EXPERT CONCLUSION ON THE SEISMIC HAZARD ASSESSMENT FOR THE AREAS OF SAKHALIN-1 PROJECT ONSHORE FACILITIES CONSTRUCTION

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1. INTRODUCTION

The present Expert Conclusion (hereinafter Conclusion) is prepared at OOO ABB Lummus Global request and in order to provide for the services on seismic hazard assessment for construction of five (1-5) Sakhalin-1 Project facilities (Table 1, Fig. 1).

This problem is discussed in dozens of Studies and Reports (see Attachment). Most of them cover a wide range of methodological approaches and area often based on different initial data. This fact mainly justifies the various estimations for the value of possible seismic impact on construction facilities considered below.

The most professional Studies and Reports are provided by ABS-Consulting Company and Institute of Marine Geology and Geophysics (IMGG, Yuzhno-Sakhalinsk). These data were especially noted by Expert.

As construction of adequate model for earthquake source zones (zones of generation of earthquake foci) is the main and the most important stage in seismic hazard assessment, the major problem was to choose the most justified source zone model and to perform calculations of seismic hazard assessment for the facilities mentioned based on this model. The main accent was put on the application of the seismic hazard assessment methodology adopted in Russia and developed during construction of regulatory probabilistic set of General Seismic Zoning Maps for the Russian Federation — OSR-97 (see SNiP-II-7-81*, 2000).

<u>The main results of executed researches:</u>

1. Results of Studies and Reports on seismic hazard assessment performed by Russian and foreign companies for the area of Sakhalin-1 Project facilities future construction were revised and generalized. List of these data see in Attachment to the present Conclusion. Additional Reports and Articles were revised along with these data. The additional data comprise the results obtained earlier in the Institute of Physics of the Earth, RAS, in the course of investigations on General Seismic Zoning for the Russian Federation (OSR-97), and during construction of the Provisional Seismic Zoning Map of Sakhalin Oblast (VS-95) after disastrous Neftegorsk earthquake in 1995.
2. At the first stage checking calculations were performed based on the initial data contained in Studies and Reports and probabilistic methods used for construction of official regulatory maps set OSR-97 (A, B, C). Analytical review was also performed on seismotectonic data and models prepared by other specialists. Contradictions between analysis results obtained by Expert and other specialists are explained. The main attention was paid to earthquakes source models proposed by IMGG (A.I. Ivaschenko, Yuzhno-Sakhalinsk) and ABS-Consulting Company (Paul C. Thenhaus, Risk Consulting Division) upon Customer approval.
3. At the second stage the efforts (meetings, discussions and communications) were made to improve earthquake sources model for Sakhalin Island and the adjacent area in order to eliminate the existing uncertainties and contradictions. On September 30 the discussion of seismological problems with Dr. P.C. Thenhaus (ABS-Consulting) was extremely useful. Dr. P.C. Thenhaus is director of Seismic Hazard Service and one of the leading authors of

Sakhalin earthquake sources model by ABS. Dr. G.S. Johnson (HPA), Dr. A.I. Ivaschenko (IMGG), Yuri Dershteller, Sakhalin-1 Project Coordinator (ExxonMobil) and his assistant M. Sandler (ExxonMobil) took part in the discussion. As a result of the discussion the problem was solved and principal proximity of Russian and American approaches to probabilistic seismic hazards analysis was found out. At the same time there is a difference in earthquake sources model construction and their seismological parameterization.

4. At Expert's request Dr. P.C. Thenhaus has additionally provided the quantitative data on geometrical and seismological parameters of earthquake sources model for Northern Sakhalin. These data are required for seismic hazard assessment using OSR-97 technology. The same data were provided by A.I. Ivaschenko from IMGG (after long delay). Based on these data a great scope of data processing for OSR-97 technology and Geographic Information System (GIS ESRI ArcView 3.3 and Arc GIS 8.3) was carried out. Also a great number of tables and diagrams were complied, some of them are presented below. New results of the study of paleoseismodislocations recently determined by IMGG specialists in Sakhalin, including by request from ABS-Consulting Company, played an important part for the final IMGG model of zones of generation of earthquake foci.

5. Expert provided the Customer with weekly Informational Reports in the course of investigation and after inspections and calculations. These Reports contained the analysis of the data available, and the results of current calculations purposed for earthquake sources model improvement and verification of the results obtained by the principal investigators — IMGG and ABS Consulting. It took particularly long time to introduce iterationally the required corrections to earthquake sources model presented by A.I. Ivaschenko that was changed many times (till the last moment).

6. Special attention was paid to the development of basic models of earthquake source zones and their seismological parameterization because adequacy and validity of all the consequent models and calculations depend on them. Finally four alternative models of zones of generation of earthquake foci in Sakhalin were considered: (1) Provisional Seismic Zoning Map of Sakhalin — VS-95, developed just after disastrous Neftegorsk earthquake in 1995; (2) a model used in OSR-97; (3) the most recent model of ABS, presented by Dr. P.C. Thenhaus, and (4) IMGG-model, presented by Dr. A.I. Ivaschenko after a number of iterations. As a result the most justified alternative of IMGG model that was improved by Expert and A.I. Ivaschenko was taken as the basis for calculations under OSR-97 technology.

7. As it was specified by Customer to perform seismic hazard assessment the emphasis should be made on 1000-year recurrence period of seismic impact. It is shown below that due to the new data on paleoseismodislocations observed in Sakhalin and longer periods of earthquake occurrence along them, than assumed before, the seismic hazard assessment for North-Eastern Sakhalin represented by OSR-97 Maps is overestimated by 0.6–0.8 points (See difference in right column of Table 1). It should be noted that according to the adopted in Russia (and in former USSR) seismic intensity assessment in integer units of MSK-64 Scale (Points) the boundaries between zones of different intensity on regulatory maps of OSR-97 Set are drawn along the estimated isolines corresponding to 5.5, 6.5, 7.5, 8.5,9.5 etc. points. Indeed as it can be seen in Table 1 in the prevailing number of cases the differences between new and former assessments are fractions of point. But it is enough to displace the official assessment of OSR-97-B Map (1000-year recurrence) for the whole point to the less value of seismic impact.

Table 1

No	Facility	Latitude, ^{0}N	Longitude, ^{0}E	OSR-97-B	IMGG-2003	Δ_{MSK}
1	Chayvo OPF	52.505	143.185	9.89	**9.09**	**0.80**
2	Chayvo Drill Pad	52.477	143.284	9.66	**8.98**	**0.68**
3	Odoptu South Drill Pad	53.066	143.277	9.68	**9.01**	**0.67**
4	Odoptu North Drill Pad	53.146	143.260	9.81	**9.16**	**0.65**
5	De-Kastri Export Terminal	51.497	140.832	8.19	**7.59**	**0.60**

Therefore, the respective seismicity values, which correspond to a recurrence period of 1000, were substantiated and accepted as basic for Sakhalin I designed facilities (1-5): Chayvo OPF – 9, Chayvo DP – 9, Odoptu South DP – 9, Odoptu North DP – 9, De-Kastri Export Terminal – 8 MSK-64 points for II Category soils as per SNiP-II-7-81*.

2. BRIEF DESCRIPTION OF SAKHALIN ISLAND SEISMICITY

Extremely intensive seismicity of Sakhalin Island is caused by its location at the joint of Pacific and Eurasian litospheric platforms (Fig. 1 and 2).

