GA–C23333

DIRECT ENERGY CONVERSION FISSION REACTOR

for the period January 1, 2002 through March 31, 2002

by

L.C. BROWN

Prepared under
Nuclear Energy Research Initiative (NERI)
Program. DE-FG03-99SF21893
for the U.S. Department of Energy

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DISCLAIMER

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Nuclear Energy Research Initiative (NERI)
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Technical Progress Report
January 1, 2002 through March 31, 2002

Highlights

- Cooling of the vapor core reactor and the MHD generator was incorporated into the Vapor Core Reactor model using standard heat transfer calculation methods.
- Fission product removal, previously modeled as independent systems for each class of fission product, was incorporated into the overall fuel recycle loop of the Vapor Core Reactor. The model showed that the circulating activity levels are quite low.
- Material distribution calculations were made for the "pom-pom" style cathode for the Fission Electric Cell. Use of a pom-pom cathode will eliminate the problem of hoop stress in the thin spherical cathode caused by the electric field.

Introduction

Direct energy conversion is the only potential means for producing electrical energy from a fission reactor without the Carnot efficiency limitations. This project was undertaken by Sandia National Laboratories, Los Alamos National Laboratories, The University of Florida, Texas A&M University and General Atomics to explore the possibilities of direct energy conversion. Other means of producing electrical energy from a fission reactor, without any moving parts, are also within the statement of proposed work. This report documents the efforts of General Atomics. Sandia National Laboratories, the lead laboratory, provides overall project reporting and documentation.

Current Quarter Accomplishments

Magnetically Insulated Fission Electric Cell Reactor

A cathode design, the "pom-pom" cathode, is proposed which eliminates some of the fabricability and structural concerns of the thin shell cathode. A conductive cathode consisting of a thin (~1 micron) conductive shell of fissile material will be very difficult to fabricate and very difficult to mount on the central support rod. An even more serious problem is the high electric field between the cathode and anode results in outward electric force that must be balanced by a hoop stress in the shell. This hoop stress exceeds the tensile strength of most materials. The pom-pom cathode avoids the hoop stress problem by replacing the thin shell with strong fibers that are bound to the central support as shown in Fig. 1. The ends of the fibers will repel each other in the electric field and the fissile material, which is coated on the tips of the fibers, will effectively form a dilute spherical shell. The hoop stress in a thin membrane is replaced by a pure tensile stress in the fiber.

The pom-pom cathode does add additional material, the fiber, which can attenuate fission products. The distribution of mass in the pom-pom cathode is shown in Fig. 2. The case shown assumed that a 4 mm diameter, 1 micron shell of uranium metal was replaced by a bundle of 0.5 micron fibers 4 mm long with a 1 micron coating of uranium metal on the outer 1 mm length of each fiber. The central core is modeled as a spherical region of close packed fibers and the fibers are assumed to be radial outside the core. For this cases the central core is 47 microns, which is small compared with the center support fiber, as will be the case for any case of interest.

