

Delft University of Technology
Department of Aerospace Engineering

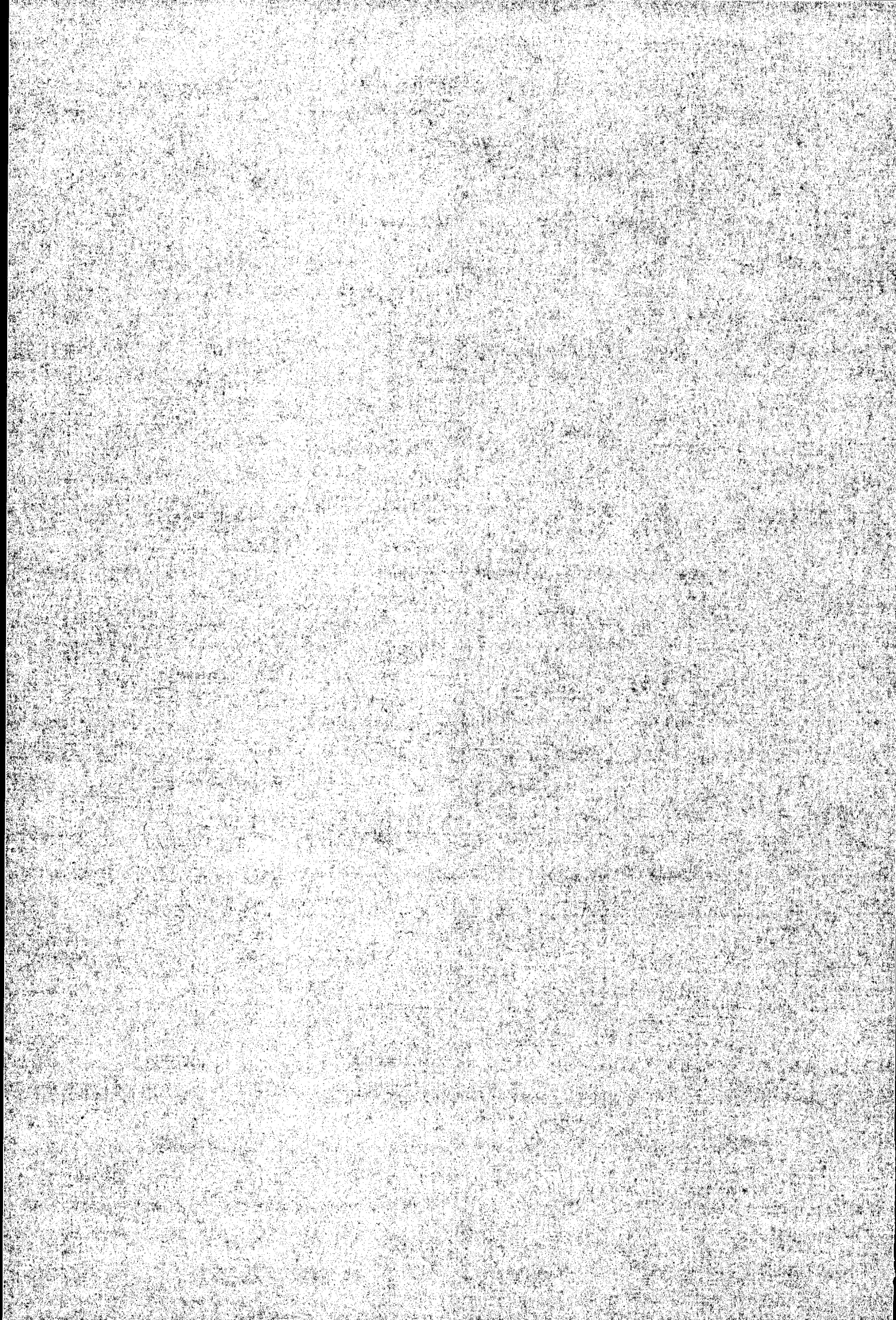
Prins Maurits Laboratory TNO
Rijswijk

Report LR - 392
Report PML 1983 - 128

SOLID FUEL COMBUSTION CHAMBER PROGRESS REPORT III

Second Phase January - June 1983

**H.F.R. Schöyer
P.A.O.G. Korting
J.B. Vos
J.P.M. Versmissen**



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1. INTRODUCTION

The second phase (1 January - 30 June 1983) of the Solid Fuel Combustion Chamber Project, DLR 11.0120 is described.

