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VBA

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It has apparently become a long-standing tradition, dating all the way back to the 1975 Stanford Accelerator Conference, that an accelerator "user" entertain those hold-out attendees who could not make more convenient arrangements for leaving on the many post-conference tours. Having been so honored before, and having used up all my accelerator jokes last time, and having failed to replenish these even after a long interview with R. R. Wilson, I now embark on a very serious and perhaps controversial subject: world cooperation to build a Very Big Accelerator complex (see Table I for context).

Brief History

A meeting of physicists and laboratory managers representing all the active centers of high energy physics in the world took place in New Orleans, in March, 1975.[1] The subject of a world laboratory was raised in a determined manner, probably for the first time in this quasi-official assembly. It was vigorously debated before the official report of the chairman was accepted, containing a recommendation for the formation of a study group to pursue the question of a world accelerator complex.

The study group met in Serpukhov and Moscow in June, 1976. Representatives from Eastern and Western Europe, the U.S. and Japan reviewed the status of high energy physics and the need for higher energy, the current status of regional plans for the next generation and the technology of multi-TeV accelerators. A final report[2] recommended that planning and studies towards VBA should be continued by a working sub-committee under the aegis of IUPAP Division of Particles and Fields. A paraphrase of these recommendations follows:

1. Coordination of the next generation of regional facilities in order to optimize diversity.
2. Availability of regional facilities to all users.
3. International collaboration towards realization of VBA (accelerator requiring the pooling of resources).
4. IUPAP DPF sponsorship of a sub-committee to pursue recommendations.

The members of this subgroup have been named by all regions involved and it is expected that the first meeting, to be called by Bernard Gregory, Chairman of IUPAP, DPF, will take place this spring or early summer.

Arguments For (and Against) a World Accelerator Laboratory

(The designation World Laboratory gave our Soviet colleagues considerable difficulty - perhaps because of the collectivist implications; this author accepts credit for the substitute designation Very Big Accelerator (Complex) or VBA.

The positive arguments are stated very simply: i) The next step in fixed target proton accelerators must be in the $\geq$ 10 TeV range to provide a significant increase in c.m. energy over the 400 GeV labs in Batavia and Geneva; this is because a look at the existing activity indicates that by ~ 1985 hadron physics up to ~ 2 TeV will have been very well explored. ii) There are clear physics needs for a fixed target accelerator, matching in some sense, the p x p rings (ISABELLE, LSR, FNAL Doubler x MR) anticipated for the 1980's.[2]

There are also sharp questions which will require yet another generation of pp storage rings than those shown in Table I providing > 1 TeV in the c.m.

The new physics very strongly points towards e^+e^- colliding rings in the 100 x 100 GeV range. iii) These facilities are each estimated to cost at least three times the sum previously expended in any single accelerator.

In view of the world economic situation, it seems unlikely that any one region can increase its annual expenditure for construction by a factor of three (see following table). Thus world collaboration is essential if we are to realize the facilities that we perceive our subject requires.

TABLE II

HEP FUNDING - Estimates *

U.S.	Operations		~ $225 M
	Construction Avg. 1960-75	~ $45 M/yr.	
W. Europe	Operations		~ $350 M
	Construction Avg. 1960-76	~ $55 M	
U.S.S.R.	(Estimate)		
	Operations		~ $200 M
	Construction	~ $30 M	
Japan	(Estimate)		
	Operations		~ $ 60 M
	Construction	~ $15 M	

Total World Construction Funds Available ~ $145 M/yr.

Reasonable Scale for VBA ~ $1 B/Decade.

* All but U.S. are personal estimates.

History teaches us that technological innovation has only served to brake the relationship of energy to cost, and to date, not by a very big factor:

AGS: 30 GeV: Cost: \$30 M

1/2 (SPS + FNAL): 400 GeV:
Cost: \$300 M .

The "arrival" of superconducting magnets should improve things by a factor $\sim$ 3:

2 x 200 GeV: Cost: \$150 M .

(This could improve to a factor $\sim$ 10 with optimism.)

The final positive argument is vague and idealistic and has to do with the political and social benefits of international collaboration, especially in this global manner. One line of reasoning says that scientists, intrinsically internationalists, and motivated to get the accelerator, will learn to solve the hard political problems associated with VBA and this will serve as a model for the solution of more profound problems of world collaboration. After all, CERN was started before the common market and this sequence may be significant.