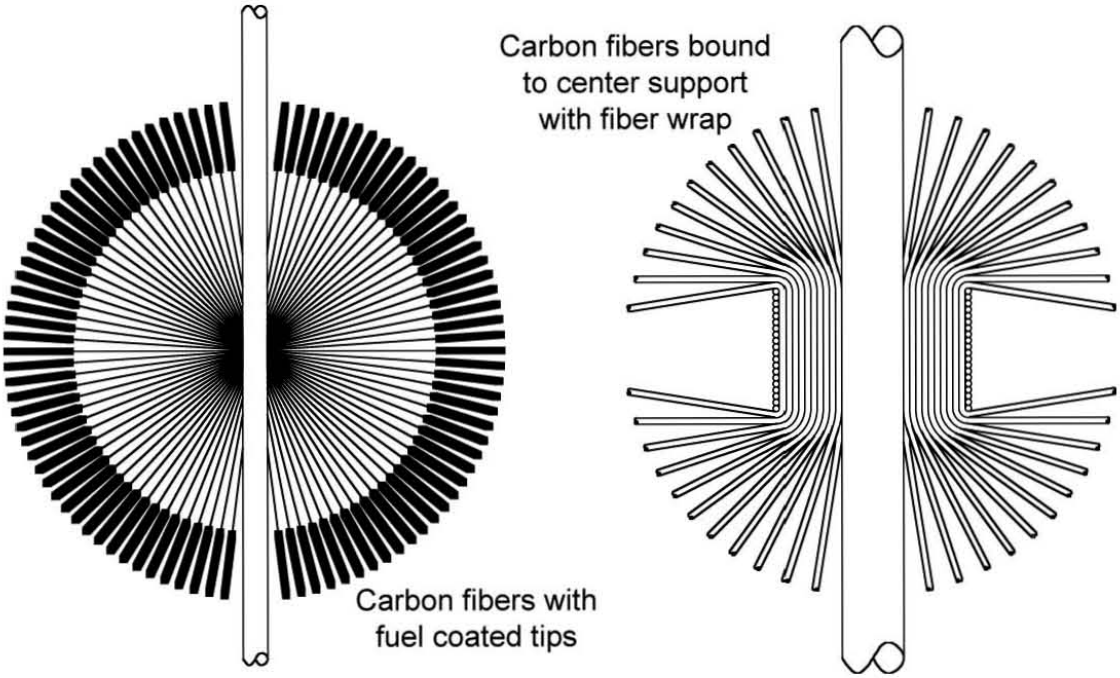

Fig. 1. Pom-pom cathode and detail of interior structure.

