Tracking of Nuclear Shipments With Automatic Vehicle Location Systems

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INTRODUCTION

In January 1968 I started to work in nuclear transports. At this time, the safety precautions for nuclear shipments were only based on the use of proper containers. The IAEA regulations already existed and were applied worldwide. The word "terrorist", however, was completely unknown and nobody thought of a danger that sensitive material might be stolen. It was possible then to receive a licence for the transport of plutonium in the trunk of a passenger car, if it only was properly packed in a Type B container.

Since then we have gone a long way. You all are aware of the precautions taken today for the shipment of sensitive material. Constant radio contact between vehicle and central base and the communication of voice and data is state of the art today. The latest development is the requirement of the authorities to constantly track and monitor the position of the transport vehicle in real time fully automatically, without any involvement of the crew of the vehicle or vehicles and without any possibility for the crew to take any influence on the transfer of the data. The accuracy requested typically is a few hundred meters.

Thanks to the technical development during the last few years this is possible today. In the following, I will try to explain the different methods of how it can be done.

A complete Automatic Vehicle Location System (AVL) consists of three main elements:

1) The location sensor in the vehicle.
   This device constantly determines the coordinates of the vehicle's position.
2) The radio link between vehicle and central base.
3) The data processing and display in the central base.

For all three elements there are several solutions. The optimal combination of the different techniques depends on the requirements of the special application. There are a couple of questions to be answered before the optimal system can be designed like:

- What precision of location determination is required?
- What area is to be covered?
- What kind of vehicles will be used?
- How many vehicles have to be tracked at the same time?
- Are there data from other sensors to be transmitted?
- What is the updating method of the position data?

  * Polling from the central base? How often?
  * Automatic transfer from the vehicle?
    = Regularly? How often?
    = Upon certain events?
- Should the data be encoded?
- What equipment is already available?
  * In the vehicle?
  * At the central base?
- What is the licensing situation?
- How much may the whole system cost?
  * in terms of investment?
  * to operate?
- What kind of data processing, especially display of vehicle location, is required?

Let me explain in more detail what techniques are available today to form an automatic vehicle location system:

1. LOCATION SENSOR.

There are two principally different ways for the determination of the position coordinates:

- Radio navigation and
- Dead reckoning.

1.1 Radio Navigation.

Many different ways, methods and systems have been developed using radio waves. We distinguish between active and passive systems.

1.1.1 Active systems have an emitter in the vehicle. The radio waves from the vehicle are received by at least two receivers outside the car. By measuring the time difference for the reception of the same signal by different receivers the location of the car can be calculated in a central base station. Another method is to measure the directions from which the radio waves approach to the receivers.

Except systems for sea rescue or systems used by the police to track certain cars, I am not aware of any system which has been realized using landbased receivers. There are, however, plans to build such systems using receivers in space satellites. The company Geostar in the USA has developed a system which uses a transmitter in the vehicle, the signals of which are received by at least two space satellites. These satellites work as relay stations. They transmit these signals to a central base station. There the difference in propagation time of the two signal paths is used to calculate the position coordinates of the vehicle.

These data then are transferred via conventional communication links like telephone or telex to any place wanted. They may also be forwarded to the vehicle itself by using one of the satellites.

The company Locstar in France has taken a license from Geostar for this system and plans to set up such a system for Europe and Africa.

Several different satellite systems are in operation since years which use single satellites. These systems use the Doppler shift when passing a transmitter on the surface of the earth. The capabilities of these systems are, however, limited, they are mainly used for research purposes like the french system "Argos" or rescue purposes like the "Sarsat" system.

1.1.2 Passive systems have a receiver in the vehicle which uses the radio signals from emitters outside the vehicle for the calculation of the position coordinates in the vehicle. Again we have to distinguish between systems using landbased emitters and systems with emitters in space satellites.

The first systems with land based emitters already have been developed during World War II, mainly for maritime purposes. For this reason the emitters are mainly placed along the shore lines to cover coastal waters.