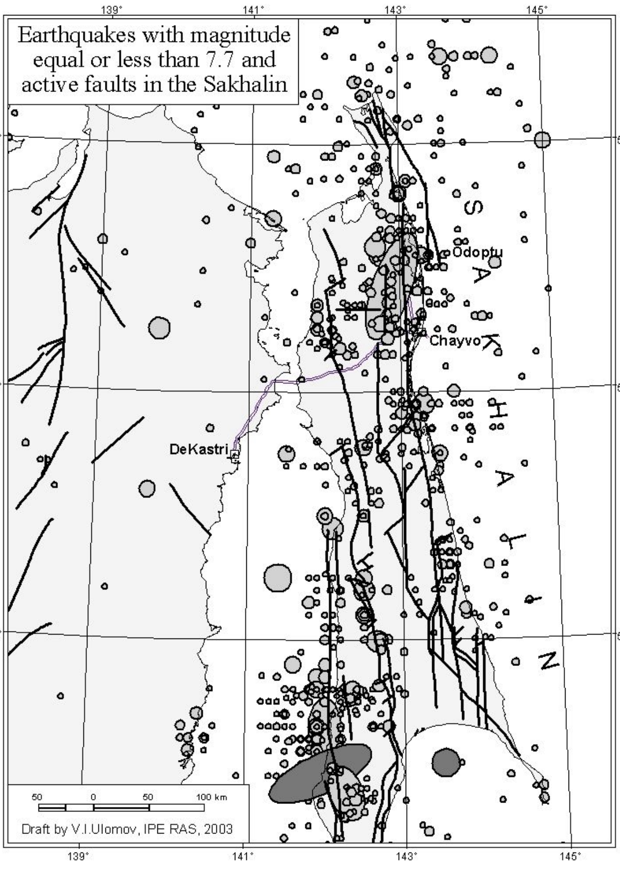


Fig. 1. Seismicity and Seismic Active Faults of Sakhalin Island and Adjacent Area. M = 6.5 and less earthquakes sources are indicated with circles, M = 7.0 and more — with ellipses. Orientation and length of ellipses correspond to stretch and dimensions of seismic sources. The sources inside earth crust are marked with light gray, earthquakes with deep sources are marked with dark gray. The locations of Odoptu, Chayvo and Sakhalin-1 Project route facilities are indicated as well.

The majority of weak and moderate earthquakes foci is concentrated here in the earth crust upper part at the depth up to 15-20 km. The maximum of its distribution is located at 10 ± 2 km depth. The strongest seismic events create shocks with intensity 9-10 and more points on MSK-64 Scale in epicentral areas, and cause significant earth surface residual deformation. At earthquake with magnitude Ms ≥ 7.0 the probability of source fault appearance on the surface is very high. The Kurils-Kamchatka zone of the Pacific lithosphere plate depression under the continent is characterized by the deepest (up to 650 km) earthquake centers. Deep-focus earthquake centers of this area are traced under the southern part of Sakhalin Island. The seismic effect of deep earthquake centers on the earth surface is relatively low.

Strong crust earthquakes in the northern and central part of Sakhalin are the most dangerous for Sakhalin-1 Project facilities. These earthquakes are confined to the largest tectonic faults — Piltun-Garomay, that is stretched in north-south direction along the eastern coast of Sakhalin mainland, and Verkhne-Piltun, that is the south-west branch of the first one. The source of disastrous Neftegorsk earthquake in 1995 (Ms = 7.4…7.7, I_0 = 9…10 points) was confined to Verkhne-Piltun fault. Till this moment the seismicity of Sakhalin was estimated as moderate and before the New Set of General Seismic Zoning Maps for the Northern Eurasia (OSR-97) was plotted in 1991-1997 by United Institute of Physics of the Earth (UIPE) the earthquakes of I_0 = 6…7 points intensity were expected for this region (Fig. 2, above).

Neftegorsk earthquake was the most destructive one in the history of the Russian territory. Nearly 2000 people died. As a result Neftegorsk industrial urban village was completely destroyed. It is possible that technogenic factors have acted as a trigger for the already existent elastic geodynamic tensions in the area, as well as in the event of disastrous Gazli earthquakes in Uzbekistan in 1976-1984. As it has been already noted, Neftegorsk earthquake source belongs to one of the south-western branches of extended Piltun-Garomay fault, which is located in the immediate proximity of Sakhalin-1 Project construction sites — Chayvo and Odoptu.

Moneron earthquake (1971, Ms = 7.5) is the other known major earthquake that occurred on the shelf in 40 km to the southwest of Sakhalin Island. Its hypocenter, as well as Neftegorsk earthquake hypocenter, was at 17-18 km depth. The recent Uglegorsk earthquake (2000, M = 7.1, $I_o \approx 9$ points) was also a considerable seismic event. It occurred in the southern part of the island far from inhabited areas and thus did not cause significant damage, but confirmed the high seismic hazard of Sakhalin shown in OSR-97 Maps (see Fig. 2). It can be noted that OSR-97 Maps validity is proven by another earthquake (M = 7.5) occurred in 2003 in Altai where such strong seismic events were never observed before. At the same time due to detailed study of paleoseismodislocations and the structure of regional seismicity the lineaments with Mmax = 7.5 ± 0.2 were included into the regional earthquakes sources model during OSR-97 Maps construction.

Estimation of Neftegorsk earthquake magnitude is in direct relationship to adequate assessment of seismic hazard for North-Eastern Sakhalin territory. However, the significant variations of magnitude values obtained by data from different authors often cause their arbitrary choice by different investigators. The data taken from International Seismological Center (ISC) are shown in the Table below. Magnitude mb, determined by body seismic waves, should be eliminated from consideration because as it is known starting from mb > 6.0 its value is saturated and cannot be used for the assessment of magnitude of such major events as Neftegorsk earthquake.

The value Ms = 6.9 (EIDC) also raise doubts, possibly it is a mistake. It should be noted that Russian seismologists usually use Ms magnitude determined by surface waves and corresponding to MLH value as basic one. Unfortunately in Russia (and former USSR) till the recent time there were no reliable instrumental data required for moment magnitude, Mw, determination. So to develop OSR-97 Maps MLH values were converted into Mw using the accepted relationship between these values.

Thus the value Ms = 7.6 can be accepted as average one based on 7.5 (NEIC), 7.7 (BJI), 7.7 (MOS) и 7.4 (ISC) values of magnitude. To perform seismic hazard assessment for especially important facilities which are Sakhalin-1 facilities the more conservative estimation, Ms = 7.7, provided by two sources, including Moscow, shall be used.