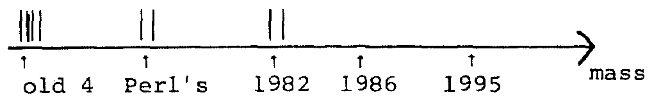
A somewhat cynical counter argument to this is: "If they cannot even negotiate world peace and universal disarmament, how are we ever going to agree on (something as hard as) the world laboratory?"

Another counter argument has several components. A transient (but unfortunately ever-present) concern is that governments, learning about VBA, will withold funding of more immediate projects presumably to save a factor of three in costs. A more serious one involves nationalism, regionalism, the loss of presence of gifted faculty and students, the expenditure of funds in remote areas with no preferential economic benefit, and the mind-boggling area of organizational and political issues that must be faced.

Physics[4]

Let me begin by saying that there are very good and deep theoretical physicists who are so pleased with recent progress as to state that it is essentially all over - we know (almost) everything! Those who are more skeptical must still be capable of discerning a well defined program which looks beyond the not yet discovered results of PEP and PETRA, beyond the even more distant results from the FNAL Doubler, SPS, $\bar{p}p$, ISABELLE. All of these regional accelerators will contribute relevantly to the problems, which, however, are certain to demand higher energy or more luminosity: i.e. we assert that we are confident that the next generation of regional machines will not solve all the problems. Here we recognize a problem. How do we answer the very reasonable question of the enlightened statesman: "I agree that it is indeed important to discover the fundamental building blocks of matter and the forces that act between them - but how will you know when you have found them all - how will you know when your problem is solved?
Answer: We'll know.

When our present list of questions are answered and no new questions arise. Of course, there are some questions that are open ended - like: how many leptons? The result could be:



i.e. a very long gap with nothing - and no indirect evidence or need. Then watch our theorists: they will lose interest and turn to something else, e.g. what is life or telepathy - when Feynman and Lee and Gell-Mann and their younger replicas lose interest, then we know.

So what are the fundamental questions? Do quarks exist? If so, are they forever confined inside hadrons? What are the dynamics of quark-quark forces? Is Weinberg-Salam gauge theory of weak interaction absolutely correct? If so, Z^o, W will be found before VBA. Then - what happens? What new phenomena take place at 1 TeV in the c.m.? If the gauge theory cancellations do hold, then there must be Higgs scaler particles. What are their masses? How many H's? How many W's? How many leptons? How many quarks: u, d, s, c, b, t, ...?? Is there quark-lepton symmetry? Are leptons structureless particles? In strong interactions, we enter the "epoch of the logarithm". Sensitive tests require a change in the log of energy by a factor 10!

Then there are the phenomena at high $P_\perp$ - these are supposed to probe quark dynamics. If we take the ISR data as parameterized by the CCR group, at $P_T > 50$ GeV, there should be a role reversal in which

weak > electromagnetic > strong .

It could be that it is here that the clues to the global unification of forces may be found.

Collisions of electrons and protons in storage rings and competing high intensity muon beams can be used to study quark dynamics. It is easy to see that 10 TeV muon beams of very high luminosity ($\sim 10^{36}$cm^{-2} sec^{-1}) can be achieved.

Finally we note that the availability of intense beams in the laboratory $\sim$ 10 TeV challenges us to devise incisive tests of some of the most fundamental issues at distances $\sim 10^{-17}$ cm:

i) limits of validity of QED,
ii) limits of validity of baryon conservation,
iii) limits of validity of the conservation laws,
iv) limits of causality,
v) limits of Lorentz invariance,
vi) non-linearity of quantum mechanics at ultra-short distances.

These are some of the questions we can ask. However, it is the questions we are too ignorant to ask which, if history is any guide, will dominate the scheduling committees of 2000 A.D.

Experimental Techniques

These will change dramatically at VBA energies. Improvements in spatial resolution (towards 1 μ!) can result in the use of smaller magnets with larger solid angle than are now in use at Fermilab. Look at any drawing of a high energy physics experiment at FNAL or SPS. What, besides the box at the lower right, determines the scale? Answer: spatial resolution and beam spot size. If these can be reduced e.g. 1 mm $\rightarrow$ 1 μ, then all dimensions can be reduced by 1/1000! Calorimetry, where the length goes as log E, will become more important. Transition and synchrotron radiation or detectors sensitive to the contracted EM field of a many-TeV particle will be used.

Storage ring luminosities will go up dramatically because of the high density of stored beams. At 10^{36}, beam loss by beam-beam collisions will dominate. Secondary beams of rare particles become thinkable. Pion storage rings and direct pion-pion scattering experiments become thinkable.