A pair of emitters sends timely coordinated signals. The receiver in the vehicle measures the difference of the propagation time of the signals from the two emitters. The position of the vehicle must be on a certain "line of position", for which the difference in propagation time is constant. This line is a hyperbel. By using at least two pairs of emitters (which can be formed by three emitters, a "master" and two "slaves") two lines of position (two hyperbels) are defined, the crossing point of which is the position of the vehicle. Such systems are called hyperbel systems.

The main hyperbel systems are

- Decca
- Loran C
- Omega.

Decca: European coastal waters are rather well covered, cheap receivers are widely used by yachts and fishermen. The system is, however, rather useless on land because of the lack of coverage. The future of the system is uncertain. The northern parts of Germany are covered. Exhibit "Decca Results" shows a plot of "Decca-positions" of a trip on the highway there.

Loran C is a system, which has been set up by the US Coast Guard. Also major parts of the US territory away from the shore lines are covered so that the system can also be used by land vehicles and airplanes in the US.

Certain areas outside the US are also covered, there exist plans for further Loran C chains in different parts of the world. The central part of Europe is not covered, we only have a chain in Norway and one in the Mediterranean Sea area.

The receivers are rather cheap and can easily be installed in trucks and passenger cars.

Omega is a system which uses very low frequencies. Eight emitters, equally distributed over the world, cover the whole globe. The accuracy of the system is rather low, the calculated position may be inaccurate by as much as 10 km. The picture "Omega Results" shows a typical plot of a trip in Germany. The receivers are, compared to Decca and Loran C, rather big and expensive. The installation in a vehicle is not easy, mainly because of the large antenna.

Systems with satellite based emitters are in operation since years. By placing the emitters aboard space satellites, a better accuracy and a better coverage can be gained. Such systems have been installed mainly for military purposes by the USA (Transit) and the USSR (Zikade). For the US-system civilian receivers can be purchased and operated by everybody. Both systems are rather similar, it therefore is sufficient to describe only the system Transit.

Transit works with 6 satellites, which circle the world in a height of about 1000 km. From a certain point of the earth a satellite passing is "visible" for about 15 minutes. During this time the receiver regularly measures the frequency of the signals from the satellite which change because of the Doppler-shift. Using this effect, one position can be calculated during one satellite pass. The time between two satellite passes varies, on the average it is about one hour.

New systems to replace these existing systems are in the process of being installed now in the USA and USSR. Again both systems are rather similar, it therefore is sufficient to describe only the US-system called GPS, which stands for Global Positioning System. The USSR-system is called Glonass (Global Navigation System).

Civilian receivers for GPS can be purchased and operated by everybody, a variety of receivers can be purchased from producers in different parts of the world. No receivers for Glonass are available for users in the western world so far. The USSR has, however, offered to make the system available also for users in the western world. Nothing has to be paid for the use of GPS.

The space segment of GPS consists of 21 satellites which circle the world in about 20,000 km height. At every moment and at every point of the globe at least 4 satellites can be "seen". The satellites carry atomic clocks by which the signals emitted are very precisely synchronized.

GPS-receivers today are about the size of a car radio and need a very small antenna only. They can easily be installed in trucks or passenger cars. The receivers calculate the position several times per second, the precision is well below 100 m. The prices for such receivers, so far rather high, have already come down to acceptable levels. Within a few months we will be able to buy them at prices of 2 - 3 thousand US $.

Because of the shuttle disaster the launching schedule for the satellites has been delayed substantially. Six or seven operating satellites are in orbit at present; they provide "working conditions" for about 2 hours per day. It can be assumed that sufficient satellites will be launched in the near future to provide satisfying operating conditions already in the next year.

1.2 Dead Reckoning.

Contrary to all radio navigation systems, dead reckoning works completely autonomous; the vehicle navigates completely independent of any infrastructure outside the vehicle solely with the help of on board equipment.

The principle is as follows: the vehicle starts at a point, the coordinates of which are precisely known and fed into the system. The vehicle is equipped with sensors to constantly measure distance and direction travelled. After each way increment of a few meters, the new position is calculated.

The disadvantage of this method is that the unavoidable errors, typically being in the range of 1 - 3 % of the way driven, are cumulative. After travelling 100 km, the error is between 100 and 300 m, after 200 km 2000 - 6000 m ....