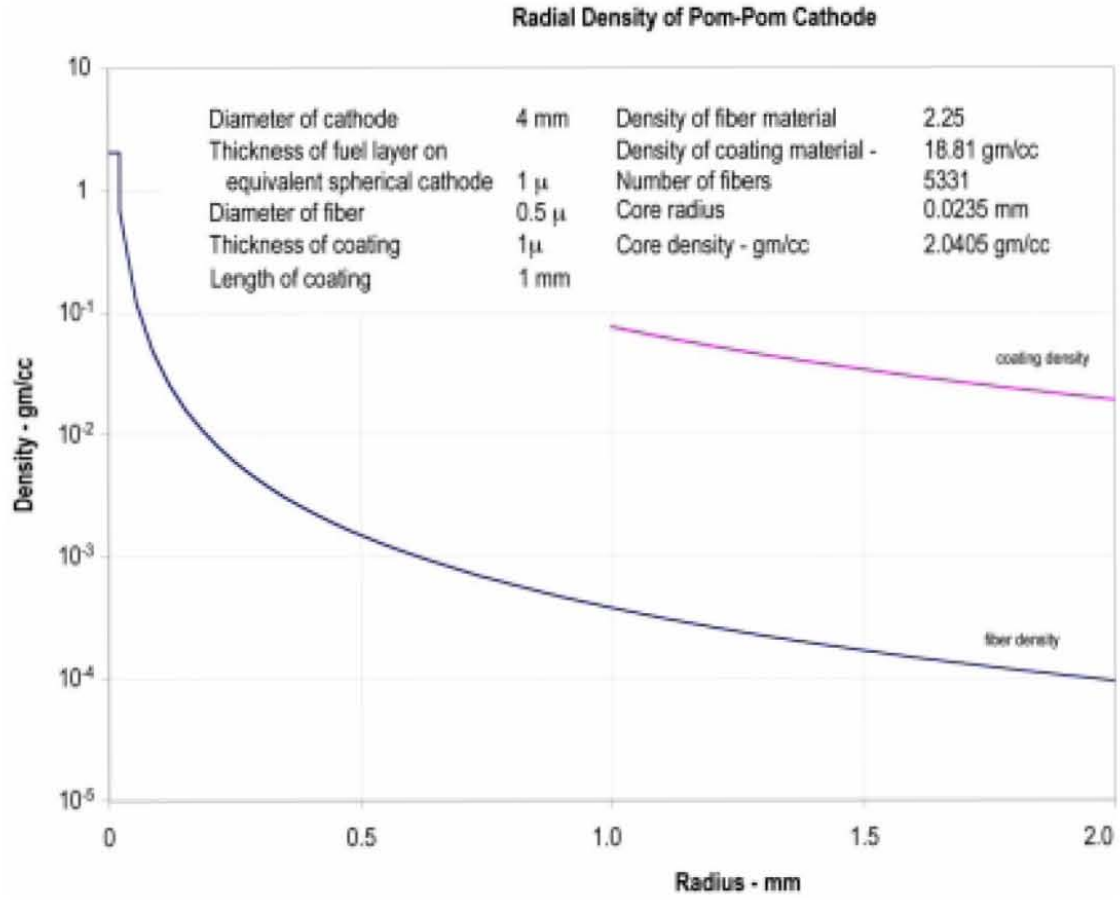

Fig. 2. Radial density of pom-pom cathode.

Fission Fragment Magnetic Collimmater Reactor

No work was done on the fission fragment magnetic collimator reactor during this period.

Vapor Core Reactor

Modeling of the gas recycle loop of the Vapor Core Reactor (VCR) continued. A simplified process flow diagram of the main simulation (Fig. 3) shows where fission product separation processes are located relative to the fuel/coolant recycle system components. Fission products are removed in three different places according to their volatility relative to UF_4.

