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**INSERTION DEVICE AND BEAM LINE PLANS
FOR THE ADVANCED PHOTON SOURCE**

**A Report and Recommendations by the
Insertion Device and Beam Line Planning Committee**

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Contents

Page

Abstract.....	1
1. Background.....	1
2. Charge to the Committee.....	2
3. Technical Cost Basis for IDs and Beam Line Components.....	3
4. Recommendations for Possible ID/Beam Line Distribution Plans....	5
5. Recommendations for Refinement of the Technical Cost Data Base..	10
6. Summary of the Proposed Plans.....	11
Acknowledgements.....	12
References.....	13
<u>Attachment A</u>	
ID Replication Cost Break Studies.....	14
<u>Attachment B</u>	
Parameters for the Hybrid Undulator A.....	15
<u>Attachment C</u>	
Parameters for the Hybrid Wiggler A.....	16

Tables

1. Average cost in K\$ of major component group for the IDs and bending magnet.....	4
2. Possible number of partially equipped beam lines with one kind of radiation source, Plan A.....	7
3. Possible number of partially equipped beam lines with one kind of radiation source, Plan B.....	9

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Abstract:

In the 7-GeV Advanced Photon Source (APS) Conceptual Design Report (CDR), fifteen complete experimental beam lines were specified in order to establish a representative technical and cost base for the components involved. In order to optimize the composition of the insertion devices and the beam line, these funds are considered a "Trust Fund." The present report evaluates the optimization for the distribution of these funds so that the short- and long-term research programs will be most productive, making the facility more attractive from the user's point of view. It is recommended that part of the "Trust Fund" be used for the construction of the insertion devices, the front-end components, and the first-optics, minimizing the cost to potential users of completing a beam line. In addition, the possibility of cost savings resulting from replication and standardization of high multiplicity components (such as IDs, front ends, and first-optics instrumentation) is addressed.

1. Background:

The 7-GeV Advanced Photon Source (APS) Conceptual Design Report (CDR)[1] includes the specification of 15 complete experimental beam lines costing approximately \$40,066,000. The major motivation for the conceptual design of these sample beam lines was to establish a representative technical and cost base for the components involved.

In their report on the 1987 APS CDR, the ER Review Committee, chaired by L. E. Temple, Jr., recommended that the funds allocated to the construction of insertion devices (IDs) and beam lines on the APS be considered as a 'Trust

Fund' [2]. The make-up of the IDs and the beam lines should be optimized so as to result in the most productive short- and long-term research programs making the facility most attractive from the user's point of view.

The construction of a specific number of IDs and partial beam lines by the facility would substantially reduce the cost of developing the rest of the beam line by a research group using external funding. It is expected that such an approach would also contribute to the engineering and construction cost savings associated with standardization and replication of appropriate ID and beam line components. In order to build a qualified APS/ANL staff to provide new technical know-how to the users, the plan should also include provision for the construction of a few complete beam lines using the Trust Fund. Thus the total plan should include the construction of the IDs, complete beam lines and partial beam lines on the storage-ring, the cost of which has to be covered by the Trust Fund.

A charge was given to this Committee on 'Insertion Device and Beam Line Planning' by Dr. David Moncton, Interim Associate Laboratory Director of the Advanced Photon Source, to develop a technical and cost base which could be used for a distribution of the 'Trust Fund'. The full charge is presented in Section 2 of this report. This report represents the findings and evaluations based on the present technical cost base information. The report also contains recommendations for the refinement of the cost base to include the impact of standardization and replication.

2. Charge to the Committee:

The charge presented to the Committee by D. E. Moncton was to develop alternative distribution plans for the construction of the initial complement

of IDs and partial/full beam lines. In conjunction with these plans, the Committee should:

1. Develop a technical and cost data base for IDs and beam line components to be used as a basis for the new plans.
2. Determine the possible cost benefits resulting from standardization and replication of appropriate technical components. This includes components such as:
 - the four types of IDs given in the 7-GeV APS CDR, namely,
 - Undulator A
 - Undulator B
 - Wiggler A
 - Wiggler B
 - all front-end instrumentation, and
 - first-optics (premonochromators and/or mirrors)
3. Provide advice on issues related to the standardization of ID and beam line components versus the flexibility and innovation.

3. Technical Cost Basis for IDs and Beam Line Components:

A beam line consists of the following component groups:

- x-ray source (ID or Bending Magnet),
- front-end,
- first-optics, and
- beam transport and experimental station.