The scope of this project, which primarily aims at understanding and describing the flow and combustion processes in a solid fuel grain, have been described extensively elsewhere⁽¹⁾. SFCC's have a potential for energy conversion systems, coal gasification, clean combustion of waste, propulsion for aerospace applications, and possible others.

The applicability of SFCC's for waste combustion, electric power generation and coal gasification has been investigated. These studies have been published in separate reports^(2,3).

The project is sponsored by the Netherlands Foundation for Technical Research (Stichting voor de Technische Wetenschappen, STW) and the Project Office for Energy Research (Projectbureau Energie Onderzoek, PBE).

In addition money and manpower is made available by a special funding of Delft University of Technology (Beleidsruimte THD) and the Prins Maurits Laboratory TNO.

Finally this report outlines the intended activities for the period July - December 1983.

2. FINANCIAL SUPPORT

In the previous progress report⁽⁴⁾ difficulties concerning the financial support by DAEDUT were mentioned. These difficulties have been solved by financial support from a special funding of Delft University of Technology (Beleidsruimte THD).

This financial support amounts to Hfl. 77.500,-- including Hfl. 15.000,-- computer costs and Hfl. 62.500 for equipment, materials and travel expenses. In addition 2 man-year for a computer programmer has been made available. The financial support is for the period 1 January 1983 - 31 December 1986.

The computer programmer may be hired in 1984.

3. EXPENDITURES

During the period 1 January 1983 - 30 June 1983 the following expenditures have been paid by STW.

| | |
|---|----------------|
| Various components for the gas-supply system | Hfl. 39.569,43 |
|---|----------------|

In addition the following payments have been made by PML/TNO but have not yet been submitted to STW for refunding.

| | |
|--------------------------|-----------------|
| Gas-supply system | Hfl. 172.976,51 |
| Equipment and components | Hfl. 58.258,31 |
| | <hr/> |
| | Hfl. 231.234,82 |

For foreign travel expenses a request for refunding has been submitted to STW

| |
|---------------|
| Hfl. 2.661,14 |
|---------------|

(J.B. Vos to Courses at Von Kàrmàn Institute, Brussels)

By DAEDUT the following expenses for the project have been made on the account of the special funding (Beleidsruimte). Only approximate figures are given.

| | |
|--|----------------|
| Pressure transdures, fabrication of SCMC, Pilot flame burner | Hfl. 11.940,-- |
|--|----------------|

4. PROJECT MANAGEMENT

The project management is the same as outlined in ref. 4.

5. LIST OF PEOPLE INVOLVED IN THE SFCC-PROJECT DURING THE PERIOD JANUARY - JUNE 1983

In addition to people employed by DAEDUT, PML/TNO and ZWO, the following people have contributed to the project.

| | |
|---------------|---|
| T. Breed | Apprentice MTS Alkmaar Aug. 2, 1982 - July 15, 1983 Installation and testing of gas-supply system. Calibration Sonic Choke. |
| A. van Lingen | Apprentice H.T.S. Zwolle Aug. 2, 1982 - Jan. 28, 1983 Control system electronics. |
| R. Surquin | Apprentice H.T.S. Haarlem Dec. 1, 1982 - Feb. 25, 1983 Design 3-way valve and vitiator. |
| H. Albers | Apprentice H.T.S. Zwolle Jan. 19, 1983 - July 9, 1983 Manufacturing, testing and documenting Control System. |
| J. Hoogkamer | Apprentice H.T.S. Haarlem March 1 1983 - June 15, 1983 Design Sonic Chokes. |
| E. Koeleman | Apprentice H.T.S. Amsterdam Dec. 1, 1982 - June 17, 1983 Installing and testing gas-supply system. |

Mr. P. Kuypers, in partial fulfillment of the requirements for his engineering degree (H.T.S.) made a preliminary design for a Solid Fuel Combustion Chamber.

Mr. J. Kops, in partial fulfillment of the requirements for his engineering degree (THD) investigates the elementary structure of a PMMA-Air flame. His advisers are prof.ir. H. Wittenberg and ir. H.F.R. Schöyer.

