Assessment of Planned Scientific Content of the CRAF Mission: Letter Report (1987)

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On Mary 27, 1987, Dr. Robert O. Pepin, chair of the Committee on Planetary and Lunar Exploration, sent the following letter to Dr. Geoffrey A. Briggs, director of NASA's Solar System Exploration Division.

On May 31, 1985, the Committee on Planetary and Lunar Exploration (COMPLEX) of the Space Science Board communicated to you its first detailed review of the planned scientific content of the Comet Rendezvous-Asteroid Flyby (CRAF) mission, in the context of the committee's recommended science strategies for comet and asteroid exploration. Our conclusions at that time were summarized as follows: "The committee finds that science planning for the CRAF mission is proceeding within the guidelines established by COMPLEX for in situ cometary exploration and preliminary asteroidal reconnaissance. We feel confident that the few points of concern expressed by the committee at this stage of the mission strategy development will be addressed by the selected science teams. A later assessment will deal specifically with these concerns, noted below, and with the critical matter of measurement capabilities of the selected instrumental packages as they relate to the measurement requirements specified in the COMPLEX strategy report."

At its April 1987 meeting, COMPLEX carried out a second review of the CRAF mission, based in part an presentations by M. Neugebauer/CRAF Project Scientist on investigations and instruments selected for accommodation study, and by R.F. Draper/CRAF Project Manager on the profile, schedule, and engineering development for the mission.

ASSESSMENT SUMMARY

The committee finds that the scientific capabilities of the CRAF mission, as defined by the science payload selected for accommodation study, are (1) congruent with the prioritized scientific objectives recommended by COMPLEX for in situ comet exploration and asteroid reconnaissance; and (2) are in generally good accord with the specific measurement requirements established by COMPLEX to meet these objectives. We note in particular that the principal reservation expressed by the

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committee in 1985, concerning allocation of sole responsibility for acquisition of primary data on comet nucleus composition to a penetrator experiment, has been well addressed by inclusion in the science payload of several techniques for dust compositional measurements that require neither penetration of nor landing on the nucleus. Collectively, these techniques constitute a robust backup for essential elemental composition measurements to be carried out by the selected penetrator experiment.

We emphasize that preliminary analysis of the Halley flyby measurements has brought into sharper focus the intrinsic physical and chemical complexity of the cometary environment, and has mandated detailed study of a comet by a long-term and well-instrumented rendezvous mission such as CRAF. In all respects, the selected CRAF science payload instruments represent significant advances over their Halley counterparts, and add essential capabilities that were not present on the various Halley spacecraft. They promise the substantial complement of accurate measurements needed to address the COMPLEX science objectives.

HALLEY RESULTS AND THE CRAF SCIENCE PAYLOAD

There have been two major developments since 1985 that prompt a second assessment of the CRAF mission at this time: (1) the initial dissemination of the scientific results of spacecraft encounters with comets Halley and Giacobini-Zinner; and (2) selection of the CRAF science payload experiments for accommodation study. It is therefore important for the Committee to reassess the COMPLEX science objectives for comet exploration in the light of these results, and to ask whether the selected payload is well suited to the accomplishment of these or modified objectives.

To summarize briefly, the comet science objectives stated in the report "Strategy for the Exploration of Primitive Solar System Bodies—Asteroids, Comets, and Meteorites: 1980-1990," focused on the composition and physical state of the nucleus, processes that govern the development and behavior of the cometary atmosphere, and interaction with the solar wind, in that order of priority. The information returned by the encounter spacecraft has confirmed important aspects of the general picture of the volatile-rich nucleus and coma deduced from traditional ground-based and Earth-orbital remote observations. Yet it has left unanswered many significant questions, and raised fundamental new questions, concerning coma composition and the structures that arise from solar wind interaction. The new data have provided only rudimentary (size, shape, albedo) information on the physical state of the nucleus (e.g., there is currently a factor of at least two uncertainty in the density of the nucleus). Dust measurements on the Halley flybys provided the first in situ information on the composition of cometary solids. Although considerable diversity was seen among submicron particles, the mean composition deduced from the analysis of many particles is consistent with chondritic abundances. The only compositional anomalies in the mean dust are higher abundances of carbon and nitrogen than are seen in chondrites.

Due to intrinsic limitations of the flyby type of mission, uncertainties in the measurements are large, and the data clearly fall short of the analytic goals specified in the 1980 COMPLEX strategy report. Halley measurements did not cover a sufficiently broad range of elements and compounds, and were not of adequate accuracy to permit comparison of the comet with compositional patterns seen in chondrites. Isotopic measurements were likewise too inaccurate to see effects at the levels displayed by bulk meteorites. The diversity and relative abundances of organic compounds were not determined. The Halley results do indicate that comets are primitive objects, and underscore the importance of implementing rendezvous missions where more sensitive measurements can be made. Overall, in terms of the primary goal of the investigation of comets stated by COMPLEX in 1980, "to determine their composition and structure and to deduce their history in order to increase our knowledge of the chemical and isotopic composition and physical state of the primitive solar nebulan…" results from the comet Halley encounters, at least so far, are ambiguous.