The cost basis for the above component groups in the 15 sample beam lines, including the IDs presented in the 7-GeV APS CDR [1,2], was used in the present study. The cost for each group was taken as the average of the APS CDR cost data; these values are given in Table 1.

Table 1. Average cost in K\$ of major component group for the IDs and bending magnet [1].

Source	Source Cost	Front-End	Beam Transport First-Optics	Experimental Station
Undulator	1326	487	476	1196
Wiggler	683	447	476	1196
Bend. Magnet	-	351	-	952

Based on these figures, the average cost for each of the three types of complete beam lines is:

	(K\$)
- undulator:	3485
- wiggler:	2802
- bending magnet:	1333

The Committee reviewed the above data base and arrived at the following conclusions:

1. The cost data as presented in the CDR [1] for major components are reliable and provide an adequate estimate.

2. The data are sufficient in their present form to be used in this analysis and in generating a Plan. The cost base was developed for the CDR using available resources of information from other DOE sister laboratories and vendors. Further refinement of the original cost data should be based on actual engineering studies, if needed, developed by the APS staff with assistance from other DOE sister laboratories and by manufacturers with construction experience for a given component. The Committee's recommendations for refining the data base are given in Section 5.

4. Recommendations for Possible ID/Beam Line Distribution Plans:

PLAN A (5m long IDs):

The Committee considered various combinations of complete and partially equipped beam lines, all using radiation from 5m long IDs. It was concluded that a complement of at least eight complete beam lines including 5m long IDs be constructed by the APS facility using the Trust Fund. This recommendation strongly reflects the Committee's desire to develop a well qualified staff at the APS/ANL which can provide the know-how and operational experience on the new IDs, front-ends, and first-optics. The scientific objective of each of these eight beam lines should be decided based on scientific interests and policies for user access to APS developed at the time when the beam line construction phase is reached. This complement may or may not include some of the 15 sample beam lines described in the CDR. It was concluded that a viable and representative complement of the eight complete beam lines should consist of the following:

- three 5m undulator beam lines,
- two wiggler beam lines, and
- three bending magnet beam lines.

The recommendation from the Committee is based on the following arguments. The bending-magnet-based beam lines should be built first since they will be the first sources of x-rays during the storage ring commissioning. They will provide the APS/ANL staff with beam line diagnostic and control procedures so very essential for the commissioning. The sources can also be utilized to pursue initial scientific research using hard x-rays.

The undulator and wiggler beam lines, recommended by the Committee for construction involving the APS/ANL staff using the Trust Fund, will provide the necessary technical knowledge. Given the tunability range of the two undulators A and B presented in the 1987 APS CDR, the Committee feels that these are viable options for standard undulator x-ray sources. Commissioning such devices and developing procedures for fully utilizing their radiation by the APS/ANL staff will generate needed information for the PRTs and other users in implementing their own beam lines.

The Committee also addressed the question of developing specialized insertion devices. We recommend that the cost of a specialized device be absorbed by the research group responsible for such a beam line.

The total cost for the configuration of eight complete beam lines described above with 5m long IDs is then K\$20,058. Given the total Trust Fund of K\$40,066 for IDs and beam lines, this leaves approximately K\$20,008 for partially developing remaining beam lines and sources.

The Committee felt there are two options for partial completeness of the beam lines which are viable. They are:

- (a) provide ID and its front-end, and
- (b) provide ID, its front-end, and first-optics.

The option (b) of including the first-optics station in addition to the ID and front-end in a partially completed beam line would mean that the facility assumes the responsibility for delivering and handling all aspects of the primary x-ray beam. This should be reflected in the number of experienced APS staff available during the operation period. The research team developing the complete beam line is then responsible only for its own specialized optics, beam transport and experimental station. The downstream optical components such as monochromators and mirrors are difficult to standardize at this time given the expected diversity of beam line design. The beam line safety components and the generic experimental hutch designs will be provided by the facility.

Given the eight complete beam lines, the possible number of additional partially equipped beam lines depends on the type of x-ray source considered. The resulting distribution for each type of the radiation source (undulator, wiggler or bending magnet) for the two options is shown in Table 2.

Table 2. Possible number of partially equipped beam lines with one kind of radiation source, Plan A. These are in addition to the eight complete beam lines. The components included are for the two options explained in the text. The undulators are 5m-long.

Radiation Source	Option (a) ID + Front-end	Option (b) ID + Front-end + First-Optics
All Undulators	11	8
All Wigglers	17	12

In option (b), where the first-optics station is included in the partially completed beam line, the remaining investment necessary to make the complete beam line and experimental station operational is approximately \$1,000,000. This is nearly a third of the cost for a complete beam line including the ID, and represents a much lower start-up cost for a research team interested in developing a beam line.