6. EXPERIMENTS

During the period January - June 1983 no combustion experiments took place as the old gas-supply system was broken down while a new supply system was being installed.

The results of the experiments carried out during the previous phase of this project still need to be analyzed.

Experiments with the small SFCC in the near future will primarily be aimed at determining the applicability of spectrographic analyses. Other combustion experiments will be based upon the results of the previous experiments.

Recently the gas-supply system has become available for the calibration of the O₂-Sonic Choke. At the time of writing of this report the results have not yet become available.

7. THEORETICAL DEVELOPMENTS

The theoretical investigations during this period can be divided into two parts. In the first part the set of basic equations describing the 3D-time dependent flow of a multicomponent mixture has been elaborated. Attention has been given to radiative heat transfer, which may be important if the solid fuel pyrolysis is studied, and to turbulence modelling. Favre-averaging and Reynolds-averaging of the conservation equations has been studied and mutually compared. Favre-averaging of the conservation equations leads to a set of equations which is simple in form and has a clear physical meaning. The Favre-averaged conservation equations must be completed with a turbulence closure model. Four turbulence closure models are studied. For our applications, the $\bar{k}-\bar{\epsilon}$ model seems to be the best available model. In the second phase the basic equations are simplified to the equations describing a 2 dimensional rotationally symmetric flow without chemical reactions and without heat and mass transport at the walls. Attention has been given to the boundary conditions and to the choice of a numerical scheme.

8. STATUS OF THE NEW EXPERIMENTAL FACILITY

(See ref. 4)

8.1. Gas-supply system

The installation of the gas-supply system by HOEK-LOOS has taken much more time than was anticipated. Although delivery should have taken place by February 1983, at the time of writing the gas-supply system still does not function satisfactorily. Therefore final delivery has not yet taken place. It is expected that the gas-supply system will be operational by the end of August 1983.

8.2. Vitiator

The construction drawings of the vitiator and valve system, near completion. It is anticipated that construction of the vitiator will start at the end of this summer.

8.3. SFCC

A preliminary design for a new SFCC has been completed. Based upon this design detailed construction drawings will be made. These are anticipated to be ready at the end of this year.

The existing SFCC has been modified as to allow for spectrographic measurements through the injection chamber.

8.4. Control system

The electronic hardware of the control system has been installed and tested. The system meets its requirements

The software is presently being tested. The testing, evaluation and possibly modification of the software may require a few more months.

8.5. SCMS's

The O₂-SCMC has been integrated in the gas-supply system and is presently being calibrated.

Detailed construction drawings for the CH₄ and Air SCMC's have been made and construction has started.

9. USERS COMMITTEE

The users committee was convened for the second time on May 18, 1983 at PML/TNO. The following members were present:

| | | |
|----------------------------|---|--------------|
| Ir. H.F.R. Schöyer | } | SFCC-project |
| Ir. P.A.O.G. Korting | | |
| Ir. J.B. Vos | | |
| Ing. J.P.M. Versmissen | | |
| Dr.H.J. Reitsma | | PML/TNO |
| Dr. R. van Duinen | | Fokker |
| Prof.Dr.Ir. J.A. Steketee | | DAEDUT |
| Dr.Ir. R. Roos | } | NIVR |
| Ir. R.M. Neubauer | | |
| Ir. F.C.H.D. van den Beemt | | |

The following themes were presented:

| | |
|------------------------------|-----------------|
| Status of the project | ir. Schöyer |
| Gas-supply system | ir. Korting |
| Control System | ing. Versmissen |
| Progress on theoretical work | ir. Vos |

The next meeting will be around the end of 1983.

10. UTILIZATION

As a result of a discussion with Dr.Ir. M.E.A. Hermans at the users committee (October 21, 1982) an analysis has been made of the applicability of SFCC's for power generation and coal gasification. This has been published⁽³⁾ as SFCC publication no. 4. It appears that for both applications high efficiencies may be achieved.

By PML/TNO a revised proposal for the investigation of the combustion of waste in a SFCC has been submitted to PBE. A decision is now expected by the end of 1983. A similar proposal has been submitted to TNO Special Projects (Beleidsruimte). It is not expected however that TNO will allocate fundings for 1984.

