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John Irvine; Ben R. Martin

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● **ABSTRACT**

This paper presents the results of a study comparing the past scientific performance of high-energy physics accelerators in the Eastern bloc with that of their main Western counterparts. Output-evaluation indicators are used. After carefully examining the extent to which the output indicators used may be biased against science in the Eastern bloc, various conclusions are drawn about the relative contributions to science made by these accelerators. Where significant differences in performance are apparent, an attempt is made to identify the main factors responsible.

Basic Research in the East and West: A Comparison of the Scientific Performance of High-Energy Physics Accelerators

**John Irvine and
Ben R. Martin¹**

Nations in both the East and West are increasingly being forced to consider how best to formulate appropriate and effective policies for science and technology.² One response has been the development of improved techniques for monitoring research outputs — whether they be contributions to scientific knowledge, or to technological innovation and economic development. Over the past five years, we have undertaken various studies of the scientific outputs from major research facilities in several Big Science specialties (radio astronomy, optical astronomy and electron high-energy physics). The overall aim of this work has been to develop and refine appropriate techniques for evaluating performance in basic research.³ In this paper, we report the results of a comparative evaluation of the scientific outputs from accelerators in the Eastern bloc over the 1960s and 1970s. While we give particular attention to

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the major accelerators at Dubna and Serpukhov, we also consider low-energy research facilities at four other laboratories, so that we cover a very large part of the Eastern bloc's effort in experimental high-energy physics. Our evaluation is based upon the method of 'converging partial indicators', described elsewhere;⁴ it involves comparisons with similar facilities in Western Europe and the United States in terms of their outputs of research publications, the subsequent impact of those publications on the advance of scientific knowledge (as indicated by various citation statistics), and systematic peer-evaluation data obtained from interviews with scientists in Eastern and Western research institutes.

The paper begins by briefly reviewing recent Western work on the performance of Eastern-bloc science. Some major problems identified as restricting research in the Eastern bloc are discussed, along with the limitations of conventional sources of data on the subject — recollections of emigrés, reflections of visiting Western scientists, and international data-banks on publications and citations. These limitations are then taken into consideration when the differences in output between Eastern-bloc and Western accelerators are analyzed in detail. We argue that biases in the various indicators are, in fact, insufficient to account for the apparent differences in the output of similar research facilities in the East and West; this conclusion is supported by our peer-evaluation results. Finally, we attempt to identify some of the principal factors determining the scientific performance of Eastern-bloc accelerators, drawing on our interviews with a significant part of the world high-energy physics community.

The Growth of Interest in Eastern-Bloc Science

Two motives appear to underlie much previous work on Soviet and Eastern-bloc science. First is an obvious curiosity in the dynamics of a social system which, since 1917, has pursued a novel path of development, based in large part on policies attempting to make 'rational' use of all resources, including science and technology.⁵ The Soviet revolution had profound ramifications for scientific research, and there was an upsurge of Western interest in the Soviet research and development system in the 1930s, following the congress on 'Science at the Crossroads' held in London in 1931.⁶ Stalinist purges and the rise of such 'distorted' sciences as Lysenkoism provoked

further interest. From this time on, and notwithstanding certain criticism, various groups of Western socialist scientists have drawn upon positive aspects of Eastern-bloc science to urge a fundamental reorientation of Western research towards a 'science for the people'.⁷

However, informed understanding of Eastern-bloc science really only began with, first, the exodus of emigré scientists with first-hand experience of working in research laboratories, and, second, the development (in the early 1960s) of exchange visits by scientists, of international collaborative projects,⁸ and of conferences attended by researchers from East and West. This growth in personal contact allowed scientists to reflect upon the merits and weaknesses of each system, as well as opening up new opportunities for those studying comparative science policy⁹ and the sociology of science.

A second motive is reflected in the emergence of systematic monitoring by the West of Eastern-bloc science, since this is now regarded as a key strategic element in industrial and military policy. Both at a public level (through organizations such as OECD), and at more covert levels, significant efforts have been devoted to studying the strengths and weaknesses of the main Eastern-bloc R&D sectors, and of the associated basic sciences. Such studies have not only considered the inputs to science and technology (funding levels, numbers of scientists and engineers,¹⁰ and so on), but have also attempted to evaluate the outputs from R&D, particularly their potential value to military technology.¹¹ Political interest has, at times, clearly influenced the provision of government funds for academic studies of Eastern-bloc science.¹²

What We Know about Eastern-Bloc Basic Research Performance

Despite the recent proliferation of literature on Soviet and East European R&D, there is still remarkably little 'hard' quantitative data on the performance of its scientific system — certainly little that would be generally accepted in both East and West. Part of the problem is the reliance on personal recollections of emigré scientists which are, almost inevitably, strongly influenced by political values. The impression gained from emigré writings is one of chronic inefficiency, with the underlying cause located in an all-pervasive bureaucratic structure, the operation of which discourages creative

and productive scientific research, especially among experimentalists.¹³ The emphasis on long-term planning, in particular, is widely criticized on the grounds that it is difficult, if not impossible, to match the ever-changing and often unpredictable demands of experimental research with a relatively inflexible long-term plan based on prior identification of scientific problems. However, many other difficulties are also identified, most of them attributable to bureaucratic dysfunctions: these include those faced by creative young scientists in challenging conventional wisdom; the generally poor level of scientific management (in turn related to the over-centralized control of research); the stagnation of research institutes due to 'ageing' of their staff and a lack of mobility between laboratories; over-concern with secrecy; inadequate links between the Eastern-bloc scientific system and the rest of the world;¹⁴ and, finally, poor links between research institutes and high-technology industry resulting in the stunted development of many areas of experimental science denied modern instrumentation and adequate computing facilities. In short, emigrés argue, most areas of basic research (with only a few exceptions) are uncompetitive with the West because the conditions essential for successful research are generally lacking.

From the point of view of comparative science-policy analysis, the opinions of visiting foreign scientists have one advantage over emigré writings: although visitors clearly have less knowledge about the detailed operation of the scientific system, they are more likely to hold a balanced view.¹⁵ While visitors tend to confirm reports of obsolete experimental equipment and computing facilities, a poor scientific communication system, an over-developed bureaucracy, and weak links between scientific research and technology-based industry, they also recognize that in several areas of science (particularly the theoretical branches) the performance of Eastern-bloc researchers has been amongst the best in the world, at least partly because young scientists are given a thorough grounding in theory.

Prominent among the initiatives aimed at promoting collaborative research has been the US-USSR Inter-Academy Exchange Program, which has been reviewed (together with other aspects of American-Soviet scientific collaboration) by the US National Academy of Sciences.¹⁶ American scientists who had visited the USSR were asked in a postal questionnaire to assess their experiences, and to comment upon the quality of Soviet scientists

and the strength of their respective disciplines.¹⁷ This approach yielded useful qualitative peer-evaluation data on a field-by-field basis; for example, Soviet theoretical physicists and mathematicians were judged to be among the very best in the world, while particle physics was generally regarded as lagging 'between five and ten years behind that in the United States and Western Europe'.¹⁸ Important quantitative information was also provided on American scientists' perceptions of the overall performance of Soviet science; just under 80 percent regarded the Soviet Union as less advanced scientifically than the United States. However, little attempt has been made to relate such opinion surveys to more systematic evaluations. Moreover, the extent to which the views of American scientists accord with those of their Soviet colleagues remains a matter for speculation, since the Soviet Union decided it would be inappropriate for a parallel survey of scientific opinion to be undertaken by the Academy of Sciences in the USSR. Nevertheless, as L. R. Graham (rapporteur to the NAS review) has pointed out, 'this is the first attempt made by qualified American scientists to evaluate Soviet science . . . systematically.'¹⁹ As such, it represents a valuable addition to the literature on Soviet science.

A further source of data is the series of macro-level statistics on publications and citations produced by the Institute for Scientific Information (ISI), as a by-product of their *Science Citation Index (SCI)*. Attempts to use such data to compare research outputs have been critically received by many Western scientists, who tend to prefer traditional methods for assessing research performance based on expert peer-review. Yet the analysis of publication and citation data has become widely used as a method of comparing national scientific outputs, particularly since the appearance in *Science Indicators 1972* of field-by-field counts of the scientific papers published by the major industrialized countries, and figures on the frequency with which they are cited.²⁰ According to those who produced these data,

. . . publication counts were used as indicators of national scientific activity, while the citation counts were used as indicators of national scientific 'quality' or 'significance'.²¹

On these indicators, the USSR compares relatively poorly with most other major countries, and in particular the US. Such findings are now integrated into the conventional wisdom of Western science

policy, as the following statement reveals:

By any measure — whether Nobel prizes, frequency of citation by fellow specialists, origin of major breakthroughs, or simply quantity of publications — US scientists lead their Soviet colleagues in most disciplines, and in many there is simply no competition.²²

Uncritical acceptance of these figures as indicators of national scientific performance is, however, extremely dangerous, since the ISI data-base has intrinsic methodological limitations. This is especially true for comparisons between East and West: the coverage of journals in the *SCI* is very unevenly distributed across countries, with English-language nations faring particularly well. In physics, for example, while 160 Soviet and 191 US physics journals were held in 1973 by the extremely comprehensive British Library Lending Division,²³ only 14 of the Soviet journals (less than 10 percent) compared with 40 for the US (over 20 percent) were scanned by ISI — a discrepancy also evident in abstract counts.²⁴ Such bias is likely to lead to underestimates of Soviet publication output. If physics is typical, then Soviet journals are under-represented by a factor of just over two. A recent study of the adequacy of the ISI data as an indicator of relative international scientific activity was forced to conclude that in ‘the case of the USSR, the coverage is so deficient that international activity indicators based on this Soviet coverage would be seriously affected’.²⁵ Bias is also inevitably present in the citation data. If less than 10 percent of all Soviet (but over 20% of US) physics journals are scanned by ISI, then Soviet physics publications are ‘losing’ a far larger number of their citations (in the unscanned journals) than are American ones. ISI-based data purporting to reveal the low ‘quality’ of Eastern-bloc science should thus be regarded with the same scepticism as data on relative numbers of publications.

The overall conclusion is that the evidence available on the performance of Eastern-bloc science is not at present sufficiently reliable to support the critical views often heard in the West. Publication and citation data apparently corroborate the views of emigré scientists, the impressions gained by Western visitors, and the general findings of Western surveys of R&D output. Yet this does not necessarily mean that the collective picture is a faithful one, since these sources all have major biases and technical limitations. Is it possible to conduct more systematic studies of scientific

performance that are less susceptible to 'bias', and which would, therefore, be as acceptable to the scientific community and science-policy analysts in the Eastern-bloc countries as they are in the West?

An Alternative Framework for the Evaluation of Research Performance

The results of work at the Science Policy Research Unit over the last seven years suggest that such evaluation techniques can indeed be developed. In what follows, we describe an approach, based on a number of 'partial indicators' of scientific progress, for making comparisons of major experimental facilities (high-energy physics accelerators) and of the scientists who use them.

High-energy physics exemplifies 'curiosity-oriented science' — that is, research funded primarily because of the contributions it is likely to make to the advance of knowledge. It also leads to substantial educational benefits (in the form of highly trained scientific personnel), to various types of technological 'spin-off',²⁶ and even to broader political benefits such as increased national prestige and improved international cooperation. Yet these secondary reasons cannot explain why, over the last decade, nations have spent around \$1,000m a year on the subject.²⁷ Our assessment therefore focuses on the contributions to scientific knowledge ('scientific' contributions) associated with different high-energy physics accelerators.

In previous work, we have developed a 'method of converging partial indicators' for comparing scientific contributions. The method employs various partial indicators of the scientific progress made by users of different research facilities: publication counts, citation statistics (total citations, citations per paper, and numbers of highly cited papers or 'discoveries'), and extensive peer-evaluation rankings of the relative outputs of the facilities. These indicators can be applied to matched groups of researchers using similar research facilities and publishing in essentially the same body of journals. In each of the three Big Science specialties in which we have used the method, a certain convergence between the results based on each partial indicator has been obtained; reasonably unambiguous conclusions can then be drawn about the relative contributions to scientific progress from each experimental facility.²⁸ The main elements of the method are summarized in Table 1.