Such a system therefore needs to be updated from time to time: the system must get information about the real position. This can be done fully automatically when the vehicle passes "sign posts", little radio or infrared emitters with limited range, which inform the vehicle about the true position at this point.

Such systems with sign posts have been realized in urban areas. They are, however, complicated and expensive.

Another method is updating with "transit fixes", positions received from a transit satellite receiver. The exhibit: "Dead Reckoning, updating by transit fixes" shows a typical plot of dead reckoning positions updated by transit fixes. A better method is the so called "map - matching". The on-board-computer has stored a digitized road map of the area. The computer constantly compares the calculated position with this road map. When it realizes that the position has been calculated to be besides the road, it corrects the position by placing it back on the road.

Of course, the system must be able to realize when the vehicle really is leaving the road and it must realize when the vehicle reenters a digitized road.

Such systems have been developed by several companies. The disadvantage of such systems is, that they need a digitized map of the area which again needs updating from time to time to take care of the changes. The maps will be stored on laser-discs (CD ROMS). One such disc can store all streets of a country like Germany.

The accuracy of such systems is better than 20 m.

2. RADIO LINK.

The answer to the question which is the right radio connection for a certain application mainly depends on the area to be covered or, in other words, the distance between vehicle and central base.

For short distances normally VHF is the answer. The problems here are related to frequency allocation, available empty channels etc. As nuclear shipments in most cases are long distance, we do not regard this technique in more detail.

For long distances we have three alternatives: HF, mobile telephone and satellite communication.

HF normally is not available for everybody. For nuclear shipments, however, licences are granted by the authorities in most countries. The problems are related to the fact, that HF provides a very unreliable connection. Depending on the location of the vehicle and the central base station, time of the day, time of the year, weather condition and other influences, a certain allocated frequency may be usable or not. Nuclear shippers therefore must choose between several frequencies allocated to them. During one long distance trip they often have to change frequencies one or several times to keep the contact. This, of course, is not easy for an automatically working system. Both stations, vehicle and central base, have to be synchronized to one of the available frequencies which work and have to switch fully automatically to another one if it does not work any longer. This means extra equipment, but it can be done.

Mobile telephone seems to be a good solution. The problems experienced here are the following:

- No connection can be built up for a longer period, as the system is overcrowded.
- No connection possible, as the area is not covered by the system.

This, of course, varies in the different countries. The experience that we have with our mobile telephone system in Germany demonstrates, that the above mentioned problems are so serious, that the use of mobile telephone as the only radio link cannot be recommended for security shipments so far.

Satellite communication is becoming more and more interesting for the transfer of data to and from the vehicle. We today have techniques which enable us to do this with very small devices in the vehicle and - most important - with very small antennas, which do not need to be directed to the satellite.

Of course it would be rather complicated and expensive, if a user would have to rent a satellite channel for himself. This, however, is not necessary, as the first organisations start to offer commercial services for everybody. Inmarsat in London is extending its maritime service to land mobile services now. A newly developed terminal for the use in the vehicle which is about as small as a car radio together with a small antenna can easily be installed in a truck or passenger car. A data telegram emitted from this so called Standard-C-Terminal will be received by one of the three geostationary satellites of Inmarsat and then be forwarded to one of the central ground stations. From there the message is sent via conventional communication links like telephone or telex to the central base of the vehicles operator. The same way can be used in the other direction for data telegrams from the base to the vehicle.

The 3 geostationary satellites of Inmarsat are placed over the Atlantic, the Pacific and the Indian Ocean. They cover the whole world except the pole areas. By this means a really worldwide communication of data is possible. The Standard-C-Terminal is not able to transfer voice. This service is running now on a trial basis. Commercial service will start within a few months. The fees for this service will be charged related to the quantity of data transferred. The charge will be around 1 US $ for 1 KBit. The disadvantage of this service will be, that it cannot be in real time. It will take a certain time to build up the conventional communication links between the central ground station and the home base of the vehicle. If we assume this time to be one minute and the speed of the vehicle to be only 60 km/h, this means, that the vehicle has moved 1 km until the message reaches home. Of course the message itself will include the exact time when the vehicle was at the position transmitted, so that the consequences of this delay are not so severe.