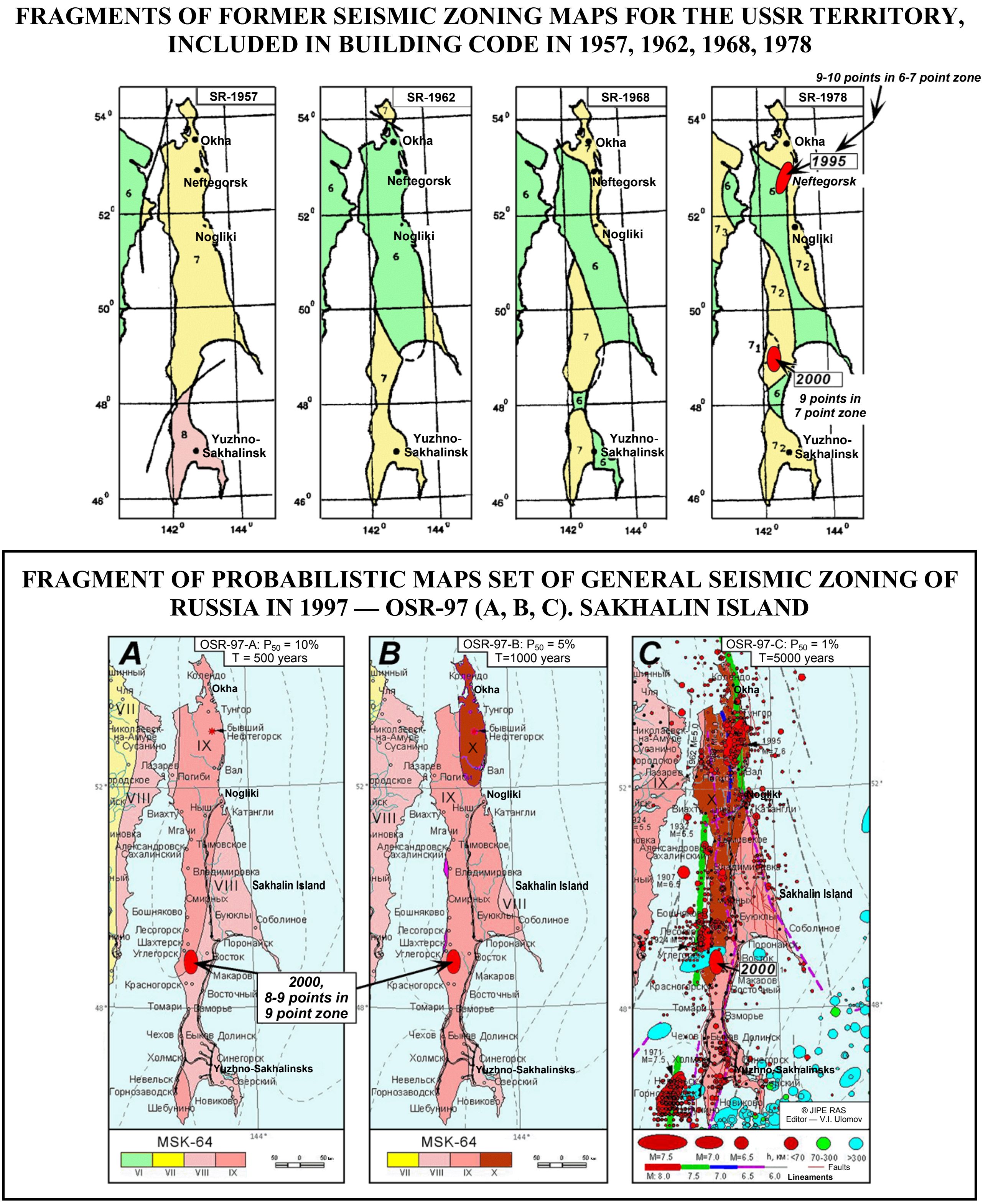


Fig. 2. Fragments of previous seismic zoning maps for Sakhalin Island of 1957, 1962, 1968, and 1978 and New Set of Probabilistic Regulatory Maps OSR-97 (A, B, C). The sources of the known earthquakes for the territory under consideration are shown on OSR-97 Map. The event of 2000 that occurred after OSR-97 set completion is also marked.

Table 2

Type and Value Magnitude		Number of Stations	Source
mb	6.4		NAO
mb	5.8	24	EIDC
MS	6.9	8	EIDC
mb	6.7	99	NEIC
MSZ	7.5	45	NEIC
Mw	7.1		HRV; NEIC
Mw	7.1		GS; NEIC
mb	5.9		BJI
Ms	7.7		BJI
mb	7.1	39	MOS
Ms	7.7	15	MOS
mb	6.5	173	ISC
Ms	7.4	67	ISC

Based on the data received by Sakhalin seismologists some other relationship between these magnitudes is obtained (Fig. 3). In spite of significant variations of magnitude values especially in the area of small values IMGG relationship (1 in Fig. 3) can be recommended for seismic hazard assessment for Sakhalin. However these values of magnitude are not obtained directly based on seismograms from Sakhalin seismic stations. They are obtained by comparison of MLH values taken from Seismological Bulletin of the Far East (for 1971 and 1990-2001) and Mw values from Main NEIC Catalogue for the same earthquakes.

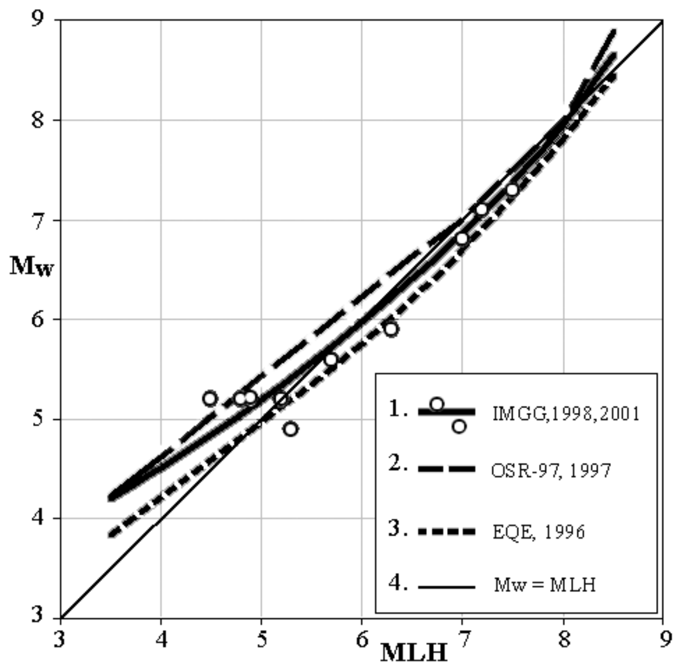


Fig. 3. MLH and Mw Magnitude Relationship according to the Data from Different Authors. 1 — averaged curve by Institute of Marine Geology and Geophysics (IMGG) data obtained during experimental observations (circles) in Sakhalin; 2 — relationship used for OSR-97 Maps construction; 3 — EQE data; 4 — a straight line corresponding to the case when MLH = Mw.

3. SEISMIC ZONING OF RF TERRITORY

As it has been already noted Provisional Seismic Zoning Map of Sakhalin — VS-95 (Executive editors — V.I. Ulomov, A.I. Ivaschenko) was developed in United Institute of Physics of the Earth, RAS, together with the Institute of Marine Geology and Geophysics (IMGG) FED RAS. It was developed based on source zones model presented in Fig. 5.

In accordance with VS-95, seismic hazard for Sakhalin-1 Project facilities located on the north-eastern coast of Sakhalin was estimated as 9 points with average recurrence period of 1,000 years.

As the technology of OSR-97 Maps Set construction approved in 1998 is an official one for seismic hazard assessment for Russian territory, see its general description below.