TABLE 1
Main Problems with the Various Partial Indicators of Scientific Progress and Details of how their Effects may be Minimized Using the Method of Converging Partial Indicators

Partial Indicator Based on	Problem	How Effects May be Minimized
A. <i>Publication Counts</i>	1. Each publication does not make an equal contribution to scientific knowledge 2. Variation of publication rates with specialty or institutional context	Use citations to indicate average impact of a research facility's publications, and to identify very highly cited papers Choose matched research facilities producing similar types of papers within a single specialty
B. <i>Citation Analysis</i>	1. Technical limitations with <i>SCI</i> : (a) first author only listed; (b) variations in names; (c) authors with identical names; (d) clerical errors; (e) incomplete coverage of journals (2) Variation of citation rate during lifetime of paper — unrecognized advances on the one hand, and integration of basic ideas on the other 3. Critical citations 4. 'Halo effect' citations 5. Variations of citation rate with type of paper and specialty 6. Self-citation and 'in-house' citation (SC and IHC)	Not a problem when dealing with a research facility Check manually Not a serious problem for Big Science Not a problem if citations are regarded as an indicator of impact, rather than quality or importance Choose matched research facilities producing similar types of papers within a specialty Check empirically and adjust results if the incidence of SC or IHC varies between groups
C. <i>Peer Evaluation</i>	1. Perceived implication of results for own central facility and competitors may affect evaluation 2. Individuals evaluate scientific contributions in relation to their own (very different) cognitive and social locations 3. Conformist assessments (e.g. 'halo effect') accentuated by lack of knowledge on contributions of different research facilities	1. Use large representative sample 2. Use verbal rather than written survey in order to press evaluator if a divergence between expressed opinions and actual views is suspected 3. Assure evaluators of confidentiality 4. Check for systematic variations between different groups of evaluators

Use only indicators that yield convergent results

Our approach in this study was to identify the main Eastern-bloc experimental high-energy facilities, and then to compare their scientific outputs with those from the nearest equivalent facilities in the West. The data-base for the publication and citation indicators has been carefully examined to assess the extent of any bias against Eastern-bloc science, and hence to overcome, as far as possible, the main problems with previous use of such data. These bibliometric data are complemented by a survey of scientific opinion on the relative performance of Eastern-bloc accelerators, involving interviews with nearly 200 high-energy physicists in both East and West; again, the results were carefully analyzed for any systematic bias. Although there are definitely biases in all the output indicators, one can estimate their approximate magnitudes, and so allow for their effects. The indicators, where they converge, can then be used to draw what we believe are reasonably accurate conclusions about the relative performance of Soviet and East European experimental high-energy physics. There appears to be no reason in principle why such an evaluation could not be applied to other areas of Eastern-bloc science.

Eastern-Bloc Accelerators and their Closest Competitors

High-energy physics has been comparatively well supported in both East and West. In Western nations, it has at times accounted for 40 percent or more of total state expenditures on basic natural science.²⁹ Initially, during the 1950s and early 1960s, this favoured position seems to have stemmed from an implicit belief that significant contributions would be made to nuclear-energy research.³⁰ When this belief later became untenable, high-energy physicists began to emphasize the 'fundamental' nature of the field, and its potential contributions to other sciences.³¹ In the Eastern bloc, such considerations have gone hand in hand with matters of national prestige. (Great effort, for example, was put into ensuring that the Serpukhov facility, then the highest-energy accelerator in the world, was ready in 1967 to celebrate the fiftieth anniversary of the Russian revolution.) As a result, according to the senior American high-energy physicist, R. R. Wilson, 'the scope of the accelerator laboratories in the USSR is comparable to that of the American and European programs'.³²

Table 2 lists the main Eastern-bloc accelerators operating from

TABLE 2
Eastern-Bloc Accelerators and Their Closest Competitors, 1960–82

Accelerator	Date of First Operation	Beam Energy (GeV)	Approximate Cost (US\$m) ^a
PROTON >25GeV			
Serpukhov (USSR)	1967	76	~100
CERN PS (W. Europe)	1959	28	45
Brookhaven AGS (USA)	1960	33	31
CERN ISR (W. Europe)	1971	31	75
Fermilab (USA)	1972	500	250
CERN SPS (W. Europe)	1976	500	250
PROTON <25GeV but >5GeV			
Dubna (E. Europe)	1957	10	~30? ^c
Moscow (USSR)	1961	7 ^b	~20? ^c
Berkeley (USA)	1954	6	34
Argonne ZGS (USA)	1963	13	50
Rutherford (UK)	1963	7	28
ELECTRON >5GeV			
Yerevan ARUS (USSR)	1967	6	~10? ^{c,d}
Cambridge CEA (USA)	1962	6	12
Hamburg DESY (FRG)	1964	7	19
SLAC (Stanford) (USA)	1966	22	114
Daresbury NINA (UK)	1966	5	12
Cornell (USA)	1967	12	12
LINEAR e ⁻ <5GeV			
Kharkov (USSR)	1964	2	~10? ^c
Stanford Mk III (USA)	1952	1.2	7
Orsay (France)	1959	2.3	14
e ⁺ e ⁻ COLLIDERS			
Novosibirsk (a) VEPP1 (USSR)	?	0.16	?
(b) VEPP2	1965	0.5	~2? ^c
(c) VEPP2M	1974	0.7	?
(d) VEPP3	1970	3	?
(c) VEPP4	1979	7	~20? ^c
Orsay (a) ACO (France)	1965	0.5	2
(b) DCI	1976	1.8	13
Frascati ^e ADONE (Italy)	1969	1.5	9
Stanford ^e SPEAR (USA)	1972	4	~24
Hamburg DORIS (FRG)	1973	5	45

a. Actual prices (unadjusted for inflation) based on official exchange rates.

b. Subsequently raised to 10 GeV.

c. Estimates only, based on the costs of similar Western machines.

d. A smaller Soviet electron synchrotron at Tomsk cost two million roubles. Since the capital cost of an accelerator increases approximately linearly with energy, one would expect the Yerevan electron synchrotron with five times the energy of the Tomsk accelerator to have cost approximately five times as much — i.e. ten million dollars, if one assumes an exchange rate of 1 rouble = 1 US dollar.

e. This laboratory did operate a smaller collider in the early 1960s, but it was used more as a test-bed for accelerator physics than as an experimental high-energy physics research facility.

1960 to 1982, together with their nearest equivalent Western competitors. The list includes virtually all the world's largest accelerator facilities.³³ All the Eastern-bloc facilities are in the Soviet Union, while the main Western accelerator centres are in the US and Western Europe. Since 1967, the largest Eastern-bloc facility has been the Soviet 76 GeV (billion or giga-electron volts) proton synchrotron operated by the Institute for High-Energy Physics (IHEP) at Serpukhov. From 1967 to 1972, this was the most powerful accelerator in the world, just as the 10 GeV synchrophasotron at the international Joint Institute for Nuclear Research (JINR) at Dubna had been for a brief period towards the end of the 1950s.³⁴ Another major proton accelerator is the 7 GeV (subsequently upgraded to 10 GeV) machine operated by the Institute for Theoretical and Experimental Physics (ITEP), Moscow. As for the electron machines, there are the 6 GeV synchrotron at Yerevan in Armenia, the 2 GeV linear accelerator at Kharkov in the Ukraine, and various electron-positron colliders at Novosibirsk in Siberia. Table 2 classifies the various accelerators according to energy-range and particles accelerated, this being the most obvious way of identifying the main sets of competing facilities. Thus, the Serpukhov accelerator is most directly comparable with the slightly older and lower-energy synchrotrons at CERN (the Proton Synchrotron or CERN PS) and Brookhaven National Laboratory (the Alternating Gradient Synchrotron or AGS) on the US East Coast, as well as the CERN Intersecting Storage Rings (ISR) and the 'Super' Proton Synchrotrons at CERN (the CERN SPS) and Fermilab in the US Mid-West. Similarly, the Dubna and Moscow proton accelerators can be compared with the machines at Argonne National Laboratory near Chicago³⁵ and Rutherford Laboratory in Britain, with the slightly older Bevatron at Berkeley in California, and to a certain extent with the somewhat larger but contemporary CERN PS and Brookhaven AGS. Among electron machines, the Yerevan synchrotron had several virtually identical rivals at Cambridge in Massachusetts, at the German Electron Synchrotron Laboratory (DESY) near Hamburg, and at Daresbury Laboratory in Britain.³⁶ The higher-energy synchrotron at Cornell University and the linear accelerator at the Stanford Linear Accelerator Center (SLAC) in California also provide useful comparisons. The Kharkov electron linear accelerator is very similar to machines operated for many years by Stanford University (the Mark III), and by the Orsay Laboratory in France. Finally, the

Novosibirsk electron-positron colliders can be compared with those operated by Orsay, Frascati Laboratory (in Italy), SLAC, and DESY.

How great have been the scientific contributions from these various Eastern-bloc accelerators, especially from the principal machine at Serpukhov, compared with those from their Western counterparts? A recent official US Congress Report concluded (on the basis of rather limited evidence) that 'to date, few significant physics discoveries have been attributed to research conducted on Soviet accelerators.'³⁷ How accurate is this assessment?

Accelerator Outputs

Scientific Publications

Publication counts are one of the most frequently used, but also most problematic, indicators of scientific output. Their use as an output indicator rests on the assumption that scientists (in basic research, at least) prefer to present the end-result of most research in scholarly publications. Not only is this thought to be an effective way to transmit information to the scientific community, but it also constitutes an important means of securing recognition in that community; furthermore, it acts as a convenient accounting device for funding agencies in ensuring that scarce resources have been effectively used.

Because of the differing institutional, social and political pressures to publish in different countries, publication counts need to be undertaken with considerable care (both technical and conceptual).³⁸ It must be recognized, for example, that publications do not all have an identical impact on the advance of scientific knowledge, and that the same results are sometimes republished in different forms (often first in conference proceedings, and later in a journal). Moreover, in attempting to compare the scientific outputs of different research facilities, one must ensure that only 'like' is compared with 'like'; for example, the apparently greater publication output of one high-energy physics laboratory compared with a rival operating similar research facilities may be because the former has a large theory group attached (theorists tend to publish rather more frequently than experimentalists).³⁹

In comparing publication outputs, we have tried to ensure that our

methods are as unbiased as possible. Only high-energy physics papers reporting new (that is, previously unpublished) experimental data have been included. Preprints and conference papers were excluded since revised versions are generally published later. And, since we are only comparing experimental outputs (which provide the rationale for constructing costly accelerators), we have excluded all theoretical, instrumental and review papers. We also attempted to ensure full coverage of all the main Eastern-bloc and Western journals. This was done by asking physicists to identify the journals used to publish the bulk of experimental high-energy physics results; analysis of the results showed that most papers are published in eleven major international journals (listed in note (b) to Table 3). Four of the journals are Soviet, five are West European, and two are American. We scanned all these journals from 1961 to 1982, classifying experimental high-energy physics papers in terms of the accelerator (or accelerators — see note (c) to Table 3) used.⁴⁰ The resulting publication list was then cross-checked against various data compilations and lists of papers provided by research laboratories. This search yielded about five percent more items: some of these involved borderline decisions on whether the results reported were 'experimental' or 'high-energy physics' (if there was any doubt, they were included); the remainder were in journals other than the eleven scanned. The final totals for each accelerator are shown in Table 3.

Before examining the figures, we must look critically for possible sources of bias. One may arise from journals that have not been scanned — in particular, national physics journals and those of individual Soviet Republics. Whereas such journals probably account for 10 percent or less of all experimental high-energy physics publications in the West, the corresponding figure in the East is likely to be rather higher. This is especially true for smaller accelerators such as those at Kharkov and Yerevan (the users of which sometimes publish in the *Ukraine Physics Journal* and the *Proceedings of the Armenian Academy of Sciences* respectively), and for Dubna, where visitors from Eastern Europe publish at least some papers in domestic physics journals. The effect is probably greatest for Kharkov, where we estimate that up to 25 percent of papers are published in unscanned journals; but for the Serpukhov, Moscow and Novosibirsk facilities, the figure appears to be only 10 to 15 percent,⁴¹ much closer to the value for Western accelerators. Although we have made some attempt to include such publications by using various other publication lists (see note (b) to Table 3), our

TABLE 3
Numbers of Experimental High-Energy Physics Papers^a Published in International Journals^b during the Preceding Two Years

Accelerator ^c	1962	1964	1966	1968	1970	1972	1974	1976	1978	1980	1982
PROTON >25GeV											
Serpukhov	–	–	–	–	29	63	109	123	136	129	110
CERN PS	37	157	211	215	236	254	229	278	246	108	67
Brookhaven AGS	17	58	127	166	178	150	153	93	60	51	31
CERN ISR	–	–	–	–	–	21	38	58	51	51	62
Fermilab	–	–	–	–	–	5	107	176	182	179	116
CERN SPS	–	–	–	–	–	–	–	–	26	78	130
PROTON <25GeV											
Dubna	69	64	42	33	34	22	20	29	36	24	19
Moscow	7	15	15	27	24	24	43	36	24	24	15
Berkeley	143	122	82	95	83	60	34	13	10	5	3
Argonne ZGS	–	–	13	55	88	97	102	68	57	29	21
Rutherford	–	–	17	21	23	26	32	20	20	22	2
ELECTRON >5GeV											
Yerevan ARUS	–	–	–	–	2	10	7	7	9	11	10
Cambridge CEA	–	11	16	35	22	10	8	–	–	–	–
Hamburg DESY	–	–	11	39	24	37	33	22	17	4	1
SLAC	–	–	–	21	54	82	74	79	68	33	15
Daresbury NINA	–	–	–	–	9	18	13	10	10	12	5
Cornell	–	–	–	–	14	17	14	18	18	8	3
LINEAR e⁻ <5GeV											
Kharkov	–	–	–	6	20	31	23	29	18	22	14
Stanford Mk III	14	19	22	18	12	6	2	1	–	–	–
Orsay	2	11	11	11	5	4	3	–	–	–	–
e⁺e⁻ COLLIDERS											
Novosibirsk	–	–	–	3	1	9	1	0	6	4	10
Orsay ACO+DCI	–	–	–	1	7	4	4	4	2	6	9
Frascati ADONE	–	–	–	–	5	16	26	17	12	10	5
Stanford SPEAR	–	–	–	–	–	–	4	30	36	21	25
Hamburg DORIS	–	–	–	–	–	–	1	10	30	16	10

a. 'High-energy physics' is defined here as physics carried out with accelerators able to produce primary particles at an energy higher than 1 GeV. 'Experimental' high-energy physics papers are those which contain new (i.e. previously unpublished) experimental data. We have excluded theoretical papers, reviews or compilations of data, preprints, book articles, conference proceedings and theses. Also excluded are papers on instrumentation, nuclear level structure, and studies of cosmic rays.