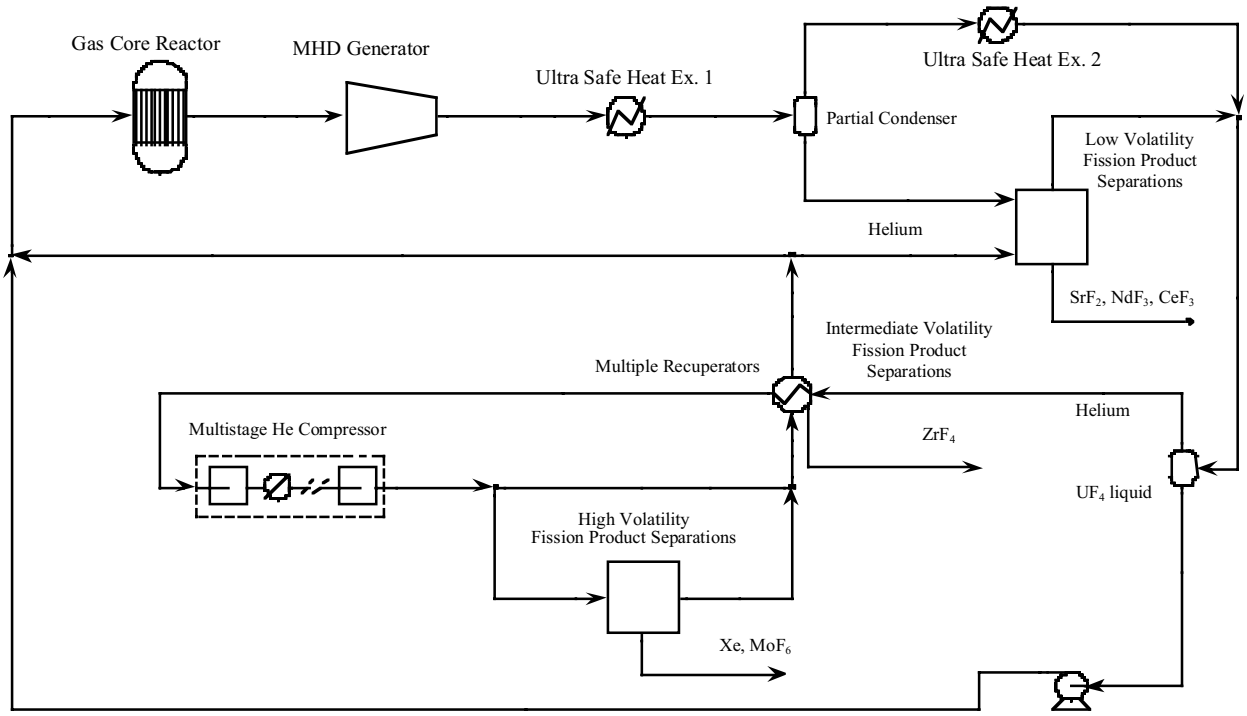

Fig. 3. Simple PFD locating fission product separations.

The low volatility fission products, SrF_2, CeF_3, and NdF_3, are concentrated by partial condensation of a small fraction (3%) of the UF_4 and processed to extract the fission products. The Ultra Safe Heat Exchanger is separated into two units with a liquid knock-out drum between them. The first heat exchanger reduces the temperature from 1800 K to 1772 K, resulting in condensation of 3% of the UF_4. Removal of a small amounts of liquid from a gas streams is difficult without introducing high pressure drop elements so only 10% of the liquid, or 0.3% of the UF_4 is removed for further processing. The UF_4 is stripped from the liquid in a series of five wetted wall columns as illustrated in Fig. 4. Helium, split from the hot, compressed recycle stream is used to strip the UF_4 from the low volatility fission products and return it to the main flow. Essentially all of the low volatility fission products remain in the liquid stream and pass to waste along with a trace UF_4. Multiple stripping columns are employed to minimize the amount of UF_4 which is sent to waste along with the fission products.

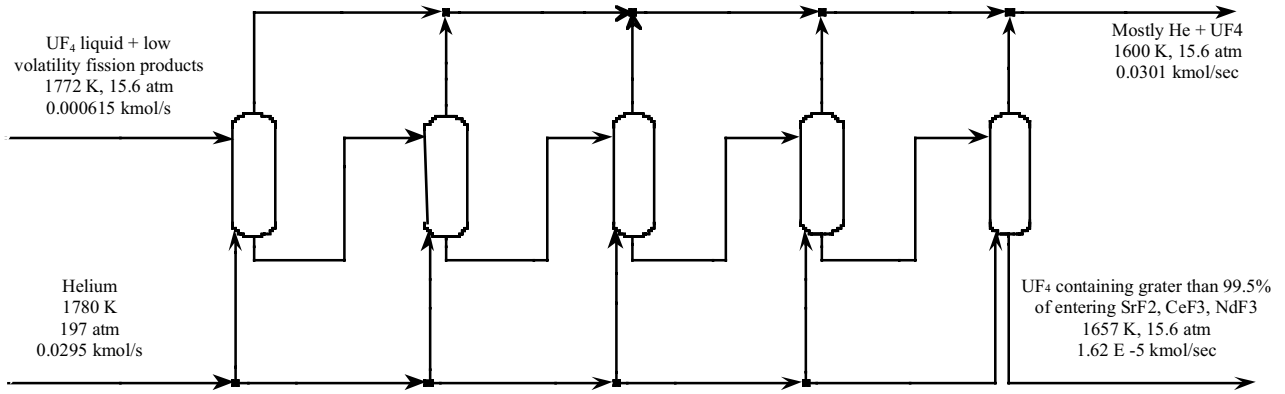

Fig. 4. Low vapor pressure FP separations.

Intermediate volatility fission products like ZrF_4, are separated from the helium stream after condensation and separation of the UF_4 liquid. The ZrF_4 plates out in the heat exchangers while cooling the helium to near room temperature. It is necessary to cool the helium so that it can be efficiently compressed. Parallel recuperation systems are used to cool the helium: one system is offline so that the ZrF_4, which had plated out in the recuperator, can be volatilize with hot purified helium and trapped in a solid adsorbent for disposal. Essentially all of the ZrF_4 is removed by this means.

