in the Centres activities on a contracted basis, contact have been established with the "Research School on Wood and Fibre" (financed by SJFR/Formas), The Centre for Forest Biotechnology and Chemistry in Umeå (financed by SSF, Stiftelsen för Strategisk Forskning), the MISTRA (Stiftelsen för Miljöstrategisk forskning) project "Eco cyclic pulp mill" administered by STFI and the Forest Products Industry Research College (FPIRC) (financed by SSF). WURC has further been marketed domestically by its interactive internal seminars with the pulp and paper industry and *on-site* seminars.

WURC has also been presented by the Director and Chairman at several national/international pulp and paper related symposia in Sweden as well as promoted by popular articles in the industries magazines (*Appendix 2*).

Through the above activities and with respect to the international networks that WURC's senior scientists already have, good conditions for future international cooperation is ensured. WURC has of course its own homepage (*http://www-wurc.slu.se*) in which its aims, organization structure and research projects are outlined.

5. *WURC & SLU*

5.1 Organization & Financing

WURC forms part of the Swedish University of Agricultural Sciences in Uppsala and lies under the Forest Falculty. WURC is the only competence centre of its type at SLU and currently ranks as one of the major ventures within the Falculty of Forestry. WURC is formally located at the newly created Department of Wood Sciences (1999) where it forms an integral part and represents about 50 % of the Department. WURC is well known at SLU and its activities and on-going research have been subject for visits to the university by scientists and industrialists. WURC is highly appreciated by SLU and the Falculty of Forestry and is often referred to as an example of successfully organized collaboration between industry and university. Similarly, WURC is mentioned in SLUs annual report and also in other publications from the university. Concrete examples of support are as follows:

According to the general financing formula for competence centra, approximately one third of WURC's budget is expected to be derived from joint natural contributions from SLU, STFI, KCL, CTH; with SLU representing the dominating partner. The natural contributions from SLU have increased progressively during the last three years and by the end of 2001 will almost by itself match one third of WURCs total budget, reflecting the interest and strategic support of SLU. Funding consists of contributions for the support of senior and post-doctoral scientists and more recently Ph.D students. In this respect WURC has had a privileged position at SLU and funding has been allocated from both the Falculty of Forestry (e.g. TEMA research program and for research assistants) and Rector's research program for financing post doctoral positions, thus allowing for the establishment and development of the Department of Wood Science following its creation in 1999.

The financial situation has changed considerably over the last five years in the Swedish University system and most departments, also within the Falculty of Forestry at SLU, derive a significant part of their budget from external sources - up to 75 % of their budget in some cases. By participating in WURC's activities, external financing has been derived by the Department of Wood Science for projects (5), Ph.D students (currently 4), administrative and technical staff, overheads (e.g. local costs) as well as the funding of advanced equipment (e.g. Environmental-SEM).

Undoubtedly, WURC forms an important part of SLU and by the nature of its method of financing, interaction with the pulp and paper industry and interdisciplinary approach across several universities and institutes WURC is quite unique within SLU.

5.2 Economy

Administration of WURC with its many partners and projects has not been the easiest of tasks and the reporting of time allocation from individuals is foreign to the university world (a different situation exists at research institutes such as STFI). WURC has been supported in its economic administration from SLUs central administration and during 2001 a further person from the Forest Faculty became engaged consistent with changes in SLUs economy system. For phase 3 the economic administration of WURC will be dealt with in a slightly different way which will make it easier to follow-up the economic situation.

The economy for WURC phase 2 is outlined in Tables 5-8. In Table 5 the income budget for the entire phase is outlined including both cash and "*in-kind*" contributions by industry and universities including STFI. As can be seen, the in-kind contribution from industry is expected to rise from 32 % in 1999 to 42 % in 2001.

Table 5

WURC Phase 2
Income budget (MSEK)

1999		From: Industry	Universities	VINNOVA	Total
	Cash	3,00	0,00	4,40	7,40
	In kind	1,40	4,40	0,00	5,80
		4,40	4,40	4,40	13,20

2000		From: Industry	Universities	VINNOVA	Total
	Cash	3,20	0,00	5,00	8,20
	In kind	1,80	5,00	0,00	6,80
		5,00	5,00	5,00	15,00

2001		From: Industry	Universities	VINNOVA	Total
	Cash	3,50	0,00	6,00	9,50
	In kind	2,50	6,00		8,50
		6,00	6,00	6,00	18,00

In Table 6, the realized income for years 1999 and 2000 are given. As can be seen the in-kind contribution from industry is lagging behind budget, whereas the opposite is the case for the universities with SLU being the dominant contributor. During 2001, it has been detected that the reporting of in-kind contributions from industry for years 1999 and 2000 has not considered all contributions. This is presently being corrected.

Table 7 shows in gross terms how costs have been distributed and realized. As can be seen, WURC has not fully used its cash resources during 1999 and 2000 (cf below).

Table 8 shows the allocation of cash resources as per mid August 2001.

By the end of Phase 3 it is predicted that the total university *in-kind* contributions will with good margin meet that budgeted. By the end of the fiscal year 2001, SLU will have increased its *in-kind* contributions to more than that budgeted for all university contributions. It is possible that industry will end up with a deficit in in-kind contributions. If so, this could be compensated by additional cash money.

As can be seen from Table 8, WURC has, as of August 2001, a cash surplus. There are several reasons contributing to this including the completion of projects before time, maternal leave for students and the accumulation of funds at SLU through a surplus in WURC's central organization (e.g. for guest researchers) and in individual projects. This situation was brought to the attention of the board at its June meeting, 2001. Use of the remaining funds for the purchase of advanced equipment

to the centre, the initiation of pilot projects during the remainder of year 2001 and early start of projects given priority for WURC phase 3 are currently under consideration by the board. Decision is expected to be taken before the end of August.

Table 6

Income result phase 2 (MSEK)

1999		From: Industry	Universities	VINNOVA	Total
	Cash	3,00	0,00	4,40	7,40
	In kind	0,90	5,10	0,00	6,00
		3,90	5,10	4,40	13,40

2000		From: Industry	Universities	VINNOVA	Total
	Cash	3,20	0,00	5,10	8,30
	In kind	1,70	5,00	0,00	6,70
		4,90	5,00	5,10	15,00

Table 7

Costs, result phase 2 (MSEK)

1999		At: Industry	Universities	Total
	Cash		6,00	6,00
	In kind	0,90	5,10	6,00
		0,90	11,10	12,00

2000		At: Industry	Universities	Total
	Cash		8,00	8,00
	In kind	1,70	5,10	6,80
		1,70	13,10	14,80

Table 8

Allocation of cash resources as decided yearly by the board

(MSEK)

	Year 1999	2000	2001	Phase 2	%
Management group	0,13	0,42	0,42	0,97	4
I. Models of wood and pulp fibers	0,42	0,45	0,65	1,52	6
II. Cell wall structure/morphology	1,82	2,01	2,49	6,32	26
III. Fibre chemistry/wood polymer/molecular level	1,00	1,00	1,20	3,20	13
IV. Other areas	0,80	0,65	0,25	1,70	7
V. Physical properties of fibre material	0,90	1,00	1,10	3,00	13
VI. Fiber damages and changes	0,42	0,43	0,50	1,35	6
VII. WURC Jointly (Note 1)	1,74	1,90	2,26	5,90	25
Total budget	7,23	7,86	8,87	23,96	100
Available	7,40	8,20	9,50	25,10	
Reserved for later decision during the year (Note 2)	0,17	0,34	0,63	1,14	

Note 1 WURC Jointly - specification	Year 1999	2000	2001	Phase 2
Guest scientists	0,30	0,30	0,50	1,10
International Seminar	0,08	0,10	0,12	0,30
International Advisory Group	0,06	0,06	0,08	0,20
Laboratory staff	0,32	0,34	0,36	1,02
Rent	0,69	0,80	0,70	2,18
Low vacuum - SEM	0,30	0,30	0,50	1,10
Total	1,74	1,90	2,26	5,90

5.3 *Impact on the Research Infrastructure*

The nature of WURC and particularly its method of financing, interaction with industry and inter-disciplinary approach across several universities is new. WURC has allowed the development of a national and internationally reknown Centre of excellence on *Wood fibre ultrastructure* to be developed at SLU. This type of concentrated effort on wood fibre cell structure is currently unique in the world. The Centre has further allowed for the establishment of the Department of Wood Sciences within the Falculty of Forestry. In addition, by the integrated and cross-disciplinary nature of WURC, close cooperation has been established with STFI, KTH, CTH and UU. Prior to WURC some types of cooperation (mainly between individuals) were taking place but the concept of WURC and the financial possibilities has provided the incentive to extend and develop these interactions to new levels – namely a major research effort in terms of coordinated projects. WURC has further contributed to a change in research orientation within the Falculty of Forestry at SLU, a change which is in line with the demands of the industry.

5.4 *Impact on Education*

WURC has so far not been formally involved as a unit in the education of undergraduate or post-graduate students. Normally Ph.D students within WURC participate in courses given in Departments at their own Universities and also by Ph.D schools established during the mid- 1990's in Sweden. For example, WURC Ph.D students have often attended courses on aspects of wood

structure and participated on study trips organized by the "*Research School on Wood and Wood Fibre*". Therefore to date the Centre has decided not to offer courses in WURC's main research areas of interest as these are already available as general or specialized courses at the various universities. The aspect of providing undergraduate courses within WURC's research field will be reviewed once more before the start of WURC phase 3 as it is recognized that this represents a primary source of potential Ph.D students. WURC scientists and Ph.D students are however actively involved in teaching at their respective departments and universities.

6. *WURC's Future Plans & Activities*

6.1 *Analysis of Current Situation*

The research activities for phase 2 have followed the plan and have been concentrated on wood and kraft pulp fibres from spruce. WURC has continued to grow throughout phase 2 and the scientific output has progressively increased. Both the industry and SLU have progressively increased their *in-kind* contributions during phase 2. The number of projects in WURC's portfolio has also increased from eight at the start of WURC phase 1 to fourteen near the end of phase 2. While WURC carries out research in a wide area of wood fibre ultrastructure, its focus has been maintained on kraft fibres from spruce. Industry-academia interactions have increased during phase 2 in several ways and a better mutual understanding between the groups has been developed. The number of Ph.D students and post doctoral scientists involved in WURC's activities has also increased. One Ph.D student has left WURC in an unplanned way but only after completing a "Licenciate" degree. Interactions between Ph.D students/post docs have been good while similar interactions between the senior scientist group have improved but need further development. Also, the contacts with industry have grown.

6.2 *Research Aims for Phase 3*

As part of the strategy planning for phase 3, WURC's board recomfirmed that WURC should maintain its original focus (c.f. 3.1) and conduct fundamental research on wood fibre ultrastructure:

WURC should continue its development as an internationally recognized competence Centre, further promoting interdisciplinary research and cooperation on wood fibre ultrastructure; provide a research environment where companies within the forest industry sector are actively participating; and further develop its competence profile and research program giving WURC a clear identity within the Swedish research infrastructure.

An important consideration made as part of the strategy planning was that it was felt that WURC has now reached the stage where it is time to apply the knowledge on some industrial problems where it is thought that ultra structural knowledge can provide answers. Such projects are now considered for phase 3 (c.f. 6.3) and will also help to link WURC to industry.

6.3 *Visions & Strategies*

As WURC comes to the end of its second phase several projects will be completed and a number of Ph.D students graduating. Thus in order to secure WURCs critical mass and to continue the level of research activity attained during phase 2, it will be necessary to start a number of new projects. In order to avoid any delay in the initiation of projects (as experienced during the start of WURC phase 1), scientists working in WURC's research area were invited to submit early project proposals (October 2000) in–line with WURC's main research theme. Since the choice of projects will have significant implications for WURC's future development over the next 3-5 years, WURC's board, industry advisory and management groups have had, as already mentioned, "strategy meetings" at the end of year 2000 and during the beginning of 2001 to discuss the proposals and WURC's future development.

Discussions between the various groups have resulted in a number of projects being given priority while discussions are continuing with additional projects. WURC's board is further deciding on the early start (i.e. autumn 2001) of certain priority and pilot projects in order to maintain research impetus in key research areas. It should be emphasized that the development of project ideas involves people and interactions from both industry and academia.

As a new stimulus for WURC phase 3, the industrial partners have identified certain project areas of industrial importance within WURC's area of competence including: Ultrastructural changes in fibre structure during processing, fibre refining, fibre-water and fibre-fibre interactions, fibre drying and fibre fracture. These areas are currently being discussed and of which certain are planned for interactive projects during the next phase. This marks an approach where competence and techniques developed within WURC will be applied to industrial problems. WURC's board and industrial partners have, as already mentioned, emphasized the need to retain WURC's main focus to carry out fundamental research of wood fibre ultrastructure and retain a high international standard.

The preliminary program for WURC phase 3 is provided in a separate booklet (WURC, Research Program Phase 3). In brief, during the next 3-5 years WURC should carry out fundamental research on wood fibre ultrastructure concentrated in the following major areas: *I.* Wood and pulp fibre models; *II.* Cell-wall ultrastructure and fibre defects; *III.* Fibre chemistry of wood polymers at the molecular level; *IV.* Physical properties of fibre materials. This will involve research on:

- Modelling of fibre cell wall and pulp fibre organization; macro- and microstructural aspects, molecular modelling of fibre cell wall lignification (biosynthesis);
- Nanostructure of fibre cell-wall layers including the surface ultrastructure of chemical and mechanical pulp fibres, enzymatic modification and characterization of pulp fibre surfaces with novel enzymes;
- Molecular and ultrastructural aspects of wood-fibre biosynthesis, including the isolation and characterisation on novel enzymes from cambium tissues and their use in fibre modification;
- Supermolecular structure of cellulose modification during kraft pulping including ultrastructural studies to characterize chemical changes in individual cellulose microfibrils and their association with hemicelluloses; develop new methods for studying pore structure and their distribution in pulp fibres;
- Characterisation of wood fibre delignification correlating advanced chemical and ultrastructural approaches;
- Ultrastructural changes in fibre structure during processing, fibre fracture studies, fibre refining, fibre-water and fibre-fibre interactions.

WURC's portfolio will comprise of about fifteen major projects, in which five to six full time post doctoral scientists and about ten Ph.D students are working. WURC will have the possibility for starting new "pilot" projects for shorter periods of time. WURC will also build and rebuild new project groups in a more dynamic and flexible manner in order to encourage interaction.

A major aim is to form a cohesive program of interacting projects.

7. *Scientific Output*

7.1 *Research Program Development*

The main aim of research activities during phase 2 has been to increase substantially the knowledge about the chemical, mechanical and enzymatic impact on the morphological and chemical structure as well as on the physical properties of fibres from spruce, particularly the influence of kraft pulping on the ultrastructure of the fibre wall.

Already from the start of WURC, a number of *key* research areas of interest were put forward:

- Models of wood and pulp fibres;
- Ultrastructure of wood fibre cell walls;
- Fibre chemistry of wood polymers at the supermolecular level;
- Other compounds in fibres (i.e. metals, extractives, proteins);
- Physical properties of fibre materials;
- Fibre surface chemistry;
- Fibre deformation and annomalies.

Discussions at the end of phase 1 identified a further research area: *Wood fibre biosynthesis* (ultrastructural, molecular and biochemical/biotechnological aspects). It was clear that future and current possibilities of fibre modification ultimately lies in understanding how fibres are formed by nature. Essentially these key areas have remained central to WURC's research program.

It was at an early stage decided that WURC should concentrate initially on spruce wood fibres.

After thorough discussions with industry, six projects were selected for financial support in phase 1. At the beginning of WURC phase 2, four additional projects were financed and finally during the middle of phase 2, two more projects were supported. At the start of year 2001, WURC was supporting fourteen projects. During the autumn of 2001 plans have been made to include a further three projects partly to replace finished projects and also to further deepen WURC's research in specific areas.

Together, the projects in WURC can be considered as constituting a network of research tasks which are more or less integrated depending on the specific aspect studied and which are carried out by experts in a cross-disciplinary approach. In two large cooperative projects, industry selected and carefully produced a range of well characterised unbleached and bleached kraft pulps using a variety of cooking and bleaching methods to be used in WURC projects thus creating standard materials and synergy between the projects.

The six major project areas in which the projects have been organised during phase 2 are outlined below giving the location (university/institute) where the research has been concentrated.

7.2 Project Areas & Projects

I. Wood and pulp fibre models

1. Fibre models (SLU)
14. Molecular modelling (UU)

II. Cell wall ultrastructure

2. Fibre surface ultrastructure (SLU)
9. Ultrastructural studies of wood fibres using specific enzymes (SLU/UU)
10. Fibre cell wall biosynthesis (SLU)

III. Fibre chemistry of wood polymers at the molecular level

4. Cellulose and hemicellulose structure (STFI)
11. Fibre wall supermolecular chemistry (STFI)
7. Lignin and hemicellulose structures in wood fibres (KTH)

IV. Other subjects

6. Ultrastructural modelling of wood with respect to metal ions (CTH)
13. Influence of sulphate cooking on metals ions in wood (CTH)

V. Physical properties of fibre materials

5. Fibre strength of pulp fibres (KTH)
8. Mechanical cooperation and orientation of wood polymers in the wood structure (STFI)
12. Ultrastructural modifications after mechanical processing and drying of pulp (STFI)

VI. Fibre defects and structural changes

3. Dislocations in wood fibres (SLU)

These projects are briefly outlined below with some of the achievements described.