b. This publication list was derived by scanning the following journals: *Soviet Physics-JETP*; *JETP Letters*; *Soviet Journal of Nuclear Physics*; *Soviet Physics-Doklady*; *Nuclear Physics B* (and before that, *Nuclear Physics*); *Physics Letters B* (and before that, *Physics Letters*); *Nuovo Cimento*; *Lettere al Nuovo Cimento*; *Physical Review D* (and before that *Physical Review*); *Physical Review Letters*; and *Zeitschrift für Physik C*. Additional information came from Annual Reports and publication lists provided by the various laboratories, and data compilations such as Particle Data Group, *An Indexed Compilation of Experimental High-Energy Physics Literature* (Berkeley, Calif.: Lawrence Berkeley Laboratory, LBL-90, 1978). As a result, the final publications list contains a small number of papers published in a variety of other journals.

c. All the papers were scanned to establish which accelerator was used to obtain the experimental results. In a small number of cases (2.4%), more than one accelerator was used. For such cases, each accelerator used was credited with that paper.

coverage of them is still rather incomplete. When the overall coverage of papers from Western accelerators (90 to 95 percent) is compared with that for papers from Eastern-bloc facilities (between 75 and 90 percent), it can be seen that a bias of some 10 to 15 percent remains against the latter (and rather more in the case of Kharkov).

A second potential source of bias lies in differing publication practices. Pressures to publish may be greater in the West (because of the use of publications to determine promotion and project funding), and this may lead researchers to break up their experimental data into several short articles when a single substantial paper would suffice, or to publish results prematurely to achieve 'priority'. In the East, priority is achieved by submitting work to state committees charged with scrutinizing research results before publication can take place. The long process of publication, beginning with formal defence of work within the laboratory, and the need to obtain the signatures of senior administrators, may thus not only reduce the relative number of publications but improve their overall quality. However, such effects should be revealed in the citation data, since one would expect longer, more substantial, and higher-quality papers to earn more citations. (This question is considered later in note 54.)

A third source of bias is that it has become customary for certain Eastern-bloc researchers to publish their results twice — once in Russian in a Soviet journal, and once in English in a West European one. This particularly affects Serpukhov, and, according to physicists interviewed in Eastern Europe, tends to arise most in East-West collaborations. We estimate that this introduces a bias *in favour* of Serpukhov of 10 percent or so,⁴² which almost cancels out the first source of bias discussed above.

Finally, our figures are in general biased against those facilities that are used for types of research other than high-energy (particle) physics (such as nuclear physics or synchrotron-radiation work.) This applies particularly to the three electron linear accelerators, and in recent years has also become the case with the proton accelerators at Dubna, Moscow and Berkeley. Thus, in evaluating the *high-energy physics* outputs of these accelerators, we are considering only part of the research work they undertake. (The distribution of activity at such facilities around the world is probably much the same, so this source of bias may not be particularly important.)

Given these reservations, what do the figures in Table 3 tell us?

Although the annual output of papers from Serpukhov has been just over twice as great as that from the CERN Intersecting Storage Rings,⁴³ it was appreciably less than from not only the larger Fermilab accelerator, but also the lower-energy machines at CERN and (initially) at Brookhaven (until its productivity plummeted in the mid-1970s as American experimentalists migrated to the more powerful facility at Fermilab). Similarly, the outputs from the Dubna, and particularly the Moscow, accelerators were in general considerably smaller than those from the nearest equivalent American machines at Berkeley and Argonne (and only a fraction of those from the somewhat higher-energy CERN PS and Brookhaven AGS accelerators), although they were roughly similar to that from the British accelerator at Rutherford Laboratory. Such an imbalance also appears for the world's main electron accelerators. The synchrotron at Yerevan produced relatively few papers, less even than the Daresbury machine. Indeed, of all the Eastern-bloc accelerators, only that at Kharkov appears to have produced a comparatively high number of research papers (though this may be less a reflection of its relative efficiency than the fact that, by the early 1970s, the interest of high-energy physicists in the West had moved on from the rival facilities at Stanford University and Orsay to other accelerators).

Even allowing for the possible bias of up to 15 percent discussed earlier, it must be concluded that, overall, the publication output from the Eastern-bloc accelerators is low in world terms — typically a factor of two below that of equivalent Western facilities. In particular, neither Dubna nor, to a lesser extent, Serpukhov, seems to have capitalized on their temporary positions as the highest-energy machines in the world in the same way that, in their respective periods, the CERN PS and Brookhaven AGS, and later the Fermilab accelerator, appear to have done. However, publication counts on their own are only a very limited indicator of scientific contributions. We need to know more about the relative impact on the advance of scientific knowledge of these papers. It may well be that, because the career structures of Eastern-bloc scientists are less subject to the 'publish or perish' syndrome, they have tended to publish only more substantial papers. If the contribution to scientific progress made by Eastern-bloc papers has, on average, indeed been higher than that by Western papers, then this might offset the generally much lower publication output of Eastern-bloc accelerators. Is there any evidence for such a countervailing effect?

Overall Impact of Scientific Publications

In an attempt to provide a means of 'weighting' publications according to their relative contribution to the advance of knowledge, science-policy analysts have in recent years turned to citation data. However, as we have argued elsewhere,⁴⁴ citation figures provide not so much an indicator of the 'quality' or 'importance' of papers, as of their 'impact' on the advance of knowledge. A high-quality paper in a stagnating field may contribute little to the advance of knowledge, and hence receive less citations than a paper of similar quality in a more active field. A paper's 'importance' is the influence it would achieve were scientific communication completely free from institutional, social and political constraints. Thus, a potentially very influential paper may go unnoticed and uncited if it is written in an obscure journal by a not-very-prominent author, or in a non-English language. A publication's 'impact', in contrast, describes its *actual* influence on the advance of knowledge, and it is this for which citations provide a (partial) indicator.⁴⁵

The citation records of each of the experimental publications in our list were obtained by manual scanning of the *SCI* for the years 1961–82. Unlike computer scanning, this method enables most of the technical problems associated with the *SCI* (misspelt names, incorrect references, and so on—see Table 1) to be easily overcome. Since the *SCI* covers the eleven main international high-energy physics journals, as well as most of the subsidiary journals occasionally used by Western high-energy physicists, the citation data for accelerators in the West should be between 90 and 95 percent complete (like the publication totals). In contrast, the citation data for Eastern-bloc accelerators are almost certainly much less complete.

There are three main sources of likely bias. First, there are the papers in our list that 'lose' citations from articles in journals not scanned by ISI. We have seen that up to 20 percent or so of Eastern-bloc papers are published, not in the eleven major international journals, but in the national physics journals of either East European states (which are generally scanned by ISI), or of individual Soviet Republics (which are not). Citations from articles in these latter journals are 'lost'. On the basis of the estimate that 10 to 20 percent of high-energy physics papers in the Eastern bloc are published in unscanned journals, we can expect a bias of similar magnitude in the

citation counts,⁴⁶ although it is likely to be under 10 percent for the more international accelerators (Serpukhov and Dubna) since these earn a larger fraction of their citations from Western journals, nearly all of which (for this field at least) are scanned by ISI.

A second bias involves those experimental publications omitted from our list altogether; these 'lose' all their citations. If such publications were on average cited with the same frequency as publications in the list, the resulting citation bias against Eastern-bloc accelerators would be of the same magnitude as that in the publication data⁴⁷ — that is, 10 to 15 percent, and slightly more than 20 percent in the case of Kharkov and Yerevan. However, it is clear from our data on papers published in the physics journals of Soviet Republics that these are cited far less often than papers in the international journals (which have a larger audience and therefore reach more potential citers).⁴⁸ Hence, this particular bias is somewhat smaller, perhaps 10 percent or less.⁴⁹

A third possible source of bias, which is rather harder to estimate, is that papers published in the main Soviet journals tend to contain less references on average than those in equivalent Western journals. Full-length Soviet papers typically contain around three-quarters as many references as Western articles, and 'letters' only half as many.⁵⁰ There are three possible explanations: either Eastern-bloc physicists draw less heavily on previous results because such work has less impact on them; or they cite fewer references because their own literature is not so extensive as that of the West, and therefore contains fewer potentially citable articles; or they are more discriminating in their use of references. If the last is true, then each Eastern-bloc citation implies a greater degree of indebtedness than a Western citation. This would suggest that, in comparing the relative scientific impact of research between East and West, one should 'weight' Eastern-bloc citations more heavily. Assuming an average figure (for both full-length articles and 'letters') for the East/West 'weight' ratio of about two-thirds implies that 'unweighted' citation data will be biased by 33 percent against the Eastern bloc. However, Eastern-bloc research earns a substantial fraction of its citations from articles in Western journals, thereby reducing the effect to nearer 20 percent. Even this is probably an over-estimate of the residual bias, since the first explanation of the lower number of references in Eastern-bloc papers (previous work having less impact) is at least partly valid. Moreover, the bias should be considerably smaller for work of international interest (such as that

at Serpukhov), since this will be referred to more equally by Western and Eastern authors.

Taking all three sources of bias together,⁵¹ it appears that an overall citation bias against Eastern-bloc accelerators in the region of 30 to 50 percent might be expected; the larger machines probably fall in the lower part of this range, and the smaller ones in the upper part. This means, for example, that the 'crude' citation figures for the Kharkov accelerator should be doubled, while those for Serpukhov or Dubna should be increased by just under a half. Such biases should be borne in mind when examining Table 4.

Table 4 presents the numbers of citations achieved by each accelerator over four-year periods from 1961 onwards as listed in even-year editions of the *SCI*. The figures suggest that publications from Serpukhov had the greatest impact between 1974 and 1976, these citations being to experiments in the early 1970s when the accelerator was briefly the world's highest-energy machine. Overall, however, the impact of Serpukhov publications over the accelerator's first twelve years appears to have been very much less (even allowing for a possible 30 percent bias) than papers from the lower-energy CERN PS and Brookhaven AGS accelerators over their first twelve years, and even smaller than the impact of papers from the Fermilab accelerator. Similarly, the number of citations earned by publications from the Dubna and Moscow accelerators is approximately an order of magnitude less than that for the CERN PS and the Brookhaven AGS, even after allowing for bias. These two Eastern-bloc machines have also made considerably less impact than similar accelerators at Berkeley and Argonne, and probably slightly less even than the Rutherford Nimrod accelerator. Similarly, the impact of the Yerevan accelerator has been an order of magnitude less than all the other large electron accelerators (except for Daresbury). The various Novosibirsk machines have done little better, with an impact an order of magnitude less than those at Stanford and Hamburg. The gap between the Kharkov accelerator and its rival is somewhat smaller, but this may be because in the West this particular energy-region was fairly thoroughly explored during the 1960s, and because by the early 1970s the interests of experimenters had switched elsewhere.

Overall, then, we conclude that, although the Serpukhov accelerator achieved a relatively high impact during the first half of the 1970s, the evidence points to this having been exceptional among Eastern-bloc accelerators. Even allowing for the various sources of

TABLE 4
Numbers of Citations to Experimental Journal Articles
Published During the Preceding Four Years

	1964	1966	1968	1970	1972	1974	1976	1978	1980	1982
PROTON >25GeV										
Serpukhov	-	-	-	139	273	482	494	318	311	301
CERN PS	375	1280	1327	1195	1153	1322	1135	1174	774	250
Brookhaven AGS	597	1265	1350	1202	959	757	779	419	174	116
CERN ISR	-	-	-	-	271	825	706	590	443	528
Fermilab	-	-	-	-	19	778	1903	2622	1318	804
CERN SPS	-	-	-	-	-	-	-	317	523	801
PROTON <25GeV										
Dubna	73	116	64	40	31	37	66	47	44	34
Moscow	10	50	25	23	31	42	58	17	34	26
Berkeley	909	780	497	517	353	216	61	57	25	16
Argonne ZGS	-	54	248	399	485	467	360	405	312	113
Rutherford	-	102	176	139	97	123	60	51	93	37
ELECTRON >5GeV										
Yerevan ARUS	-	-	-	0	9	14	8	5	28	32
Cambridge CEA	33	146	198	169	105	47	15	-	-	-
Hamburg DESY	-	18	304	279	246	181	88	97	14	3
SLAC	-	-	95	457	671	664	466	420	328	129
Daresbury NINA	-	-	-	19	73	71	41	19	15	13
Cornell	-	-	-	87	72	105	104	82	48	9
LINEAR e⁻ <5GeV										
Kharkov	-	-	5	18	31	71	25	21	19	29
Stanford Mk III	119	178	220	113	64	16	9	6	-	-
Orsay	17	40	36	15	7	13	6	-	-	-
e⁺e⁻ COLLIDERS										
Novosibirsk	-	-	40	27	29	31	2	6	10	15
Orsay ACO + DCI	-	-	16	119	107	58	24	21	34	42
Frascati ADONE	-	-	-	5	63	170	231	49	45	28
Stanford SPEAR	-	-	-	-	-	6	866	826	363	304
Hamburg DORIS	-	-	-	-	-	0	90	357	462	115

Note: These figures were obtained by manual scanning of the *Science Citation Index*.

bias, their impact on the advance of knowledge in high-energy physics seems, in general, to have been uniformly low compared with their Western equivalents. Such a conclusion is not, however, the only possible one: for example, citation totals may be largely determined by the scale of research activity at each accelerator, and because this is generally smaller in the Eastern bloc, this may be the reason for the lower citation figures. To examine this possibility, we

have calculated the average number of citations per paper (the 'citation rate') for each accelerator.⁵² These figures are given in Table 5.