In 1991-1997 first seismic zoning was performed for the large area of Northern Eurasia including platform regions and the shelfs of adjacent and internal seas. OSR-97 Set (Executive Editor — V.I. Ulomov) consists of three maps — A, B и C, representing 10% — (OSR-97-A Map), 5% — (OSR-97-B) and 1% (OSR-97-C) probability of possible exceedance (or 90%, 95% and 99% non excess) of estimated seismic intensity for 50 years, that corresponds to 500, 1,000, and 5,000 years seismic impact recurrence period on the Earth surface (accurately, 475, 975, and 4,975 years).

In 1998 the set of OSR-97 Maps for the territory of Russia was approved by Russian Academy of Science and accepted by the State Committee of the Russian Federation for Civil Engineering and Municipal Housing (Gosstroy of Russia) as a regulatory document and in 2000 was included into Construction Standards, SNiP-II-7-81* Construction in Seismic Regions. Fig. 2 shows a segment of these maps for Sakhalin Island and adjacent territory.

The differential assessments of seismic hazards allow using OSR-97 set for designing and construction of earthquake resistant facilities of various categories of importance and service life. The OSR-97-D Map has been created for especially important facilities — such as nuclear power plants, radioactive waste burials, etc. This map corresponds to the average reiteration of the seismic effect on the earth surface once in 10, 000 years. The OSR-97-A Map presents the accelerations of soil oscillation and is a part of the first World Global Map of Seismic Hazards published in 1999 in the US under the aegis of UN (Global Seismic Hazard Assessment Program — GSHAP).

A detailed description of the methodology and technology of OSR-97 Maps construction is provided in the Internet: http://seismo.ethz.ch/gshap/neurasia/report.html

4. MODELS OF EARTHQUAKE SOURCES

Model of Earthquake Sources Zones, Used for OSR-97

In 1991–1997 UIPE developed a new methodology of probabilistic seismic zoning and constructed the first homogeneous seismogeological and geological-geophysical electronic database for the territory of Northern Eurasia. Lineament-domain-focal (LGF) model of the source zones (zones of generation of earthquake foci) in 3D representation formed a basis for seismic hazard assessment. Four scaled levels of earthquake sources are considered in LDF-model concept (Fig. 4) — large genetically monolithic *region* characterized by definite long-term average seismic regime, and its three main structural elements: *lineaments*, that generally are the axes of 3D seismic active fault or shear structures and representing the structural seismicity; *domains*, that cover tectonically and geodynamically quasihomogeneous volumes of geological media and are characterized by scattered (more exactly, not subjected to structuring at this scale level) seismicity; *possible sources* of earthquakes, indicating the most hazardous areas of lineament structures and faults segments determined based on paleoseismodislocations, etc.

Lineaments, domains, and possible sources as well as earthquakes are classified by the value of maximum magnitude (M_{max}). The upper level of magnitudes (M_{max}) is determined by actual seismic and geodynamical situation and the lower one (M_{min}) – by minimum seismic hazard that shall be taken into account for construction facilities. In OSR-97 M_{min} = 4.0, and seismic activity is I_{min} = 5 points.

According to source zones model the earthquakes with magnitude M = 6.0 and more belong to lineament structures, and with M = 5.5 and less — randomly scattered around the domains. All lineaments with M_{max} contain lineaments of lower ranges till M = 6.0, that randomly deviate (by Monte-Carlo Method) from the main lineaments axis corresponding to the value of standard deviation σ(km) as per distribution function (see Fig. 4).

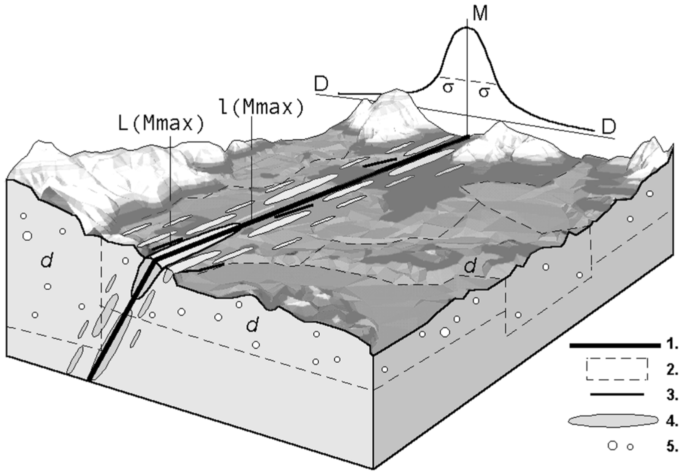


Fig. 4. Diagram of LDF-model of source zones. 1. — Axial planes of lineament structures $l(M_{max})$; 2. — Outlines of volume domains *d*; 3. — Active faults; 4. — Sources of earthquakes $L(M_{max})$ with magnitude *M* = 6.0 and more, that deviated from lineament axes for value *D* reverse proportional to earthquake magnitude *M* (see background plot); 5. — Sources of earthquakes with magnitude *M* = 5.5 and less, randomly scattered around the domains.

Before the final model covering the RF territory and adjacent seismic active regions developed for the earthquakes source zones in Northern Eurasia, just after Neftegorsk Earthquake the model of source zones in Sakhalin was created. This model presented in Fig. 5 was used for construction of Provisional Seismic Zoning Map of Sakhalin — VS-95. As it is shown in Summary (Table 8), according to this schematic map the area of all Sakhalin-1 Project facilities in the north-eastern part of the island is characterized by 9 points with 1,000 years recurrence period.

Fig. 6 shows the fragment of source zone model for the Northern Eurasia updated with new data on the age of paleoseismodislocations investigated by Dr. E.A. Rogozhin (UIPE) for Verkhne-Piltun fault. As a result he was the first who determined the 400-500-year occurrence period of events similar to Neftegorsk one for this fault. These as well as the other initial data (included in the Catalogue of Japan Sea Earthquakes) cause the increase of seismic hazard assessment for north-eastern part of Sakhalin compared to VS-95 Provisional Map.

As it is shown below due to recent (2002-2003) detailed investigations performed by A. Kozhurin, A. Strom etc. (Russian geologists) and Japanese scientists and specialists from ABS-Consulting, the assessment of recurrence period for large seismic events were increased to 1,000 and to 2,000 years and more. This fact as well as more detailed data on some other unknown before faults caused one more update of seismic hazard assessment for the territory of Sakhalin based on the investigations of detailed seismic zoning (DSZ). The expert review of these investigations is given below.

Lineaments and their segments at pitch 0.5 ± 0.2 of magnitude unit are shown with line segments of different thickness in the fragment of LDF-model of source zones in Sakhalin used at OSR-97 (Fig. 6). It shall be noted that only one domain covering the whole island and its shelfs was determined in this model. (It will be shown below that in the modern model of source zones approved by the present Conclusion there are nine domains and significantly more lineaments determined.)

In accordance with the concept adopted in OSR-97, for each genetically monolithic region of the Northern Eurasia and including Sakhalin-Japan Area long-term average characteristics of seismic regime were determined and the whole range of seismic events of corresponding magnitudes was distributed proportional to its size and in accordance with the range between all seismic generating structural element of source zones. Seismological parameterization performed in such a way formed the base for long-term seismicity modeling and virtual seismic regime for each of the structural elements of source zones. Virtual seismic “activation” of source zone model in its turn forms the basis for seismic impact recurrence calculations and seismic hazard assessment for the whole territory of the Northern Eurasia.