11. CONTACTS

During the period January - June 1983 the following contacts should be noted.

| Institute | Person(s) | Subject |
|----------------|--------------------------------------|---|
| KEMA Arnhem | Dr.Ir. M.E.A. Hermans Ir. Tummers | Application of SFCC's for power generation and coal gasification. |

| | | |
|---|-----------------------|--|
| Naval Weapons Center China Lake | Dr.R.L. Derr | Data Exchange Agreement; Visit to U.S. Laboratories and Industries; Solid Fuel Ramjets |
| United Technologies Chemical Systems Division, Coyote | Prof.H. Wolff | Gas-supply systems; Solid Fuel Ramjets; Visit to U.S. Laboratories and Industries |
| University of Utrecht Central Research Lab. for objects of Art and Science | Prof.Dr. G. Dijkstra | Spectroscopy |
| PBE Apeldoorn | Dr.Ir. E. Mot | Combustion of Waste |
| University of Boulder Colorado | Prof.Dr. D. Kassoy | Combustion |
| NLR | Ing. J.P.F. Lindhout | Computational Fluid Dynamics |
| Working Group Turbulence | Ir. C. Nieuwvelt | Turbulence |
| DFVLR Lampoldhausen | Dipl.Ing. G. Schulte | Solid Fuel Ramjets |
| European office of Aerospace Research and Development | Lt.Col. O. Mancarella | Visit to U.S. Laboratories and Industries |

Ir. J.B. Vos attended two courses (Turbulent Shear Flows & Computational Fluid Dynamics) at the Von Kàrmàn Institute, Brussels⁽⁵⁾.

The contacts with Lt.Col. O. Mancarella have led to an offer by the U.S. Airforce for a scientific exchange program: For a period up to two years a U.S. scientist would work with our group after which one of the scientists of our group could work for the same time at a U.S.-laboratory. This is in a preparatory status.

The U.S. Airforce and U.S. Navy have offered to contribute in the travel expenses for a visit to U.S. Laboratories and Industries.

12. STATUS OF THE PLANNING PERIOD JANUARY - JUNE 1983⁽⁴⁾

| | <u>Planning</u> | <u>Status</u> |
|-----|---|---|
| i | Installation and testing of the Gas-supply System | Nearly completed* |
| ii | Design, manufacturing and calibration of two SCMC's | Design completed; Drawings sent to machine shop |
| iii | Design and manufacturing of the vitiator | Drawings completed |
| iv | Design of SFCC | Preliminary design completed |

| | | |
|------|--|---|
| v | Construction, installation and testing of the control system | Construction and installation completed. Testing nearly completed |
| vi | Software for microprocessor | In development and test stage |
| vii | Software for data reduction | Continuous development. Various programs operational |
| viii | Theoretical work main emphasis on flow and combustion modelling | results published in ref. 6 |
| ix | An elementary computer simulation model for flow (without combustion) in an SFCC | Under development |
| x | Preparatory work for flame spectroscopy | Modification of small SFCC for spectrographic measurements |
| xi | - | Calibration O ₂ -SCMC |
| xii | - | Design and testing of pilotflame |

* The installation of the Gas-supply system took much more time than the contractor (HOEK-LOOS) had promised. In addition an unexpectedly large number of failures and malfunctions occurred, requiring much attention and time of the group. This adversely affected the available time for other aspects of the programme.

13. PLANNED PROGRAM FOR THE PERIOD JULY - DECEMBER 1983

- i Testing gas-supply system
- ii Integration of the control system with the gas-supply system (including software microprocessor, and testing)
- iii Control system for SCMC's
- iv Manufacturing and testing of two SCMC's
- v Manufacturing and installing of vitiator and valve system
- vi Designing, manufacturing and installing of the support for the vitiator, valve system and SFCC
- vii Design of large SFCC
- viii Limited number of experiments with the small SFCC as to determine
 - the feasibility of spectrographic analysis
 - correlation with new computer codes
- ix Decision about the use of a spectrograph
- x Development of elementary computer simulation model for flow (without combustion) in an SFCC

- xi Software for data reduction
- xii Theoretical work: accounting for heat and mass transfer at the boundaries. Initial work for the selection of a combustion model.