Again, the figures in Table 5 may be biased against Eastern-bloc accelerators. Of the three sources of bias discussed for Table 4, the second (papers omitted from our publication list) is obviously unimportant, since it merely reduces the sample size for averaging.⁵³ As we saw earlier, the total estimated bias from the other two sources

TABLE 5
Average Number of Citations Per Paper for Journal Articles
Published During the Preceding Four Years

	1964	1966	1968	1970	1972	1974	1976	1978	1980	1982
PROTON >25GeV										
Serpukhov	-	-	-	4.8	3.0	2.8	2.1	1.2	1.2	1.3
	-	-	-	(10.7)	(6.4)	(4.6)	(3.9)	(2.6)	(2.3)	-
CERNPS	1.9	3.5	3.1	2.6	2.3	2.7	2.2	2.2	2.2	1.4
Brookhaven AGS	8.0	6.8	4.6	3.5	2.9	2.5	3.2	2.7	1.6	1.4
CERNISR	-	-	-	-	12.9	14.0	7.4	5.4	4.4	4.7
Fermilab	-	-	-	-	3.8	6.9	6.7	7.3	3.7	2.7
CERNSPS	-	-	-	-	-	-	-	12.7	5.2	3.8
PROTON <25GeV										
Dubna	0.5	1.1	0.9	0.6	0.6	0.9	1.3	0.7	0.7	0.8
	(0.8)	(1.3)	(1.8)	(1.2)	(1.0)	(2.3)	(1.9)	(2.1)	(2.0)	-
Moscow	0.5	1.7	0.6	0.5	0.6	0.6	0.7	0.3	0.7	0.7
	(2.0)	(2.5)	(1.0)	(0.6)	(3.5)	(1.0)	(1.0)	-	-	-
Berkeley	3.4	3.8	2.8	2.9	2.5	2.3	1.3	2.5	1.7	2.0
Argonne ZGS	-	4.2	3.6	2.8	2.6	2.3	2.1	3.2	3.6	2.3
Rutherford	-	6.0	4.6	3.2	1.9	2.1	1.1	1.2	2.2	1.5
ELECTRON >5GeV										
Yerevan ARUS	-	-	-	-	0.8	0.8	0.6	0.3	1.4	1.5
Cambridge CEA	3.0	5.4	3.9	3.0	3.3	5.9	2.3	-	-	-
Hamburg DESY	-	1.6	6.1	4.4	4.0	2.6	1.6	2.5	0.7	0.6
SLAC	-	-	4.5	6.1	4.9	4.3	3.0	2.9	3.2	2.7
Daresbury NINA	-	-	-	2.1	2.7	2.3	1.8	1.0	0.7	0.8
Cornell	-	-	-	6.2	2.3	3.4	3.3	2.3	1.8	0.8
LINEAR e⁻ <5GeV										
Kharkov	-	-	0.8	0.7	0.6	1.3	0.5	0.4	0.5	0.8
Stanford Mk III	3.6	4.3	5.5	3.8	3.5	2.0	-	-	-	-
Orsay	1.3	1.8	1.6	0.9	0.8	1.9	0.9	-	-	-
e⁺e⁻ COLLIDERS										
Novosibirsk	-	-	13.3	6.8	2.9	3.1	-	1.0	1.0	1.1
	-	-	-	-	(2.8)	(3.6)	-	(2.5)	(1.3)	-
Orsay ACO + DCI	-	-	-	14.9	9.7	7.3	3.0	3.5	4.3	2.8
Frascati ADONE	-	-	-	1.0	3.0	4.0	5.4	1.7	2.0	1.8
Stanford SPEAR	-	-	-	-	-	-	25.5	12.5	6.4	6.6
Hamburg DORIS	-	-	-	-	-	-	8.2	8.9	10.2	4.4

Note: These statistics are based on the data contained in Tables 3 and 4. The figures in brackets refer to the average citation rates for just the articles published in Western journals.

is probably in the range between 20 and 40 percent. However, the bias will only be this large for papers published in Eastern-bloc journals; for papers published in Western journals, it should be very much smaller.

Table 5 shows that papers from Serpukhov initially achieved quite a high citation rate — higher, for example, than those from early work at the CERN PS (the scale of research activity at the PS was, however, very much greater, as can be seen from Table 3). Indeed, for papers published in Western journals, the average Serpukhov citation rate came from close to the initial rate for the CERN ISR and SPS, appreciably ahead of Fermilab and even the Brookhaven AGS. It may be that the ‘better’ one-third papers reporting early Serpukhov results were channelled towards Western journals, because physicists from Europe and the US were involved in many of the early experiments. In contrast, the average impact of the remaining two-thirds of Serpukhov papers appears to have been very low indeed. As a result, apart from a brief period early in the 1970s, papers from the CERN PS and the Brookhaven AGS seem to have had a greater average impact than those from Serpukhov, despite the latter’s considerable advantage in terms of energy and more recent construction.

Of the other Eastern-bloc accelerators, papers from Dubna, Moscow, Yerevan and Kharkov all consistently achieved a comparatively low impact, even after allowing for a bias of up to 40 percent. Only the earliest papers from Novosibirsk had a relatively high average impact, presumably because that collider was briefly the largest such facility in the world, and (in contrast with Dubna, which also temporarily held a world lead) its users exploited this advantage by carrying out at least a few novel and important experiments. However, this lead was short-lived, and, as Table 3 demonstrates, only a very small number of papers was published during this period. Overall, therefore, even after allowing for possible bias and the smaller scale of research activity, we must conclude that the average impact of publications from these machines seems to have been low in world terms.⁵⁴

Highly-Cited Papers and Discoveries

A major criticism of all the output indicators discussed so far is that, while they provide comparative data on the total output of papers

(most of which, at best, add only a small increment to the sum of scientific knowledge), they do not necessarily reveal which accelerators have been responsible for the occasional crucial or even 'revolutionary' discovery. However, such discoveries — and also slightly lower-level but nevertheless important 'advances' — can generally be identified from data on highly cited papers.⁵⁵ Out of our list of approximately 9000 articles published between 1961 and 1982, the top 2 percent earned 30 or more citations in a year. (The corresponding figures for the top 8 percent, 0.5 percent, and 12.5 percent are 15, 50 and 100 citations respectively.) Data on these highly-cited papers are given in Table 6.

We should again note the likely bias in these figures. There are two possible sources: from papers excluded from our list; and from papers which are included, but which 'lose' some of their citations. The first is likely to have a negligible effect, since the more important experimental results are almost without exception published in one of the major international journals.⁵⁶ However, the second is far from negligible — as much as 30 percent for the more international of the Eastern-bloc facilities (Serpukhov and Dubna), and rather more than this for the others. The two right-hand columns of Table 6 present the 'crude' data on highly cited papers adjusted to take account of biases of 20 and 40 percent.

In its early years, the Serpukhov accelerator produced a relatively large number of highly cited papers. Assuming a bias of approximately 20 or 30 percent, its record over the period 1969–72 is comparable with that of any other major accelerator: indeed, it was responsible for the only paper cited over one hundred times in a year.⁵⁷ Since then, however, it has yielded a negligible number of highly cited papers, far fewer even than the earlier-vintage and lower-energy CERN PS and Brookhaven AGS accelerators, let alone the new machines at Fermilab and CERN. As for the other Eastern-bloc accelerators, their record is relatively poor, even after adjusting for a bias of 40 percent. Perhaps the best that can be said is that some of them have come close to equalling the record of the less successful of the main Western facilities.

Peer-Evaluation

Our previous studies have suggested that, while indicators based on publication and citation counts provide essential information on

TABLE 6
 Numbers of Highly Cited Experimental Papers for the Period 1961-80; Number of Papers Cited n or More Times in One Year

	1961-64					1965-68					1969-72					1973-76					
	$n \geq 15$	$n \geq 30$	$n \geq 50$	$n \geq 100$	$n \geq 15$	$n \geq 30$	$n \geq 50$	$n \geq 100$	$n \geq 15$	$n \geq 30$	$n \geq 50$	$n \geq 100$	$n \geq 15$	$n \geq 30$	$n \geq 50$	$n \geq 100$	$n \geq 15$	$n \geq 30$	$n \geq 50$	$n \geq 100$	
PROTON >25GeV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Serpukhov	-	-	-	-	-	-	-	-	12	4	2	1	7	0	0	0	0	0	0	0	0
CERN PS	9	1	0	0	46	1	0	0	19	1	0	0	18	4	2	0	0	0	0	0	0
Brookhaven AGS	24	5	1	1	42	12	1	0	22	1	0	0	15	5	2	1	0	0	0	0	0
CERN ISR	-	-	-	-	-	-	-	-	13	4	2	0	28	12	2	1	0	0	0	0	0
Fermilab	-	-	-	-	-	-	-	-	4	3	3	0	71	26	9	0	0	0	0	0	0
CERN SPS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PROTON <25GeV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dubna	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Moscow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Berkeley	33	5	2	0	9	0	0	0	8	1	0	0	2	0	0	0	0	0	0	0	0
Argonne ZGS	-	-	-	-	6	0	0	0	7	0	0	0	5	0	0	0	0	0	0	0	0
Rutherford	-	-	-	-	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ELECTRON >5GEV	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Yerevan ARUS	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0
Cambridge CEA	1	0	0	0	7	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Hamburg DESY	-	-	-	-	10	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
SLAC	-	-	-	-	4	1	0	0	21	4	2	0	14	2	1	0	0	0	0	0	0
Daresbury NINA	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0
Cornell	-	-	-	-	-	-	-	-	4	0	0	0	1	0	0	0	0	0	0	0	0
LINEAR $e^- < 5\text{GeV}$	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kharkov	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stanford Mk III	7	1	0	0	8	1	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0
Orsay	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e^+e^- COLLIDERS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Novosibirsk	-	-	-	-	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orsay ACO + DCI	-	-	-	-	1	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0
Frascati ADONE	-	-	-	-	-	-	-	-	2	1	0	0	3	1	1	1	1	1	1	1	1
Stanford SPEAR	-	-	-	-	-	-	-	-	0	0	0	0	23	12	7	5	0	0	0	0	0
Hamburg DORIS	-	-	-	-	-	-	-	-	0	0	0	0	3	2	1	0	0	0	0	0	0

Note: These figures were obtained by manual scanning of the Science Citation Index.

relative contributions to scientific progress, they must always be considered alongside peer-evaluation data. This conclusion probably applies even more strongly to East–West comparisons where, as we have seen, the bibliometric data are significantly biased. How, then, in the opinion of high-energy physicists in the East and West, do the scientific outputs from Eastern-bloc accelerators compare with those from equivalent facilities in Western Europe and the US?

We obtained peer-evaluation data for all the accelerators in the present study by interviewing 182⁵⁸ experimental and theoretical high-energy physicists during late 1981 and early 1982. Our sample consists of 52 physicists in the US, 112 from six countries in Western Europe (including a number who had worked on experiments in the Eastern bloc), and 18 from groups in three East European countries regularly using accelerators in the Soviet Union. The interviews were intensive (typically lasting 1½ to 2 hours) and structured, being based on a common set of questions but with some additional questions for special groups of researchers. After giving brief details of their background and career, interviewees were asked first to describe their own research and perceived contributions to high-energy physics; next, to identify the principal contributions of the various collaborations in which they had worked; then those from the accelerators they had used; and, finally, the overall contributions from the world's other major accelerator facilities. This sequence helped respondents prepare themselves for the peer-evaluation section of the interview. In this, they were invited to rank the accelerators at fourteen laboratories in order, according to their overall contributions to high-energy physics during the period from 1969 to 1978. Relatively few were able to rank all fourteen in full order from first to fourteenth: most regarded at least two as having made equivalent contributions, particularly among those lower in the order; others preferred to identify five or six distinct groups of accelerators, and then to rank these in order. Only eight percent found the ranking too difficult, or refused for personal or professional reasons. We then calculated average rankings on a scale of 1 (top) to 14 (bottom);⁵⁹ the results are given in Table 7. (The final column of the Table converts the overall rankings back into the relative positions of the accelerators at the fourteen laboratories.)