3. DATA PROCESSING AND DISPLAY.

The data transferred from the vehicle to the central base have to be processed. There are many possibilities what can be done. The normal method will be the display of the vehicle's position on a map. In the past this was done with sophisticated devices using slide projections or by moving mechanical pointers over a paper map. Today this is done with digitized maps on a computer screen. There are two principally different ways to produce such electronic maps: vectorized maps and pixel maps.

A vectorized map is designed with a CAD system. It consists of points and vectors drawing a line from one point to the next point. By this means a picture of the street net is generated, which can be shown on the screen in any scale. You may see the territory of the USA on one screen and you may zoom into the picture to see just the main streets of a city or you may further zoom in to see just the crossing of two streets. The disadvantages of this technique are, that it is very expensive to generate these maps and to keep them up-to-date and that the picture is rather unusual for the spectator. The advantage is, that the amount of data needed to generate a map is rather small. A further advantage is the fact that attributes can be added to the map like street names or area names like cities, counties or states. The system is then able to inform the user in which state, county, city and street the vehicle is moving now and which local authorities have to be informed in case of an incident. The system could also be informed about the route a vehicle should use. An alarm could be generated automatically in case the vehicle leaves this pre-programmed route. It would also be possible to program a time schedule for a certain trip and to have a constant comparison of how the vehicle lies in this time schedule and what the expected time of arrival will be.

A pixel graph map is made by scanning an existing paper map. Every detail of this paper map will also be contained in the digitized map and shown on the screen. The computer storage capacity required for this type of digitized maps is much larger than for vectorized maps. Zooming of details is not possible. To see different scales on the screen maps of different scale have to be digitized. Attributes and all the information and calculation as with vectorized maps is not possible.

The advantages are that such maps can be generated faster and cheaper than vectorized maps and that people like them more as they are used to this type of maps. The ideal solution probably will be a combination of both types. While the position of the vehicle is shown on the screen on a pixel graph map, all the calculations are done in the background on a not visible vectorized map.

After this explanation of how automatic vehicle location systems can be set up, let us discuss the advantages to be gained by such a system. The emphasis lies on the word "automatic". The system must work completely independent of the crew of the vehicle. It must be impossible for the crew to take any influence on the data transferred. This means among other things, that it must be impossible to take the location sensor out of the vehicle and place it into another vehicle, which then would do the trip to cheat the central base. It must also be impossible to feed false data into the system, for instance from a taped previous trip of the route. Furthermore, cheating of the central base with data sent from a similar device in another vehicle must be prevented.

Assumed that all these precautions have been taken, an automatic vehicle location system allows the surveying central base to take immediate action in case of any incident. Together with the information features as described above, the system can inform the central base crew immediately not only about the place of the incident but also about the competent local authorities, fire department, next airfield and many other matters of interest. An alarm can be generated automatically if the vehicle stops at unforeseen places or if it leaves the pre-programmed route.

In case the system will be deactivated, for instance by destroying the antennas, the position where this happened will be known and the search can start from there on.

A location system does not only mean advantages with regard to tracking vehicles from a central base. Also in the vehicle itself new safety features can be realized. The compartment with the cargo can be locked in such a way that it can only be opened at certain pre-programmed places. In general it can be said, that our imagination probably is not sufficient to think of all the applications that will be done with vehicle location systems in the future. All operators of vehicle fleets will gain advantages from these devices, not only in the field of nuclear shipments. These advantages will be in the areas of

- safety and security
- economy and
- efficiency

We will see these devices very soon in many different types of vehicles. Let me close with the remark, that these devices may help to demonstrate to the public the safety in shipping nuclear materials and that this may help to regain the public acceptance which we all miss so bitterly today.