I. Wood and pulp fibre models

Project 1. Fibre models

Aim: To generate morphological models of spruce fibres.

Achievements: Studies have shown: a large variation in dimensional thickness of cell walls along the fibre axes, the need for several models for describing different cell types (e.g. early-latewood, juvenile compression wood), the great variation in microfibril orientation of the S2 layer among spruce fibres and even within single fibres, and for each fibre to have a specific shape which to a large extent is maintained during kraft pulping. Techniques for the 3D modelling of whole spruce fibres have been developed and have given new in-sights into spruce fibre morphology.

Project 14. Molecular modelling

Aim: To understand at the molecular level fundamental interactions leading to lignin formation in the cellulose/hemicellulose matrix, and to describe key reactions in lignin removal during pulping processes. (project started July 2000).

Achievements: High level quantum chemical calculations have been used to investigate structural features of different intermonomeric linkages in lignin as well as reveal mechanistic details of dimerization reactions leading to the formation of dilignols from monolignols to try and simulate lignin polymerization. Results reveal that small changes in the structure of dilignols can have severe affects on lignin structure and there is a correlation between stability of linkage bond and its abundance in lignin. Calculations also revealed radical-radical addition mechanisms for initial monolignin coupling to be more favourable than other mechanisms and that the kinetics of the process depends largely on subsequent intramolecular rearrangement. Molecular dynamic simulation techniques have been em-

ployed to study the properties and interactions of lignin monomers and their radical forms in aqueous solution and in phospholipid membranes. Currently high level studies of the reaction mechanisms of present-day bleaching chemicals are being undertaken.

II. Cell wall ultrastructure

Project 2. Fibre surface ultrastructure

Aim: Characterise the surface ultrastructure of wood fibres and investigate how this changes after various chemical, mechanical and enzymatic treatments.

Achievements: Using techniques such as FE-SEM, Cryo-FE-SEM, the surface ultrastructure of kraft pulp fibres during processing has been characterized showing a progressive delineation of the cellulose microfibril structure and variable increase in porosity as encrusting materials (lignin/hemicellulose) are removed. A technique for the analysis of single pulp fibres by XPS (ESCA) has been developed allowing for correlated spectroscopic and morphological observations to reveal cellulose and residual lignin/extractives on fibres. The importance of hemicellulose content on the surface aggregation of macrofibrils was determined (low hemicellulose level causes microfibril aggregation), and the distribution of the hemicellulose glucomannan on cellulose microfibrils traced using correlated TEM-replica and immuno- techniques. Freeze fracture and cryo-FE-SEM techniques have further revealed new interesting features of the ultrastructural organization of the secondary cell wall layers (i.e. S1, S2, S3). Results have given new insights on the morphological surface ultrastructure of chemical pulp fibres.

Project 10. Fibre cell wall biosynthesis

Aim: Identification and functional characterization of enzymes involved in wood fibre cell wall biosynthesis and modification with emphasis on aspen.

Achievements: The project involves three major interacting phases including: Identification and characterization of enzymes involved in wood cell wall formation; localization of enzyme activity during the formation of wood fibre cell walls (e.g. by confocal and electron microscopy); and investigations on the role of enzyme function for cell wall ultrastructure using transgenic plants. Using the the EST-sequence data base of wood forming tissues, and cloning of genes found in aspen xylem cambium, several families of enzymes which potentially play a role in fibre synthesis, (e.g. cellulose synthetase, cellulase, xyloglucan endo transglycosylase (XET), expansins) have been identified in colloboration with KTH. Moreover microarrayanalyses have identified unknown genes that are specifically expressed during the formation of the secondary wall. Using a robust expression system for several of the target enzymes in *E. coli*, antibodies to several of the enzymes have been produced and their expression in developing cambium tissues using immunolocalization techniques in conjunction with confocal lazer and TEM carried out. Studies on the role of some of these enzymes for cell wall ultrastructure is being investigated using "*up and down*" regulation *in-planta* with clones. Mutant trees are studied using micro- and macrostructural techniques, and subsequently their global expression of genes and proteins will be characterized.

Project 9. Ultrastructural studies of wood fibres using specific enzymes

Aim: To increase the knowledge on the ultrastructure and composition of wood cells and pulp fibres using specific enzymes as tools. (project start January 2000).

Achievements: From a *battery* of structurally and mechanically well characterized "novel" cellulase enzymes purified from the wood inhabiting fungi *Trichoderma reesei* and *Phanerocahete chrysosporium*, the cellulase cellobiohydrolase (CBH-58) from *P. chrysosporium* was chosen. The binding domain (CBD) has been removed from the enzyme and purified, coupled to a fluorescent dye (FITC) and used successfully as a marker molecule for the specific labelling of cellulose in the

cellulose/lignin/hemicellulose matrix of wood and pulp fibres. The CBD is currently being biotinylated allowing for the use of the marker in ultrastructural studies using TEM and SEM. The marker is currently being used for characterization and measurement of exposed cellulose on pulp fibres.

III. Fibre chemistry of wood polymers at the molecular level

Project 4. Fibre chemistry: structure of cellulose and hemicellulose

Aim: To elucidate important relations between structural characteristics of wood cellulose and hemicellulose and the reactivities and properties of the fibre substrate.

Achievements: Analyses using solid state ^{13}C-NMR on the structure of spruce wood fibres and other morphological cell types has shown a similar supermolecular structure. Studies have concentrated on the supermolecular structure of kraft pulp fibres. These studies have shown among other things the crystallinity of cellulose to increase significantly during kraft processing; for structures contributing to inaccessible surfaces in the interior of the cellulose fibril lattice to be converted to Iβ causing an increase in the degree of order of cellulose; for changes in the spectral order of hemicelluloses to occur and for a progressive increase in lateral fibril aggregate dimension to occur. The major increase in fibril aggregate dimensions coincided with the large removal of hemicellulose (especially galactoglucomannan) and smaller loss of lignin during initial kraft pulping. These results together with results from projects 2 and 5 have given exciting new in-sights into changes caused by the kraft pulping process.

Project 11. Fibre wall supermolecular chemistry

Aim: To clarify the mechanisms which determine changes in the supermolecular structure of cell wall polysaccharides during kraft pulping to provide background knowledge for expanding the possibilities for optimization of pulp production. (project start January 2000).

Achievements: Studies have included: construction of a multivariate calibration model for analysis of cellulose in cellulosic samples using solid state NMR; the development of methods and mathematical models for separate measurement of concurrent adsorption and transport processes in fibre cell walls; and methods for calculating polymer adsorption to cellulose and fibre surfaces.

Project 7. Lignin and hemicellulose structures in wood fibres (initial financial support by SJFR)

Aim: To clarify the molecular structures of lignin and hemicellulose in spruce wood using advanced mass spectrometry (MS), GPC and NMR. Traditionally, biopolymers like lignin and polysaccharides have been analyzed after different kinds of gross wet chemical analyses. The purpose of this project was to selectively degrade wood polymers and via MS analyze high molecular compounds.

Achievements: The standard thioacidolysis method for lignin degradation in spruce has been optimized producing greater yields of the main lignin monomer. Several new trimeric lignin products from thioacidolysis followed by Raney-nickel desulphuration of spruce lignin have also been detected. Preliminary results with periodate oxidation of TMP Bauer-McNett suggest that middle lamella lignin is more condensed than that found in the secondary cell wall of spruce fibres. Studies further emphasize that milled wood lignin should be considered as "degraded" rather than native lignin.

IV. Other subjects

Project 6. Ultrastructural modification of wood with respect to metal ions

Aim: Determine the occurrence, localization and extractability of different metal ions in wood treated with various chemicals in aqueous solution.

Achievements: Distribution of various metal ions in wood before and after acid treatment or

chelation has been demonstrated on a micro-level by applying a new technique for wood i.e. by Synchrotron Radiation Microbeam X-ray Fluorescence Analysis. The analyses have shown the non-homogeneous distribution of metals corresponding to the different cell types and morphological regions in wood. Results imply that most of the metal ions are loosely bound to the wood matrix through electrostatic attraction between cations and carboxyl groups. However, a large part of the Fe and Cu was found to be strongly attached to wood. Non-extractable iron is arranged in precipitates of low solubility or else is present in the ray cells. Loosely bound Fe was shown to be present in the tracheid walls.

Project 13. Influence of sulphate cooking on metals ions in wood

Aim: To increase the knowledge on the behavior of metal ions during sulphate cooking carried out under laboratory and industrial situations.

Achievements: Increased understanding on the behavior of different metal ions during sulphate cooking has been obtained by analysing the content of metals ions in different process streams during industrial pulp production. Using a special basket technique, the redistribution of metal ions (Ca, Mn) was studied in an industrial digester. The results implied that Ca and Mn once released to the cooking liquor do not, to any large extent, end up as strongly attached metal ions in the pulp. The technique "Microbeam X-ray fluorescence" (μ-XRF) has been applied for the first time to wood material subjected to pulping conditions and proven as a suitable method for determining the micro-structural distribution and redistribution of metals during pulping processes.

V. Physical properties of fibre materials

Project 5. Fibre strength of pulp fibres

Aim: To increase the knowledge on how changes in molecular composition, polymer structure and ultrastructure influence the strength properties of pulp fibres, and how this depends on pulping conditions. This knowledge can then be used to design chemical pulping processes that will retain or provide better fibre characteristics.

Achievements: Kraft pulps were produced under severe conditions to produce pulps with variations in cellulose/hemicellulose content, molecular weight distribution and cellulose II content. The cellulose/hemicellulose content in kraft pulps influenced the mechanical properties of handsheets. The ratio did not influence fibre strength but a high cellulose/hemicellulose ratio gave a high tear index and low tensile index at a certain bonding strength; a feature which may be caused by a difference in fibre wall stiffness. Variations in the molecular weight of spruce kraft pulps influenced the degree of fibre damage during refining, the fibre strength of unbeaten fibres, and the mechanical properties of handsheets. The mechanical properties of the handsheets seemed to be more related to the degree of damage during refining than to the fibre strength. The molecular weight distributions of spruce and birch kraft pulps have also been studied after more and less homogenous degradation reactions. Increasing the content of cellulose II in kraft pulps had a negative impact on the paper properties. This result may be due not only to the crystalline structure of cellulose II but also to a more compact fibre wall.

Project 8. Mechanical cooperation and orientation of wood polymers in the wood structure (initial financial support from SJFR)

Aim: To clarify the extent by which the wood polymers hemicellulose, lignin and cellulose cooperate mechanically in the wood structure and how the polymers are affected by pulp processes. This will increase the knowledge of the mechanical properties and open up possibilities for better utilization of fibres.

Achievements: Application of dynamic FTIR-spectroscopy has shown the close association of the hemicellulose glucomannan with cellulose, while xylan is freer and more associated with lignin. Analysis of pure cellulose by dynamic FTIR has shown the strain distribution at the molecular level to proceed via glucose rings, glycosidic linkages between the rings and the O (3)H-O(5) intramolecular hydrogen bond. No change in the interactive behavior between cellulose and hemicelluloses was observed as a consequence of kraft pulping. Dynamic spectra for sulphite and kraft softwood pulps have confirmed changes in the structure of cellulose for kraft- but not sulphite pulps and shown the importance of precipitated xylan on the surface of kraft fibres.

Project 12. Ultrastructural modifications after mechanical processing and drying of pulp
Aim: To determine how refining and drying of pulp fibres affects the ultrastructural and fracture-mechanical properties of fibres in paper structures. (project start January 2000)
Achievements: The ultrastructural organisation of the secondary cell wall structure of spruce wood and kraft pulp fibres has been characterized using atomic force microscopy (AFM). The secondary wall layers constituting fibre cell walls have been characterized and their organization shown comprised of aggregated cellulose microfibrils organized into discrete concentric lamellae. Studies of cross-sections of fibres has shown changes in the ultrastructure of the aggregated microfibrils during kraft pulping, the aggregates enlarging during the initial stages of the cooking process; results consistent with those achieved in other WURC projects using other techniques.

VI. Fibre defects and structural changes

Project 3. Dislocations in wood fibres
Aim: To study dislocations or weak points in the fibre cell wall and the ultrastructural background to their occurrence and impact on the properties of paper fibre.
Achievements: The diverse and numerous contradictory reports in the literature on the nature, occurrence and structural features of pulp- and wood fibre dislocations has been reviewed. Methods have been developed to determine and assess the occurrence of dislocations in pulp fibres and ultrastructural studies performed to characterize changes taking place in the individual secondary cell wall layers and microfibrillar organization resulting from the development of dislocations.

7.3 Scientific Publications & Examinations

A list of the scientific publications and symposia presentations for WURC from 1997 until September 2001 is given in Appendix 2. Since a major part of the research involves Ph.D students, it is natural that the concentration of publications is at the end of the four-year educational period, which for many of WURC's students is now approaching. In addition, the oral and poster presentations which have been given at WURC's five international seminars as well as at the interactive seminars given by industry representatives and WURC scientists on-site or during WURC's annual internal seminars are given at the end of Appendix 2. By the end of phase 2, four Ph.D and five "Licentiate" theses originating from WURC will have been defended (shown below). WURC scientists and industry have also collaborated on several student diplomas and internal research reports (see Appendix 2). Together scientists within WURC have produced about one hundred scientific publications and made about fifty presentations (oral and poster) at international and national symposia.

Examinations

i) Ph.D theses

Name	*Title of Thesis*	*Employer*
K. Wickholm March 2001	Structural Elements in Native Celluloses (KTH, Stockholm).	**STFI**
E-L. Hult April 2001	CP/MAS^{13}C-NMR Spectroscopy Applied to Structure and Interaction Studies on Wood and Pulp fibres (KTH, Stockholm).	**STFI**
I. Duchesne Nov. 2001	Electron microscopic and spectroscopic studies on the surface ultrastructure of kraft pulp fibres (SLU, Uppsala).	**SLU**
U. Molin Dec. 2001	Fibre strength of pulp fibres (In preparation) (KTH, Stockholm).	**KTH**

ii) Licentiate theses

Name	*Title of Thesis*	*Employer*
A. Berglund October 1999	Morphological investgation of metal ions in spruce wood (CTH, Gothenburg).	**CTH**
I. Duchesne Sept. 1999	Surface ultrastructure of Norway spruce kraft pulp fibres (SLU, Uppsala).	**SLU**
K. Nyholm May 2001	Dislocations in wood and pulp fibres of Norway Spruce (SLU, Uppsala).	**SLU**
M. Åkerholm March 2001.	Dynamic FT-IR spectroscopy applied to studies on wood polymers (KTH, Stockholm).	**STFI**
J. Fahlén November 2001.	Ultrastructural arrangement of the polymers in the wood fiber wall (KTH, Stockholm).	**STFI**

iii) WURC Industry & University Diploma Work

Name	*Title*	*Employer*
E. Sjöblom 1999	A comparative study between two-phase and single stage oxygen delignification using experimental design (MoDo/WURC) (Degree project in Chemical Engineering)	Umeå Univ./MoDoWURC
C. Östmark 1999	Enzymer av *Trichoderma reesi* och dess påverkan på fluffmassa (Degree project in Chemical Engineering) (In Swedish)	Mälardålens Högskola Korsnäs/WURC
A. Gouget 2000	Characterization of expression of *PttXyn10,* a putative xylan hydrolase from poplar wood-forming tissues (Dept.of Forest Genetic and Plant Physiology)	SLU, Umeå/WURC
Nov. 2001	In preparation	Korsnäs/STFI

8. Industrial Involvement, Benefits & Effects

8.1 Industrial Involvement & Interactions

During phase 2 the industry has been actively involved and interacting at all levels within the Centres activities. At the start of phase 1, WURC had seven industrial partners, *viz* the forest industry companies AssiDomän, Korsnäs, MoDo, SCA Graphic, StoraEnso, Södra Cell and one chemical company EKA Chemicals. Although, as explained in section 1.2.1, major structural changes have taken place in many of these companies, it is reasonbly correct to say that the same companies have continued to support WURC throughout phase 2. Over the latter part of year 2001, WURC will present its new program to its current supporting companies and potential new partners. WURC's industrial partners have contributed significantly to the development of WURC during its five-year existence.

During the introductory period and establishment of WURC, the chairman (Håkan Jöves, Korsnäs, 1995/6) was from industry and the Director (Brita Swan, Stora Enso, 1996-1999) during phase 1 was also from industry.

Research personnel and senior scientists from the industrial partners have been active as members of the Industrial Advisory Group, various project groups and as contact persons for Ph.D students (outlined above) during the last five years. The Industrial Advisory Group has had regular meetings (*ca* 8 per year) to discuss current and new projects and their interrelations. During late 2000 and early 2001, the Industrial Advisory Group was involved in *"strategy meetings"* for the future development of WURC's projects portfolio for phase 3. This resulted in the definition of six projects for consideration during phase 3 having a direct link to known industrial phenomena.