Although there was a slight tendency for Americans to rank their own accelerators rather more highly than did West Europeans, and vice versa, the rankings by these two groups are, overall, very

TABLE 7
Peer-Evaluation Rankings of the Contributions to High-Energy Physics
Made by Accelerators at 14 Laboratories between 1969 and 1978

Accelerator(s)	Rankings ^a by high-energy physicists in:			Self-ranking (sample size)	Peer-ranking (sample size)	Overall average rankings (n = 168)	Average relative position
	US (n = 49) ^b	W. Europe (n = 105)	E. Europe (n = 14)				
Serpukhov	9.0(±0.3)	8.8(±0.2)	7.1(±0.6)	6.7(±0.4) (n=19)	9.0(±0.2) (n=149)	8.7(±0.2)	7=
CERN(PS,ISR,SPS)	2.6(±0.1)	2.4(±0.1)	2.0(±0.2)	2.3(±0.1) (n=108)	2.6(±0.1) (n=60)	2.4(±0.1)	2
Brookhaven AGS	3.6(±0.2)	3.7(±0.1)	3.6(±0.3)	3.5(±0.2) (n=47)	3.7(±0.1) (n=121)	3.7(±0.1)	4
Fermilab	2.8(±0.1)	3.3(±0.1)	3.0(±0.3)	2.6(±0.1) (n=45)	3.3(±0.1) (n=123)	3.1(±0.1)	3
Dubna	12.0(±0.2)	11.5(±0.1)	10.2(±0.5)	11.2(±0.4) (n=9)	11.5(±0.1) (n=159)	11.5(±0.1)	12
Moscow	12.5(±0.2)	12.1(±0.1)	12.2(±0.3)	-	12.2(±0.1) (n=168)	12.2(±0.1)	13=
Argonne ZGS	6.8(±0.2)	8.0(±0.2)	7.8(±0.5)	7.5(±0.5) (n=12)	7.6(±0.1) (n=156)	7.6(±0.1)	6
Rutherford	9.2(±0.2)	9.0(±0.2)	10.1(±0.5)	7.5(±0.4) (n=23)	9.4(±0.1) (n=145)	9.1(±0.1)	9=
Yerevan ARUS	12.3(±0.2)	12.2(±0.1)	11.9(±0.4)	-	12.2(±0.1) (n=168)	12.2(±0.1)	13=
Cambridge CEA	8.9(±0.3)	9.3(±0.2)	10.2(±0.4)	-	9.2(±0.1) (n=165)	9.2(±0.1)	9=
DESY (7GeV, DORIS)	5.7(±0.2)	5.3(±0.1)	5.4(±0.3)	5.1(±0.4) (n=17)	5.4(±0.1) (n=151)	5.4(±0.1)	5
SLAC (20GeV, SPEAR)	1.3(±0.1)	1.2(±0.1)	1.6(±0.2)	1.1(±0.1) (n=17)	1.3(±0.1) (n=151)	1.3(±0.1)	1
Daresbury NINA	10.1(±0.2)	9.8(±0.1)	10.7(±0.5)	-	10.0(±0.1) (n=163)	10.0(±0.1)	11
Cornell	8.2(±0.2)	8.6(±0.2)	9.1(±0.5)	-	8.5(±0.1) (n=165)	8.5(±0.1)	7=

a. These rankings are based on the results of interviews carried out in 1981 and 1982. b. n = sample size.

similar. The Western rankings are also fairly consistent with those made by Eastern-bloc physicists, with two exceptions — while the latter gave virtually the same rankings to the Moscow and Yerevan accelerators as did Westerners, they ranked somewhat higher the work at Dubna and Serpukhov. Either East Europeans hold inflated views on the past performance of these two machines; or Western physicists are unaware of some of their contributions. Let us consider the first possibility. In this survey, as in others we have carried out, there is a small but significant tendency for researchers to over-rate the significance and contributions from research facilities they have used. Thus, for example, as Table 7 shows, physicists who have used the Fermilab accelerator gave it a 'self-ranking' of 2.6 — significantly better than the 'peer-ranking' of 3.3 given by those who have done their experimental work elsewhere. However, it seems doubtful whether this can explain all the variation between Eastern and Western rankings of Serpukhov and Dubna: at least part is likely to be due to an 'ignorance' effect among Western physicists. However, even if one allowed for this, it would only raise Serpukhov from a position to seventh equal with the Cornell accelerator to sixth equal with Argonne, well behind the main Western proton accelerators; and the Dubna machine would only rise from twelfth to eleventh equal with Daresbury, still behind Argonne and Rutherford (and almost certainly the Berkeley Bevatron, if it had been included in the list). As for Moscow and Yerevan, physicists in both East and West agreed that their scientific records over the period 1969–78 put them at the bottom of this list of the world's highest-energy accelerators.⁶⁰

However, the peer-ranking data in Table 7 only give a rather general picture of the output from the accelerators at the fourteen laboratories. Since certain laboratories, such as CERN and SLAC, operate several accelerators, it was necessary to obtain more specific information on scientists' perceptions of the relative performance of *individual* accelerators. The data also only represent the judgements of scientists who have attempted, for each accelerator laboratory, to weigh up the relatively small number of discoveries or major advances for which it has been responsible with the very much greater number of lower-level contributions.⁶¹ Such general rankings are not without utility, but more specific data are also required. We therefore focused in detail upon six of the world's principal proton facilities: the CERN ISR, PS and SPS; the Brookhaven AGS; and the Fermilab and Serpukhov

synchrotrons. High-energy physicists were asked to assess these on a ten-point scale (10 = most successful), distinguishing between their records in making 'discoveries' and in producing 'more precise measurements'. The results are given in Table 8. For 'discoveries', Brookhaven was consistently placed ahead of the other five, while the CERN PS was judged the most successful in terms of 'more precise measurements'. Again differences appear between the views of Eastern-bloc researchers and those of Western

TABLE 8
Assessments (on a 10-point scale^a) of main proton accelerators in terms of (a)
'discoveries' (b) providing more precise measurements

	Assessments by High-Energy Physicists in:			Self-Assessment	Peer-Assessment	Overall Average Assessments	
	United States	Western Europe	Eastern Europe				
<i>Discoveries</i>	IHEP Serpukhov (76GeV)	2.1(±0.2) ^b (n=50) ^c	2.8(±0.2) (n=104)	4.2(±0.5) (n=15)	3.8(±0.5) (n=20)	2.6(±0.1) (n=149)	2.7(±0.1) (n=169)
	CERNPS (28GeV)	6.0(±0.3) (n=50)	7.2(±0.2) (n=104)	7.7(±0.4) (n=15)	7.1(±0.2) (n=86)	6.7(±0.2) (n=83)	6.9(±0.1) (n=169)
	Brookhaven AGS (33GeV)	9.6(±0.1) (n=50)	9.0(±0.1) (n=104)	8.6(±0.5) (n=15)	9.5(±0.1) (n=48)	9.0(±0.1) (n=121)	9.2(±0.1) (n=169)
	CERNISR (31+31GeV)	5.8(±0.3) (n=50)	5.8(±0.2) (n=104)	8.4(±0.3) (n=15)	6.8(±0.3) (n=36)	5.9(±0.2) (n=133)	6.1(±0.2) (n=169)
	Fermilab (500GeV)	7.1(±0.2) (n=50)	7.1(±0.2) (n=104)	8.3(±0.3) (n=15)	7.4(±0.3) (n=46)	7.1(±0.1) (n=123)	7.2(±0.1) (n=169)
	CERNSPS (500GeV)	5.3(±0.2) (n=50)	5.8(±0.2) (n=104)	6.8(±0.4) (n=15)	5.9(±0.3) (n=68)	5.6(±0.2) (n=101)	5.7(±0.1) (n=169)
	<i>More precise measurements</i>	Serpukhov	2.8(±0.2) (n=49)	3.7(±0.2) (n=103)	4.9(±0.6) (n=15)	4.3(±0.5) (n=20)	3.5(±0.2) (n=147)
CERNPS		8.3(±0.2) (n=49)	8.6(±0.1) (n=103)	8.7(±0.4) (n=15)	8.5(±0.1) (n=86)	8.5(±0.1) (n=81)	8.5(±0.1) (n=167)
Brookhaven AGS		7.4(±0.2) (n=49)	7.0(±0.2) (n=103)	8.1(±0.4) (n=15)	7.1(±0.2) (n=47)	7.2(±0.2) (n=120)	7.2(±0.1) (n=167)
CERNISR		6.5(±0.3) (n=49)	7.0(±0.2) (n=103)	8.3(±0.3) (n=15)	7.3(±0.3) (n=35)	6.9(±0.2) (n=132)	7.0(±0.1) (n=167)
Fermilab		6.1(±0.2) (n=49)	5.8(±0.2) (n=103)	7.9(±0.3) (n=15)	6.3(±0.2) (n=46)	6.0(±0.2) (n=121)	6.1(±0.1) (n=167)
CERNSPS		8.0(±0.2) (n=49)	8.3(±0.1) (n=103)	8.0(±0.3) (n=15)	8.2(±0.2) (n=67)	8.2(±0.2) (n=100)	8.2(±0.1) (n=167)

a. 10 = most successful. The assessments are based on the judgements of high-energy physicists of the relative scientific outputs from the accelerators over their entire period of operation up to the time of the interviews in late 1981/early 1982.

b. The figures in brackets indicate the root-mean-square variations between the assessments made by the different groups of high-energy physicists, giving some approximate idea of the divergence of opinion within each group.

c. Sample size.

Europeans and Americans on the scientific performance of the Serpukhov accelerator. However, even the Eastern-bloc physicists placed Serpukhov considerably behind all five Western facilities in both rankings.

An Overall Assessment

We stressed earlier that, if reliable conclusions are to be drawn about the relative scientific performance of Eastern and Western accelerators, there must be some convergence between the different partial indicators used in the assessment. To what extent, then, do the peer-evaluation results accord with those based on bibliometric data?

Taking first the Serpukhov accelerator, we have seen that its annual output of experimental publications was less than that of all the major Western proton machines with the exception of the CERN ISR;⁶² and, even after allowing for any bias, those papers have generally earned less citations. This strongly suggests that the overall impact of Serpukhov work on the advance of knowledge has been less than that of its main Western competitors; confirmatory evidence for this comes from the peer-evaluation assessment using the criterion of 'more precise measurements'. As for 'discoveries', even assuming a citation bias of up to 30 percent, the figures still reveal that Serpukhov produced slightly fewer highly-cited papers than the ISR, and considerably less than the other major Western proton machines;⁶³ this is again consistent with the peer-evaluation results.⁶⁴ The conclusion is that users of the Soviet accelerator failed to capitalize fully upon its position between 1967 and 1972 as the world's highest-energy accelerator — in marked contrast to users of the Brookhaven AGS, and to a lesser extent the CERN PS, who exploited new machines that, between 1960 and 1967, held a similar comparative advantage — as, indeed, did Fermilab from 1972 to 1976.

Similar, but even heavier, criticism can be levelled against the Dubna accelerator. This held a world energy lead from 1957 to the end of 1959, and it might have been expected to remain a front-line machine through the 1960s. The publication and citation records of machines of roughly similar energy (Berkeley, Argonne and Rutherford) show that, even after 1960, when higher-energy facilities came into operation at CERN and Brookhaven, much

important experimental work could still be carried out in this energy region. According to our data, however, Dubna users could not take advantage of its energy;⁶⁵ even allowing for bias, Dubna's publication and citation record is appreciably worse than Berkeley and Argonne, and also worse than the slightly smaller Rutherford accelerator. Furthermore, this conclusion is evidently shared by the large majority of our interviewees, although they did place Dubna slightly ahead of the accelerators at Moscow and Yerevan — again consistent with their bibliometric records.

The Kharkov and Novosibirsk accelerators were not included in the peer-ranking exercise, and so we have no systematic peer-evaluation data for them. Nevertheless, we obtained a range of qualitative data, in particular about the output of Novosibirsk; a number of physicists cited the centre's early results on electron-positron collisions as significant during the mid-1960s (which is consistent with the data on highly-cited papers). There was also a widespread view among physicists, in both East and West, that Novosibirsk had contributed significantly to the development of accelerator physics and technology, and was rated highly in terms of this criterion even compared with most large Western laboratories.⁶⁶ As for the Kharkov linear accelerator, its experimental work seems to have had virtually no impact outside the Soviet Union.

In summary, although the various partial indicators used in this study are without doubt biased against the Eastern bloc, we can estimate the approximate magnitude of these biases and adjust the output indicators accordingly. The adjusted partial indicators based on publications, citation counts, highly-cited papers and peer-evaluation do appear to yield reasonably convergent results. Certain conclusions can then be drawn about the relative contributions to scientific progress made by the various Eastern-bloc accelerators. In each case, the contributions have been generally rather small when compared with equivalent Western facilities. While the more successful accelerators have perhaps come close to matching the scientific performance of the least successful of their Western competitors, others have not managed even this. One East European physicist aptly summarized this conclusion:

Scientists in both the East and the West have the same opinions and views concerning the high-energy physics labs where the most important scientific results and innovations have been made. These are all in the West. (Interview, 1982)⁶⁷

Let us now analyze some possible reasons for this difference in scientific performance between East and West.