Neutrino experiments get very long (10 km) but simpler since cross sections go up and beam divergences go down. Modest size bubble chambers followed by particle identifiers should be powerful here.

Finally we know that new inventions will appear. Every generation of new accelerators has had its new detection devices. Let me here describe the specifications for a device which we will desperately need for future hadron machines: we need a new kind of scintillation counter! The ones we have make a "click" when a 1 MeV pion hits it and they make the same click with a 20 TeV Ω^-! Clearly this is stupid and should be improved, as soon as possible.

Accelerator Technology

Here I am at a great advantage since I do not have to be responsible. The following (probably obsolete) parameter list indicates that serious people are thinking seriously. Let me make an assortment of random thoughts, all of them overheard in the corridors of FNAL, CERN and the Raperband near DESY.

CERN-SD Note No. 6
14 May 1976

VBA Parameter List
(Compiled by R. Billinge)

General

Peak Energy	E	1 TeV/Tesla
Bending Radius	ρ	3336 m
Average Radius	R	5000 m
Superperiodicity	S	6
Periodicity	N	450
Period Length	L_p	69.8 m
Period Structure		FODO
Approximate Tune	Q_H, Q_V	50
Approximate Transition	γ_{tr}	50
Injection Energy	E_{inj}	100 GeV
Betatron Function (max)	β	145 m
Betatron Function (min)	β	71 m
Momentum Compaction	α_p	2.9 m
Chromaticity	C_V	-1.04

Magnet System

No. of Dipoles	4680
Magnetic Length	4.475 m
Bore Diameter	100 mm
Coil Inner Radius	50 mm
Coil Outer Radius	100 mm
Mean Current Density (peak)	264 Amm^{-2}
Lamination Diameter	340 mm
No. of Quads	900
Magnetic Length	3.0 m

The new accelerator should be designed with the storage ring applications in mind. Fermilab experience with the doubler design is clearly relevant. A filled, highly compressed magnet ring is an excellent target. See Fig. 1 for VBA "plan".

Let me quote from Willis' paper which illustrates an approach to cost savings:

"First, it seems to me that the ring should be completely self-contained in a single pipe, as nearly as possible. Almost all the labor then occurs in a factory, with very little associated with installation. Thus, all the helium lines should be within this pipe. The electrical power should all be carried on superconducting cables within the cryostat. The controls, which should all be multiplexed on a few high data rate lines, should be within or attached to this overall enclosure. Probably, the provisions for precision alignment should be internal and remotely controlled. Auxiliary stations on the rings, distant from the injection-ejection-interaction region points, should sustain themselves from the main ring pipe, that is, there should be no need for further utility distribution around the ring.

"The cryostat would be continuously welded, with a minimum of valves, bellows, etc. Rather elaborate fixtures would be used to allow a section to be cut out and replaced with a minimum of disturbance to the sustenance of adjacent sections.

"In the existing design studies, the cost of refrigeration is relatively quite large, prohibitively large if scaled to this accelerator. Three very important changes can be made in this situation.

"First, the cycle time must be long enough so that cyclic losses are negligible. Once this is true, it pays to provide somewhat more elaborate heat shielding in the cryostat, with cooling gas at two temperatures, accepting most of the heat load at a higher temperature than that of the magnet. The net heat load can then be a fraction of a watt per meter.

"Second, the load due to the magnet current leads is much reduced when long magnet charging times are used. This is a source of most important savings.

"Last, since the program would be committed to the use of the superconductors with higher critical temperatures, we are talking about refrigeration not at 4^oK, but about 8^oK. This leads to a big factor just from the Carnot relation, but the effect is really much bigger than that. The thermodynamic properties of gaseous helium are very unfavorable for a refrigerant at 4^oK, while there are many problems involved in the use of liquid helium. The result is that there are really big savings in using a magnet running at 8^oK.

"Since the circumference of the rings is from 60-250 km, the number of individual magnet units to be manufactured is of the order of 10^4-10^5. Also, the construction procedures for these magnets seem more susceptible to automated production than those of large conventional magnets with their heavy copper bars and potted insulation. It seems unlikely that if a substantial investment were made in man production equipment, and if it were acceptable to run the factory for a few years, the cost of production of the main ring assembly could be made very low, by the standards of accelerator construction. Since the design is such as to minimize the costs of installation, these savings would be meaningful in the overall cost picture."