In addition, the companies have been active in supporting the research of the Centre in many ways. Typical examples of interactions include:

- Provision of representative spruce wood samples and pulps for experimental purposes in the different projects; (e.g. fibre modelling, project 1.);
- Provision of a series of unbleached (phase 1) and bleached (phase 2) Kraft pulps produced by a cooperative effort in which all the companies interacted. Industry cooperated from all stages of tree selection, felling, chipping, cooking, bleaching, paper characterization etc. to produce a unique experimental material which has subsequently used in the majority of WURC's projects. WURC scientists are currently carrying out an interactive project to characterize these special pulps;
- Provision for industrial practice for Ph.D students;
- Provision of specialized pulps aimed at improved ultilization of the inherent strength properties of fibre materials (project 5);
- Provision of special pulps made in chippers with knives of different qualities for studies on fibre damage (project 3);
- Experimental facilities made available for WURC scientists to conduct work in industry;
- Industry has also been actively involved in WURC's internal seminars presenting results of their on-going research etc (*Appendix 2)* as well as giving advice to WURC's researchers;
- Industry has also been involved in the supervision of several diploma works at the company sites;
- Organization of study trips to industry for Ph.D students and scientists.

During these activities senior scientists as well as technical staff in all the supporting companies have participated.

8.1.1 Mobility of Personnel in WURC

Direct mobility of personnel between WURC and member companies has occurred primarily via the Centres provision of industrial practice for Ph.D students and through seminars at industry sites by WURC scientists and Ph.D students (e.g. at SCA, Stora Enso, Korsnäs, MoDo, EKA Chemicals). Scientists from industry have also utilized specialized equipment at WURC and vice-versa. WURC industrial practice (*ca* 2 month period) was introduced during phase 2 in order give students a chance to experience the working environment of industry. Students have either worked on specific aspects of their projects in industry using special equipment or have worked generally in the company. This approach has been rather successful and to date four Ph.D students (Isabelle Duchesne, EKA Chemicals, Sweden/Holland; Ulrika Molin, SCA, Germany; Jonas Brändström, AssiDomän, Sweden; Annica Sundén, Södra Cell, Sweden) have carried out practice with concrete plans already made for two more students at EKA Chemicals and Södra Cell during the autumn 2001. Internal reports concerning industrial practice or work conducted have resulted.

The market for employment of persons directly within the pulp and paper industry in WURC's area of competence is presently rather limited. This reflects the fact that industry itself is moving its in-house research closer to product development. This in fact strengthens the importance of WURC as an area "backstream", where joint knowledge building is suitable. An, at least temporary, effect of the reorganisation between the companies, mentioned in Section 1.2.1 is also a reduction in research staff due to synergies. Thus, the need for employment of researchers in general has been lower in the last years. Mobility in this respect is not likely to improve in the near future. Despite efforts it has not been possible to initiate so called industrial licentiate or industrial Ph.D students, i.e. persons

employed by companies but on leave of absence for work in WURC. Every effort is being made to change this situation for WURC phase 3 and the provision of industry formulated projects is seen as a possible development in this area.

8.2 Industrial Benefits & Expectations

The expectations from WURCs industrial partners has been discussed at both board level and within the industrial advisory. This has been discussed by WURCs industrial partners and has been formulated:

- A possibility to jointly with representatives from other companies and scientists from university/ institutes, influence the orientation of research within an important field of research

Companies involved in WURC have indicated the following (mutual) benefits:

- Access to scientific knowledge on wood fibre ultrastructure of value to their research personnel;
- Possibility to interact with academia and further develop contacts with university;
- Opportunity to create and develop new ideas;
- A possibility to solve specific problems by new approaches;
- Through cooperation between participants in the centre at several levels and on several fronts, an improved general impression and awareness is created in the companies regarding the importance of fibre ultrastructure for their products;
- Opportunity to interact with the international scientific community on aspects of wood fibre ultrastructure.
- The establishment of a platform for recruitment of personnel with research education. This shall be seen in light of the predicted shortage of persons with technical education, in which situation the pulp and paper industry might not be in the most favoured situation. The connection of WURC to SLU is particularly important in this respect.

The research carried out at WURC is primarily of fundamental nature with long term industrial relevance. Results are published in scientific journals and communicated at international symposia etc. So far WURC has not produced any patents or has specific examples of the commercialization of results. However WURC member companies have benefited from the new knowledge of wood fibre ultrastructure as expressed by their comments (Appendix 3) to WURC's research.

WURC member industries have emphasized the importance for WURC to represent and maintain a clear competence profile in the Swedish research infrastructure as well the importance of developing sufficient critical mass. Industry have indicated the following expectations:

- WURC should further develop and become an internationally recognized Centre;
- Continue its main theme of fundamental research on wood fibre ultrastructure;
- Perform a limited number of carefully selected industrial orientated projects;
- Transfer of knowledge from academia to industry should develope via direct participation of industry personnel in WURC projects.

WURC competence profile should be further developed via:

- Continued generation of new knowledge on wood fibre ultrastructure and development and application of the most recently available techniques;

- Further recruitment of Ph.D students and post doctoral scientists in order to bring in new ideas and increase critical mass;
- Further develop its international and national networks and increase the number of visits to member companies.
- Avoid overlapping research with other research groups in Sweden.
- Integrate further the project portfolio and the interactions between the unique set of competences existing in WURC.

Appendix 1. Project List 1999-2001

Appendix 1.

WURC Project list overview *(Project leader in italics)*

WURC Project 1. Fibre models
Project group: PhD-student Jonas Brändström, *Thomas Nilsson*, Geoffrey Daniel, Stig Bardage, SLU; Lennart Salmén, STFI. ***Industrial contact persons:*** Inger Eriksson, SCA; Gunilla Söderstam, Stora Enso.

WURC Project 2. Fibre surface ultrastructure
Project group: PhD-student Isabelle Duchesne, *Geoffrey Daniel*, Thomas Nilsson, SLU; Bert Pettersson, STFI. ***Industrial contact persons:*** Inger Eriksson, SCA; Lars Wågberg, MittHögskolan (previously SCA).

WURC Project 3. Dislocations in wood fibres
Project group*:** PhD-student Karolina Nyholm, *Paul Ander*, Geoffrey Daniel, Thomas Nilsson, Stig Bardage, SLU; Bert Pettersson, STFI; Gunnar Henriksson, KTH. ***Industrial contact persons: Ann Marklund, MoDo (now M-Real).

WURC Project 4. Fibre chemistry: structure of cellulose and hemicellulose
Project group: ***PhD-student Eva-Lena Hult,* Tommy Iversen, *Thomas Larsson, STFI; Ants Teder, Göran Gellerstedt, KTH.*** Industrial contact persons: ***Torsten Nilsson, Korsnäs; Monica Ek, Stora Enso (now KTH); Ulla Johansson, Södra.***

WURC Project 5. Fibre strength of pulp fibres
Project group: PhD-student Ulrika Molin, *Ants Teder*, Göran Gellerstedt, Ants Teder, KTH; Tommy Iversen, STFI; Thomas Nilsson, Geoffrey Daniel, SLU; Lars Ödberg, AssiDomän. ***Industrial contact persons:*** Stefan Högman, Korsnäs; Ann Marklund (now M-Real), Modo; Sture Backlund, SCA;Frank Peng, StoraEnso; Martin Waubert de Puiseau, Södra.

WURC Project 6. Ultrastructural modification of wood with respect to metal ions
Project group: PhD-student Annica Sundén (Berglund), Rune Simonson, Harald Brelid, CTH; Thomas Nilsson, Geoffrey Daniel, SLU; Ants Teder, KTH; Jiri Basta, EKA Chemicals; ***Industrial contact persons***: Ann Marklund, MoDo (now M-Real); Jiri Basta, EKA Chemicals; Per Larsson, Södra

WURC Project 7. Lignin and hemicellulose structures in wood fibres
Project group: *PhD-student Hans Önnerud,* Göran Gellerstedt, *Tord Eriksson, KTH*

WURC Project 8. Mechanical cooperation and orientation of wood polymers in the wood structure
Project group: PhD-student Margaretha Åkerholm, *Lennart Salmén*, STFI; Göran Gellerstedt, KTH.

WURC Project 9. Ultrastructural studies of wood fibres with specific enzymes
Project group: *PhD-student Lars Hildén,* Gunnar Johansson, *Göran Pettersson, UU, Thomas Nilsson, Geoffrey Daniel, SLU; Bert Pettersson STFI.*

WURC Project 10. Fibre cell wall biosynthesis
Project group: Björn Sundberg, *SLU Umeå, Geoffrey Daniel, SLU Uppsala; Jerry Ståhlberg, SLU/ BMC; Tuula Teeri, Kristina Blomqvist, Harry Brumer, KTH.*

WURC Project 11. Fibre wall supermolecular chemistry
Project group: Tomas Larsson, *Tommy Iversen, Kristina Wickholm, STFI; Thomas Nilsson, Geoffrey Daniel SLU; Ants Teder, Göran Gellerstedt, KTH.*

WURC Project 12. Ultrastructural modifications after mechanical processing and drying of pulp
Project group: PhD-student Jesper Fahlen, *Lennart Salmén*, Ulla-Britt Mohlin, Sören Östlund, STFI; Ulf Gedde, KTH; Thomas Nilsson, Geoffrey Daniel, SLU.

WURC Project 13. Influence of sulphate cooking on metals ions in wood
Project group: *Harald Brelid*, Rune Simonson, Anders Ringby, CTH; Thomas Nilsson,, Geoffrey Daniel, SLU; Jiri Basta, EKA Chemicals; Ann Marklund, MoDo (now M-Real); Per Larsson, Södra.

WURC Project 14. Molecular modelling
Project group: Ph.D-student Bo Deerbej, *Leif Eriksson,* Yan Ni Wang, UU; Geoffrey Daniel, Thomas Nilsson, SLU.

Appendix 2. Scientific Output: Publications, Symposia, Seminars

Scientific output

Conference presentations and publications 1997-2001

General

Daniel, G. 1999. WURC. Biotechnology in Mälardalen, Uppsala University, October 1999.

Daniel, G. 1999. The Wood Ultrastructure Research Centre. Minisymposium: Microbes, Trees, Wood and Forest Ecosystem, SLU, Uppsala.

Daniel, G. 2000. The Wood Ultrastructure Research Centre (WURC). Ekmandagarna 2000, SPCI, Stockholm, 7-9 February 2000. (Abstract).

Daniel, G. & Ander. P. 2000. Internationella forskare gäster vid WURC-seminarium. Svensk Papperstidning 103:7, 20. (In Swedish).

Daniel, G. and Brolin, A. 2000. "Varför djup kunskap om vedfibrer är viktig för skogsindustrins utveckling." Kompetenscentrumdagen, Matematiskt-informationsteknologiskt centrum, Uppsala Universitet, 25 oktober 2000.

Swan, B. 1997. WURC – Wood Ultrastructure Research Centre, Centrum för forskning om vedfiberns ultra struktur. Svensk Papperstidning 100:4, 17. (In Swedish).

Swan, B. 1997. Mycket duktiga forskare knyts till WURC. Svensk Papperstidning 100:5, 12. (In Swedish).

Swan, B. 1998. Stort intresse för årets WURC-seminarium. Svensk Papperstidning/Nordisk cellulosa 101:6, 67-68. (In Swedish)

Krantz, T. 1999. WURC seminariet - Cellulosastruktur och biosyntes. Svensk Papperstidning 102:6, 35-35. (In Swedish)

Eriksson, L. 1999. Från genmanipulering inom massa- och papper: forskning och framsteg inom massa- och pappersindustrin. Svensk Papperstidning 102:9, 48-52. (In Swedish)

Ödberg, L. 2001. Seminariedag om vedfiberns ultrastruktur. Svensk Papperstidning 104:7, 54-55. (In Swedish)

WURC Internal Reports (University/Industry)

Molin, U. 1999. Egenskaper hos massor framställda med olika kokmetoder – resultat för "WURC" massorna. Internal report nr 1.

Duchesne, I., C.G. van Leerdam, G. Daniel and J. Basta. 2000. Surface composition of Kraft pulp fibres using XPS and FE-SEM. Internal report nr 2.

Söderstam, G. *et al.*, 2001. Influence of cooking and bleaching conditions on pulp and fiber properties of softwood spruce pulp: A laboratory study. Internal report nr 3. (In preparation).

Author	Bardage, S.L. 2000.
Title of paper	Three-dimensional visualisation of wood fibres: 3D modelling.
Journal/conference	Proc. Workshop Fibre Wall & Microfibril Angle, COST Action E20 Wood Fibre Cell Wall Structure, 11-13 May, 2000, Margi Hotel, Greece. Printed by NTUA, Athens, Greece and MC/WG of COST Action E20, p. 20.
WURC Project No	**1**

Author	Nilsson, T. 2000.
Title of paper	Microfibril angle in spruce wood.
Journal/conference	IAWS conference. Reading, U.K., July 2000
WURC Project No	**1**

Author	Brändström, J., G. Daniel & T. Nilsson. 2001.
Title of paper	Use of soft rot cavities to determine microfibril angles in wood; advantages, disadvantages and possibilities.
Journal/conference	Submitted to Holzforschung.
WURC Project No	**1**

Author	Bardage, S.L. 2001.
Title of paper	Three-dimensional modeling and visualization of whole Norway spruce latewood tracheids.
Journal/conference	Wood and Fibre Science. (In press)
WURC Project No	**1**

Author	Bergander, A., J. Brändström, G. Daniel & L. Salmén. 2000.
Title of paper	Fibril angle variability in earlywood of Norway spruce using soft rot cavities and polarization confocal microscopy.
Journal/conference	J. Wood Science. (Accepted)
WURC Project No	**1**

Author	Singh, A.P. & G. Daniel. 2000.
Title of paper	The S2 layer in the tracheid walls of *Picea abies*: inhomogeneity in lignin distribution and cell wall microstructure.
Journal/conference	Holzforschung. (In press)
WURC Project No	**1**

Author	Brändström, J. 2001.
Title of paper	Micro- and ultrastructural aspects of Norway spruce tracheids: A review.
Journal/conference	IAWA J. (In press)
WURC Project No	**1**

Author	Bardage, S. L., G. Daniel & A. Singh. 2001.
Title of paper	Three-dimensional analysis of the collapse behavior of Kraft cooked Norway spruce fibers.
Journal/conference	Submitted to Wood and Fibre Science.
WURC Project No	**1**

Author	Daniel, G. 1997.
Title of paper	Use of HR-Cryo-FE-SEM for studies on wood and pulp fibre ultrastructure.
Journal/conference	International Cryo-Electron Microscopical Meeting, York, UK, June 1997.
WURC Project No	**2**

Author	Daniel, G. 1997.
Title of paper	Studies on wood and pulp fibre ultrastructure using HR-Cryo-FE-SEM.
Journal/conference	Proc. Tappi Biological Sciences Symposium, San Francisco, USA, p. 447.
WURC Project No	**2**

Author	Awano, T. K. Takabe, M. Fujita & G. Daniel. 1998.
Title of paper	Immuno-FE-SEM reveals distribution of xylan in beech.
Journal/conference	49th Annual meeting of the Japanese Wood Research Society, April 1998.
WURC Project No	**2**

Author	Daniel, G. & I. Duchesne. 1998.
Title of paper	Revealing the surface ultrastructure of spruce fibres using Field Emission SEM.
Journal/conference	7th Int. Conf. Biotechnology Pulp Paper Industry, Vancouver BC, June 1998, pp 81-84.
WURC Project No	**2**

Author	Daniel, G., K. Takabe, & I. Duchesne. 1999.
Title of paper	Visualization of the Surface Ultrastructure of Spruce Pulp Fibres Using Field Emission-SEM and TEM-Replica Techniques.
Journal/conference	In "Microscopy as a Tool in Pulp and Paper Research and Development, June 21-22, STFI, Stockholm, p. 18-27
WURC Project No	**2**

Author	Daniel, G., 1999.
Title of paper	Processing samples for light and electron microscopy.
Journal/conference	In "Microscopy as a tool in the pulp and paper industry - Workshop on sample preparation" (EC Fair -98-3681), KCL, Espoo, Finland, 28-29/10 1999, p. 1-31.
WURC Project No	**2**

Author	Duchesne, I. & G. Daniel. 1999.
Title of paper	The ultrastructure of wood fibre surfaces as shown by a variety of microscopical methods.
Journal/conference	In "Microscopy as a tool in Pulp and Paper Research and Development" (EC Fair -98-3681), STFI, Stockholm, June 21-22, 1999.
WURC Project No	**2**

Author	Duchesne, I. & G. Daniel. 1999.
Title of paper	The ultrastructure of wood fibre surfaces as shown by a variety of microscopical methods - a review.
Journal/conference	Nordic Pulp Paper Res. J. 14: 129-139.
WURC Project No	**2**

Author	Duchesne, I. & G. Daniel. 1999.
Title of paper	Changes in spruce fibre surface ultrastructure during kraft pulping – A Field Emission SEM study.
Journal/conference	In "Microscopy as a tool in the pulp and paper industry - Workshop on sample preparation", (EC Fair -98-3681). KCL, Espoo, Finland, 28-29/10-1999, p. 165.
WURC Project No	**2**

Author	Awano, T., K. Takabe, M. Fujita & G. Daniel. 2000.
Title of paper	Deposition and localization of glucuronoxylans in the secondary cell wall of Japanese beech as observed using immuno FE-SEM.
Journal/conference	Protoplasma, 212: 72-79.
WURC Project No	**2**