COMPLEX thus concludes that the scientific results from the recent comet encounters (for which we must applaud our colleagues who conducted those missions) only reaffirm the goals originally stated in the strategy report and preserve the order of priority of the science objectives. Moreover, the extreme variability exhibited by Halley, determined from both in situ and remote observations, confirms the need for a rendezvous mission. At this writing, it seems likely that fast flyby comet missions will not contribute to the stated COMPLEX exploration objectives at the level inherent in the CRAF type of mission.

The encounter results also provide a yardstick for assessing the in situ measurement capabilities of the experiments selected for the CRAF payload. Instruments for analysis of solids are much more powerful than those on the Halley encounter missions, and they appear capable of accomplishing the first-order priorities outlined by COMPLEX. Gamma-ray spectrometry, x-ray fluorescence, and gas chromatography will yield abundances of a significant set of major and minor elements (and some trace elements) of cosmochemical importance. The target precisions of 0.5% for major elements set by COMPLEX are probably not generally attainable, but accuracies of a few percent are practical for most elements and should be adequate for meaningful bulk characterization. Bulk analyses of both collected coma dust and in-place solids on the cometary crust are critical elements in the CRAF plan because of the possibility of chemical fractionation between the cometary surface and the active gas-producing regions; inactive regions observed on the Halley surface could be thick lag deposits of devolatilized material. The compositional diversity seen in micron and submicron Halley dust suggests that individual particle measurements from the SEMPA and COMA instruments on CRAF will provide critical data for comparison of cometary matter with chondritic and interstellar grain models. If all comets—and other primitive bodies—have approximately chondritic non-volatile bulk composition, then the diversity at the individual grain level will be the only significant means for comparing materials formed by different processes in different environments.

Instruments on CRAF will yield first measurements of the compositions and

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abundances of organic materials in a comet. These are essential data for comparison of cometary and meteoritic organic species, and of chemical evolutionary processes in the two environments. The CHON particles found in Halley are strong presumptive evidence for the presence of organic compounds, but no definitive detection or characterization of complex molecules was possible in the flyby mission mode. Gas chromatography in the PENL (DSC/EGA) and CIDEX experiments on CRAF will be diagnostic for relatively simple compounds in the comet nucleus and in coma dust particles. Composition of parent organic molecules in coma gas is an important objective of the NIMS measurements.

Another example is isotopic mass discrimination, such as the resolution of ^{13}C from ^{12}CH. High mass resolution will be possible for both dust and gas components of the coma. Large isotopic effects recently seen in meteoritic carrier components and in separated grains from interplanetary dust particles suggest that valuable isotopic information on particles will be returned from CRAF, although the ultimate precision of the spacecraft instruments is not yet well determined.

The penetrator experiment. The penetrator warrants separate comment in view of COMPLEX's earlier reservations about the technological readiness of this technique to carry by itself the responsibility for acquiring high priority data on nuclear composition, without backup by other techniques in the event of deployment failure. Two characteristics of the selected CRAF science payload address these concerns. First, a major strength of the payload is the inclusion of four instruments, three on the main spacecraft, for compositional measurements an solids. All of the instruments (PENL, CIDEX, SEMPA, and COMA) have unique capabilities that are important for characterizing complex solid materials within the nucleus, or emitted from it over a range of comet activity. However, in that they all measure composition, a level of redundancy is provided for critical data acquired by techniques that have never been employed in spacecraft or cometary environments—including, for example, SEMPA as well as PENL. Second, the penetrator experiment selected for accommodation study exceeds the baseline penetrator concept—primarily elemental compositional analysis—in capability. The DSC/EGA augmentation is designed to determine the bulk phases (structures) of the water ice, and the molecular composition and modes of trapping of volatile species within it, and is thus responsive in a unique manner to the prime scientific goal of determining the conditions under which cometary ices formed. While the ambient temperature regime at penetrator depth may have erased some of this information, such in situ analysis of ice structures and volatile contents presents one of the better opportunities, short of pristine, thermally insulated sample return, for diagnosing cometary formation conditions.

COMPLEX continues to caution that substantial development' work during the accommodation study is required to demonstrate the viability and reliability of the penetrator concept, and of the selected augmented penetrator experiment. Outstanding issues include assurance of penetration and retention within the nucleus for a wide range of possible surface conditions, and investigation of the effects of penetrator passage and sample collection on the ice-volatile sample and on the measured thermal diffusivity of the penetrated medium. We are confident that these and other issues are being addressed by the experiment team. While the penetrator remains an unproven means of obtaining data, the data are of extraordinary interest and do not—in the case of DSC/EGA analyses, for example—appear accessible by any other means. Developments of penetrator technology and experimental sophistication appear to have been substantial over the past two years—as they have been for SEMPA, to note a parallel instrumental case—and there are thus excellent reasons for encouraging the continuing development of both instruments for inclusion in the final CRAF science payload.

Please feel free to contact me with any questions you may have regarding this assessment, or for further discussion.