High volatility fission products do not condense in the recuperator and must be removed from the helium after compression. Processing all of the helium stream to remove volatile fission products would be expensive, both in terms of equipment cost and energy. We assume that 10% of the helium is processed through a pressure swing adsorption system to remove xenon and MoF_6. Pressure swing adsorption (PSA) consists of two (or more) packed beds in parallel, each packed with an appropriate adsorbent. The adsorbent is chosen such that it adsorbs the impurity at high pressure and desorbs it at low pressure. It is assumed that MoF_6 cannot be desorbed from a bed capable of adsorbing xenon so we assume that the MoF_6 is permanently adsorbed and the bed is removed when its xenon capacity is diminished due to permanent MoF_6 adsorption. The purge stream containing xenon and helium is cooled to cryogenic temperatures to condense the xenon and the helium is returned to the flow loop. The liquid xenon can be stored until it has decayed sufficiently for release to the atmosphere.

The effect of gas core reactor wall cooling was incorporated into the simulation successfully. The model assumes that the helium wall coolant can be modeled using the standard heat transfer formula, $Q = U\,A\,\Delta T_{lm}$. where U is the overall heat transfer coefficient, A is the wall area and, ΔT_{lm} is the standard log mean temperature difference calculated from the inlet and outlet temperatures of the cooling helium and the reactor coolant. The heat transfer coefficient and heat transfer area are parameters which can be varied as the reactor designs matures. Initial calculations use a heat transfer coefficient of 13 watt/m^2 K estimated based on chemical engineering heuristics and an area of 4.3 m^2 estimated based on the size of a vapor core reactor as illustrated in several literature articles. Using these estimated there is a negligible temperature rise of the helium coolant. A similar approach was used to model wall cooling associated with the MHD generator. The large estimates of heat transfer coefficient (30 watt/m^2 K) and surface area (14 m^2) result in a 5 K temperature rise of the coolant helium.

Various heat integration opportunities were successfully incorporated into the simulation. Excess heat from the helium-UF_4 liquid separations was reintegrated into the simulation using multiple recuperator loops. The resultant temperature of the hot, compressed helium recycle stream, including the wall cooling effects of the gas core reactor and MHD generator, was approximately 1580 K.

Planned Next Quarter Activities

We will continue to model the separation of fission products from the VCR gas recycle loop, including additional study to quantify the energy costs associated with xenon and MoF_6 separation from helium. Other work will include the modeling of the Brayton and Rankine cycles, which will enable a complete overview of the entire power generation process.

Schedules and Budgets

The overall project is behind schedule, as previously reported by Sandia. A decision was made at meeting at Sandia to delay the down selection to a single Direct Energy Conversion concept. Status of all tasks of the combined project schedule is indicated in Table 1 and Fig. 5. Expenditures to date and projected expenditures for the rest of Phase 2 are given in Fig. 6.