MODEL OF EARTHQUAKE SOURCES FOR PROVISIONAL SEISMIC ZONING MAP OF SAKHALIN (VS-95)

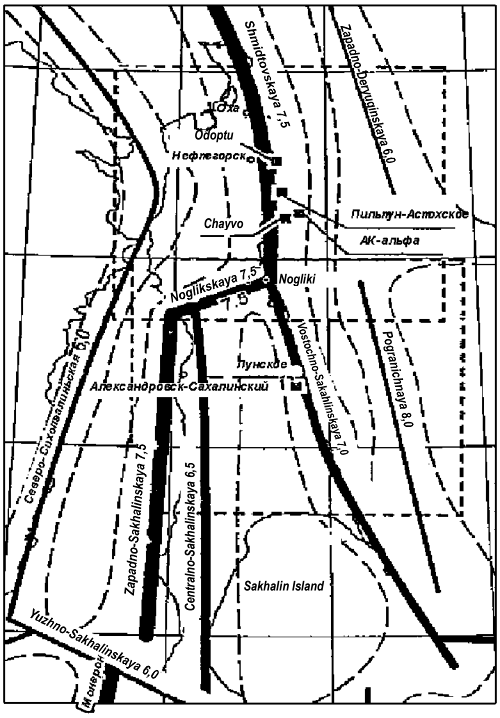


Fig. 5. Source Zones Model Used for Provisional Seismic Zoning Map for Sakhalin — VS-95.

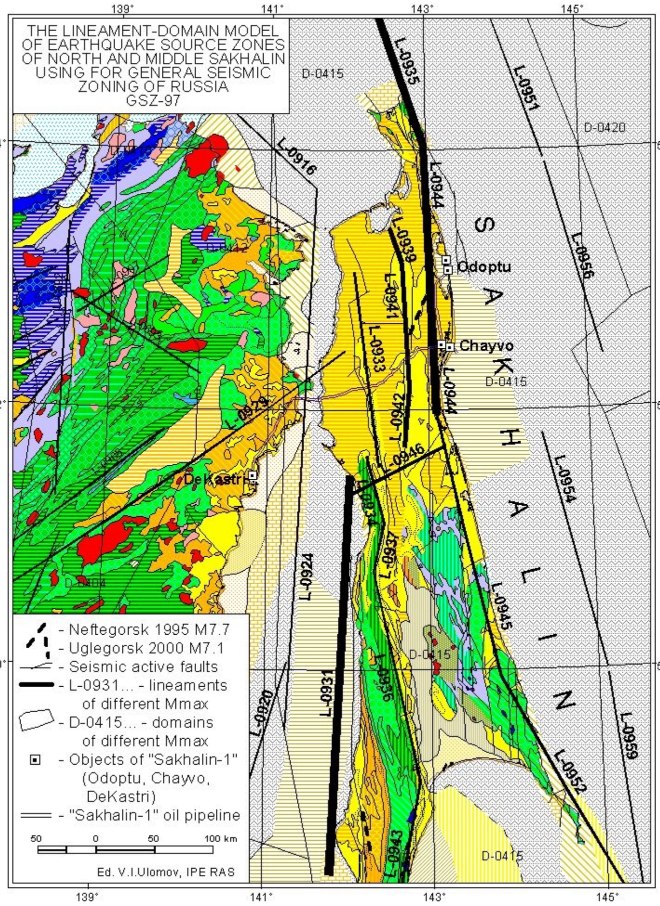


Fig. 6. Fragment of LDF-model of Earthquakes Source Zones in Sakhalin and Adjacent Territory Used for New Set of Probabilistic Maps OSR-97. Quantitative Description for Each Lineament and Domain are Shown in the Table below.

Tables 3 and 4 contain data from OSR-97 database for source zones model used for OSR-97. The explanations are given below. In order to facilitate further comparison in Table 3 of Piltun-Garomay lineament (L-0944) parameters are marked with bold. This lineament corresponds to the cognominal fault considered in OSR-97 as monolithic without division into segments. It can be noticed that the accepted in OSR-97 recurrence period is about 180 years for the events with M = 7.5 along this fault.

The Probabilistic Seismic Hazard Analysis (PSHA) for Chayvo and Odoptu facilities (Fig. 7) is performed by Monte Carlo Method based on Earthquake Model Catalogue and adequate seismological parameterization of source zones model taking into account seismic impact attenuation with the increase of distance from earthquake sources. It is shown that based on

OSR-97-B and OSR-97-C Maps seismic impact can reach 10 points that requires Project Specific Design Code development as per SNiP-II-7-81*.

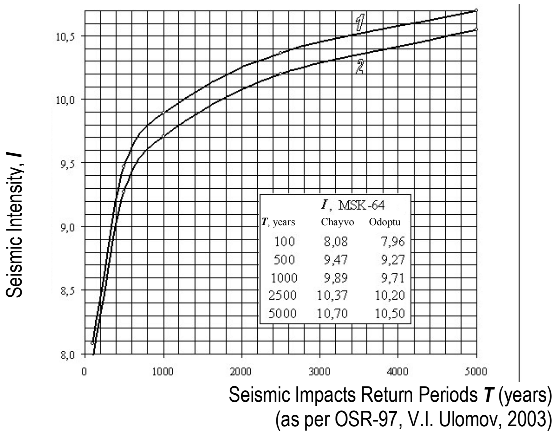


Fig. 7. Seismic Hazard Probabilistic Analysis Curves for the Areas of Chayvo (1) and Odoptu (2) Facilities as per OSR-97 Data.

Table 3

Parameters of Seismolineaments Used for Seismic Hazard Assessment in Sakhalin for OSR-97 Map
(On the map (Fig. 6) their number are marked with bold italic)

Name	M_{max}	H_{min}	H_{max}	$T_{8.5}$	$T_{8.0}$	$T_{7.5}$	$T_{7.0}$	$T_{6.5}$	$T_{6.0}$	Az	e-1	de-1	e-2	de-2	l, km
L-0916	6,0	2,40	12,4						2611	118	90	20	0	0	120
L-0917	6,0	3,00	13,0						2747	222	90	20	0	0	114
L-0920	6,0	2,00	12,0						1835	205	90	20	0	0	171
L-0924	6,0	4,50	14,5						679	185	90	20	0	0	463
L-0929	6,0	1,70	11,7						786	245	90	20	0	0	398
L-0931	7,5	5,00	30,0			121	75	140	149	184	90	20	0	0	342
L-0933	6,5	4,10	19,1					284	303	169	90	20	0	0	168
L-0934	6,5	5,00	20,0					814	869	158	90	20	0	0	57
L-0935	7,5	4,80	29,8			304	188	351	374	150	90	20	0	0	136
L-0936	6,5	5,00	20,0					259	276	162	90	20	0	0	184
L-0937	6,5	5,00	20,0					1133	1206	199	90	20	0	0	42
L-0939	7,0	5,00	25,0				804	1497	1597	149	90	20	0	0	32
L-0941	7,0	5,00	25,0				240	446	476	175	90	20	0	0	107
L-0942	7,0	5,00	25,0				498	929	990	189	90	20	0	0	51
L-0943	6,5	5,00	20,0					320	341	196	90	20	0	0	149
L-0944	**7,5**	**5,00**	**30,0**			**181**	**112**	**209**	**223**	**177**	**90**	**20**	**0**	**0**	**228**
L-0945	6,5	5,00	20,0					206	220	160	90	20	0	0	231
L-0946	6,5	5,00	20,0					514	548	252	90	20	0	0	92
L-0951	6,0	5,00	15,0						355	149	90	20	0	0	143
L-0952	6,5	3,90	18,9					220	235	140	90	20	0	0	216
L-0954	6,0	5,40	15,4						246	159	90	20	0	0	207
L-0956	6,0	5,40	15,4						299	156	90	20	0	0	170
L-0959	6,0	5,10	15,1						261	170	90	20	0	0	195