Author	Duchesne, I. & G. Daniel. 2000.
Title of paper	Changes in surface ultrastructure of Norway spruce fibres during kraft pulping – Visualization by Field-Emission-SEM.
Journal/Conference	Nordic Pulp Paper Res J. 15: 54-61.
WURC Project No	**2**

Author	Duchesne, I., E.-L. Hult, U. Molin, G. Daniel, T. Iversen & H. Lennholm. 2000.
Title of paper	The effect of hemicellulose on fibril aggregation of kraft pulp fibres as revealed by FE-SEM and CP/MAS ^{13}C-NMR.
Journal/Conference	Cellulose. (In press).
WURC Project No	**2**

Author	Daniel, G, U. Molin, I. Duchesne & S. Bardage. 2001.
Title of paper	Ultrastructural (FE-SEM, TEM) observations on PFI refined novel spruce kraft pulp fibres of varying molecular weight.
Journal/conference	8th Int. Conf. Biotechnology Pulp Paper Industry, June 4-8, 2001, Helsinki, Finland, PII/92, p 253-254. (Poster).
WURC Project No	**2**

Author	Daniel, G., J. Volc, & M-L. Niku-Paavola. 2001.
Title of paper	TEM immunocytochemical and HR-Cryo FE-SEM studies on white rot decay of lignocellulose.
Journal/conference	8th Int. Conf. Biotechnology Pulp Paper Industry, June 4-8, 2001, Helsinki, Finland, O4/17, p 42 - 43.
WURC Project No	**2**

Author	Duchesne, I., G.C. van Leerdam, G. Daniel & J. Basta. 2001.
Title of paper	Characterisation of pulp fibre surfaces using X-ray photoelectron spectroscopy and field emission-scanning electron microscopy.
Journal/conference	Proc. Workshop on advanced methods for lignocellulosics and paper products characterisation. June 18-19, Grenoble, France.
WURC Project No	**2**

Author	van Leerdam, G.C., J. Basta, I. Duchesne & G. Daniel. 2001.
Title of paper	The use of micro-analytical techniques for the characterization of pulp.
Journal/conference	9th European conference on applications of surface and interface analysis, 30 September - 5 October 2001, Avignon, France.
WURC Project No	**2**

Author	Duchesne, I., G.C. van Leerdam, G. Daniel & J. Basta. 2001.
Title of paper	Combining XPS and FE-SEM for studying the surface composition of kraft pulp fibres.
Journal/conference	Submitted to J. Pulp Paper Science.
WURC Project No	**2**

Author	Singh, A., G. Daniel & T. Nilsson. 2001.
Title of paper	Ultrastructure of the S2 layer in relation to lignin distribution in *Pinus radiata* tracheids.
Journal/conference	J. Wood Science. (In press).
WURC Project No	2

Author	Ander, P., K. Grabner, G. Kandioller, E. Srebotnik, K. Poppius-Levlin, S Semar, H. Anke, M.-L. Niku-Paavola, L. Viikari & K. Messner. 1998.
Title of paper	The in vitro ^{14}C-labelled kraft pulp assay as used for evaluation of laccases and mediators intended for pulp bleaching.
Journal/conference	7th Int. Conf. Biotechnology Pulp Paper Industry, Vancouver BC, June 1998, Vol. A, pp A111-A115.
WURC Project No	3

Author	Nyholm, K. & P. Ander. 1999.
Title of paper	Dislocations in wood fibres.
Journal/conference	SPCI' 99 June 1-4, Stockholm. (Poster).
WURC Project No:	3

Author	Nyholm, K. & P. Ander. 1999.
Title of paper	Dislocations in wood fibres.
Journal/conference	Skogskonferensen "Trädets variationsrikedom - problem och möjligheter", SLU, Uppsala, 30 Nov. -1 Dec. 1999. (Poster)
WURC Project No	3

Author	Nyholm, K. & P. Ander. 2000.
Title of paper	Dislocations in wood fibres.
Journal/conference	Proc. Workshop Fibre Wall & Microfibril Angle. COST Action E20 Wood Fibre Cell Wall Structure, 11-13 May, 2000, Athens, Greece. Printed by NTUA, Athens, Greece and MC/WG of COST Action E20, p. 58. (Poster).
WURC Project No	3

Author	Ander, P. & K. Nyholm. 2000.
Title of paper	Deformations in wood and spruce pulp fibres: Their importance for wood and pulp properties.
Journal/conference	Proc. Int. Symp. on Wood Machining, Properties of wood and wood composites related to wood machining. 27-29 September, Vienna, Austria, p. 3-19, ISBN 3-9501315-0-7.
WURC Project No	3

Author	Ander, P. & Nyholm, K. 2001.
Title of paper	The effect of cellulases, hemicellulases and laccase/HBT on spruce pulp fibre deformations.
Journal/conference	Proc. 8th Int. Conf. Biotechnol. Pulp Paper Ind., June 4-8, 2001, Helsinki, Finland, O6/33, p.71-73.
WURC Project No	3

Author	Nyholm, K. & P. Ander. 2001.
Title of paper	The connection between spruce pulp fibre dislocations and balloon swelling.
Journal/conference	Proc. 8th Int. Conf. Biotechnol. Pulp Paper Ind., June 4-8, 2001, Helsinki, Finland, PI/5, p. 95. (Poster).
WURC Project No	3

Author	Ander, P. 2001.
Title of paper	Dislocations and balloon swelling in spruce pulp fibres – Effect of cellulases, xylanase and lacase/HTB.
Journal/conference	Special Issue, Biotechnology in the Pulp and Paper Industry, Progress in Biotechnology, Elsevier Science. (Submitted).
WURC Project No	**3**

Author	Nyholm, K., P. Ander, S. Bardage, & G. Daniel. 2001.
Title of paper	Dislocations in pulp fibres - their origin, characteristics and importance - a review.
Journal/conference	Submitted to Nordic Pulp Paper Res. J.
WURC Project No	**3**

Author	Nyholm, K. & G. Daniel. 2001.
Title of paper	Morphological aspects of fibre ballooning and dislocations in spruce fibres - Light and electron microscope observations.
Journal/conference	Submitted to Holzforschung.
WURC Project No	**3**

Author	Larsson, P.T., K. Wickholm & T. Iversen. 1999.
Title of paper	Structural elements in cellulose I.
Journal/conference	10th ISWPC, Yokohama, Japan, June 7-10, 1999, Vol. 1, 602-606
WURC Project No	**4**

Author	T. Iversen, E.-L. Hult, P.T. Larsson & K. Wickholm. 2000.
Title of paper	CP/MAS 13C NMR spectroscopy applied to structure studies on cellulose I.
Journal/conference	219th ACS National Meeting, San Francisco, CA (2000) CELL 145.
WURC Project No	**4**

Author	Wickholm, K., E.-L. Hult, P.T. Larsson & T. Iversen. 2000.
Title of paper	Quantification of cellulose forms in complex cellulose materials.
Journal/conference	Proc. 6th European Workshop on Lignocellulosics and Pulp (EWLP), Bourdeaux, France, September 3-6, 2000, p. 19-22.
WURC Project No	**4**

Author	Hult, E-L., P.T. Larsson & T. Iversen. 2000.
Title of paper	A comparative CP/MAS 13C-NMR study of cellulose structure in spruce wood and kraft pulp.
Journal/conference	Cellulose 7 (1): 35-55.
WURC Project No	**4**

Author	Hult, E-L., Larsson P. T. & Iversen, T. 2000.
Title of paper	Determination of the supermolecular structure of polysaccharides in unbleached sulphite pulps by CP/MAS ^{13}C-NMR.
Journal/conference	Submitted to Holzforschung.
WURC Project No	**4**

Author	Duchesne, I., E.-L. Hult, U. Molin, G. Daniel, T. Iversen & H. Lennholm. 2000.
Title of paper	The effect of hemicellulose on fibril aggregation of kraft pulp fibres as revea led by FE-SEM and CP/MAS ^{13}C-NMR
Journal/conference	Cellulose. (In Press).
WURC Project No	**4**

Author	Wickholm, K., E-L. Hult, P. T. Larsson & T. Iversen. T. 2000.
Title of paper	Quantification of cellulose forms in complex cellulose materials: A chemometric model.
Journal/conference	Submitted to Cellulose.
WURC Project No	**4**

Author	Hult, E.-L. 2001.
Title of paper	Ultrastructure of wood and pulp fibers.
Journal/conference	Ekmandagarna, SPCI, 5-7 January, 2001, Stockholm, Sweden
WURC Project No	**4**

Author	Hult, E.-L., T. Iversen, P.T. Larsson & K. Wickholm. 2001.
Title of paper	CP/MAS ^{13}C NMR spectroscopy applied to structure and interaction studies on cellulose.
Journal/conference	EUROCARB XI, Lisboa, Portugal.
WURC Project No	**4**

Author	Hult, E-L., P. T. Larsson & T. Iversen. 2001.
Title of paper	A study of supermolecular changes in the cellulose and hemicellulose structure during kraft pulping.
Journal/conference	Nordic Pulp Paper Res. J. 16 (1): 46-52.
WURC Project No	**4**

Author	Hult, E-L., T. Larsson & T. Iversen. 2001.
Title of paper	Cellulose fibril aggregation – An inherent property of kraft pulps.
Journal/conference	Polymer 42 (8): 3309-3314.
WURC Project No	**4**

Author	Hult, E.-L., T. Liitiä, S.L. Maunu, B. Hortling & T. Iversen. 2001.
Title of paper	A CP/MAS ^{13}C NMR study of cellulose structure on the surface of refined kraft pulp fibers.
Journal/conference	Submitted to Carbohydr. Polym.
WURC Project No	**4**

Author	Molin, U. 1999.
Title of paper	Hemicellulosa/cellulosa och styrka.
Journal/conference	Ekmandagarna, SPCI, 19-20 January, 1999, Stockholm, Sweden
WURC Project No	**5**

Author	Molin, U. & A. Teder. 1999.
Title of paper	Influence of changes in cellulose and hemicellulose proportions on fibre and paper properties.
Journal/conference	Submitted to Nordic Pulp Paper Res. J.
WURC Project No	**5**

Author	Molin, U, & H. Lennholm. 2000.
Title of paper	The influence of molecular weight on mechanical properties of pulp fibres.
Journal/conference	Proc. 54th Appita Annual Conf., Vol. 2, 615-621.
WURC Project No	**5**

Author	Molin, U. & H. Lennholm. 2000.
Title of Paper	The influence of molecular weight on mechanical properties of pulp fibres.
Journal/conference	Submitted to APPITA J.
WURC Project No	**5**

Author	Berggren, R., U. Molin, F. Berthold & H. Lennholm. 2001.
Title of paper	Alkalisk nedbrytning av cellulosa i björk och gran. Är tid och alkalihalt utbytbara?
Journal/conference	Ekmandagarna, SPCI, 5-7 februari 2001, Stockholm, Sweden
WURC Project No	**5**

Author	Duchesne, I., E.-L. Hult, U. Molin, G. Daniel, T. Iversen & H. Lennholm. 2000.
Title of paper	The effect of hemicellulose on fibril aggregation of kraft pulp fibres as revealed by FE-SEM and CP/MAS ^{13}C-NMR.
Journal/conference	Submitted to Carbohydr. Polym.
WURC Project No	**5**

Author	Berggren, R., U. Molin, F. Berthold, H. Lennholm & M. Lindström. 2001.
Title of paper	Alkaline degradation – influence of degradation conditions om molecular mass distributions and fibre strength.
Journal/conference	Manuscript
WURC Project No	**5**

Author	Berglund, A., H. Brelid & R. Simonson. 1999.
Title of paper	Spatial distribution and chemical attachments of metal ions in spruce wood.
Journal/conference	Proc. 10th Int. Symp. Wood Pulping Chemistry (ISWPC), Yokohama, Japan, 7-10 June, 1999, Vol. 1, p. 90-94.
WURC Project No	**6**

Author	Berglund, A., H. Brelid, A. Rindby & P. Engström. 1999.
Title of paper	Spatial Distribution of Metal Ions in Spruce Wood by Synchrotron Radiation Microbeam X-ray Fluorescence Analysis.
Journal/conference	Holzforschung 53: 474-480.
WURC Project No	**6**

Author	Berglund, A., H. Brelid, A. Rindby & P. Engström. 2000.
Title of paper	Spatial distribution and chemical attachments of metal ions in spruce wood.
Journal/conference	J. Pulp Paper Science 26: 352-357.
WURC Project No	**6**

Author	Önnerud, H., M. Palmblad, T. Eriksson & G. Gellerstedt. 1999.
Title of paper	Analysis of the native lignin structure using FT-ICR-MS
Journal/conference	10th Int. Symp. Wood Pulping Chemistry, Yokohama, Japan (1999), Vol. I: 166-171.
WURC Project No	**7**

Author	Önnerud, H. & G. Gellerstedt. 2001.
Title of paper	Inhomogenities in the chemical structure of spruce lignin.
Journal/conference	11th Int. Symp. Wood Pulping Chemistry, Nice, France (2001), Vol. I: 59.
WURC Project No	**7**

Author	Vickes, M. 1999.
Title of paper	Tvådimensionell FT-IR korrelationsspektroskopi, exempel på samverkan mellan cellulosa och hemicellulosa studerad med denna teknik.
Journal/conference	Poster at Svenska Kemistsamfundets Analysdagar, Uppsala 14-17 maj 1999.
WURC Project No	**8**

Author	Hinterstoisser, B. & L. Salmén. 1999.
Title of paper	Two-dimensional step-scan FTIR: A tool to unravel the OH-valency range of cellulose.
Journal/conference	Cellulose 6: 251-263
WURC Project No	**8**

Author:	Åkerholm, M. & L. Salmén. 1999.
Title of paper	Interactions between wood polymers studied by dynamic FT-IR spectroscopy.
Journal/conference	Polymer 42: 963-969.
WURC Project No	**8**

Author	Hinterstoisser, B. & L. Salmén. 2000.
Title of paper	Application of dynamic 2D-FTIR to cellulose.
Journal/conference	Vibrational Spectroscopy 22: 111-118.
WURC Project No	**8**

Author	Åkerholm, M. & L. Salmén. 2001.
Title of paper	Kolhydratsamverkan studerad med dynamisk FTIR-spektroskopi.
Journal/conference	Ekmandagarna, SPCI, 5-7 February, 2001, Stockholm, Sweden.
WURC Project No	**8**

Author	Åkerholm, M. & L. Salmén. 2001.
Title of paper	Interactions between wood polymers studied by dynamic FT-IR spectroscopy.
Journal/conference	11th Int. Symp. Wood Pulping Chemistry, Nice, France, June 11-14, 2001, Vol. I: 17-20.
WURC Project No	**8**

Author	Hinterstoisser, B., Åkerholm, M. & Salmén, L. 2001.
Title of paper	Effect of fiber orientation in dynamic FTIR study on native cellulose.
Journal/conference	Carbohydrate Research. (In Press).
WURC Project No	**8**

Author	Åkerholm, M. & L. Salmén. 2001.
Title of paper	Dynamic FT-IR spectroscopy for carbohydrate analysis of wood pulp.
Journal/conference	J. Pulp Paper Science (Submitted).
WURC Project No	**8**

Author	Hildén, L., G. Johansson, G. Daniel & T. Nilsson. 2001.
Title of paper	The ultrastructure of wood studied with specific enzymes.
Journal/conference	COST Action E20 Wood Fibre Cell Wall Structure, Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden. (Poster).
WURC Project No	**9**

Author	Terashima, N., J. Hafrén, U. Westermark, Y. Xie, K. Fukushima, C. Lapierre & D. L.van der Hart. 1999.
Title of paper	Proposed 3D structural model for softwood lignin.
Journal/conference	10th Int. Symp. Wood Pulping Chemistry, Yokohama, Japan, June 7-10, 1999, Vol. I, p. 106-109.
WURC Project No	**10**

Author	Mellerowicz, E. J., K. Blomqvist, V. Bourgin, H. Brumer, M. Christiernin, S. Den man, S.Djerbi, M. Eklund, Å. Kallas, J. Lehtiö, S. Raza, S. Regan, U. Rudsander, B. Sundberg & T. Teeri. 2000.
Title of paper	Cell wall enzyme discovery using high throughput sequencing and in-depth expression analysis in poplar wood forming tissues.
Journal/conference	Proc. Symp. "Friendly and Emerging Technologies for a Sustainable Pulp and Paper Industry". Taiwan Research Institute, Taipei, Taiwan. 25-27 April, 2000.
WURC Project No	**10**

Author	Bourquin, V., E. Mellerowicz, S. Denman, M. Eklund, T. Terri & B. Sundberg. 2000.
Title of paper	Immunolocalization of xyloglucan endotransglycosylase (XET16A) from Poplar wood-forming tissues.
Journal/conference	Graduate student meeting in Gothenburg 10-14 August 2000.
WURC Project No	**10**

Author	Gray-Mitsumune, M., E. J. Mellerowicz, K. Blomqvist, S. Regan, V. Bourquin, J. Lehtiö, T. T. Teeri & B. Sundberg. 2000.
Title of paper	Expansins involved in the wood fiber formation in poplar.
Journal/conference	Plant Cell Walls - Gordon Conference, Meriden, New Hampshire, Aug 20-25, 2000
WURC Project No	**10**