Table 1. Summary of NERI Tasks – Phases 1-3

Identification Number	Milestone/ Task Description	Planned Completion Date	Actual Completion Date	Comments
1A(i).	Preliminary critical review of previous work	Jan 2000	Jan 2000	Work completed
1A(ii).	Review foreign literature	Nov 2000	N/A	Task abandoned due to classification issues
1B.	Identify opportunities for improvement	Mar 2000	Mar 2000	Work completed
1C.	Develop new/alternate concepts	May 2000	May 2000	Work completed
1D.	Characterize/compare alternate concepts	Jun 2000	July 2000	Work completed
1E.	Screen to 3 promising concepts	Jul 2000	Sept 2000	Work completed
1F.	Final (annual) Report for Task 1	Nov 2000	Nov 2000	Work completed
2A.	Identify and develop 3 concepts	Apr 2001	Apr 2001	Work completed
2B(i).	Identify critical technology issues	May 2001		Behind schedule Expected 4/02
2B(ii).	Define key experiments	Jun 2001		Behind schedule Expected 4/02
2C.	Compare and assess conceptual designs	Jun 2001	Nov 2001	Work completed
2D.	Prioritize concepts	Aug 2001	Nov 2001	Work completed
2E.	Final (annual) Report for Task 2	Oct 2001	Jan 2002	Work completed
3A.	Preliminary design of most promising concept	Mar 2002		Behind schedule Expected 4/02
3B.	Analyze technical performance	Jul 2002		Initiated 11/01
3C.	Analyze economic performance	Jul 2002		Initiated 11/01
3D.	Identify manufacturability issues	Jun 2002		Start expected 4/02
3E.	Perform selected experiments	Sep 2002		Delayed indefinitely (new NERI proposal submitted)
3F.	Complete Phase 3 and project	Oct 2002		Phase 3
3F'.	Final Report for Phase 3 and project	Oct 2002		Phase 3

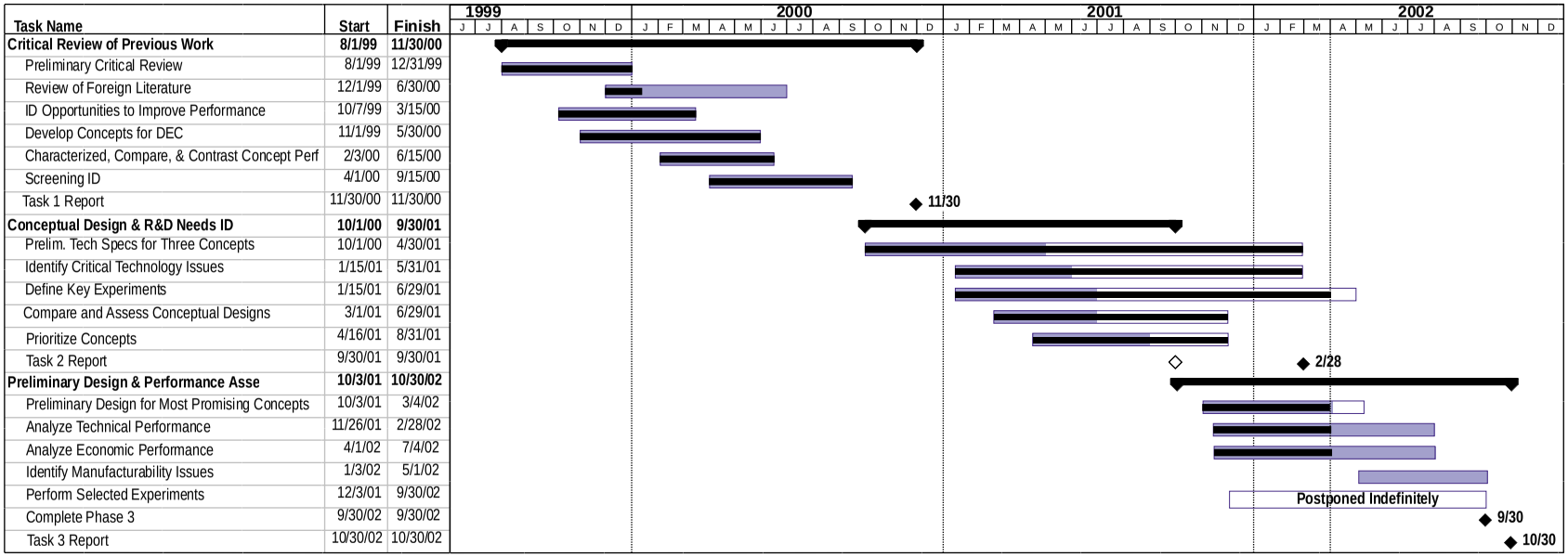

Fig. 5. Project Schedule.