Table 4

Parameters of Domain Used for Seismic Hazard Assessment in Sakhalin for OSR-97 Map

Name	M_{max}	H_{min}	H_{max}	$T_{5.5}$	$T_{5.0}$	$T_{4.5}$	$T_{4.0}$	Az	e1	de1	e2	de2	S, th. km^2
D-0415	5,5	5	10	**4,1**	**1,5**	**0,6**	**0,2**	0-360	0-180	0	0	0	350,46

Where: Name — type of seismic source; L-nnnn — lineaments, D-nnnn — domains, nnnn — number; M_{max} — maximum possible magnitude corresponding to MLH, that is converted to M_w for seismic hazard assessment; H_{min} — minimum depth of seismic source upper boundary that corresponds to the depth of occurrence of consolidated crust upper boundary, km; H_{max} — maximum depth of earthquake hypocenter, km; T_M — recurrence period for earthquakes of different magnitudes (including M_{max}), that occur in each of the seismic sources zones (i.e. without reduction of event set to length unit or source area, because all the sources were parameterized beforehand taking their sizes into consideration); Az — azimuth of lineament horizontal axis orientation (set taking possible deviations into consideration); e-1 — tilt angle relative to lineament structures and earthquakes model sources plane horizon; de-1 — possible deviations of tilt angle lineament structures and earthquakes model sources plane horizon; e-2 — other possible cases of tilt angles relative to horizon; de-2 — possible deviations of these tilt angles; l — horizontal length of lineament, km; s — domain area, thousand km^2.

In comparison to former native approaches and methods the following advantages of a new OSR-97 methodology and its software and mathematical instruments can be noted:

- Regional approach to earthquake source model construction, that provides for the adequate seismological parameterization of source zones (estimation of magnitude of maximum possible earthquakes, realistic parameters of seismic regime etc.).
- Presentation of different magnitude earthquakes occurrence not as simple exponential diagrams as before but taking into consideration various data on seismicity, seismic regime and seimogeodynamics (including the data on paleoseismodislocations, historical data etc.).
- Presentation of earthquakes sources not as dots but in accordance with their natural dimensions, magnitude, spatial orientation and distribution with depth etc.
- Application of stress-drop, seismic moments, momentum magnitudes M_W (except traditional M_S and M_{LH}) and other quantitative parameter as energy parameters for earthquakes sources.
- Description of incoherent radiation field in the area of the extended source that allowed solving the problem of increased seismic intensity at small epicenter distances and to model isoseists ellipticity in the near zone of the extended earthquakes source of large magnitudes.
- Consideration of the probabilistic assessments for one or another result or initial data validity (scattering of seismic intensity value at the given magnitude and distance, fluctuations of tilt angles of lineament structure planes, distribution with source depth, etc.) at all stages of investigation.
- Construction of maps set (not one map as before) of probabilistic seismic zoning (OSR-97), that is used for antiseismic construction of facilities with different categories of importance and service life.

In the same time as OSR-97 Maps are plotted in relatively small scale (1:2,500,000) and do not represent the details of local geotectonics, these assessments can be (and shall be) updated based on the additional data obtained by detailed seismic zoning and microzoning.

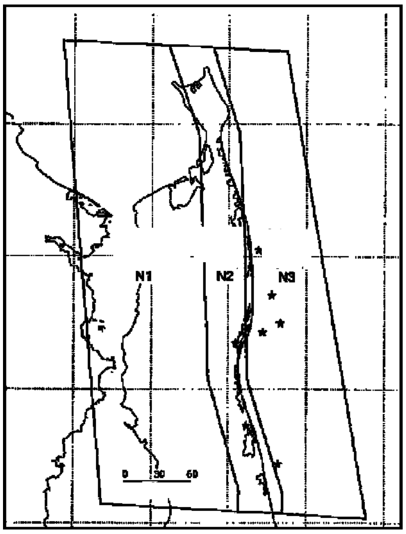
This was the main objective of the present Conclusion. New calculations were based on the updated model of earthquakes sources (zones of generation of earthquake foci). Native technology of seismic hazard assessment developed for OSR-97 was preferred.

Earthquake Sources Models Suggested and Used by Other Authors

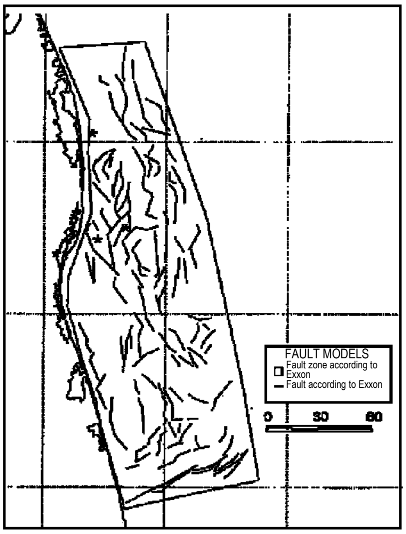
It should be noted that all ABS-Consulting Reports supplied to the Expert are well prepared due to their fundamental character and careful study of minor details. From this point of view Russian scientists reports are much poorer. The main purpose is that the majority of Russian colleagues are not familiarized with the scientific basis and software and mathematical instruments of native origin in this area, and first of all, they do not know OSR-97 technology. At best Russian specialists use the available American Seisrisk-III software. In many cases trying to earn more from Russian and foreign companies contracts they do not invite specialists that are familiar with OSR-97 technology.

Earthquake sources models developed by ABS-Consulting and Institute of Marine Geology and Geophysics, FED RAS, are considered below.

As in OSR-97 technology structured seismicity is the simplified models of "scattered seismicity" suggested by EQE and ExxonMobil (Fig. 8) are unacceptable. Such models sufficiently decrease seismic hazard assessments by "smoothing" the seismic events with large magnitude across wide area.



Zone of Distributed Faults by EQE (Zones of areal earthquakes sources for Northern Sakhalin water areas and onshore areas of facilities, marked with *)



Models of Offshore Faults according to ExxonMobil Data for Offshore Construction Facilities in the Northern Part of Sakhalin (marked with *)

Fig. 8. Examples of Unacceptable Models with Distributed Earthquake Sources.

Two model are acceptable for discussion and calculations as per OSR-97 technology — ABS-Consulting model (Author — Dr. P.C. Thenhaus, Fig. 9) and IMGG model presented by A.I. Ivaschenko and updated by the Expert under his permission. The final revision of IMGG model fully satisfies the requirements of OSR-97 technology by its structure and seismological parameterization.