Factors Affecting the Scientific Performance of Eastern-Bloc Accelerators

We adopted two approaches to identify and analyze the factors responsible for the difference in scientific performance between East and West. First, high-energy physicists, after ranking Serpukhov and the other main accelerators in terms of 'discoveries' and 'more precise measurements', were questioned about possible reasons for differences in performance. We classified the content of the responses in terms of ten general categories (these are obviously to some extent related). The results are summarized in Table 9. Second, at the end of each interview, we asked physicists to complete an attitude survey containing approximately thirty statements on many of the issues discussed in the interview. Some of these statements were rather controversial, so we have to provide a fairly wide set of response categories, using a 7-point scale. Thus, for each statement, interviewees had the option of (1) 'agreeing strongly', (2) 'agreeing', (3) 'agreeing with reservations', (4) 'being neutral or holding mixed views', and so on, up to (7) 'disagreeing strongly'. While the first approach produces qualitatively better information, the statistics yielded by the content analysis give only a minimum limit for the percentage of interviewees believing each factor to have been important (see note to Table 9). The second approach is much better from the latter point of view, and we use it at various points in the text to support our conclusions.

For example, the first statement in the attitude survey was aimed at establishing the degree of satisfaction (or dissatisfaction) felt by interviewees towards the research facilities at the laboratories where they had carried out experiments. The statement was of the following form:

The system for providing experimental facilities for high-energy physicists at CERN/at Brookhaven/at Fermilab/in Eastern-bloc laboratories is working so well that it does not need changing.

The responses suggest that CERN users were most satisfied with the research facilities available to them; 60 percent agreed with the

TABLE 9
Factors Explaining the Relative Scientific Performance of the Serpukhov Accelerator
(percentage of interviewees believing this factor to have been important)

	Users of Serpukhov Accelerator (n=20)	Others (n=93)	All Interviewees (n=113)
1 Poor/inadequate detectors—e.g. as a result of lack of fast electronics	65%	68%	67%
2 Poor computer facilities	55%	28%	33%
3 Accelerator poorly designed (old-fashioned) and inadequate performance (e.g. poor beams)	35%	17%	20%
4 Accelerator energy not high enough—only a factor of two increase on previous machines . . . soon overtaken	20%	16%	17%
5 Insufficient resources (e.g. as a result of industrial supply problems) and technical support	60%	45%	48%
6 Poor scientific management at Serpukhov	30%	30%	30%
7 Poor contacts between research groups in Eastern Europe, and between East and West	35%	26%	27%
8 Poor competitive ethos in Eastern Europe—little scope for individual initiative, motivation problems, and so on	25%	23%	23%
9 Researchers have less experimental experience than in the West	5%	16%	14%
10 General bureaucratic problems of Eastern European scientific system—e.g. inflexible five-year plans	56%	57%	58%

Note: These figures represent minimum values only, since they are based on a content analysis of answers to a general question concerning the factors structuring Serpukhov's scientific performance. If the interviewees had instead been taken systematically through the above list of factors, we would undoubtedly have obtained considerably higher figures for the percentage believing each factor to have been important.

statement, while only 36 percent disagreed. Fermilab users were also relatively satisfied — the corresponding figures were 54 percent and 37 percent respectively. The situation was rather different for Brookhaven, where major reservations and criticisms about the management of the ISABELLE project (to build a large proton-proton collider) were reflected in the results — only 19 percent agreed, while 70 percent disagreed. However, it was the users of the Eastern-bloc accelerators who appeared most dissatisfied — none agreed, while 94 percent disagreed with the relevant statement. So with what aspects of the facilities were they particularly dissatisfied? We will now focus mainly on Serpukhov since this is the main Soviet facility used by non-Soviet researchers, as well as the largest Eastern-bloc accelerator.

Table 9 shows that one of the main problems facing Serpukhov has concerned the provision of adequate detectors. Although the accelerator itself was officially completed in 1967, much of the subsidiary instrumentation and all the main detector facilities were not ready until several years later; by then the larger Fermilab accelerator was operating. The same situation had afflicted the CERN PS a few years earlier,⁶⁸ putting its experimental programme at an appreciable disadvantage to the Brookhaven AGS during the early 1960s. At Serpukhov, whereas the construction of the accelerator itself received priority in the national plan, so that adequate resources and highly-skilled technical personnel were made available, the equally important task of preparing instrumentation and detectors seems to have had lower priority. Responsibility for this cannot simply be placed on apparent rigidities in the planning system (see factor 10, below), making it more difficult to obtain priority for secondary equipment; some blame must also be attached to the scientific community. As one East European scientist commented,

If you want to build a new machine, you must think in advance about the detectors and experimental apparatus. The big mistake we made was not to think in advance about how to use the machine effectively. The result, therefore, was that the machine has not been used effectively. (Interview, 1982)

Given that a similar situation had arisen ten years earlier at Dubna, it is perhaps surprising that this mistake was not anticipated and avoided. Moreover, as several researchers pointed out, the main detectors were not only late, but some at least (for example, the

Ludmilla and SKAT bubble-chambers) suffered various technical problems, and most had limited performance compared to their far more sophisticated Western equivalents. Only relatively simple (though important) first-generation experiments were therefore possible, leaving the more sophisticated experiments to be performed elsewhere. Even then, much of the early work of high impact was carried out using Western-built detectors, particularly the French bubble-chamber, Mirabelle.

Many of our interviewees felt that the key problem in developing sophisticated instrumentation is obtaining access to high-technology industry. Since that industry has met the requirements of the Soviet military and space programmes, it clearly *could* in principle meet the needs of experimental high-energy physicists. However, firms gain significant prestige by working on military and space projects: some work only on such projects, while others are willing to undertake technologically advanced contracts in other sectors because this allows them to fulfil quotas set by the national plan. High-energy physics has no such advantages. Except when resources are specifically marshalled to construct a large accelerator, particle physics does not have sufficient priority to warrant the special attention of high-technology industry. High-energy physicists, therefore, are not the most attractive of customers; trying to meet their very exacting demands is risky, and they order only small numbers of each item. As one researcher put it:

Firms do not want to work for high-energy physics centres since there is not enough profit in it, as well as being demanding and risky work. The factories see it as more profitable to stick to mass-production goods. (Interview, 1982)

It is thus extremely important for researchers to have strong, day-to-day, personal links with high-technology firms to gain access to state-of-the-art equipment and techniques in, for example, fast electronics — yet this is something most Eastern-bloc scientific centres find it difficult to achieve.⁶⁹ In contrast, the Western market mechanism has produced small advanced-technology firms which specifically service the needs of accelerator centres.⁷⁰ Irrespective of whether the market mechanism is the most appropriate way of determining industrial priorities, it does offer an explanation for the differing fortunes of experimental high-energy physics in the East and West.

The same industrial supply problems probably account for the second factor cited as limiting Serpukhov's scientific performance —

its computing facilities. Computers are necessary not only for the control and automatic operation of the accelerator (especially for monitoring the particle beam), but also for the transfer and processing of data. Initially, the Soviet-made computers at Serpukhov had rather limited capacity, and were, by all accounts, unreliable. The situation improved early in the 1970s when, after high-level discussions between the UK and US governments, authorization was given for the sale of large ICL mainframe computers. However, the computing capacity at Serpukhov remained limited as experimental activity increased, while servicing and using these foreign computers efficiently have led to problems (for example, authorization is needed for foreign-currency purchases of spare parts or additional equipment). Moreover, although the central computing facilities at Serpukhov have been considerably improved, most Eastern-bloc user-groups have rather poor home facilities, with the result that researchers can take weeks to complete data-processing that would take hours in most Western universities.

A third factor is the intrinsic quality of the Serpukhov accelerator itself.⁷¹ Its design represented an extrapolation from the earlier CERN PS and Brookhaven machines, and was therefore not particularly innovative in world terms. The resulting accelerator has a poor repetition-rate and produces beams of relatively low intensity, two factors which have greatly constrained its experimental output; and, because of the computer problems, interviewees reported that the beam was neither very accurate nor especially well controlled. There have also been difficulties with the external beams, especially the neutrino beam. Originally, it had been hoped to avoid at least some of the technical problems anticipated with accelerator control and detector construction by encouraging the participation of Western scientists in experiments at Serpukhov, bringing with them, *inter alia*, some of the modern technology not readily available to high-energy physicists in Eastern Europe. However, the accelerator's inherent limitations soon dampened the interest of Western scientists, despite the significant Western investment in equipment for Serpukhov, by CERN and the French Government in particular. Most of the Western users of Serpukhov whom we interviewed reported being disillusioned by the accelerator's quality during these crucial early years when it was the world leader.

Also contributing to this fairly rapid loss of interest was the fact

that the accelerator's energy represented a rather modest increase on that of previous machines (see factor 4 in Table 9). This relatively narrow, new energy range proved not to be very exciting compared with that opened up by the Brookhaven AGS and CERN PS accelerators, which in 1960 had had a four- to five-fold energy advantage over previous machines. By the time the major Serpukhov detectors were operational, the Fermilab accelerator, with its higher energy and more advanced experimental facilities, was coming into operation, as was the CERN ISR. Many Western high-energy physicists therefore inevitably migrated from Serpukhov to prepare for experiments elsewhere.

Whereas factors 1 to 4 relate essentially to problems with the Serpukhov accelerator and its hardware, factors 5 and 6 are concerned more with the way in which the facility has been supported and operated. Although we have no reliable figures on the funding levels of Eastern-bloc high-energy laboratories, their annual operating budgets seem to be much lower than for equivalent Western facilities. Of those interviewed, 88 percent agreed with the statement, 'Soviet accelerator centres have not been given sufficient technical resources to enable them to compete successfully with their Western counterparts', while none disagreed. In the opinion of many (see factor 5 in Table 9), national plans do not, in general, allocate to high-energy physics the financial and technical resources it requires. Furthermore there is a shortage of human resources. In Western Europe and the USA, a highly developed and extensive community of users, based largely in universities, carry out experiments at the major accelerator centres. Apart from Serpukhov and Dubna, Soviet accelerators tend, for a mixture of institutional and geographical reasons,⁷² to have only a very restricted user-community, and are not so intensively used as Western facilities.

A number of other scientists (30 percent — see factor 6) criticized the senior scientific management at Serpukhov, comparing it unfavourably with that of large Western laboratories. This problem was, in turn, seen in a wider socio-political context.⁷³ Interviewees were particularly critical of what they saw as the overly hierarchical structure of Eastern-bloc science, with strategic decisions being made by a small and rather elderly élite, whose promotion is not always for entirely scientific reasons. Running a large research institute involves significant administrative and political responsibilities, leaving little time for active involvement in

research. Given that there appears to be little inter-institute mobility, and no formal retirement age for directors, it is perhaps not surprising that many interviewees claimed that senior management does not always retain a firm grasp of recent research developments. Such leaders cannot be in the strongest position to plan an experimental programme to exploit a new research facility, nor to decide which of the experiments proposed should be given priority. Of the East Europeans interviewed, three times as many agreed as disagreed with the statement: 'The system by which the allocation of time on Soviet accelerators is decided tends to encourage too much routine research rather than highly innovative but risky experiments'. Some argued further that the concentration of decision-making in the hands of a small administrative élite had a stultifying effect, one casualty of which was the motivation of researchers. This was seen as generally weaker than in the West, where more aspects of scientific decision-making are decentralized, and greater opportunities consequently exist for scientists to participate in determining the direction of a laboratory's research activity.

So far, we have mainly been concerned with explaining the performance of the Serpukhov accelerator only.⁷⁴ However, Serpukhov is almost certainly accorded a higher level of priority and support than laboratories with accelerators of lower energy, where the problems discussed above are probably more, rather than less, severe.

Factors 7 to 9 refer to general problems faced by the whole experimental high-energy physics community in the Eastern bloc, rather than by the user-groups associated with one particular facility. The first concerns the relatively poor contacts both between research groups in the Eastern bloc, and between researchers in East and West. Some interviewees described the relationship between Eastern research groups as being far too secretive, rather than fruitfully collaborative, with sharing of skills and equipment. To some extent, this may reflect difficulties in telephoning, telexing, photocopying, and writing letters to, or visiting, foreign collaborators. For both Dubna and Serpukhov, it was argued that the resulting fragmentation of effort has seriously weakened the overall effectiveness of their research programmes.

However, the paucity of contacts with the Western high-energy physics community has probably had the more serious long-term repercussions. Not only are the possibilities of foreign travel

generally rather limited (except for the more senior scientists), but researchers are not well integrated into the informal communication system. This is partly due to restrictions on researchers circulating unpublished material to scientists outside their institute, particularly those in the West. Late in the 1960s, for example, Serpukhov researchers were slow to recognize the importance of Western developments on the discovery of 'scaling' and the formulation of the parton model.⁷⁵ If their significance had been appreciated earlier, Serpukhov workers might have embarked upon at least some experiments in this leading-edge of physics, and these could conceivably have had a very considerable impact early in the 1970s.