The Committee recommends that the responsibility of the facility should in fact extend up to and include the first-optics station of a given beam line. This conclusion is based primarily on personnel safety issues and the stringent requirements on components exposed to the primary x-ray beam.

PLAN B:

A second possible scenario which the Committee felt was viable involved the possible implementation of undulators which are half the proposed length of the 5 meters in the 1987 APS CDR. These shorter devices would have the following advantages: A prototype would have been well tested at CHESS by the APS/ANL staff prior to the construction of undulators, as well as design of the first-optics to handle large power densities. The technical problems associated with the very high power densities from 5 m long devices can be addressed after the commissioning and operation of the shorter devices. The shorter devices will deliver lower brilliance and flux. However, this reduction is more nearly linear with the undulator length for the APS positron beam emittance than quadratic as expected for single-particle trajectory. If more flux is required on a beam line at a later date, either two such smaller devices or one longer undulator could be installed on the straight section.

Based on these points, the Committee felt that it is worthwhile to consider a distribution in which 2.5 m long undulators are initially constructed. The cost of such a device was estimated to be 0.6 times the cost of

a 5 m long undulator or equal to K\$796. This factor is based on a preliminary estimate. All other component costs in the beam line were assumed to remain constant. Recommendations for refining the cost base for such a device are given in Section 5.

The estimated cost of a complete beam line containing a 2.5 m long undulator is approximately K\$2,955 (compared to K\$3,485 for one with a 5 m long undulator). The total cost of eight complete beam lines consisting of three 2.5 m long undulators, 2 wigglers and 3 BM sources is K\$18,468. This leaves K\$21,598 (from the Trust Fund of K\$40,066) to partially equip remaining beam lines.

As discussed in Plan A (with 5 m long undulators), two options for completeness of the beam lines were considered. The option (a) includes the ID and front-end, and the option (b) includes the ID, front-end, and the first-optics. The analysis and resulting number of partially completed beam lines for the two options is given in Table 3. As before, these are in addition to the eight complete beam lines. Other than for the undulator beam lines, all other cost data are the same as those used in Table 2.

Table 3. Possible number of partially equipped beam lines with one kind of radiation source, Plan B. These are in addition to the eight complete beam lines. The components included are for the two options of completeness explained in the text. The undulators are 2.5 m-long.

Radiation Source	Option (a) ID + front-end	Option (b) ID + Front-end + First-Optics
All Undulators	17	12
All Wigglers	19	13

The investment necessary to complete the beam line and experimental station is on the order of \$1,000,000. The net result of the shorter undulator is an overall increase in the number of partially equipped beam lines.

5. Recommendations for Refinement of the Technical Cost Data Base:

As mentioned, the major task involved in the refinement of the beam line technical components cost base is to investigate the possible cost savings associated with replication of some components on the beam line. These include:

- ID sources,
- front-end components, and
- first-optics station.

Of particular interest for the case of IDs is the engineering and possible construction cost savings which may be associated with replication of a standard unit. The Committee recommends that an engineering estimate be made for the cost break points versus the number of units produced for the standard undulator A and wiggler A. The specification of devices for this study to be conducted by the manufacturers of insertion devices is given in Attachment A.

An additional refinement of the cost data base is needed to determine the relative cost of 5-m and 2.5-m long undulators mentioned in Plan A & B. The specifications for the cost data required is given in Attachment A and again should be solicited from the ID manufacturers.

For the case of front-end components, the Committee recommends that an estimate be made of possible construction cost savings due to replication of these components. Such information is contained in the cost data base pre-

sented in the APS CDR. It may be worthwhile to obtain figures for the cost reduction due to replication also from the industry.

Since the conceptual design of the first-optics station was based on the cost of an upgraded version of a commercial double-crystal monochromator, the Committee suggests that a realistic production schedule be defined and the possible savings associated with multiplicity be estimated.

In spite of the above recommendations by the Committee to obtain realistic cost estimates from vendors which might lead to cost savings for multiple devices, it does not recommend that these savings be included in cost estimates at this stage of planning. The average cost for a device does not represent the true cost of a single device or one where a small number of units are involved. This could result in serious problems if the production plans are changed close to the construction phase.

Also, a certain amount of reduction in the engineering costs of high multiplicity components has been included in the cost data base in the APS CDR. This is perhaps the most straightforward reduction to account for and is a predictable function of the replication factor. Hence, further estimates in the cost reduction should not be included in the planning stage.