ABS-Consulting Model

ABS-Consulting model presented by Dr. P.C. Thenhaus (Fig. 9) was studied in two ways. The first type of calculations was performed without any changes in geometry and seismological parameters of the model, in the second case model parameterization on magnitude was adopted for OSR-97 technology.

In spite of orderliness and strictness of methodology presented in ABS Reports and by Dr. P. Thenhaus (at the meeting) a number of questions have arisen.

In the first case the calculations by P. Thenhaus model gave extremely high (even in comparison with OSR-97 Maps) seismic hazard assessments for Sakhalin-1 Project facilities. The results of such calculations are shown in Summary Table in the end of Conclusion (Table 8, Columns 11-12). Of course these results shall not be considered valid. The reason for such high assessments can be in application of excessive differentiation of seismic events by magnitude (pitch — 0.05 of magnitude unit, P. Thenhaus) that is unacceptable for OSR-97 technology. In this case as it has been already noted the calculations were performed strictly in accordance with the data from P. Thenhaus, i.e. without transformation of cumulative diagram of earthquakes recurrence into interval one, as it is required by OSR-97 technology. Fig. 10 and 11 show two types of these diagrams.

In the second case all ABS data without any changes were adopted for OSR-97 technology, i.e. transformed from cumulative representation into interval diagrams of earthquakes occurrence and were grouped with pitch 0.5 ± 0.2 of magnitude. The sets of seismic events were summed up in each of these groups. The results are given in Table 5 where V=N/Year is a seismic rate and T is a recurrence period.

In spite of unusual shape of the diagrams (particularly the interval one), they absolutely do not coincide with the actually observed seismic regime of the Sakhalin territory under consideration. Thus, earthquakes with magnitude M = 6.5 do not occur once in 5,205 years as it is shown in Diagrams and Table 5, but in fact 100 times and more often. If the recurrence of such seismic events should be considered separately by faults, recurrence period will be unreal — from 11,000 to 22,000 years. The same is discovered for the assessments of recurrence of earthquakes with other magnitude values.

More realistic is the value of earthquake occurrence period for M = 8.0 at Piltun fault (period of about 8,000 years), obtained by Dr. P. Thenhaus based on the study of fault length and seismic displacement along it. Due to this fact the resulting assessments of seismic hazard obtained by ABS as per Dr. P. Thenhaus' methodology (Table 8, Columns 9, 10) appeared to be quite similar to those obtained as per the last revision of IMGG model (Columns 17, 18). Calculations performed as per OSR-97 technology gave sufficiently lower assessments (Table 8, Columns 13, 14). Probably the cause is in the processing technology. Thus the values obtained by ABS and presented in Columns 9, 10 (Table 8) shall be considered final for ABS technology.

Table 5

Lin.	Piltun		Upper Piltun		Central Sakhalin		SUM	
Mw	V	T	V	T	V	T	V	T
6.5	0.00008977	11139	0.00005804	17229	0.00000443	22583	0.0001921	5205
7	0.00006816	14671	0.0002527	3957	0.00003736	26766	0.0003582	2791
7.5	0.00001736	57603	0.0001098	9109	0.0002164	4622	0.0005631	1776
8	0.00012509	7994					0.0001251	7994

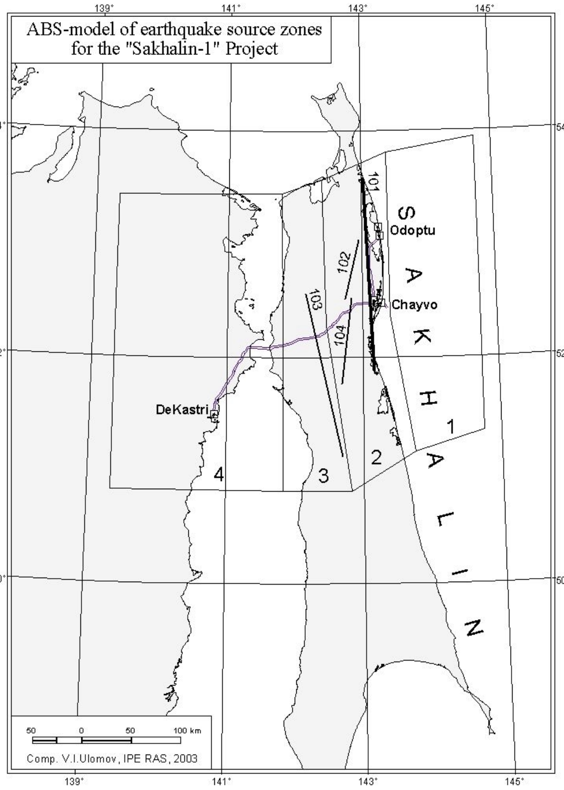
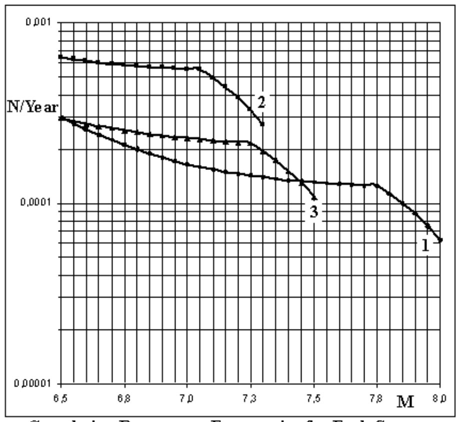
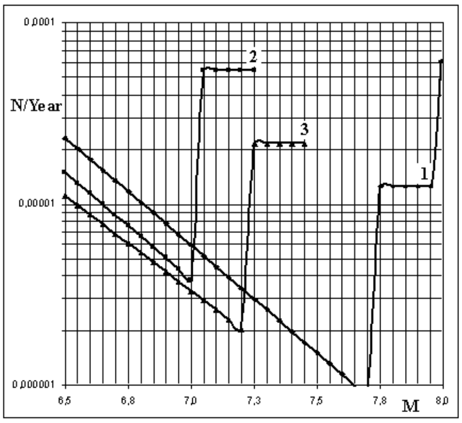


Fig. 9. ABS Model of Earthquakes Sources in the Northern Sakhalin (after P. Thenhaus).



Cumulative Recurrence Frequencies for Fault Sources:
1-Piltun, 2-Upper Piltun, 3-Central Sakhalin



Interval Recurrence Frequencies for Fault Sources:
1-Piltun, 2-Upper Piltun, 3-Central Sakhalin

(compilation by V.Ulomov, after ABS-data, 2003)

Fig. 10 and 11. Cumulative (Upper) and Interval Earthquake Recurrence Frequencies at Linear Earthquake Sources (Piltun, Upper Piltun and Central Sakhalin Faults) as per Model by P. Thenhaus.

IMGG Model

Earthquakes sources model obtained by IMGG was digitized and adapted for OSR-97 methodology and GIS technology. Dr. A.I. Ivaschenko has presented several alternatives of the model (Fig. 12–13), therefore iterational calculations were performed for 1,000 years and some other seismic events recurrence periods. Two types of earthquakes sources with different magnitudes deviation from lineaments axes were considered: ± 5 km scattering that does not depend on magnitude by A.I. Ivaschenko, and standard scattering differentiated by 0.5 of magnitude unit accepted in OSR-97. The equation of seismic intensity attenuation with the increase of distance accepted in OSR-97 was used.