Author	Gray-Mitsumune, M., E. J. Mellerowicz, K. Blomqvist, A. Gouget, J. Schrader, S. Regan, J. Lehtiö, T. T. Teeri & B. Sundberg. 2001.
Title of paper	Characterization of expansin genes specifically expressed during secondary xylem development in hybrid aspen.
Journal/conference	COST Action E20 Wood Fibre Cell Wall Structure. Proc. Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden, p. 4.
WURC Project No	**10**

Author	Mellerowicz, E., H. Aspeborg, K. Blomqvist, H. Brumer, V. Bourquin, S. Denman, M. Gray-Mitsumune, A. Gouget, S. Regan, B. Sundberg, T. T. Teeri. 2001.
Title of paper	Xylem cell formation in hybrid aspen: Enzymes involved in the cell wall formation and restructuring.
Journal/conference	COST Action E20 Wood Fibre Cell Wall Structure. Proc. Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden, p. 3
WURC Project No	**10**

Author	Bourquin, V., E. Mellerowicz, H. Brumer, S. Denman, M. Eklund, T. T. Terri & B. Sundberg. 2001.
Title of paper	Localization by indirect immunofluorescence of the xyloglucan endotransglycosylase (XET16A) in the cambial region *tissues of hybrid aspen.*
Journal/conference	COST Action E20 Wood Fibre Cell Wall Structure. Proc. Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden, p. 54. (Poster).
WURC Project No	**10**

Author	Mellerowicz, E., H. Aspeborg, K. Blomqvist, V. Bourquin, S. Denman, M. Gray-Mitsumune, S. Regan, B. Sundberg, T. T. Teeri. 2001.
Title of paper	Enzymes involved in the cell wall formation and restructuring in the wood forming tissues of hybrid aspen.
Journal/conference	4th Carboh. Bioeng. Meeting, June 10. - 13. 2001, Royal Institute of Technology, Stockholm, Sweden.
WURC Project No	**10**

Author	Aspeborg, H., S. Djerbi, M. Hertzberg, J. Schrader, B. Sundberg, E. Mellerowicz, P. Nilsson, T. Teeri & K. Blomqvist. 2001.
Title of paper	Transcript profiling of genes involved in carbohydrate metabolism in the wood forming tissue from *Populus tremula* L.X *tremuloides* Michx.
Journal/conference	4th Carboh. Bioeng. Meeting, June 10. -13. 2001, Royal Institute of Technology, Stockholm, Sweden.
WURC Project No:	**10**

Author	Mellerowicz, E. J., M. Baucher, B. Sundberg, & W. Boerjan. 2001.
Title of paper	Unraveling cell wall formation in the woody dicot stem.
Journal/conference	Plant Molecular Biology - Special issue on plant cell walls, August 2001. (In Press).
WURC Project No	**10**

Author	Larsson, T. 1999.
Title of paper	Structural Elements in Cellulose I.
Journal/conference	Biopolymer Technology (ICBT), 29 September - 1 October 1999, Universidad de Coimbra, Coimbra, Portugal.
WURC Project No	**11**

Author	Larsson, P.T., H-L. Hult, K. Wickholm, E. Pettersson & T. Iversen. 1999.
Title of paper	CP/MAS 13C NMR spectroscopy applied to structure and interaction studies on cellulose I.
Journal/conference	Solid State NMR, 15: 31-40.
WURC Project No	**11**

Author	Fahlén, J. 2000.
Title of paper	AFM: a tool for revealing details on the wood ultrastructure.
Journal/conference	Proc. Workshop Fibre Wall & Microfibril Angle. COST Action E20 Wood Fibre Cell Wall Structure, 11-13 May, 2000, Athens, Greece. Printed by NTUA, Athens, Greece and MC/WG of COST Action E20, p. 57.
WURC Project No	**12**

Author	Fahlén , J. & L. Salmén. 2001.
Title of paper	Cross sectional structure of wood during pulping viewed with AFM.
Journal/conference	11th Int. Symp. Wood Pulping Chemistry, Nice, France, June 11-14, 2001, Poster P155.
WURC Project No	**12**

Author	Fahlén, J. & L. Salmén. 2001.
Title of paper	Cross-sectional structure of the S_2 layer in native and processed wood.
Journal/conference	COST Action E11 Characterization methods for fibres and paper, 10-12 May, Louvain-la-Neuve-University, Brussels, Belgium.
WURC Project No:	**12**

Author:	Fahlén, J. & L. Salmén. 2001.
Title of paper	The lamellar structure of the wood fiber wall - radial or concentric.
Journal/conference	COST Action E20 Wood Fibre Cell Wall Structure. Proc. Workshop Interaction between cell wall components, 26-28 April 2001, SLU, Uppsala, Sweden, p. 25.
WURC Project No	**12**

Author:	Brelid, H., K. Nåhem & A. Sundén 2001.
Title of paper	The behaviour of Ca and Mn in spruce wood chips during kraft pulping.
Journal/conference	11th Int. Symp. Wood Pulping Chemistry, Nice, France, June 11-14, 2001, Oral 7.3.
WURC Project No:	**13**

Author	Brelid, H., A. Sundén & P. Olofsson. 2000.
Title of paper	Metal removing pretreatments of softwood chips: effects on the metal ion distribution in kraft pulp.
Journal/conference	Submitted to Nordic Pulp Paper Res. J.
WURC Project No	**13**

Author	Wang, Y. & L.A. Eriksson. 2001.
Title of paper	Molecular Dynamics Simulations of Lignin Monomers in Solution.
Journal/conference	Submitted to Mol. Physics
WURC Project No	**14**

Author	Durbeej, B. & L.A. Eriksson. 2001.
Title of paper	A Density Functional Theory Study of Coniferyl Alcohol Intermonomeric Cross Linkages in Lignin - Three-Dimensional Structures, Stabilities and the Thermodynamic Control Hypothesis.
Journal/conference	Submitted to Biophysical J.
WURC Project No	**14**

Author	Wang, Y. & L.A. Eriksson. 2001.
Title of paper	Diffusion of lignin monomer in a lipid bilayer membrane; A molecular dynamics simulation study.
Journal/conference	Manuscript
WURC Project No	**14**

Author	Durbeej, B. & L.A. Eriksson. 2001.
Title of paper	The dehydrogenative lignin polymerization process studied by density functional theory.
Journal/conference	Manuscript
WURC Project No	**14**

WURC-Industry Interactive Seminars

Duchesne, I.; The ultrastructure of wood fibre surfaces. Presentation of WURC Project 2. at SCA Research. Jan. 1999.

Brändström, J. (2000) "Fiber modeller". AssiDomän Corporate R & D Piteå. Oral presentation

Bardage, S. L.; "3D visualisering av trä- och massafibrer". WURC board meeting, 30 May 2000, Arlanda, Sweden.

Duchesne, I.; Surface composition of kraft pulp fibres using XPS and FE-SEM. April 26-27, 2000. Eka Chemicals, Bohus, Sweden.

Duchesne, I.; Preliminary XPS and FE-SEM results obtained on kraft pulp fibres. March 27, 2000. Akzo Nobel Chemicals General Science, Dept. of Microstructure Analysis, Arnhem, The Netherlands.

Duchesne, I.; Results from Project 2. The ultrastructure of wood fibre surfaces. May 2, 2000. Korsnäs, Gävle, Sweden.

Hult E-L. 1999.: Fiberkemi-cellulosa och hemicellulosastruktur. Poster. Information Day STFI's Basic Research.

Molin, U. 1999; The fibre strength of pulp fibres. Presentation of WURC Project 5., SCA Research Jan. 1999.

Nyholm, K., & P. Ander. 1999; Dislokationer eller noder i vedfibrer. June 16, MoDo, Örnsköldsvik, Oral presentation.

Bardage, S. & Brändström, J. 2001. 3-dimensionell simulering av tracheid cellväggar. WURC seminarium 12 februari, SCA, Sundsvall.

Daniel, G. 2001. Ultrastrukturen hos vedfiberns ytor. WURC seminarium 12 februari, SCA, Sundsvall.

Molin, U. & Teder, A. 2001. Fiberstyrka hos massafibrer. WURC seminarium 12 februari, SCA, Sundsvall.

Brelid, H. 2001. Ultrastrukturell modifiering av ved map på metalljoner+sulfatkokets inverkan på metalljoner. WURC seminarium 12 februari, SCA, Sundsvall.

Nyholm, K. & Ander, P. 2001. Dislokationer och noder i vedfibrer. WURC seminarium 12 februari, SCA, Sundsvall.

Fahlén, J. 2001. Ultrastrukturella ändringar vid mekanisk bearbetning och torkning av massa. WURC seminarium 12 februari, SCA, Sundsvall.

WURC Internal Seminars

1) Date: 10 Mars 1998; Place: Borgvik

Molin, U-L.; Massans egenskaper. WURC Internseminarium 10/02-1998, Borgvik.

Brolin, A.; Fiberns roll i fibernätverket. WURC Internseminarium 10/02-1998, Borgvik.

Salmén, L.; Fiber och vatten – porstruktur. WURC Internseminarium 10/02-1998, Borgvik.

Peng, F.; Ved och fiberdimensioner. *Sulfatmassans egenskaper – inverkan av vedråvara och process.* WURC Internseminarium 10/02-1998, Borgvik.

Rehnberg, O.; Ved och fliskondition. *Sulfatmassans egenskaper – inverkan av vedråvara och process.* WURC Internseminarium 10/02-1998, Borgvik.

Högman, S.; Kontinuerlig kokning + O_2-delignifiering. *Sulfatmassans egenskaper – inverkan av vedråvara och process.* WURC Internseminarium 10/02-1998, Borgvik.

Jansson, U.; Batchkokning. *Sulfatmassans egenskaper – inverkan av vedråvara och process.* WURC Internseminarium 10/02-1998, Borgvik.

Holm, A-S; Blekning. *Sulfatmassans egenskaper – inverkan av vedråvara och process.* WURC Internseminarium 10/02-1998, Borgvik.

Nilsson, T.; Vedfibers uppbyggnad. *Ultrastrukturell nivå.* WURC Internseminarium 10/02-1998, Borgvik.

Duchesne, I.; Fiberytor, literatursammanställning. *Ultrastrukturell nivå.* WURC Internseminarium 10/02-1998, Borgvik.

Iversen, T.; Cellulosastrukturer i ved och massa. *Ultrastrukturell nivå.* WURC Internseminarium 10/02-1998, Borgvik.

Westermark, U.; Kondensationsreaktioner under kokning. *Ultrastrukturell nivå.* WURC Internseminarium 10/02-1998, Borgvik.

Olm, L.; Selektiv ligninutlösning i koket. *Ultrastrukturell nivå.* WURC Internseminarium 10/02-1998, Borgvik.

Brelid, H.; Metaller i ved och massa, förekomst och roll. *Ultrastrukturell nivå.* WURC Internseminarium 10/02-1998, Borgvik.

Peng, F.; Fiberdimensioner. *Fiberns morfologiska struktur.* WURC Internseminarium 10/02-1998, Borgvik.

Nilsson, T.; Fiberns ultrastruktur – vägg, yta m m. *Fiberns morfologiska struktur.?* WURC Internseminarium 10/02-1998, Borgvik.

Laine, J.; Fiberns ytkemi – laddning. *Fiberns morfologiska struktur.* WURC Internseminarium 10/02-1998, Borgvik.

Salmén, L.; Vattenupptagande förmåga. *Fiberns morfologiska struktur.* WURC Internseminarium 10/02-1998, Borgvik.

Mohlin. U-B; Fiberskador. *Fiberns morfologiska struktur.* WURC Internseminarium 10/02-1998, Borgvik.

Hult, E-L; Cellulosa och hemicellulosa. *Topokemi och kemisk struktur.* WURC Internseminarium 10/02-1998, Borgvik.

Westermark, U.; Lignin. *Topokemi och kemisk struktur.* WURC Internseminarium 10/02-1998, Borgvik.

Salmén, L.; Samverkan mellan polymerer. *Topokemi och kemisk struktur.* WURC Internseminarium 10/02-1998, Borgvik.

Eriksson, I.; Skogen, råvaran. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?* WURC Internseminarium 10/02-1998, Borgvik.

Rehnberg, O.; Vedgård och renseri. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?* WURC Internseminarium 10/02-1998, Borgvik.

Högman, S., Jansson, U. & L. Olm; Kokeri- och O_2-delignifiering. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?* WURC Internseminarium 10/02-1998, Borgvik.

Eriksson, I.; Sileri. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?* WURC Internseminarium 10/02-1998, Borgvik.

Holm, A-S; Blekning. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?* WURC Internseminarium 10/02-1998, Borgvik.

Salmén, L.; Torkning. *Var och hur i productionen borde vi kunna förbättra massans styrkepotential i papperet?* WURC Internseminarium 10/02-1998, Borgvik.

Brolin, A.; Fiberstyrka och/eller flexibilitet. *Vad är väsentlig hos fibermaterialet för att erhålla styrka hos arket.* WURC Internseminarium 10/02-1998, Borgvik.

Mohlin, U-B; Malning och formning. *Vad är väsentlig hos fibermaterialet för att erhålla styrka hos arket.* WURC Internseminarium 10/02-1998, Borgvik.

Gellerstedt, G.; Vilka kompletteringar behövs? *Vad tar programmet hand om?* WURC Internseminarium 10/02-1998, Borgvik.

2) Date: 25 May 1999; Place: Bålsta

Molin, U.; Cellulosa/hemicellulosa och styrka. *Forskningsresultat.* WURC Internseminarium 26/5-1999, Bålsta.

Hult, E-L; Cellulosa och hemicellulosa – mängd och struktur i olika massor. *Forskningsresultat.* WURC Internseminarium 26/5-1999, Bålsta.

Duchesne, I.; "Fiberytors ultrastruktur - FE-SEM iakttagelser". *Forskningsresultat.* WURC Internseminarium 26/5-1999, Bålsta.

Nyholm, K.; Dislokationer. *Forskningsresultat.* WURC Internseminarium 26/5-1999, Bålsta.

Berglund, A.; Metallfördelning. *Forskningsresultat.* WURC Internseminarium 26/5-1999, Bålsta.

Brändström, J.; Fiberstruktur – modeller. *Forskningsresultat.* WURC Internseminarium 26/5-1999, Bålsta.

Vickes, M.; Mekanisk interaktion mellan vedpolymerer. *Forskningsresultat.* WURC Internseminarium 26/5-1999, Bålsta.

Önerud, H.; Lignin och hemicellulosastruktur. *Forskningsresultat.* WURC Internseminarium 26/5-1999, Bålsta.

Basta, J. (Eka); Fiberforksning inom Akzo. *Karakterisering av massor.* WURC Internseminarium 26/5-1999, Bålsta.

Sandström, P. (SCA); Brottseghet – körbarhet. *Karakterisering av massor.* WURC Internseminarium 26/5-1999, Bålsta.

Jansson, U. (Södra); Prediktion av massastyrka med hjälp av fibermätningar. *Karakterisering av massor.* WURC Internseminarium 26/5-1999, Bålsta.

Marklund, A. (MoDo); Masastyrka – fiberdimensioner. *Karakterisering av massor*. WURC Internseminarium 26/5-1999, Bålsta.

Högman, S. (Korsnäs); Fibermaster – fiberdeformationer. *Karakterisering av massor*. WURC Internseminarium 26/5-1999, Bålsta.

Thuvander, F. (Karlstad Univ.); Ny metod för bestämning av fiberns mekaniska egenskaper. *Karakterisering av massor*. WURC Internseminarium 26/5-1999, Bålsta.

Rehnberg, O. (AssiDomän); Homogenisering eller särbehandling av råvarår – inverkan på massaegenskaper. *Egenskaper*. WURC Internseminarium 26/5-1999, Bålsta.

Lif, J. (StoraEnso); Papperets fukt- och tidsberoende mekaniska egenskaper. *Egenskaper*. WURC Internseminarium 26/5-1999, Bålsta.

Östlund, S. (KTH-STFI); Massa och papper sedda med materialtekninska ögon. *Egenskaper*. WURC Internseminarium 26/5-1999, Bålsta.

3)Date: 15 November 2000; Place: Sigtuna

Recents WURC results:

II	***Projects 2, 9, 10***	***Cell wall ultrastructure & morphology***
III	***Projects 4, 7, 11***	***Fibre chemistry of wood polymers at molecular level***
IV	***Projects 6, 6A (13)***	***Metals in wood***
V	***Projects 5, 8, 12***	***Physical properties of fibres***
VI	***Project 3***	***Dislocations and structural damages***

Industry - CURRENT PROBLEMS WHICH NEED ANSWERS; NEW PRACTICAL EXPERIENCES WHICH NEED TO BE CONSIDERED.