6. Summary of the Proposed Plans:

The Committee recommends two alternative distribution plans for IDs and beam lines. Both the plans propose the construction of eight complete beam-lines instead of the fifteen described in the APS CDR 1987. These should consist of three undulator, two wiggler and three bending magnet beam lines. The remaining funds should be used to partially equip additional IDs, front-ends and the first-optics. In plan A the Committee considered 5 m long undulators, while in plan B the undulators of 2.5 m length were included.

Both plans, A and B, include two options. One of these is to install the necessary front-ends with the ID or bending magnet ports, and the other is to include in addition the first-optics stations in the ID beam line.

Plan A would result in a total of 11 additional undulator + front-end or 17 wiggler + front-end combinations. If the first-optics is included with the front-end, the partially equipped beam lines could be 8 with undulator sources or 12 with wiggler sources.

Plan B would result in 17 undulator + front-end or 19 wiggler + front-end combinations. With the inclusion of the first-optics, the partially equipped beam lines could be 12 with undulators or 13 with wigglers.

The Committee also recommends that studies of the cost break points be done for those components where high multiplicity is expected. These should include estimates from accredited manufacturers of these components and APS-based estimates. Any cost savings resulting from studies, however, should not be included in this planning stage for IDs and beam lines, since the actual savings will depend on the production plans. The cost of a specialized insertion device source, which is not a standard type A or B described in the CDR, should be absorbed by the research group responsible for development of the beam line.

Downstream optics and components are not readily standardized due to the diversity of the applications. Cost break points and standardization should be evaluated at that time when a more specific definition of the actual beam lines is available.

Acknowledgements:

We would like to thank D. E. Moncton and E. Hoyer for many useful conversations on the subject of this report.

References:

1. "7 GeV Advanced Photon Source Conceptual Design Report." ANL Report, ANL-87-15, April 1987.
2. "Report of the DOE Review Committee on the June 9-11, 1987 Technical/Cost/Schedule/Management Review of the 6-7 GeV Synchrotron Radiation Source Project at the Argonne National Laboratory, Argonne Illinois." L. E. Temple, Jr., Chairman, July 16, 1987.

Attachment A

ID REPLICATION COST BREAK STUDIES

The Advanced Photon Source (APS) to be built at Argonne National Laboratory will require undulator and wiggler insertion devices. Since replication of insertion devices is expected, we desire a study of the possible cost reductions associated with the production of multiple devices of the same kind. An actual dollar cost for the insertion devices is not necessary at this stage. We desire, instead, the cost break points versus the number of devices for each of the type. The breakdown should specify the total cost, engineering costs, construction labor costs, and material costs.

The undulator under consideration is a 5 m long hybrid type with a period of 3.3 cm. The specifications are given in Attachment B. The wiggler is a 1.5 m long hybrid type with a period of 20 cm. Its technical specifications are given in Attachment C. The maximum number of devices should be 30 in both cases.

A second part of the study involves a relative cost comparison of a 5 m long, 3.3 cm period undulator given in Attachment B and an identical device with half the number of periods (2.5 m long) and with the same period. The open and closed gaps are the same for both cases. The relative cost should specify the engineering, construction and materials costs. Again, a dollar cost is not required at this time for either device.

Attachment B

PARAMETERS FOR THE Nd-Fe-B HYBRID UNDULATOR A

Permanent Magnet	Nd-Fe-B
Pole Material	Vanadium Permendur
Undulator Period (cm)	3.3
Magnet Gap Range (cm)	1.0 - 2.8
Pole Width in x Direction (cm)	5.0
Pole Height in y Direction (cm)	3.5
Pole Thickness in z Direction (cm)	0.62
Magnet Width in x Direction (cm)	6.6
Magnet Height in y Direction (cm)	4.2
Magnet Thickness in z Direction (cm)	1.03
Pole-Tip Overhang in y Direction (cm)	0.08 to 0.1
Peak Field Range on Axis, B_0 (T)	0.78 to 0.21
Peak Field Increase (%) at 0.1 cm Off-Axis in y Direction	2.0
Maximum Length Available for Undulator (m)	5.2
Maximum Undulator Periods	158

Attachment C

PARAMETERS FOR THE HYBRID WIGGLER A

Parameters	Wiggler A
Permanent Magnet	Nd-Fe-B
Pole Material	Vanadium Permendur
Peak Field on Axis, B_0 (T)	1.0
Gap, G (cm)	3.7
Period (cm)	15.0
Peak K Value	14
Number of Periods, N	10
Length (m)	1.5
Critical Energy, E_c (keV)	32.6

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