14. PUBLICATIONS

1. P. Korting, A. van Lingen, J. Versmissen, "Een Regel/Bedieningssysteem voor de Gastoevoerinstallatie van de Vaste Brandstof Verbrandingskamer" Report LR-366/PML 1983-101, SFCC Publication no 3, Delft University of Technology, Department of Aerospace Engineering, Prins Maurits Laboratory TNO, Delft/Rijswijk, January 1983.
2. H.F.R. Schöyer and P.A.O.G. Korting, "Application of Solid Fuel Combustion Chambers for Power Plants and Coal Gasification" Report LR-389/PML 1983-123, SFCC Publication no 4, Delft University of Technology, Department of Aerospace Engineering/Prins Maurits Laboratory TNO, May 1983.
3. J.B. Vos, "Verslag van het Volgen van twee Lecture Series bij het Von Kärman Institute 28 Februari - 11 maart 1983" Memorandum M-463/PML 1983-116, SFCC Publication no 5, Delft University of Technology, Department of Aerospace Engineering/Prins Maurits Laboratory TNO, Delft/Rijswijk, April 1983.
4. J.B. Vos, "Radiative Heat Transfer, Favre Averaging and Turbulence Closure Models for Combustion Applications" Report LR-383/PML 1983-114, SFCC Publication no 6, Delft University of Technology, Department of Aerospace Engineering/Prins Maurits Laboratory TNO, Delft/Rijswijk, May 1983.

In the monthly "Innovatie", issue June 1983, an article about the SFCC project is expected to appear.

15. PROPOSAL FOR CONTINUATION OF SUPPORT BY STW

A request for the continuation of the support by STW for this project has been submitted by June 15, 1983. A decision is expected by the end of 1983.

16. REFERENCES

1. An. "Proposal for the Investigation of a Solid Fuel Combustion Chamber" Department of Aerospace Engineering, Delft University of Technology/Prins Maurits Laboratory TNO, Memorandum M-395, Delft/Rijswijk, February 1981.
2. P.A.O.G. Korting en H.F.R. Schöyer, "Het Stoken van de Brandbare Fracties uit Huisvuil in een Vaste Brandstof Verbrandingskamer" Rapport PML 1982-110/LR-344, Prins Maurits Laboratorium TNO/Afdeling Luchtvaart- en Ruimtevaarttechniek THD, Rijswijk/Delft, februari 1982.
3. H.F.R. Schöyer and P.A.O.G. Korting, "Application of Solid Fuel Combustion Chambers for Power Plants and Coal Gasification" Report LR-389/Report PML 1983-123, SFCC Publication no 4, Department of Aerospace Engineering Delft University of Technology/Prins Maurits Laboratory TNO, in print.
4. H.F.R. Schöyer, P.A.O.G. Korting and J.B. Vos, "Solid Fuel Combustion Chamber Progress Report II, First Phase. July-December 1982". Department of Aerospace Engineering Delft University of Technology/Prins Maurits Laboratory TNO, report LR-363/Report PML 1982-159, Delft/Rijswijk, December 1982.

5. J.B. Vos, "Verslag van het volgen van twee Lecture Series bij het Von Kàrmàn Instituut 28 februari-11 maart 1983" Memorandum M-463/PML 1983-116, SFCC Publication no 5, Delft University of Technology Department of Aerospace Engineering/Prins Maurits Laboratory TNO, Delft/Rijswijk, April 1983.
6. J.B. Vos, "Radiative Heat Transfer, Favre Averaging and Turbulence Closure Models for Combustion Applications" Report LR-383/PML 1983-114, SFCC Publication no 6, Delft University of Technology Department of Aerospace Engineering/Prins Maurits Laboratory TNO, Delft/Rijswijk, May 1983.

17. ACRONYMS

| | | |
|--------|---|---|
| DAEDUT | - | Department of Aerospace Engineering Delft University of Technology |
| NLR | - | National Aerospace Laboratories Amsterdam |
| PBE | - | Project Office for Energy Research |
| PMLTNO | - | Prins Maurits Laboratory of the Organization for Applied Scientific Research |
| SCMC | - | Sonic Control and Measuring Choke |
| SFCC | - | Solid Fuel Combustion Chamber |
| STW | - | Stichting voor de Technische Wetenschappen |