Similar considerations were made by R. R. Wilson in his study of a 10 TeV accelerator. It is clear that we have every reason to be optimistic on the design of a VBA complex. All of this, remember, involves nothing really new. The challenge to this audience is to provide us the breakthrough - that will give us 20 TeV for under $1 B! Use modern things: lasers, plasmas, atomic guide fields, I don't know ... but: invent!

There are now some impressive studies of 100 GeV x 100 GeV e^+e^- rings - mainly by Richter and others at CERN. This is clearly a formidable project which qualifies by its cost, by its demands for real estate and by the physics potential for inclusion in the VBA complex.

By the authority vested in me (here), I have therefore included it.

Organizational Problems

Progress towards a VBA depends on agreements as to the technical goals, but it would be erroneous not to begin a discussion of some organizational and other non-technical problems. Many of these have already been encountered when high energy physics moved from individual university labs to national labs and again in the formation of international labs such as CERN and JINR. We must frankly appreciate the increased difficulty of some of these as we move from the regional structures cited above, to the global laboratory implied by VBA. The following paragraphs (stimulated by W. Panofsky) list some of these problems to be faced, and offer some personal opinions.

I. Organizational Problems

A. Design Group

1. Should they be assembled permanently in one place?
2. Should each region keep its own team and have frequent consultation?
3. Should there be a nationality quota on the design group, especially the senior members?

B. Site Selection

This problem delayed FNAL by several years and almost aborted the SPS.

1. What mechanisms should be established?
2. What criteria other than technical, e.g. access to major airfield, cultural center, educational center, local industry, political stability etc.?
3. Should the US and the USSR (also NATO and Warsaw Pact) be excluded from the beginning?

C. Participation

1. How do we handle underdeveloped countries?
2. At what point do we face the issue of Cuba? China? Iraq? Israel? etc.
3. What formulae and guidelines are to be established for user participation? Will there be national or regional quotas?
4. How shall an experiment selection committee be organized?

D. Operating Staff

1. How is a directorate selected?
2. Should the staff be selected on a quota system?
3. Should the staff be purely service group (individuals joining research teams as at FNAL) or should there be strong in-house physics groups (CERN, SLAC)?
4. Are staff considered international civil servants as UN employees, or are they representatives of their local regions?

E. Financial Contributions

1. How are these decided?
2. What is done about real vs. artificial exchange rates?
3. What policy is established on distribution of economic benefits of the VBA e.g. in purchases etc. This problem begins with construction, but continues with operations.

F. International Legal Problems

1. Is the site considered international territory, or is it subject to local jurisdiction?
2. The status of employees? (see D.4).
3. Is the organization established by binding 100 year treaties, or how?
4. In general, how does the VBA Laboratory become insulated from fluctuating political moods like cold war, detente, etc., and from problems of local political instability?

II. Sociological Problems

How does VBA handle the serious problems of groups working for long periods very far from home? The home institutions must be prepared for long absences of prominent members. Younger scientists and students must be prepared for residence for periods of 3-5 years if the experience at FNAL is to be used. The depletion of these talents at Universities, for example, raises the question as to whether it is useful for these institutions to be at all involved in high energy physics. Can we invent mechanisms to alleviate these problems?

Suggested Solutions to Problems

Design Group. I would assume that by 1978, a set of tentative parameters is agreed upon for a VBA (perhaps two VBA's). It would make sense to have a period of time in which regional designers stay home and work on problems which have previously been selected, perhaps with good overlap. There would then be frequent consultations - perhaps four or six per year - and perhaps rotating among the design centers. A coordinating group would gradually harden and specify the tasks. Progress on all of the other problems would of course be necessary to proceed to the next step: the convening of a design group under one roof and under a coherent and practical directorate.

It is hoped that this mechanism would ease the problem of quotas and that the "CERN Solution" would result: no rigid quotas, quality above all, but no excessive dominance of one member state.

Site Selection. It is my opinion that the U.S.S.R. and the U.S. should be excluded ab initio. A sub-committee of technicians and other wise men should be assembled soon, merely to draw up a set of technical and cultural criteria for a suitable site. This committee, which could have a lifetime of two years, should consult with governments to gauge the interest in being host to VBA. The committee would not make recommendations on site choice, but would suggest a mechanism whereby member nations could proceed to a decision. The committee should contain geologists, economists, educators, administrative experts, but all closely supervised by physicists. See Table III and Fig. 2 for site suggestions.

Participation. The most important point here is the politically sensitive one of "antagonist states". A simple formulae could be invented which would avoid painful debate: If a country is a member state of the U.N. (i.e. recognized member of the World Community of Nations), and if its educational and technological level, as measured e.g. by the number of Ph.D.'s granted in physics per year, is high enough, this country qualifies for membership in VBA.