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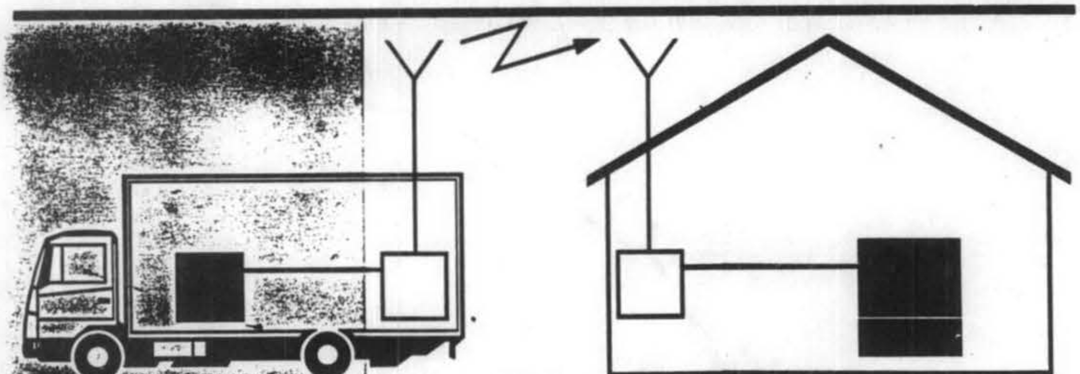

LOCATION SENSOR

Radio Navigation:
- GPS
- Glonass
- Loran C
- Decca
- Omega
- Geostar/Locstar
- Inmarsat
- RDS Locating
- Cellular Telephone

Dead Reckoning with:
- Transit Fixes
- Signposts
- Map matching

RADIO LINK

HF
VHF
Cellular Telephone
SatCom

DATA PROCESSING

Display:
- Vector graphics
- Pixel graphics

Large Displays
Documentation
Networks

COMPONENTS OF A LOCATION SYSTEM

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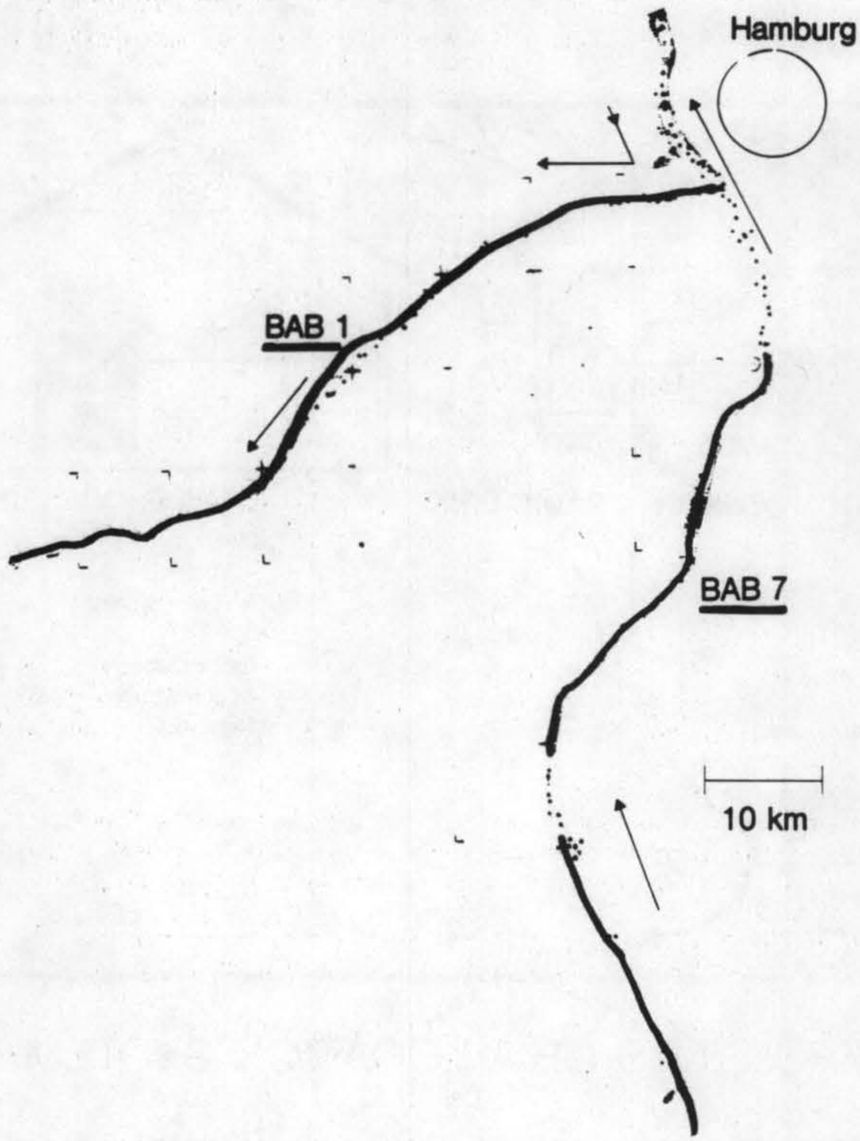