AssiDomän : SÅGVERKSFLIS - EN MASSARÅVARA MED VARIERANDE KVALITET

EKA Chemicals: BLEACHING AND FIBRE

Korsnäs: BEHANDLING AV BLEKT BARRVEDSMASSA MED CELLULASER

MoDo Paper: INVERKAN AV HUGGNINGSBETINGELSER PÅ FIBER- OCH MASSAEGENSKAPER

SCA: STYRKEFÖRLUSTER VID KOKNING OCH SYRGASBLEKNING

Stora Enso: STRENGTH DELIVERY

WURC Scientists - WHAT HAVE WE LEARNT US SO FAR ? OUR UNDERSTANDING OF FIBRES BEFORE WURC AND NOW. (*Input from all WURC project leaders and Ph.D students*)

HOW CAN WE BEST UTILIZE RESULTS SO FAR ? (*Industry)*

WHERE DO WE GO FROM HERE ? PHASE 3 ? WHAT DO WE DO NOW TO BEST UTILIZE THE RESULTS ? *(All round discussion - all WURC participants)*

TEMA *MODELLING OF FIBRES*: A TOOL FOR UNDERSTANDING FIBRE ULTRASTRUCTURE AND CHEMICAL AND PHYSICAL PROPERTIES

FIBRE, ULTRASTRUCTURE & NANOSTRUCTURE MODELLING:

a) Whole fibre and cell wall modelling (*Project 1*)
b) Molecular cell wall modelling (*Project 14- L. Eriksson, Bo Durbeej*)

WURC International Seminars

1. WURC Inauguration

Date: 10 April 1997
Place: Swedish University of Agricultural Sciences, Uppsala, Main lecture hall

WOOD ULTRASTRUCTURE SEMINAR
CHAIRMAN: *INGER ERIKSSON*, SCA AB

THE TRUE STRUCTURE OF WOOD FIBRES
Thomas Nilsson and Geoffrey Daniel, SLU, Uppsala

CONTROL OF WOOD FORMATION
Björn Sundberg, SLU, Umeå

ON THE FORMATION OF LIGNIN IN THE WOOD CELL WALL
Gösta Brunow, University of Helsinki, Finland

THREE-DIMENSIONAL STRUCTURE OF CRYSTALLINE CELLULOSE MICROFIBRILS
Olle Teleman, VTT, Finland

CHIRAL PROPERTIES OF CELLULOSE AND WOOD FIBRES
Derek Gray, PAPRICAN, McGill University, Montreal, Canada

2. International Seminar 1998

Date: 22 April 1998
Place: Swedish University of Agricultural Sciences, Uppsala, Main lecture hall

INTRODUCTION
Lennart Eriksson, STFI, Chairman, WURC

SESSION 1 Chairman: Brita Swan WURC

METAL IONS – WOOD ULTRASTRUCTURE
Annica Berglund, Harald Brelid and Rune Simonson
Chalmers University of Technology (CTH)

FUTURE CHEMICAL PULPING PROCESSES
Ants Teder, Royal Institute of Technology (KTH)

ENZYMES – TOOLS FOR ULTRASTRUCTURAL RESEARCH ON WOOD FIBRES
Paul Ander, Swedish University of Agricultural Sciences (SLU)

SESSION 2 (Invited speakers) Chairman: Inger Eriksson, SCA

TOWARDS A MORE COMPREHENSIVE MODEL FOR THE BIOGENESIS OF WOOD CELL WALLS: ORGANIZATION AT THE NANOSCALE LEVEL.
Rajai Atalla, USDA, Forest Products Laboratory, Madison, USA.

THE VARIABILITY OF LIGNIN STRUCTURE AND LIGNIFICATION PATTERNS IN WOOD SPECIES AND ANNUAL PLANTS.
Bernard Monties, INRA, Grignon, France.

MOLECULAR MODELLING OF LIGNOCELLULOSIC CELL WALLS.
Lubo Jurasek, McGill University, Montreal, Canada.

SESSION 3
Report from an EU-project

THE STRENGTH OF WOOD FIBRES ASSOCIATIONS BETWEEN HEMICELLULOSE AND CELLULOSE AT THE MOLECULAR LEVEL.
Olle Teleman and Andreas P. Heiner, Finland; Tommy Iversen and Tomas Larsson, Sweden; Bas Leeflang, The Netherlands; Gaston Gilli, Italy; PeterBiely, Slovakia.

3. ***International Seminar 1999***

Date: 21 April 1999
Place: Swedish University of Agricultural Sciences, Uppsala, Main lecture hall

INTRODUCTION TO WURC
Björn Henningsson, Swedish University of Agricultural Sciences, SLU

SESSION 1 Chairman: Björn Henningsson, SLU/WURC

DEVELOPMENT OF WURC AT THE EDGE OF THE NEW MILLENIUM
Brita Swan, WURC

SUPRAMOLECULAR STRUCTURE OF CELLULOSE IN SPRUCE WOOD AND KRAFT PULP
Eva-Lena Hult, Tomas Larsson and *Tommy Iversen*, STFI

A MULTIDISCIPLINARY APPROACH TO FIBRE WALL FORMATION – PRESENTATION OF A NEW PROJECT
Björn Sundberg, Swedish University of Agricultural Sciences (SLU), and *Tuula Teeri*, Royal Institute of Technology (KTH)

SESSION 2 (Invited speakers) Chairman: Inger Eriksson, SCA

CELLULOSE SYNTHASE GENES AND RELATED GENE PRODUCTS: ON THE ROAD TO THE FUTURE DESIGN OF CELLULOSE BIOSYNTHESIS IN THE WOOD CELL WALL
Malcolm Brown Jr., University of Texas at Austin, Austin, USA

NUMBER AND DISTRIBUTION OF CELLULOSE SYNTHASES, FIBRIL TO MATRIX RATIO, AND CELL GEOMETRY: PARAMETERS DETERMINING PLANT CELL WALL TEXTURE
Anne Mie C. Emons, Wageningen Agricultural University, The Netherlands

IMMUNOCYTOCHEMICAL STUDIES ON CELL WALL FORMATION IN WOODY PLANTS
Keiji Takabe, Kyoto University, Kyoto, Japan

SESSION 3 Chairman: Geoffrey Daniel (SLU/WURC)

COST ACTION E20 WOOD FIBRE CELL WALL STRUCTURE - SHORT INFORMATION
Paul Ander, Swedish University of Agricultural Sciences (SLU)

HIGHLIGHTS FROM WURC PROJECTS GENERATED DURING THE FIRST TWO YEARS

4. International Seminar 2000

Date:12 April 2000
Place: Swedish University of Agricultural Sciences, Uppsala, Main lecture hall

SESSION 1 Chairman: Geoffrey Daniel (SLU/WURC)

FIBRE STRUCTURE AND PAPER PROPERTIES
Ulla-Britt Mohlin, STFI

THE INFLUENCE OF MOLECULAR WEIGHT ON MECHANICAL PROPERTIES OF PULP FIBRES
Ulrika Molin, Helena Lennholm and Ants Teder, KTH

ULTRASTRUCTURE OF SPRUCE WOOD CELL WALLS
Adya Singh, Forest Research Institute, Rotorua, New Zealand

SESSION 2 (Invited speakers) Chairman: Lars Ödberg, AssiDomän AB

MOLECULAR DIRECTIONALITY IN CELLULOSE AND CHITIN MICROFIBRILS – A MICROSCOPIC APPROACH
Junji Sugiyama, Wood Research Institute, Kyoto University, Japan

SUPERMOLECULAR ARCHITECTURE OF CELLULOSE IN SOME NATIVE AND ARTIFICIAL SYSTEMS
Tetsuo Kondo, Forestry and Forest Products Research Institute, Tsukuba Norin Kenkyu, Ibaraki, Japan

NMR SPIN-RELAXATION OF SUBMICROSCOPIC STRUCTURES IN WOOD FIBRES
Roger Newman, Industrial Research Limited, Lower Hutt, New Zealand

SESSION 3 Chairman: Thomas Nilsson (SLU/WURC)

COST ACTION E20 "WOOD FIBRE CELL WALL STRUCTURE" – SHORT INFORMATION
Paul Ander, SLU

HIGHLIGHTS FROM WURC PROJECTS

5. International Seminar 2001

Date:25 April 2000
Place: Swedish University of Agricultural Sciences, Uppsala, Loftet lecture hall

SESSION 1 Chairman: Geoffrey Daniel (SLU/WURC)

DO FIBRE SURFACE PROPERTIES HAVE AN INFLUENCE ON PAPER STRENGTH?
Janne Laine (STFI)
CELL WALL STRUCTURE OF KRAFT PULP FIBRES AS DETERMINED BY DIFFERENT MICROSCOPY TECHNIQUES
Isabelle Duchesne (SLU/WURC)

ULTRASTRUCTURE OF WOOD AND PULP FIBRES
Eva-Lena Hult (STFI/WURC)

LIGNIN BIOSYNTHESIS AND DEGRADATION FROM A THEORETICAL PERSPECTIVE
Leif Eriksson (UU/WURC)

SESSION 2 (Invited speakers) Chairman: Göran Gellerstedt (KTH/WURC)

MONOLIGNOL COUPLING NETWORKS AND DOWNSTREAM METABOLISM: IMPLICATIONS FOR SAPWOOD AND HEARTWOOD FORMATION
Norman Lewis (USA)

PROPOSED 3D STRUCTURAL MODEL FOR SOFTWOOD LIGNIN IN THE CELL WALL
Noritsugu Terashima (Japan)

THE METABOLIC PLASTICITY OF LIGNIFICATION
John Ralph (USA)

SESSION 3 Chairman: Thomas Nilsson (SLU/WURC)

VARIABILITY OF MICROFIBRIL ANGLE IN SPRUCE
Jonas Brändström (SLU/WURC)

INHOMOGENEITIES IN THE CHEMICAL STRUCTURE OF SPRUCE LIGNIN
Hans Önnerud (KTH/WURC)

SUPRAMOLECULAR CHEMISTRY AT THE CELLULOSE FIBRIL SURFACES
Tomas Larsson (STFI/WURC)

CHANGES IN CELL WALL STRUCTURE DURING REFINING OF PULPS WITH DIFFERENT MOLECULAR WEIGHTS
Ulrika Molin (KTH/WURC)

REMOVAL AND REDISTRIBUTION OF METAL IONS DURING KRAFT PULPING
Harald Brelid (CTH/WURC)

Appendix 3. Reports from Industrial Partners

AssiDomän

Benefits from the membership of WURC

Some benefits of our membership of WURC are summarized as follows:

- The membership of WURC has made it possible for AssiDomän to participate in core competence research on the fiber ultrastructure in spite of the fact that the company has a limited R&D capacity.

- Some results and ideas of the WURC projects and the connected discussions/ conferences have contributed to improved products.

- Through the network created within WURC we are now very well aware of the experimental possibilities existing at Swedish Universities and Institutes in the fiber ultrastructure area.

- The international conferences arranged by WURC in Sweden have given a very good outlook into the international research in this area.

- Senior researchers and PhD students from WURC have done experimental work on our advanced equipment which has created a valuable personal network and improved our own knowledge and utilization of the equipment.

- The biotechnology part of the WURC projects has contributed to our judgement of the potential of biotechnology and genetic engineering for improved products and processes.

Piteå 2001-08-16

Ove Rehnberg

(Industrial Reference Group member)

KORSNÄS

2001-08-21 1 (1)

Benefits of being an industrial member in WURC – Wood Ultra Structure Research Centre, some aspects from Korsnäs AB

Benefits and experiences

- With the approach of fundamental research in the area of wood Ultrastructure, WURC constitutes a good supplement to the more applied research and development our company performs internally.

Korsnäs is a relatively small company with correspondingly low R&D efforts, which makes our need for access to high quality R&D in areas that are not covered by in house acitivities, even more important.

- Through our membership in WURC, our company has been able to establish contacts with researchers in new areas.

- The results from the WURC projects have been incorporated in the R&D process at Korsnäs as a valuable input of fundamental knowledge. This has and will, together with internal results, contribute to better decisions in our actitivities.

- The incorporation of WURC results has led to an improved general level of knowledge and understanding of interaction between wood structure and the process systems within our company.

- The researchers within WURC have been valuable contact partners in areas as wood structure and microscopic analysing techniques.

- Within the frame-work of WURC two interesting thesis works for MSc have been performed at Korsnäs.

Future expectations on WURC

- The gap between what is considered to be industrially applicable results and the fundamental approach of the core activities in WURC should be identified and to some extent bridged over.

- The cooperation between different research teams within WURC should be improved.

- The collaboration between WURC and industry should be improved. Initiatives for that should be taken from both sides.

KORSNÄS AB. Development Torsten Nilsson Stefan Högman

m-real

M-real's view on the membership in the Wood Ultrastructure Research Centre (WURC)

We have been members of WURC since the start in 1996. First as MoDo AB, later as Modo Paper AB and now as M-real Corporation, a fine paper producing company. Structural changes are common in our industry today and they are often accompanied by changes in the research organisations. To get continuity in the research we have to rely upon institutes, universities and competence centras.

The competence centras make it possible to concentrate the efforts on well-defined subjects, in the case of WURC on the ultrastructure of the wood fibre wall. The close co-operation between students in the different projects has characterised the work within WURC and due to different approaches of the projects to the same research material, a broader and more coherent picture of the fibre wall is emerging. However, the studies are of a fundamental nature and the results can not immediately be implemented in our processes, but they are vital to the understanding of the effects of different process steps on the fibre structure and chemistry.

The close co-operation with the industry has ensured the industrial relevance of the projects. The co-operation has manifested itself in the joint production of unbleached and bleached pulps with different chemical compositions, used as a common research material for the projects. Chips with different degree of mechanical damage has been produced both in lab and industrial scale and has been studied with regard to dislocations in the fibre wall. Equipment has been lent to the departement of Wood Science at SLU and WURC students have been performing studies using instruments in our laboratory. Students has also visited us for project presentations and discussions. The annual internal WURC meetings have had both industrial and academic presentations at the agenda and lots of fruitful discussions. To summarize, the first five years of WURC have, from our point of view, been succesful both with regard to the way of working and with regard to the amount of new and interesting results that has been produced.

2001-08-16
Ann Marklund

SCA

SCA Graphic Sundsvall AB
Inger Eriksson
R&D Manager
August 21, 2001

Membership in the Centre for
Wood Ultrastructure Research Centre (WURC)

Due to the upcoming evaluation of the NUTEK competence centre for Wood Ultrastructure Research Centre (WURC), we (SCA Forest Products) have been asked to give our view of the membership.

Relevance to membership

SCA Forest Products R&D work is today much application oriented and customer driven. Almost no basic academic R&D research are applied within SCA. We therefore rely us on universities and industries on the results of fundamental R&D. This is one of the reasons for SCA to participate in WURC.

Benefits and future expectations on WURC.

The performed projects in WURC have increased contacts and networks with industries and universities/institutes. The direct communication with the universities /institutes have been much closer and has improved in relevant areas.

During the existing period PhD students have been invited to SCA and been given seminars about their work. The results from WURC have also been spread by posters at two occasions. These activities have give good input to our internal projects and discussions. The competence of the ultrastructure for the woodfibre has increased in the company due to these activities.

We think that WURC has developed in a favourable direction concerning the content of the project portfolio during the last period. For the coming period, we like that there will be an increased amount of cross-scientific projects. A cross-functional approach has been lacking in the R&D field for the pulp and paper industry.
To gain new knowledge about the wood fibre, we strongly think we need to have a more cross-functional approach and SCA think WURC as a competence centre can promote for being a platform to perform this kind of project.

SCA believe is that the gained knowledge from WURC will result in improvements in existing process and products development.

For SCA the centre will also give possibilities to recruitment and a continued education.

STORAENSO

Stora Enso's views on and experiences from particpation in WURC

Stora Enso has been a partner in WURC since the start of the centre in 1996.

The major objective of WURC has been to significantly improve our understanding of the morphological and chemical ultrastructure and the physical interactions between the polymers of the wood fibre as a basis for industrial utilization.

Wood ultrastructure research is potentially a very wide area with numerous interfaces to other research fields. The initial approach has been to study fibres in different stages of 'deconstruction'; wood, unbleached pulp and bleached pulp. WURC has for this purpose successfully made use of advanced microscopy and NMR techniques. Morphological features have been revealed and confirmed also by complementary techniques at high resolution contributing to a deeper level of our understanding of fibre ultrastructure. Projects have been included or associated to WURC during phase II that approach the ultrastructure in the build-up phase i.e. by studying the biological fibre wall synthesis. This last approach is different from using specific enzymes for identification of ultrastructural features.

WURC has so far developed techniques based on which studies of more functionally addressed problems can be designed. Research on interaction between fibre components under strain is an example of efforts to better understand the influence of pulp fibre composition on its technical properties. The ambition to create more realistic models of fibre shape and fibre structure is also an important step in order to develop the understanding of how fibre properties can be improved and, potentially, which consequences this has on the properties of the final product.

WURC provides inspiring intellectual exchange with researchers and colleagues from the industry. Our different positioning - applied development in the company vs. the basic nature of WURC research work- constitutes a challenge which has not always been easy to bridge. This is an area for development for all parties in the cooperation in order to create concrete collaborative work.

Our expectation on WURC is that a continuation focuses on technically relevant research problems. These should be derived from the fibre materials perspective, properties of fibre and paper materials including chemical interactions and material mechanics problems. This approach would emphasise the internal and industrial cooperation within WURC as well as the applicability of research results.