Some such formula will surely exist some day. The issue is: When should the problem be faced?

Operating Staff. The CERN-JINR model will be very helpful here. It will take masterful wording in the formal papers which create VBA in order to reassure the participants, without creating a rigid, unworkable system.

Financial. I believe we should soon set up a sub-committee on finances, consisting of five or six financial experts from various governments (but under the firm chairmanship of a physicist!) to study these problems and issue their recommendations.

International Legal Problems. Here again we should encourage the creation of a sub-committee of State Department types to formulate the treaty-type papers that would be needed. This group could meet for a year or more - again, they must be kept under control by a physicist. The creation of these two committees would go a long way towards institutionalizing VBA within the member countries. It is a terribly clever way to entrap the middle level bureaucracy of the important governments and, with their help, relentlessly draw the rest of the governmental apparatus into inevitable support of our accelerator.

My final comment is on the problem raised by I.F., paragraph 4: stability. It seems to me that if the major powers, e.g. members of the UN Security Council, all have substantial investments in VBA - not only money (although the more we force them to invest, the better the argument) - but also in scientific effort and talent, that this in itself guarantees the safety and extra-territoriality of the VBA Lab.

A further guarantee of stability would come from generalizing the laboratory function to include bio-medical research, an industrial advanced technology consulting laboratory, a world technology institute, i.e. structures of intense interest to developing countries. Their concern and profit would further serve to protect the laboratory, in this case, the big powers loss of interest would be at the expense of third-world popularity.

All of the great institutions created by civilized man were beset, at inception, by vast difficulties and uncertainties. However, difficulties and uncertainties do not guarantee that a project will ultimately be great. It is clear that much wisdom is needed as we proceed. There is no reason to fear that progress will be precipitous. The incentives, to this hardy and perennial user, are fantastic.

References

1 Seminar on Perspectives for High Energy Physics. New Orleans, March 1975. Summary of V. Weisskopf, Chairman.

2 Report of the International Study Group on Future Accelerators and High Energy Physics Serpukhov, May 1976.

3 L.M. Lederman, International Conference on High Energy Accelerators, Stanford, June 1975 and SSPS CERN Study on the Use of a 10 TeV Proton Accelerator, VBA/CMS/1 1974.

4 Here the author steals completely from VBA studies by CERN (SSPS study) and Bjorken (VBA Study).

TABLE III

VBA Site Requirements

1. Availability of Power and Water.
2. Inaccessible to General Public (Island?).
3. Nearby Educational Resources.
4. U.N. Presence.
5. Geology that Permits Tunnelling - Natural Tunnels Even Better.
6. Long Enough for 10 km Straight Sections.
7. A High Rise Central Lab Building.
8. Site Should be Readily Ceded by National Government.
9. Should Have a Stirring Symbol of Aspirations of People Everywhere - or at least, Accelerator Users.

TABLE I

Machine	Site	Type	Status	E_{CM}	E_{LAB}
ISR	CERN	p × p	3d Generation Experiments	60	2 T
FNAL	Batavia	p × FT	2d-3d Generation Experiments	30	4-500
SPS	CERN	p × FT	2d Generation Experiments	27	400
FNAL DOUBLER	Batavia	p × FT	Construction (1979)	44	1 T
		p × p*	"	~ 500	
PEP	Stanford	$e^+ \times e^-$	"	30	Funded
PETRA	DESY	$e^+ \times e^-$	"	35	
CORNELL	Ithaca	$e^+ \times e^-$	"	16	
VEPP IV	Novosibirsk	$e^+ \times e^-$	"	14	
SPS/FNAL	CERN/Batavia	$\bar{p} \times p$	Design	~ 500	
ISABELLE	BNL	p × p	Hot Proposal (1984?)	450	?
UNK	Serpukhov	p × FT	≥ 1985?	62	2 T
		p × p		3600	
		e × e		34	
		e × p		410	
TRISTAN	Japan	p × FT	(1983)	17	
		p × p		360	
		e × p		110	
		e × e		34	
VBA	?	p × FT	Dream but ...	200	20 T
		p × p	1985-1995	40,000	
		e × e		200	
		e × 'p		2800	