DECCA RESULTS

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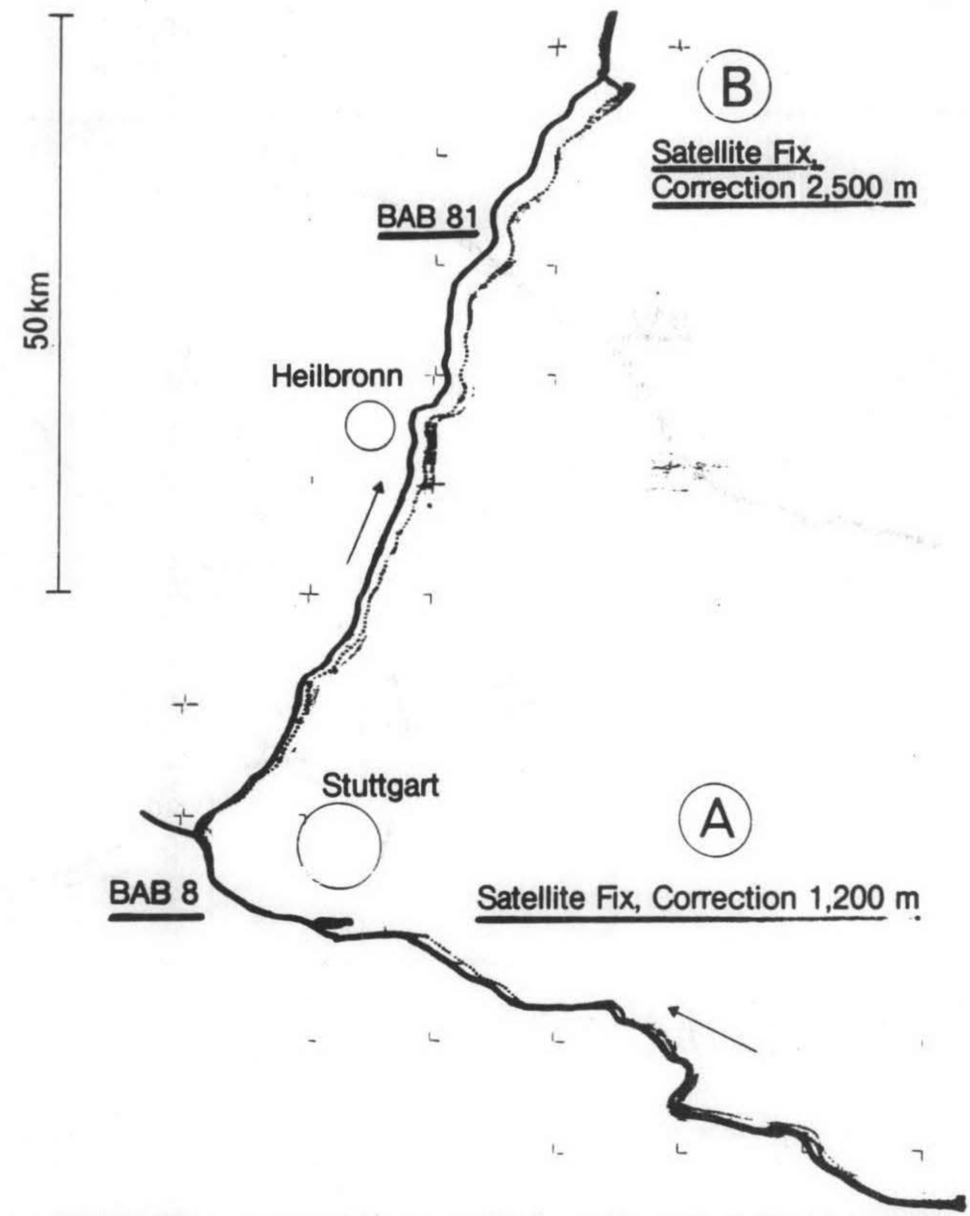
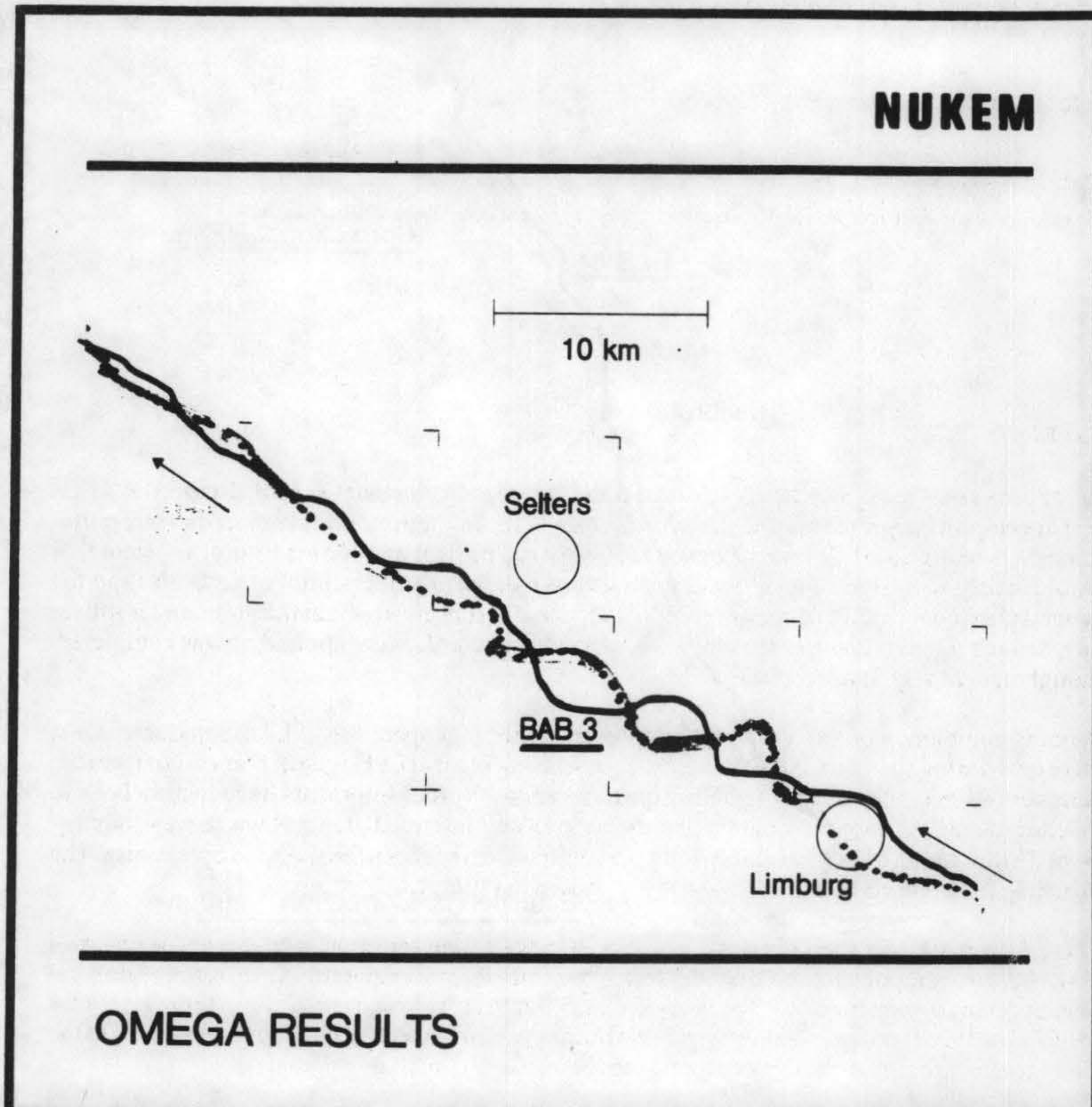


DEAD RECKONING
WITH TRANSIT FIXES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10 km
Selters
BAB 3
Limburg
OMEGA RESULTS