Gunilla Söderstam (member IRG)
Senior Specialist, Chemical Pulp
Stora Enso Research, Karlstad

Anders Brolin (WURC board member)
Research Director, Packaging Board
Stora Enso Research, Karlstad

SÖDRA

WURC Membership - Evaluation of Benefits for Södra Cell

1. General

The field of research within the WURC network is of fundamental importance for a forest industry company like Södra. Being one of the leading suppliers of pulp to world market it is vital that our competence in knowing the properties of the fibres in our pulp is improved. We strive to provide fibres with specified properties to customers rather than to sell bulk products.
Advanced knowledge of structure and properties of the fibre wall is one of the cornerstones in building up our competence in the area.
Also, when performing product development research we need help to get a better understanding of fibre basics, both in direct dialogues with the scientists at the institutes and by recruiting skilled personnel to our own R&D organisation.

2. Present activities for WURC

Up to now my experience of WURC has been limited to be a member of the Industrial Reference Group since December 2000. I have attended three personal/telephone meetings. Thus my opinion is somewhat superficial.

Close co-operation between different institutes can sometimes be difficult due to different traditions, individualism among scientists etc. Still it is very important in building up a network like WURC. My impression is though that there are close contacts between the institutes involved.

The very wide area of fundamental research that is carried out has impressed me. Some few examples:

- Behaviour of the hemicelluloses (glucomannan/xylan) in the fibre wall during kraft pulping
- Analysis of the collapse behaviour of kraft softwood fibres
- Studies of the chemical composition of fibre surfaces

Research of this kind will hopefully be helpful for us in the development projects within Södra.

The meetings in the Industrial Reference Group have been well performed, and it is stimulating to meet scientists in combination with colleagues who have similar interests. We have obtained material in advance although they sometimes could have been even more structured.

3. Expectations for the Future

Södra intends to give further support to WURC, and we are looking forward to follow the further development.

Tofte, August 20, 2001

Björn Dillner
Manager Strategic Research
Södra Cell R&D

Appendix 4. Reports from International Advisory Group

Members of WURC's International Advisory group

Professor R. Malcolm Brown, Jr.
Section of Molecular Genetics and Microbiology,
The University of Texas at Austin,
Austin, Texas 78712-1095,
USA

Professor Bernard MONTIES,
at GRIGNON: Lab.Biochimie,
INA P-G, Campus de Grignon,
78850 THIVERVAL-GRIGNON
FRANCE

Professor Keiji TAKABE,
Division of Forest and Biomaterials Science
Graduate School of Agriculture,
Kyoto University, Kyoto,
JAPAN

August 6, 2001

Professor R. Malcolm Brown, Jr.
Section of Molecular Genetics and Microbiology,
The University of Texas at Austin,
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Tel (512)471-3364
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R. Malcolm Brown, Jr.
Appraisal of the Status of the Wood Ultrastructure Research Centre (WURC) and Allied Projects

Development of the Centre

I have had the privilege to witness the development of WURC during the past three years as an invited foreign Advisory Member. I have seen steady and important progress in the growth of the projects and subject areas (to be discussed below). Wood is an extremely complex natural structural material. Thus it would be expected that expertise in many areas of science would be required to effectively analyze wood structure and properties in anticipation for *improvement* for the Swedish industrial utilization of the extremely valuable raw material. Balancing a fundamental research approach with applied aspects is no easy matter either. I understand that WURC's major goal is to carry out basic research of industrial relevance.

There is no doubt in my mind that the WURC is becoming more recognized throughout Sweden. The annual meetings in April during the past three years have brought representatives from Industry and Academia into closer associations through reports, oral presentations, posters, and social activities. I can sense that academics and members of industry are becoming more *comfortable* in communicating and interacting with each other. Academics on one had, tend to explore fundamental aspects for the simple joy of research and interest to add to our knowledge base. Applied investigators, on the other hand, tend to keep the "status quo" and not be willing to change things that work. The WURC has been very successful at bringing academics and industry together through the core program which rests with 14 research projects. In addition, expertise from other countries meet annually with WURC in the form of a selected topics symposium and all can enjoy learning about the latest in a major subject area. I should also mention that WURC is a training ground for young scientists who wish to go into Academia or Industry. Therefore, one cannot easily measure progress on a single year; however, from my perspective, I am duly impressed with the *educational* aspects of this program and the superb quality of young doctoral candidates that are participating in the program, going on to achieve their Ph.D degrees and perhaps join Industry or a university in Sweden.

Project/Subject Areas

WURC has 14 projects which are very diverse. I always have been very interested to follow the progress in each of these exciting projects. During my most recent visit in April, 2001, I found the following projects to be particularly exciting, innovative, and potentially useful for new industrial development.

Project 2-The Ultrastructure of wood fibre surfaces

This project has shown considerable advancement since I first joined WURC. I have been very impressed with the exceptionally high quality electron micrography and the successful applications of immunoelectron microscopy to study glucomannan localization on the surface of Norway spruce kraft pulp fibers. Heterogeneous distribution of glucomannan molecules over the surfaces of the cellulose microfibrils was found in at least two chemical pulps. The immunomicroscopy approach could have significance to the pulp and paper industry in identifying quality and source of various pulps. I recommend that a database of various pulps using this approach be initiated and presented to the industrial associates. The technique can easily be expanded to other molecules of interest depending on which antibodies are raised and used. Thus, the potential for this very

exciting approach certainly has been realized through WURC. Isabelle Duchesne has done a wonderful job and has spent some time in Japan as well. She will soon complete her doctorate.

Project 3-Dislocations in wood fibres

I never cease to be amazed at the beautifully shaped fiber cells in spruce kraft pulps and especially the dislocations and other damages. The work of Paul Ander and his students is of immense importance to better understand the physical quality of pulp. Microscopy is of great importance in elucidating changes which take place during the pulping process. Fundamental understanding of the damage is essential if higher strength pulps are to be produced. This is an example of a fine "marriage" between basic and applied research. I also note that Dr. Ander and his colleagues have a very active publication record on their work.

Project 5 -Fibre strength for pulp fibers

Although not well documented with publications, I find that the discovery of the importance of cellulose/ hemicellulose-ratios for pulp strength could have exciting new useful information for industrial utilization. I would like to encourage more publications on this subject and expansion of the chemical composition studies to qualitative microscopic analysis, micro tensile testing and AFM imaging of stress-induced changes. The NMR studies also offer excellent independent evidence to support fibril aggregation in relation to other important and relevant physical properties of pulps. To understand how hemicelluloses and perhaps *introduced* non-native polysaccharides and ingredients affect stiffness and brittleness would be an important aspect to continue with this project. In other words, I think that further expansion to analysis of a larger number of introduced agents in the pulping process could have important ideas for producing a stronger paper.

Project 7-Lignin and hemicellulose structures in wood fibres

This is a very interesting project in the analysis of lignin which gives new insights on how to best extract this component for pulping.

Project 8- Mechanical interactions between wood polymers and their orientation in wood structure

I am impressed with the use of dynamic FT-IR spectroscopy in studying polymer dynamics at the molecular level during the pulping process. Understanding mechanical interactions is of utmost importance in understanding paper strength and developing strategies to produce a stronger, better paper. This work is the type which could provide truly new directions for the pulp and paper industry. If only one project of this type is successful, the entire industry could benefit and the whole WURC project would be completely justified. I mention this just as an example and believe that a number of interesting projects have this potential.

Project 10- Enzymes determining wood fibre composition and ultrastructure

This is a massive project, being mostly a molecular biology approach and marginally gaining ground at the biochemical level; however, the project has an enormous potential to give us more information on the molecular components of wood and how they are assembled and controlled during assembly.. Although full length cloning on expansin and cellulases are completed, I would liked to have seen more work directed to cellulose synthase as well as hemicellulose and pectin genes, including some in the enzymes of the lignification pathway. I believe these are going to be the most important genes for understanding how to genetically modify wood for new uses. On the other hand, the expansin and cellulase work is very important for wood processing.

I would like to know if a collaborative relationship exists between the Umea lab and the Tuula Terri lab in Stockholm? I am impressed with the progress in plant transformation in Poplar, but competitors in Michigan as well as Stockholm may render this part less important. I am greatly impressed with the extensive publication record of Dr. Sundberg and his colleagues. I strongly recommend that this program continue but would like to emphasize that a greater collaboration on wood ultrastructure be correlated with the genetic modifications/ improvements so that we can begin to learn what is going on at the ultrastructural levels. The development of an immunoelectron microscopic approach to localize and study all of the enzymes critical in wood biosynthesis

would be a great undertaking in my estimation. Perhaps the Umea group could have a website similar to the one on cell walls at Stanford. Please visit: http://cellwall.stanford.edu/

Project 11-The supermolecular chemistry of the fiber wall

This is a very interesting project which like the NMR approach in project 4 should be more correlated with microscopy. I would like to see more experimental details in this project which seem somewhat sparse with present report. By all means, please try to convince the investigators to expand their efforts and have more interaction with the ultrastructural approach which is the principal mode for the WURC.

Project 12-Ultrastructural changes at mechanical treatment and drying of pulp

I have been impressed with the continuing development of computer aided analysis of wood developed by Stig Bardage in conjunction with this project and would urge expansion of the computer imaging. Since wood is such a complex material, the ultrastructural analysis absolutely requires advances in computer image processing and quantitative analysis in order to get more out of the interpretations. This project still has lots of promise and I strongly recommend that it be strengthened and expanded.

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It is clear from this diverse array of projects that members of the WURC have an immense potential to use an extremely diverse array of advanced equipment and approaches in understanding the ultrastructure of wood. I certainly do believe that this has been the best possible way to utilize equipment and to provide comprehensive training to the WURC students. I like the mixture of academic and industrially-slanted projects. I do hope that you will keep the academic mix strong, as this is more risky but can give more potential if tapped.

WURC is well known throughout Sweden and much of the research world

I would like to state that during the past 3 years, I have seen a greater publicity of WURC within Sweden as evidenced by common knowledge throughout the academic centers that I have visited as well as discussions from friends in the Swedish Pulp and Paper and Forest Products Industries. WURC is gaining prominence. In particular, people note that it is an excellent place where young scientists can get a start for a profession in the Industry. Attending ACS meetings here in the USA, I have noted that many of my colleagues and friends are now aware of WURC and its mission, whereas only a year or two ago, they knew nothing about it. As WURC continues its mission, there is no doubt that it will leave a lasting impression on the Swedish pulp and paper and forest products industries. I went to www.google.com and used the term, "WURC". I found more than 400 references, some to WURC 88.1 FM Holly Springs, USA, but it is important to know that the FIRST URLS directed me to the WURC *excellent* website. Keep up the good work (WURC)!

Industry and WURC

There is no doubt in my mind that industry has fared well in support of WURC. Not only has it received expertise that it would have paid dearly for in house, but also WURC is the training ground for future scientists to work in industry. In this regard, it has achieved its reputation already and will continue to do so, long after the project is complete. I understand the inherent difficulties in keeping industrial secrets secret and sharing information among colleagues and with other industrial contacts; however, each industry is certainly "free" to mine any and all information coming from the project. Thus, I have no problem with this aspect. I do think it is very important to keep scientific progress moving forward through discovery and publication as well as reports (which, by proceeding publication, can provide fertile grounds for patent applications). Bottom line- a very important adjunct for Industry, one which will place Sweden at the global front in forest product research and development and business.

Achievements to Date

I am very impressed with the 14 research area projects, the people who direct them, and the graduate students who are completing their degrees based on this research. I am impressed with the high degree of cooperatively among all the investigators and the interactions at the annual meetings of the WURC. I am further impressed with Geoff's articulate directorship of WURC and his imaginative collaborations and understanding of academia and industry. Together with the industrial partners, WURC has already made significant achievements which most surely will impact the future of forest and papers product development in Sweden.

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R. Malcolm Brown, Jr.

28 July 2001

Professeur Bernard MONTIES,
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France

Dear Professeur Geoff. Daniel,

The development of WURC as 'competence center' has been followed, particularly at INRA, with attention as I regularly informed the direction. Now in France, a similar but complementary structure is in preparation concerning the 'production, characterisation and industrial uses of agricultural fibres'. The organisation of this 'consortium' has been initiated by our INRA department TPV :'plant product transformation', with the aim to get better knowledges on the relations between agricultural fibres structure and properties, in relation to potential uses in standard (board,paper,..) and new products (packaging mainly). It is planed that also the 'forest' INRA departement will be associated, with also other French research organisation(CIRAD,...) and professional technical centers/agencies. As said previously to you and to other WURC managers, this organisation 'draft' will be presented in September. As for WURC, the formation of doctors for indutry, research and teaching is also a goal for the consortium; mobility between laboratories on common objectives is also a priority. Positive contacts have been soon established also between some 'young' Swedish and French scientist through the E 20 'Wood fibre cell wall structure' meetings.

Further, at the E.C. level now, such developments of WURC and INRA-consortium, could contribute to the identification of complementary 'competence centers' from the North to the South and East Europa. In this respect, 'cellulosic fibers from forest and agricultural ressources' appear now as one the safer renewable and biodegradable ressource for standard- and new-materials, in response to the irresistible increases of both consumption, waste production and related pollutions. For all these 'strategic' reasons, I thus,strongly, recommend the continuation of the dynamic of the WURC 'endeavour' in Sweden, empphasizing the potential advantages of the E.C. priorities (thus copy of this 'message' for INRA TPV-department: P. Colonna, and INRA scientific direction: G. Riba)

Concerning now the 'practice' of the WURC project itself , some few other comments.

1: Focussed practically on all the aspects of wood fibres ultrastructure, from the surface to the inside of the material with combinations of 'standard-adapted' methods and 'very new' ones, the program has brought original and coherent data, mainly by 'crossed direction' of thesis. Such organisation and orientations is to be maintained with the suggestion to 'use' more systematically the 3 foreing experts.

2 : Concerted with industry for the production of 'tailor made' fibres, one the sub-program has allowed 'complementary' sudies with original interesting results; such 'integrated style' seems to be favoured in the future, as producing first basic knowledges at short term then, possibilities at medium term of more confidential applications.

3 : Concerning now my 'so called expertise', on the (macro)molecular structure of lignins and the variability of the lignification patterns of both the 'in situ'- and of the 'industrial'- fibers, I would emphasize again the fact that even the most sophisticated current analytical methods provide only 'partial and specific' images of the total 'polymer' lignin. This comment also holds for assesment of the genetic manipulations oflignins and for the

computer simulations of lignification programs, for exemples. In this respect both at ultrastructural and at the chemical analysis point of view, the contribution of WURC current program has been very safe and relevant. These knowledges deserve interest and extension, to asses more critically, the studies on modification and simulations of 'lignin'.

4 : Considering plant fibres as 'systems of interacting macromolecules', a last (and provocative?) suggestion would be to include now... in future WURC program, more 'water', as structuring important factor of both dynamic evolution of the (ultra)structure, the reactivity and the ultimate properties of the isolated 'fibres and products'.

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Evaluation of Wood Ultrastructure Research Centre

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I am very honored to serve on the international advisory board with Professor Malcolm Brown at the University of Texas in the USA and Dr. Bernard Monties at the INRA in France.

I attended the WURC meeting in 1999, and learned that many projects from cell wall biosynthesis to wood modification were in progress. My first impression was that these projects were in the infancy stage because almost all of the projects had only just begun. I was deeply impressed by the tremendous progress in every project, however, when I attended the WURC meetings in 2000 and 2001.

An interesting feature of WURC is that most of the projects deal with the same specimen such as a kraft pulp for investigating ultrastructure, chemical nature, and physical properties using various methods. The results of the studies have been integrated and discussed by members working on the projects. Good cooperative research has been performed since WURC was founded. WURC is a most unique organization.

WURC is well known in Europe, because WURC organized the European COST action E20 meeting (Wood Fibre Cell Wall Structure) last April.

I worked in Uppsala for 4 months as a guest researcher of WURC in 1998. After my return to Japan, I gave many presentations on the WURC projects and my involvement in WURC. Yet, WURC is not well known in Japan. The Cell Wall meeting, which is now famous in Japan, is held in Europe every 3 years. Many of the presentations in this meeting, however, deal with primary cell walls. I anticipate that WURC will organize an international symposium on secondary cell walls in wood in the near future.

WURC provides younger scientists an excellent opportunity to learn of recent advances in wood science. Many exciting results have been reported by invited speakers at annual WURC meetings. In addition, WURC provides younger scientists the opportunity to work outside of Sweden for several months. The students learn new ideas and techniques from collaborating professors and are able to adapt them to their own specimens to obtain new findings. These collaborating networks around the world are an important feature of WURC.

My comments regarding the WURC projects.

Project 1 Fibre model

Many cell wall models in conifer have been proposed. These models are not sufficient to show the entire fibre structure. For example, the ultrastructure of the tangential wall might be different from that of the radial wall. Cell wall ultrastructure at the middle part of the fibres might be different from that at the tip. Unfortunately, project members were confronted with technical difficulties, and subsequently decided to cancel the three dimensional construction of microfibrils in a tracheid. I urge them to reinvestigate microfibril orientation along the fibres using new techniques.

Another aim of this project is to demonstrate the ultrastructure of the S_1 layer of the Norway spruce tracheid. Cell wall ultrastructure in wood was investigated by transmission electron microscopy in combination with the replica technique in the 1960s. New techniques for specimen preparation have been developed over the last 30 years. I hope the members will observe the ultrastructure of cell walls in the prepared specimens, using new techniques.