The Soviet Union is certainly not unaware of such constraints on its researchers, as the following interview quotation makes clear:

I am convinced and have evidence that the question of opening up Serpukhov to the West was hotly debated within the Soviet administration, with strong views in favour and against being put forward. The argument that finally won was that the disastrous experience with the Dubna synchrophasotron could not be repeated. Western experience and technology were needed to ensure an adequate experimental output from what was for years the world's highest-energy accelerator. The counter-argument concerned the 'ideological contamination' of Soviet physicists. In the end it was decided the lesser evil was to open Serpukhov up. (Interview, 1982)

However, even when Western physicists did come to work at Serpukhov, the informal mixing with other researchers was, according to those involved, disappointing — much less, for example, than at CERN, where West European experimentalists have learned a vast amount from visiting foreign scientists. Several CERN visitors to Serpukhov cited social isolation as one of the main problems during their stay in the Soviet Union.

The user-community of Eastern-bloc accelerators was also seen as having a less developed competitive ethos than in the West. One interviewee described the situation in the East as follows:

There is no competition: experiments are thought out and run by the 'bosses'. The result is that there is no motivation for young people to stand out and take the initiative. In fact, there is a general lack of criticism and debate because of the hierarchy and the wish not to offend the people at the top. It is particularly difficult for young people. (Interview, 1982)

While one must recognize the value-laden connotation of the term 'competition', as well as the negative effects upon individual

scientists of the occasionally rather ruthless behaviour found in certain Western laboratories⁷⁶ (which several East European interviewees strongly condemned), it does appear that, in the West, young physicists have greater opportunities to devise their own experiments, bid for time on accelerators, and, if successful, lead research collaborations. With this freedom and the higher level of motivation it engenders, Western researchers are more likely to have been involved in a greater number and variety of experiments than their Eastern counterparts. The latter therefore tend to have a lower level of experimental experience (factor 9 in Table 9), and thus fail to gain the tacit knowledge that is so essential if, after an unforeseen result or opportunity, an experiment's direction has to be suddenly changed in mid-stream. According to some early workers at Serpukhov, Eastern-bloc researchers not only had a poor idea of the important things to look for (in particular, quarks and the parton-structure of hadrons), but also a rather limited repertoire of experimental techniques — adequate for carrying out the simpler and more obvious experiments on the Serpukhov accelerator, but not sufficient for tackling precise and ambitious second-generation experiments, most of which, as we have seen, were left to machines in the West.

The final factor we shall consider was one of the two most frequently cited — the problem of bureaucracy in Eastern-bloc science. For the statement: 'The major problem facing the users of Soviet accelerators is the over-bureaucratized system under which these facilities are operated', no less than 88 percent of our East European interviewees agreed to a greater or lesser extent, while none at all disagreed. One of the more critical stated:

The administration and bureaucracy do not work. Partly the system is corrupt, partly it is malfunctioning, and partly no-one wants to take responsibility for anything in order to avoid being blamed for mistakes. (Interview, 1982)

This, of course, is a somewhat extreme view. (A number of Western physicists were also highly critical of certain aspects of their own administrative systems.) Nevertheless, interviewees gave many examples of the effects of bureaucracy: tasks that in the West would be carried out with little fuss in the East require much paperwork and numerous authorizing signatures;⁷⁷ the publication of research papers generally takes longer because of the need to obtain high-level authorization; activities involving several research institutes or

facilities (such as a programme of visits by a foreign scientist, or setting up a large collaboration) will typically require the agreement of three separate Ministries; an accelerator's experimental programme cannot generally be changed quickly (even if some unexpected crucial discovery demands that it should be made) since too many layers of bureaucracy have first to be negotiated. According to many interviewees, all this stems, in large part, from one root cause — the over-reliance on a centralized five-year planning system that has become rigid and inflexible. These comments are not untypical:

The Russians have a five-year plan for everything, even high-energy physics . . . A five-year horizon is the time to ask for money for experiments, and things have to be planned rigidly that far in advance. Flexible re-allocation is not possible as in the West. (Interview, 1982)

Experiments planned years in advance are in some cases dutifully carried out, even if they have long since been rendered unnecessary by developments elsewhere. Conversely, experiments that could not have been foreseen earlier sometimes cannot be integrated into the planned experimental programme. For example, in 1971, high-energy physicists suddenly became excited at the possibility of integrating electromagnetic and weak interactions under one unified theory.⁷⁸ The candidate unified theory predicted a new and previously unobserved form of interaction, involving weak 'neutral currents'. Experimentalists immediately began to search for these phenomena, and they were discovered two years later on the CERN PS. If there had been greater flexibility at Serpukhov, the commissioning of the neutrino beam could have been speeded up. An experiment might then have been mounted with the French bubble-chamber, Mirabelle, that would have stood a good chance of being first to see the predicted effects. However, such a rapid shift was never feasible, and the discovery, one of the most important in the field during the 1970s, was instead made at CERN. Many other such examples demonstrate that flexible and decentralized strategies must be adopted in running large experimental facilities in an intensely competitive branch of science characterized by rapid shifts of interest and sudden unpredicted developments. Researchers who work in a scientific system based on hierarchical control, highly-centralized decision making, and relatively inflexible long-term plans, are obviously labouring under a

considerable disadvantage.⁷⁹ To improve the situation, considerable structural reforms appear to be necessary in the organization and administration of science — a task that a number of Eastern-bloc governments now seem to view as a priority.⁸⁰

Summary and Conclusion

To conclude, we began by summarizing what is known about the state of basic science in the Eastern-bloc. We pointed to various limitations in existing sources of data, and proposed a somewhat different methodological framework for East-West comparisons. We then used this to assess the relative scientific performance of the principal Eastern-bloc high-energy physics accelerators. Even after making appropriate allowances for the likely bias in the various partial indicators employed, it was impossible to avoid the conclusion that the scientific outputs from each Eastern-bloc accelerator have been small in comparison with the nearest equivalent Western facilities. Of the main reasons for this discrepancy, some are technical in nature (inferior research facilities, scientific instruments and computers), but even these seem to be merely symptoms of a wider systemic and organizational malaise — both at the level of the research laboratory (in the limited resources available and the way these are managed), and of Eastern-bloc science in general.

• NOTES

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1. No order of seniority implied (rotating first authorship).
2. See, for example, the NATO Science Committee report, *Research Management and Zero Growth* (Brussels: NATO, 1981).
3. The evaluation techniques are described in detail in B. R. Martin and J. Irvine, 'Assessing Basic Research: Some Partial Indicators of Scientific Progress in Radio Astronomy', *Research Policy*, Vol. 12 (1983), 61–90. The techniques have been applied to two other fields: see Martin and Irvine, 'An Evaluation of the Research Performance of Electron High-Energy Physics Accelerators', *Minerva*, Vol. 14 (1981), 408–32; and Irvine and Martin, 'Assessing Basic Research: The Case of the Isaac Newton Telescope', *Social Studies of Science*, Vol. 13 (1983), 49–86.
4. See the work cited in note 3.
5. The rôles of science and technology in Soviet industrialization are comprehensively discussed in R. Lewis, *Science and Industrialization in the USSR: Industrial Research and Development, 1917–1940* (London: Macmillan, 1979).
6. N. I. Bukharin et al., *Science at the Crossroads* (London: Frank Cass, 2nd edn, 1971). The 1930s 'radical science movement' in Britain is discussed in detail in P. G. Werskey, *The Visible College* (London: Allen Lane, 1978). Interest in Soviet science was further stimulated by the publication of J. D. Bernal's book, *The Social Function of Science* (London: Routledge, 1939).
7. See, for example, *Radical Science Journal* and the British Communist Party magazine, *Science Bulletin*; also the British Society for Social Responsibility in Science publication, *Science for People*, and its American counterpart, *Science for the People*.
8. One of the first collaborative agreements was in the field of high-energy physics. It was drawn up in the late 1950s, and involved the European organization for Nuclear Research (CERN) at Geneva, and the East European Joint Institute for Nuclear Research (JINR) at Dubna in the Soviet Union. For details, see W. O. Lock, *A History of the Collaboration between the European Organization for Nuclear Research (CERN) and the Joint Institute for Nuclear Research (JINR) and with Soviet Research Institutes in the USSR 1955–1970* (Geneva: CERN, 1975). The history of US–USSR scientific co-operation is examined in L. L. Lubrano, 'National and International Politics in the US–USSR Scientific Co-operation', *Social Studies of Science*, Vol. 11 (1981), 451–80.
9. For example, T. Gustafson wrote a useful summary paper on the problems of Soviet Science, 'Why Doesn't Soviet Science Do Better?', in L. Lubrano and S. Solomon (eds), *The Social Context of Soviet Science* (Boulder, Col.: Westview Press, 1979), 31–67, as a result of participating in the US–Soviet Joint Working Group on Science Policy.
10. One of the best surveys of Soviet R&D personnel deployment is L. E. Nolting and M. Feshbach, 'R&D Employment in the USSR', *Science*, Vol. 207 (1 February 1980), 493–503.
11. A good example is S. Kassel, *The Relationship between Science and the Military in the USSR* (Washington, DC: Rand Corporation, R-1457-DORE/ARPA, 1977).
12. For example, see the many studies referenced in C. P. Ailes and F. W. Rushing, *The Science Race* (New York: Crane Russak, 1982).
13. Two comprehensive and influential emigré critiques of East European science are provided by Z. A. Medvedev, *Soviet Science* (Oxford: Oxford University Press, 1979), and M. Popovsky, *Manipulated Science* (New York, Doubleday, 1979).
14. Reasons for the limited access to the normal mechanisms of informal scientific

communication include restrictions on travel, conference attendance, and the exchange of research papers (particularly early reports on 'work in progress'), the difficulty of making long-distance and international telephone calls, and so on. See, for example, Y. Levich, 'Trying to Keep in Touch', *Nature*, Vol. 263 (30 September 1976), 366–67.

15. Interlaced with emigré accounts are the perhaps inevitable occasional exaggerations and distortions. Indeed, these sometimes give rise to accusations of misinformation — see, for example, the review of Popovsky (op. cit. note 13) by C. Holden, 'Emigré Paints Grim Picture of Soviet Science', *Science*, Vol. 205 (7 September 1979), 981–84. Such accounts must clearly be used only with great caution.

16. See C. Kaysen (Chairman), *Review of US-USSR Interacademy Exchanges and Relations* (Washington, DC: National Academy of Sciences, 1977), and R. L. Garwin (Chairman), *Review of the US/USSR Agreement on Co-operation in the Fields of Science and Technology* (Washington, DC: National Assembly of Sciences, 1977). A useful summary is given in L. R. Graham, 'How Valuable are Scientific Exchanges with the Soviet Union?', *Science*, Vol. 202 (27 October 1978), 383–90. See also Lubrano, op. cit. note 8.

17. A study was also undertaken in which eminent American scientists familiar with Soviet work were asked to evaluate the health of their specialties in the USSR.

18. See Kaysen, op. cit. note 16, 100.

19. Graham, op. cit. note 16, 383.

20. See the first chapter, 'International Position of US Science and Technology', in National Science Board, *Science Indicators 1972* (Washington, DC: US GPO, 1973). These indicators have been extended in scope in subsequent volumes, and Computer Horizons Inc., who compiled the data under contract from the National Science Foundation, have produced comprehensive digests of the main indicator series on computer tapes.

21. F. Narin and M. P. Carpenter, 'The Adequacy of the Science Citation Index as an Indicator of International Scientific Activity', *Journal of the American Society for Information Science*, Vol. 32, No. 6 (November 1981), 430–39.

22. Gustafson, op. cit. note 9, 31. An interesting recent study of highly-cited papers is described in the research note by F. Narin, J. D. Frame and M. P. Carpenter, 'Highly Cited Soviet Papers: An Exploratory Investigation', *Social Studies of Science*, Vol. 13 (1983), 307–19.

23. To the extent that even the British Library Lending Division coverage of physics journals is unlikely to be 100% complete, these figures, too, are likely to be more biased against the Soviet Union than the US because of the easier access to journals in the latter.

24. Narin and Carpenter, op. cit. note 21. See also J. D. Frame and D. R. Prokrym, 'Counts of US and Soviet Science and Technology Journals', *Scientometrics*, Vol. 3 (1981), 159–75.

25. Narin and Carpenter, op. cit. note 21, 438–39.

26. See H. Schmied, 'A Study of Economic Utility from CERN Contracts', *IEEE Transactions on Engineering Management*, Vol. EM-24 (1977), 125–38.

27. This figure on the estimated world expenditure on high-energy physics comes from Table 4 in B. R. Martin and J. Irvine, 'CERN: Past Performance and Future Prospects — I. CERN's Position in World High-Energy Physics', *Research Policy*, Vol. 13 (1984), 183–210.

28. See the work cited in note 3 for details.

29. See footnote 8 in Martin and Irvine (*Minerva*), op. cit. note 3.

30. For a discussion of the patterns structuring the postwar distributions of basic research expenditures in the West, see J. Irvine and B. R. Martin, 'What Direction for Basic Scientific Research?', in M. Gibbons, P. Gummett and B. M. Udgaonkar (eds), *Science and Technology Policy in the 1980s and Beyond* (London: Longman, 1984), 67–98.