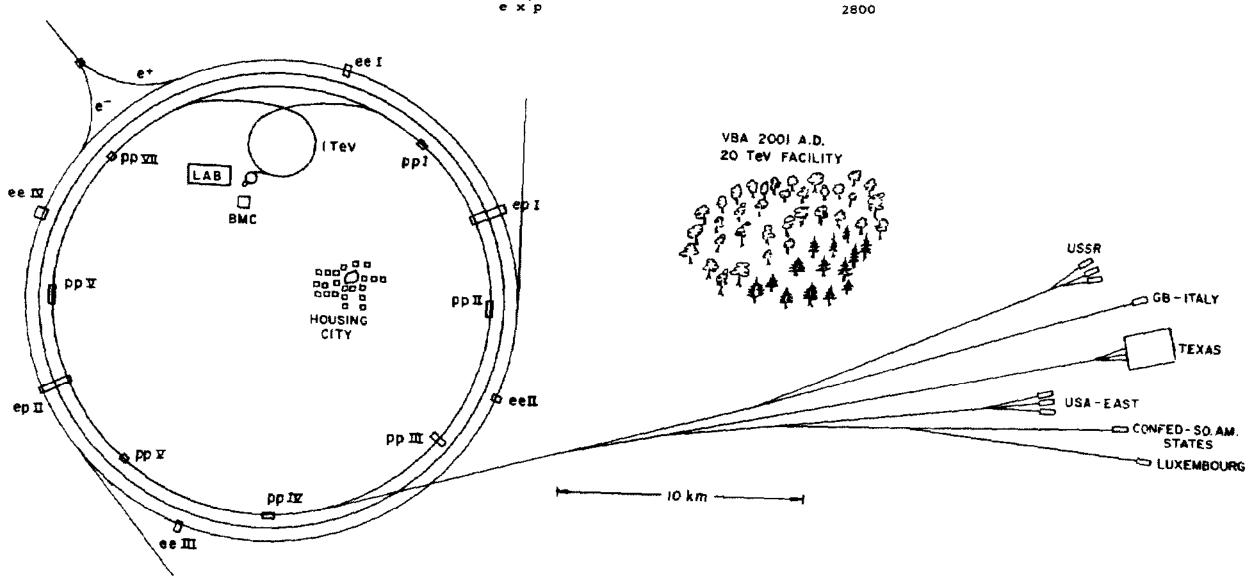


Fig. 1

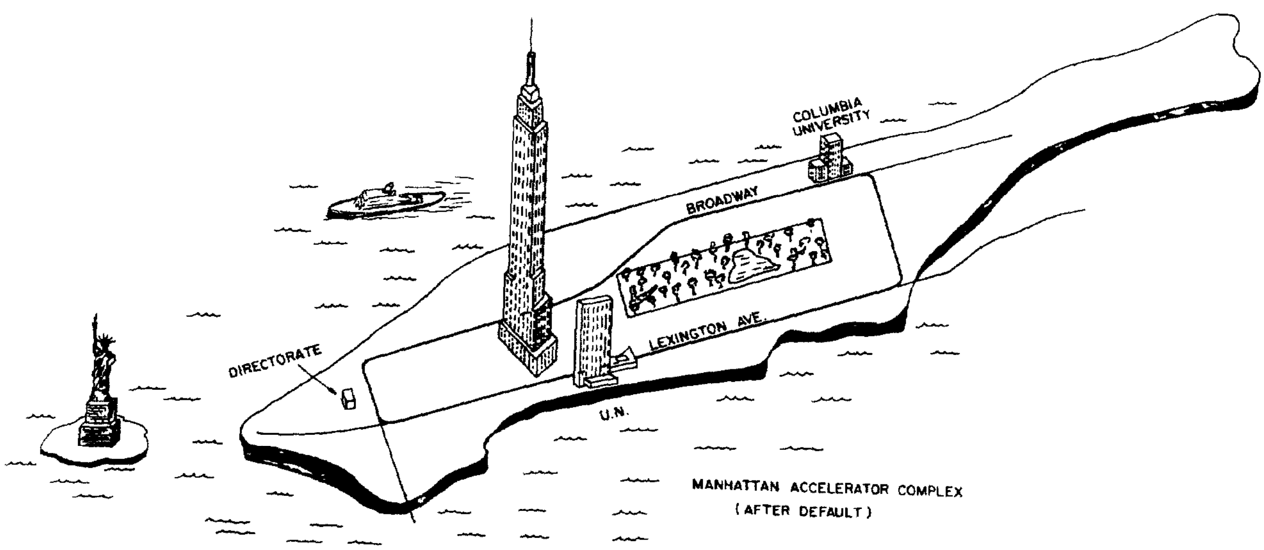


Fig. 2