Project 2 The ultrastructure of wood fibre surfaces

Information on the ultrastructure and chemical nature of wood fibre surfaces is important to evaluate the quality of paper. Particularly, hemicelluloses are believed to affect fibre-fibre bonding in paper. In this project, localization of glucomannan in wood fibre surfaces was demonstrated by immunocytochemistry coupled with freeze etching techniques. Other antibodies, such as the antibody against softwood xylan, will provide more detailed information on the relation between the surface ultrastructure and the chemical nature of fibres.

This work was performed by Isabelle Duchesne who has worked in our laboratory from October 2000 to February 2001. She came to the laboratory early in the morning, concentrated on her work, and stayed until late in the evening. She always asked me for comments on her recent results and suggestions before deciding on the next approach to obtain her goals. She set an excellent example for our graduate students of how to work in the laboratory. She was an ideal graduate student.

Project 3 Dislocation in wood fibres

Fibre disclocations are produced during many physical and chemical processes. Small dislocations give fibres flexibility, though large dislocations decrease paper strength. Microscopic observation of dislocations is useful for evaluating how these dislocations affect paper quality. This method can be applied to many kinds of fibres.

The most interesting finding of this project is the periodic distribution of fibre balloons along a fibre. This might be due to periodic changes in fibre structure in the longitudinal direction. I urge more study of the above structure using electron microscopy.

Project 4 Fibre chemistry: Structure of cellulose and hemicellulose

In this project, CP/MAS ^{13}C-NMR spectrometry in combination with spectral fitting revealed changes in the structural characteristics of cellulose and hemicelluloses during kraft pulping. Removal of galactoglucomannan from cell walls resulted in the aggregation of fibrils. These fundamental findings provide useful information for efficient utilization of wood fibres.

Project 5 Fibre strength of pulp fibres

This project revealed that a lower cellulose/hemicellulose ratio induces more tensile stiffness and a higher tensile index, and a lower tear index increases resistance to fractures and enhanced folding endurance. Fibres with a high hemicellulose content had a more porous surface structure. Hydroxide ion concentration, alkali concentration, and time of cooking also affected the degradation of fibres. These findings might be applicable for improving physical properties of paper.

Project 7 Lignin and hemicellulose structures in wood fibres

The chemical structure of lignins can be determined by examining monomers cleaved by chemical treatments such as nitrobenzene oxidation. This method is not sufficient, however, to determine the whole structure of lignins, because the yield of derivatives from lignins is very low. Though milled wood lignin is believed to be native lignin, its yield is approximately 30% of total lignin. Lignin remaining in the specimen after extraction of milled wood lignin requires further investigation. Yields of derivatives after chemical treatment is also very low. Therefore, the derivatives that could not be determined using conventional methods must be analyzed by newly developed methods.

In this project, pre-swelling of wood meal achieved a 25% higher yield of thioacidolysis monomers compared to the yield by standard thioacidolysis. In addition, thioacidolysis followed by Raney-nickel desulphuration enables determination of trimeric lignin compounds. These improved methods provide more precise quantitative information on lignin linkages. I urge development of new methods to reveal the whole structure of lignins in softwood and hardwood.

Project 8 Mechanical interactions between wood polymers and their orientation in the wood structure

Arrangement of cellulose, hemicelluloses, and lignins in the cell wall affects the physical and chemical properties of wood. This project revealed the relations between cellulose and glucomannan, and between cellulose and xylan in the cell wall using dynamic FT-IR spectroscopy. This project also demonstrated different behavior of hemicelluloses during kraft and sulfite pulping. These interesting results should be published as soon as possible.

Project 9 Studies on wood fibres with specific enzymes

Cellulose binding domain coupled with fluorescein isothiocyanate (CBD-FITC) will be a useful conjugate to demonstrate the localization of cellulose within the cell wall. Accessibility of this conjugate to cellulose microfibril, however, will be low in pulp fibre and sound wood because cellulose microfibrils are surrounded by hemicelluloses and lignins. Therefore pre-treatments might be necessary to expose the surface of cellulose. I expect the new findings of cell wall lamella structure by this new technique.

Project 10 Enzymes to determine wood fibre composition and ultrastructure

I am deeply impressed by the vigorous work performed by Björn Sundberg's group. They have focused on the enzymes responsible for cell wall formation. Full length cloning of several genes such as cellulase and xyloglucan endotransglycosylase (XET) has been completed. I hope that they will continue this work to achieve full length cloning of the genes responsible for cellulose synthesis as well as for hemicellulose synthesis.

Sundberg and his colleagues are also interested in the immunolocalization of enzymes responsible for cell wall formation. I was very surprised by the unexpected result of XET16A localization in fibres during secondary cell wall formation. In my experience, antiserum raised in a rabbit usually binds nonspecifically to developing secondary walls. Therefore, careful purification of antiserum by affinity chromatography is needed. In addition, the specificity of the purified antibody must be studied.

Sundberg and his colleagues compared fibre length in a transgenic poplar - induced antisense expansion gene with that in wild type poplar. Unfortunately, they could not find any difference in antisense lines compared with wild type. This trial, however, is very important for evaluating the role of enzymes in cell wall formation. Down- or up-regulation of enzyme activity caused by introduction of the antisense or sense gene might affect the metabolic reactions in the cells. These changes alter cell types, cell shapes, cell wall ultrastructure, and chemical composition of cell wall in transgenic plants. Therefore, these plants must be analyzed using various methods.

Project 11 The supermolecular chemistry of fibre wall

I would like to know more detailed results from this project.

Project 12 Ultrastructural changes of mechanical treatment and drying of pulp

I understand that an atomic force microscope (AFM) is a very powerful tool to study the ultrastructure of cell walls. In the last decade, radial lamella structures in the secondary wall instead of concentric lamella have been proposed. Recent work presented at the last WURC seminar in 2001 clearly demonstrated concentric organization of macro(micro)fibrils within the S2 layer. Changes in the cell wall structure during cooking were also investigated using an AFM. I hope these excellent studies will be published as soon as possible.

Project 13 The influence of sulphate cooking on metal ions in wood

Microbeam X-ray fluorescence technique is valuable for investigating the distribution of minerals such as Ca and Mn in the specimen. An interesting result from this project was the report of the different behavior of Ca and Mn during treatment. I was deeply impressed by the findings presented at an oral presentation at the WURC seminar in 1999 and/or 2000 (possibly the presentation of Project 6) of the heterogeneous distribution of minerals in the cell wall. I would like to know the dynamic changes of Ca and Mn distribution during cooking at a microscopic level.

Project 14 Molecular cell wall modeling: Lignin biosynthesis and degradation

I am very impressed with the computational chemistry of lignin biosynthesis presented at the WURC seminar in 2001. This method will provide many new insights into lignification and biodegradation of the cell wall. A better understanding of the *in situ* condition of living cells and developing cell walls is necessary to accurately simulate molecular reactions. I urge further study of the monolignol polymerization process in the presence of hemicelluloses, because lignification starts in the cellulose-hemicelluloses matrix containing water.

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Appendix 5. Curriculum Vitae Geoffrey Daniel (summary)

Curriculum Vitae Geoffrey Daniel

Personal information:

Name:	**Geoffrey Daniel**
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Telephone (home):	**+46(0) 18-322539**
Present Position:	**Professor, Wood Ultrastructure Research Centre (WURC), Department of Wood Science, Box 7008 Swedish University of Agricultural Sciences, Uppsala**
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Qualifications:

Education:

Bachelor of Science, London University, England, 1975.
Doctor of Philosophy, Portsmouth University, England 1983.
Docent, Wood products with specialization in wood mycology, Swedish University of Agricultural Sciences, Sweden, 1988.

Professional Experience:

1976-1981. Research Assistant, Portsmouth University, England. Sponsored by the British Student Research Council in collaboration with Hempel's Marine Paints, Copenhagen, Denmark.

1981. Research Associate, Portsmouth University, England. Sponsored by the International Copper Research Association, New York.

1982-1986. Research Assistant, Department of Forest Products, SLU, Uppsala. Sponsored by the Styrelsen för Teknisk Utveckling (STU). Microbiological project: Improvement of preservative treated wood against attack by microfungi.

1986-April 1991. Research Associate, Department of Forest Products, SLU, Uppsala. Specialization on "Wood fibre ultrastructure and microbial degradation of lignocellulose".

1991-April-July. Research Leader, Department of Forest Products, SLU.

1991-1997. Senior University Lecturer, Department of Wood Biology, with specialization on "Analytical electron microscopy, wood cell biosynthesis, structure and enzymatic degradation".

1997. Bitr. Professor, Swedish University of Agricultural Sciences. Btr. Professor with specialization in wood mycology.

1999. Full Professor

1999. Director of the Wood Ultrastructure Research Centre (WURC).

1999. Director of post-graduate/undergraduate studies, Department of Wood Science.

2000. Deputy Head of Department of Wood Science.

Ph.D Supervision
Department Forest products/Wood Science and Wood Ultrastructure Research Centre:
Co-supervisor: Osvaldo Encinas, Stig Bardage, Sadia Khalili, Charlotte Björdahl, Jonas Branström, Karolina Nyholm, Lars Hildén.
Head supervisor: Isabelle Duchesne.

Extended periods abroad:
Periods ranging from 3 weeks to 3 months have been spent per year abroad involved in teaching of undergraduates/post-graduates on aspects of wood biodegradation/wood structure/microstructure or involved in research or setting up of exchanges. Countries include: USA (University of Maine); Czech Republic (Czech Academy of Sciences); New Zealand (Forest products Institute); Venezuela (University of Los Andes); Japan (Kyoto University).

Experience in electron microscopy:
Ca 25 years experience on the application and teaching (national and international) of electron microscopical techniques for plant and microbiological sciences as well as maintenance of electron microscopes (TEM, SEM).

List of selected publications (1991-2001) in refereed journals/books/proceedings:

24. Daniel, G., & T.Nilsson. 1991. Antibodies to the fungus *Phialophora mutabilis* and their use in enzyme-linked immunosorbent assays for detection of soft rot in preservative treated and untreated wood. Phytopathology 81:1319-1325.

25. Daniel, G., T.Nilsson & B.Pettersson. 1991. Poorly and non-lignified regions in the middle lamella corners of birch (*Betula verrucosa*) and other wood species. International Ass. of Wood Anatomists Bulletin (IAWA) 12:70-83.

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27. Volc, J., E. Kubatova, P. Sedmera,**G.Daniel** & J.Gabriel.1991.Pyranose oxidase and pyranosone dehydratase: Enzymes responsible for conversion of D-glucose to cortalcerone by the basidiomycete *Phanerochaete chrysosporium.* Archives of Microbiology 156:297-301.

28. Daniel, G., J. Volc & T.Nilsson 1992. Soft rot and multiple T-branching by the basidiomycete *Oudemansiella mucida* (Schrad ex. Fr.) Höhn. in pine wood. Mycological Research 96, 49-54.

29. Daniel, G. S.Cragg & T.Nilsson. 1991. *Limnoria lignorum* ingest bacterial and fungal degraded wood. Holz Roh Werkstoff 49: 488-490.

30. Daniel, G., J.Volc & E.Kubatova. 1991. Pyranose oxidase: Biochemical and ultrastructural studies on a H_2O_2 producing enzyme from *Phanerochaete chrysosporium.* In: Proceedings of Symposium on cellulose and lignocellulosics chemistry, pp.203-206. May 13-15, 1991, Guangzhou.

31. Singh, A.P., T.Nilsson & **G. Daniel**. 1993. *Alstonia scholaris* vestures are resistant to degradation by tunnelling bacteria. IAWA Journal, 14: 119-126.

34. Daniel, G. J. Volc, E.Kubatova & T.Nilsson. 1992. Ultrastructural and immunocytochemical studies on the H_2O_2 producing enzyme pyranose oxidase in *Phanerochaete chrysosporium* grown under liquid culture conditions. Applied and Environmental Microbiology, 58, 3667-3676.

35. Nilsson, T., A. Singh & **G. Daniel**. 1992. Ultrastructure of the attack of *Eusideroxylon zwageri* wood by tunnelling bacteria. Holzforschung 46, 361-367.

36. Gabriel, G., J.Volc, P.Sedmera, **G.Daniel** & E. Kubatova. 1993. Pyranosone dehydratase from the basidiomy

cete *Phanerochaete chrysosporium*: Improved purification and partial characterization Achives of Microbiology, 160, 27-34.

37. Asiegbu, F. O., **G. Daniel** & M. Johansson 1993. Studies on the infection of Norway Spruce roots by *Heterobasidion annosum*. Canad. J. Botany, 71, 1552-1561.

38. Daniel, G. 1993. The importance of electron microscopy in our understanding of wood ultrastructure, biodeterioration and fibre morphology. In : Proc. Symposium Lignin biodegradation and Transformation, (Biotechnological applications) pp. 73-76, Lisbon, April, 1993.

39. Daniel, G. 1993. Use of electron microscopy for aiding our understanding of wood biodegradation. FEMS Microbiol. Rev. 13, 199-233.

40. Asiegbu, F.O., **G.Daniel**, L. Jonsson, & M. Johansson. 1993. Immunocytochemical localization of peroxidase in fine roots of Norway spruce infected by *Heterobasidion annosum*.pp. 104-107. In Proc. 8th International Conference on Root and Butt Rots, Wik, Sweden 1993.

41. Daniel, G., J. Volc, & K. Kubatova 1994. Pyranose oxidase: A major source of H202 during wood degrada tion by *Phanerochaete chrysosporium, Trametes versicolor* and *Oudemansiella mucida*. Applied Environmental Microbiol, 60, 2524-2532.

42. Singh, A., Nilsson, T. & **G. Daniel.** 1995. Resistance of *Alstonia scholaris* pit membranes to degradation by tunnelling bacteria Holzforschung 49, 95-98.

43. Asiegbu, F.O., **G. Daniel**, G. & M.Johansson. 1994. Defense related reactions of seedling roots of Norway spruce to infection by *Heterobasidion annosum* (Fr.) Bref. Physiological and Molecular Plant Pathology, 45, 1-19.

44. Asiegbu, F. O., **G. Daniel**, & M.Johansson. 1994. Infection and disintegradation of vascular tissues of non-suberized roots of spruce by *Heterobasidion annosum* and use of antibodies for characterizing infection. Mycopathologia 129, 91-101.

45. Asiegbu, F.O., **G.Daniel**, & M.Johansson. 1996. Cellular interaction between the saprophyte *Phlebiopsis gigantea* and non-suberized roots of *Picea abies*. Mycological Research, 100, 409-417.

46. Daniel, G. & T. Nilsson. 1994. Polylaminate concentric cell wall layering in fibres of *Homalium foetium* and its effect on degradation by soft rot fungi. In: Recent Advances in Wood Anatomy (L.A.Donaldson, A.P.Singh, B.G.Butterfield and L.J.Whitehouse Eds), pp 369-373.

47. Daniel, G., A. Singh & T. Nilsson. 1994. Ultrastructural and immunocytochemical studies on the window and bordered pit membranes of *Pinus sylvestris L.* (In: Recent Advances in Wood Anatomy, (L.A.Donaldson, A.P.Singh, B.G: Butterfield and L.J.Whitehouse Eds); pp 373-384.

48. Asiegbu, F.O., M. Denekamp, **G. Daniel** & M. Johansson. 1994. Immunocytochemical localization of pathogenesis related proteins in gymnosperm roots (Norway spruce) infected with *Heterobasidium annosum*. Eur. J. Forest Path. 25:169-178.

49. Singh, A., T. Nilsson & **G. Daniel**. 1994. Variable resistance of *Pinus sylvestris* wood components to attack by wood degrading bacteria. In: Recent Advances in Wood Anatomy (L.A.Donaldson, A.P.Singh, B.G: Butterfield and L.J.Whitehouse Eds); pp 408-419.

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Presentations at International/National Conferences *Ca* 50 presentations at various international scientific meetings. Also acted as chairman of sessions and organized meetings/conferences. *Ca* 60 papers/abstracts in non-refereed journals, symposia proceedings and popular journals.

Outside activities: Actively coach a team of 15/16 year olds (*ca* 20 boys) football for an elite series in Uppsala (*ca* 20 matches/year + 2-3 training passes/wk).


WURC

The Wood Ultrastructure Research Centre (WURC) is a competence centre which was initiated in 1996 by NUTEK (Swedish National Board for Technical and Industrial Development) and established in co-operation with NUTEK, SLU (Swedish University of Agricultural Sciences), six companies from the Swedish pulp and paper industry (AssiDomän AB, Korsnäs AB, Mo och Domsjö AB (now Holmen and M-real), SCA AB, StoraEnso AB and Södra Cell AB) and one chemical company (Eka Chemicals AB). NUTEK has been replaced by VINNOVA (The Swedish Agency for Innovation Systems) since January 2001.

The centre is based at SLU, but within WURC's structure, close co-operation occurs with CTH (Chalmers University of Technology), KTH (Royal Institute of Technology), and STFI (Swedish Pulp and Paper Research Institute). WURC is financed jointly by VINNOVA, the industrial companies, and by the various research-organisations.

WURC provides a creative and stimulating environment for both research and research education on wood fibre ultrastructure where industries within the forestry sector are active and involved in the long term planning of its aims. The centre's research should increase our basic understanding on the morphological architecture and chemical structure of wood fibres and thereby help in the development of new wood based processes and products. The centre should work with a comprehensive view of wood, wood fibre ultrastructure, wood properties and its utilisation.

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