31. For example, S. Weinberg, a distinguished theoretical high-energy physicist, and future Nobel Prize winner, wrote in 1973, 'To me, the reason for spending so much effort and money on elementary particle research is not that particles are so interesting in themselves . . . but rather that as far as we can tell, it is in the area of elementary particles and fields (and perhaps also of cosmology) that we will find the ultimate laws of nature, the few simple general principles which determine why all of nature is the way it is': 'Where We Are Now', *Science*, Vol. 180 (20 April 1973), 276. See also various similar claims in L. C. L. Yuan (ed.), *Nature of Matter: Purposes of High Energy Physics* (Brookhaven National Laboratory, NBL-888, 1965): for example, H. A. Bethe, 'High-energy physics is undoubtedly today the frontier of physics. The discoveries in this field of study contribute most to the advance of our fundamental understanding of nature' (ibid., 9); and R. G. Sachs, 'High-energy physics is the principal operational arm of particle physics, which, in turn, is the essence of today's science of physics' (ibid., 20).

32. R. R. Wilson, 'The Next Generation of Particle Accelerators', *Scientific American*, Vol. 242 (January 1980), 39.

33. The only exceptions are three high-energy electron-positron colliders (PETRA at Hamburg, CESR at Cornell, and PEP at Stanford) which have been excluded because they came into operation only very recently, and because, for PETRA and PEP, there is as yet no Soviet equivalent.

34. JINR is the Eastern bloc equivalent of CERN, the European Organization for Nuclear Research at Geneva.

35. The Zero Gradient Synchrotron (ZGS) at Argonne was built as a direct competitor to the Dubna machine, with funds obtained during the 'cold war' period of US–Soviet competition in the 1950s. This is discussed in Comptroller General of the United States, *Report to the Congress: Increasing Costs, Competition May Hinder US Position of Leadership in High Energy Physics* (Washington, DC: US General Accounting Office, EMD-8058, 1980), 15.

36. An assessment of the scientific performance of these various electron accelerators can be found in Martin and Irvine (*Minerva*), op. cit. note 3.

37. See Comptroller General of the United States, op. cit. note 35. Some of the Western high-energy physicists whom we interviewed shared this conclusion, one putting it rather more succinctly: 'To a first approximation, Soviet accelerators do not exist'.

38. An extensive discussion of the technical and conceptual problems of using publication counts to evaluate scientific performance is given in Martin and Irvine (*Research Policy*), op. cit. note 3. The same paper also analyzes the problems involved in using citation analysis and systematic peer-evaluation data as indicators of relative scientific contributions.

39. See D. Sullivan, D. H. White and E. J. Barboni, 'The State of a Science: Indicators in the Specialty of Weak Interactions', *Social Studies of Science*, Vol. 7 (1980), 182.

40. These figures on the outputs from each accelerator cannot be obtained from the

ISI data-base, which lists the institutional affiliation of the authors of each paper but not the research facility where the work reported was carried out. This obviously greatly reduces the utility of ISI data for science-policy purposes.

41. These various approximate estimates were derived partly from an examination of the papers listed in international data compilations, and partly from an analysis of the experimental publications cited in Eastern-bloc papers.

42. This estimate was arrived at by examining a sample of papers to identify those with virtually the same title published in Russian and English.

43. Because the number of experiments that can be carried out on a collider at any one time is very limited compared with the corresponding number for a fixed-target accelerator, colliders tend to produce fewer publications.

44. Martin and Irvine (*Research Policy*), op. cit. note 3.

45. Note that even a paper subsequently found to contain 'mistaken' results can sometimes have a significant impact on the advance of knowledge if it stimulates research that might not otherwise have been carried out, and its citation record will normally reflect this.

46. This assumes that papers in journals not scanned by ISI contain roughly similar numbers of references to those in scanned journals.

47. This bias refers to the figures on total citations and numbers of highly-cited papers. Of course, there would be no effect on the number of citations per paper, assuming that omitted publications were cited with the same average frequency as publications included in our list.

48. A further reason to assume that national and Soviet Republic journals are on average cited less is that, according to interviews carried out in Eastern Europe, researchers seem to prefer to place their better papers in the international journals when this is possible.

49. This is based on the assumption that excluded publications earn on average half as many citations per paper as those included in our list. This is probably erring on the generous side.

50. These data on the average number of references per paper for different journals came from the final volume of the 1980 edition of the *Science Citation Index* (Philadelphia: Institute for Scientific Information, 1980).

51. One other potential source of bias concerns the relatively frequent use by Eastern-bloc authors of references to preprints rather than published articles. This may be partly because of the often long delays before papers are finally published, and partly because many Eastern-bloc groups do not have easy access to certain journals and instead have to rely on informally circulated preprints. Citations to preprints listed in the *SCI* have all been credited to the papers that supersede them, the same procedure being adopted for references to articles 'in press' and 'to be published'. By using such a procedure, it seems doubtful that any appreciable systematic bias against Eastern-bloc papers is introduced.

52. The citation rate provides an indicator of the average impact per paper from each accelerator, and thus allows for differences in the scale of research activity at each facility. Hence a small but relatively successful accelerator, even if it produces too few papers to gain a large total number of citations, may still be seen as making a significant contribution to science if it achieves a relatively high citation rate.

53. If anything, the omission of what are generally less important papers from the national and Soviet Republic journals will in all likelihood serve slightly to increase the average citation rate.

54. Consequently, there seems to be little evidence from these figures to support the view expressed in some interviews that Eastern-bloc researchers tend to publish longer, more substantial papers than their colleagues in the West (who might have been assumed to be more prone to the 'publish or perish' syndrome, and hence to splitting up results to publish them in several smaller, less substantial papers).

55. Justification for this can be found in Martin and Irvine, *op. cit.* note 27.

56. Conversely, papers published in national and regional journals tend to have a much narrower audience, and therefore stand far less chance of having a major impact and being highly cited. This is particularly true, for example, in the case of papers published in the physics journals of Soviet Republics.

57. This paper reported the first indications of a rising total cross-section in hadron-hadron interactions, a result later confirmed at the CERN ISR and one which contradicted the predictions of certain fashionable theoretical models of the time.

58. This does not include a number of other interviews that were terminated prematurely when it became apparent that the interviewee had insufficient knowledge to answer the questions satisfactorily, being unable, for example, to recollect correctly which accelerators were responsible for certain experimental results.

59. Where, for example, two accelerators were ranked first equal, they were each given the ranking 1.5; where three were placed first equal, they were ranked 2 (that is, the average of 1, 2, and 3); and so on.

60. The Kharkov and Novosibirsk machines were not included in this ranking exercise.

61. These lower-level contributions generally arise from experiments reporting more precise measurements of known particles and their properties without discovering anything new.

62. See note 43.

63. This is excluding the CERN SPS accelerator, which has only been operating since the mid-1970s.

64. Further support for this conclusion comes from the results of the attitude survey described in the concluding section. None of the East Europeans interviewed agreed with the statement, 'Serpukhov has been responsible for a significant number of major discoveries compared with other major high-energy physics centres', while 94% disagreed.

65. This was probably largely because of technical problems — see note 71.

66. A similar conclusion was also evident in the more general survey of opinion on Soviet high-energy physics presented in pages 100–02 of the Kaysen Report, *op. cit.* note 16. In discussing Novosibirsk, it is noted that 'although bright new ideas in particle technology (e.g. collective acceleration and electron cooling) have originated in the Soviet Union, the work has been of an undisciplined character, and the new initiatives have been more effectively followed up in the laboratories in the West than in those where they originated' (*ibid.*, 100).

67. In the attitude survey, 76% of the East Europeans agreed to some extent with the statement, 'Soviet high-energy physics accelerators have been responsible for few major experimental discoveries', while only 18% disagreed.

68. See J. Irvine and B. R. Martin, 'CERN: Past Performance and Future Prospects — II. The Scientific Performance of the CERN Accelerators', *Research Policy*, Vol. 13 (1984), 247–84.

69. According to those interviewed, one of the strengths of Novosibirsk during the

1960s and 1970s was that its Director was generally able, by dint of his political and industrial contacts, to ensure that industry did supply the equipment needed. Other Soviet laboratories were not so fortunate.

70. See Schmied, *op. cit.* note 26.

71. Accelerators at the other Eastern-bloc laboratories have also experienced technical problems. Interviewees cited the Moscow proton synchrotron and the Dubna synchrotron as being particularly afflicted by major technical limitations such as low beam-intensity and poor-quality external beams. Even at Novosibirsk, the Soviet centre widely regarded as being the most technically advanced, it was reported in 1972 that 'there had been difficulties in obtaining a good quality reliable beam on the VEPP 3 collider': *CERN Courier*, Vol. 12 (1972), 333. Three years later, it was noted that the performance of this machine still 'remains limited by inadequate positron intensities': *ibid.*, Vol. 15 (1975), 73. This is partly a reflection of the fact that the main interest of the laboratory has been in accelerators rather than physics (both the first Director, Budker, and the present Director, Skrinsky, have made world-famous contributions to accelerator theory), and partly a consequence of the laboratory devoting a substantial fraction of its activity to the construction of accelerators for industrial and medical use — this has provided a means of helping to finance the series of VEPP machines.

72. There is, for instance, a fairly rigid distinction between, on the one hand, the Research Institutes of the Academy of Sciences and of the USSR State Committee for Atomic Energy where research is carried out but with limited staff, and, on the other, the universities, which concentrate largely on teaching. This is reflected in the Soviet participation in CERN experiments — almost all those involved are from the Research Institutes.

73. Of the East Europeans interviewed, only 18 percent agreed that 'Policy decisions relating to Soviet accelerators are determined strictly by scientific considerations rather than political ones', while 59 percent disagreed.

74. This is principally because the researchers interviewed generally had a far less intimate knowledge of the other Eastern-bloc accelerator laboratories, with the exception of Dubna, which has increasingly moved towards nuclear physics in recent years, and so is less of interest to the concerns of this paper than is Serpukhov.

75. Much of the impetus for this came from experimental work carried out at SLAC and the parallel theoretical endeavours of the American West Coast high-energy physics community. According to certain senior physicists interviewed, CERN was also perhaps a little slow to realize the significance of these developments. Given that the major contacts between Serpukhov and the West were focused around the formal agreement with CERN, this perhaps constitutes another factor underlying the delay before Eastern-bloc physicists began to appreciate the potential importance of the parton model.

76. For an interesting critique by a Western scientist of the way in which high-energy physics is currently administered and of the adverse effects of the intensively competitive pressures on younger researchers in particular, see various articles by R. J. Yaes: 'Physics Fads and Finance', *New Scientist*, Vol. 63 (22 August 1974), 462–63; 'New Generation Motivations', *Physics Today*, Vol. 29 (September 1976), 11; 'The Time Has Come to Abandon the Pumps and Run for the Lifeboats — Reflections on Leaving the Physics Profession to Study Medicine', *Bulletin of the American Physical Society*, Vol. 23 (1978), 21–22; 'The Science Establishment', in R. Arditti, P. Brennan and S. Cavrak (eds), *Science and Liberation* (Boston, Mass.: South End Press, 1980), 217–38.

77. When Western physicists were invited to submit proposals for experiments with the Mirabelle bubble-chamber at Serpukhov, these had to negotiate a rather tortuous path past not one committee but a sequence of four before final approval could be obtained: *CERN Courier*, Vol. 12 (1972), 209.

78. This example comes from one of our interviews. S. Weinberg and A. Salam in fact first proposed such a unified theory in 1967, but it was not until 1971, when G. t'Hooft showed the theory was renormalizable, that a large body of high-energy physicists began to take serious notice of it.

79. We do not wish to appear to be making a one-sided critique of the central institutions of Eastern-bloc society. There are, of course, a range of countervailing benefits to centralized planning. In particular, the socialist countries have at least been able to produce some semblance of rational mechanisms for determining priorities in science and technology, something which the Western nations are only now attempting to achieve. At the level of scientific practice, there is also less emphasis in the socialist countries on the ruthless competition that imposes tremendous burdens on many young researchers as well as distorting personal and social relations (see note 76). Nor is there much evidence of the rather wasteful competition between large laboratories to build equivalent research facilities first — as, for example, during the late 1970s, in the race between SLAC and DESY to build PEP and PETRA — a process which inevitably results in 'losers' and 'winners'. This is something which deserves analysis in a separate article.

80. In 1982, one of us was invited to lecture on the techniques of research evaluation in Bulgaria. Discussions with senior officials revealed the existence of major worries in several COMECON countries over the direction and efficiency of R&D activities.

John Irvine and Ben Martin are Fellows of the Science Policy Research Unit at the University of Sussex, where they work on a range of issues connected with policies for basic and applied research. They have in recent years acted as consultants to research-funding agencies in several countries and are the authors of a number of papers and reports on research policy, including *Foresight in Science: Picking the Winners* (London: Frances Pinter, 1984). *Authors' address:* Science Policy Research Unit, Mantell Building, University of Sussex, Falmer, Brighton, BN1 9RF, UK.