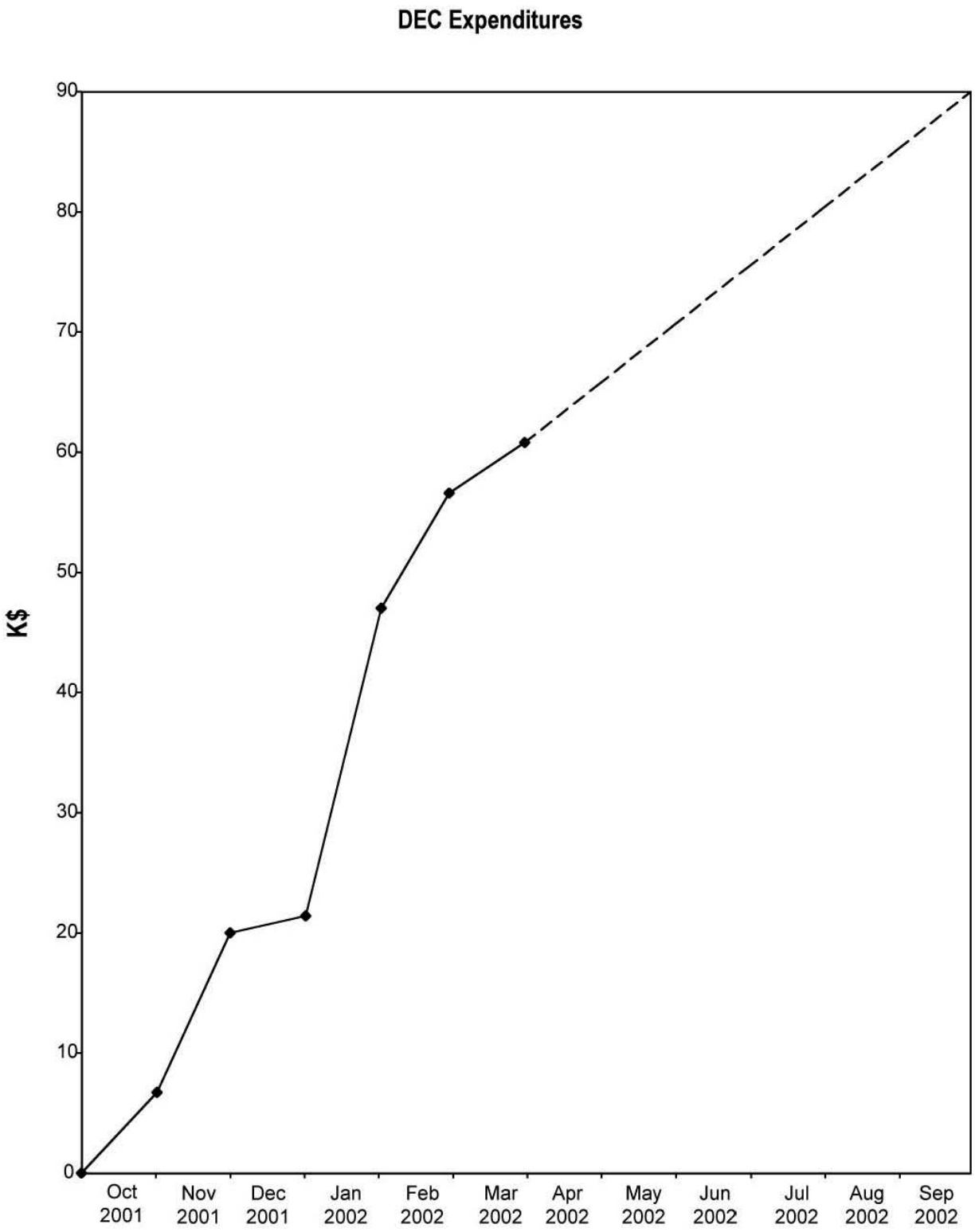

Fig. 6. Spending profile.