The results of these calculations are given in Summary Table (Columns 5, 6 and 7, 8). As it can be seen the assessments as per the first alternative of source zones model (IMGG and OSR-97 Columns) practically coincide in spite of significant deviation of sources relative to Piltun-Garomay lineament axis. Both values are lower than provided in OSR-97-B Map (Columns 3, 4) and resulting assessments shown in Summary Table 8 (Columns 17, 18).

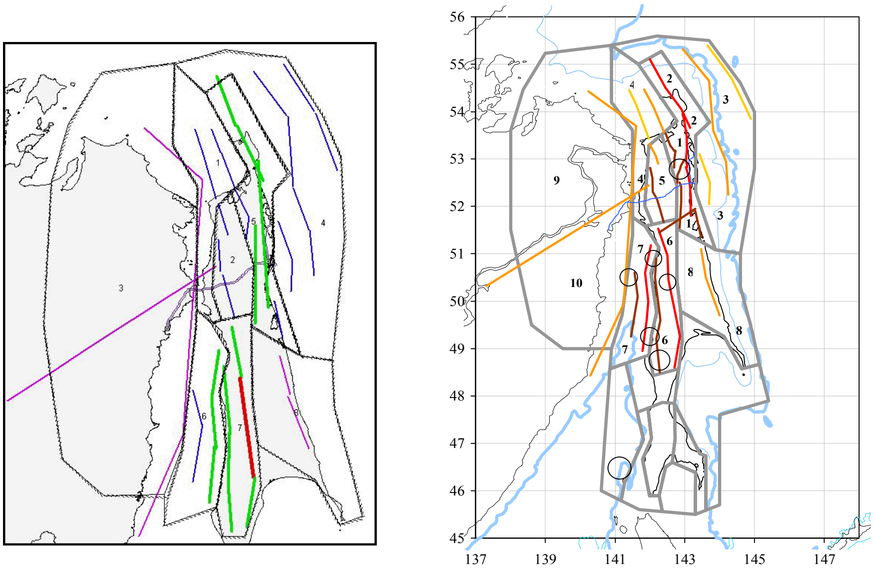


Fig. 12 Examples of IMGG Model Alternatives

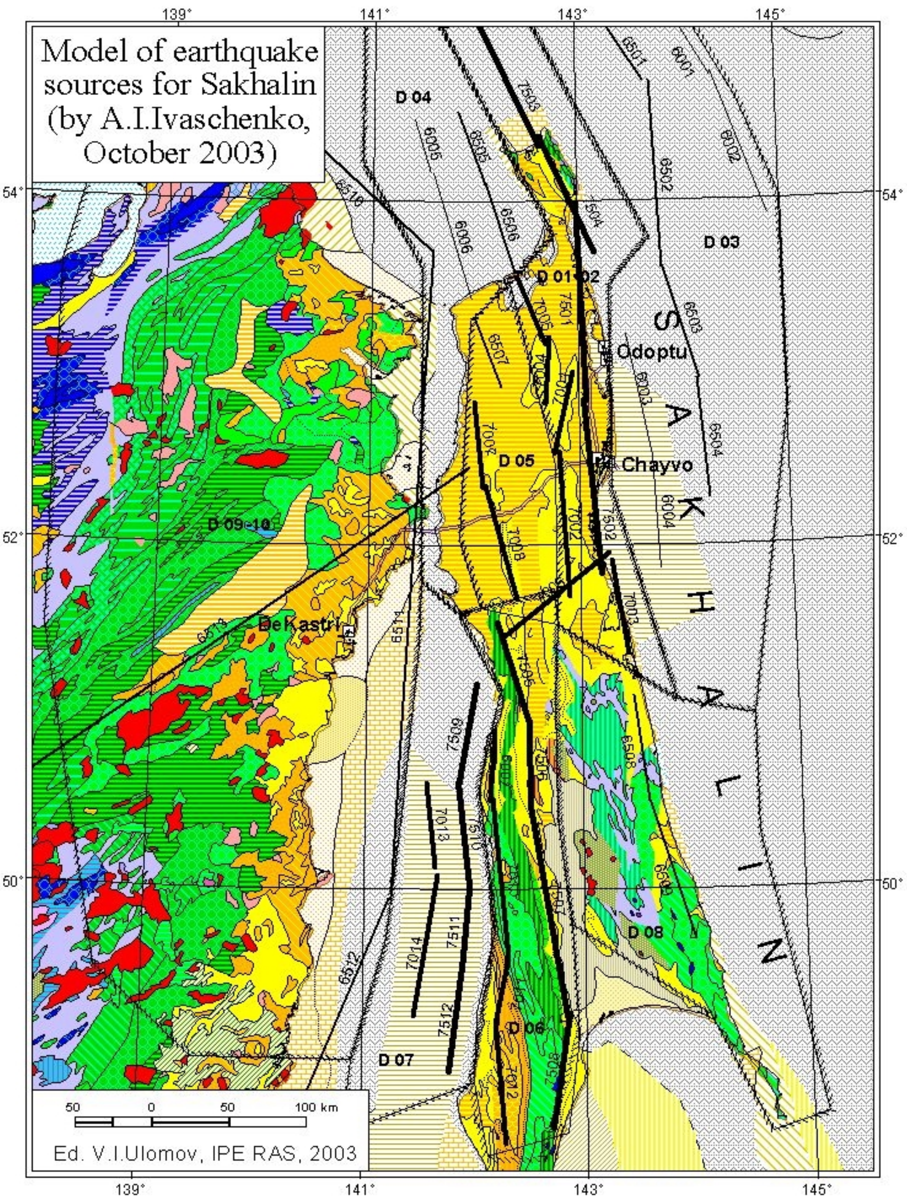


Fig. 13. Final Revision of IMGG Model of Earthquakes Sources for Northern and Central Sakhalin and Adjacent Territory

Fig. 13 shows the final revision of IMGG model of earthquakes source zones for the territory under consideration. As before lineaments are shown with numbered straight lines. The first two digits in lineament number denote maximum magnitude (Mmax) of earthquakes that are possible along the corresponding lineaments or their segments.

Domains are contoured with diagonal ruling and denoted with letter “D” with the corresponding number.

For more detail the source zones model is presented on geological basis.

Fig. 14 contains the diagrams of earthquakes recurrence for the territory under consideration, corresponding to the new source zones model. The upper diagram illustrates the initial data on earthquakes with different magnitudes recurrence obtained from the actual seismological catalogue. Here black circles indicate the observed values of annual earthquakes occurrence for magnitude interval ± 0.2 and pitch 0.5 of magnitude unit. These data are approximated with dotted line. Solid lines — diagrams of earthquakes occurrence in Kurils-Kamchatka (4.1) and Sakhalin — Sea of Japan (4.2), used for OSR-97 Maps construction (numbers 4.1 and 4.2 correspond to regions numbering accepted in OSR-97).

As a result of catalogues and their reliability analyses it was decided to increase the recurrence of earthquakes with magnitudes $M = 6.0 \pm 0.2$ and $M = 6.5 \pm 0.2$, as it is shown with hollow circles in this figure.

The lower figure represents the updated diagram. Its straight (exponential) segment with tilt angle $b = -1.0$ is constructed using maximum likelihood method for magnitude range $M = 4.0…6.0$. The equation shown below is constructed for this diagram segment continued with a dotted line to the interval of large magnitudes.

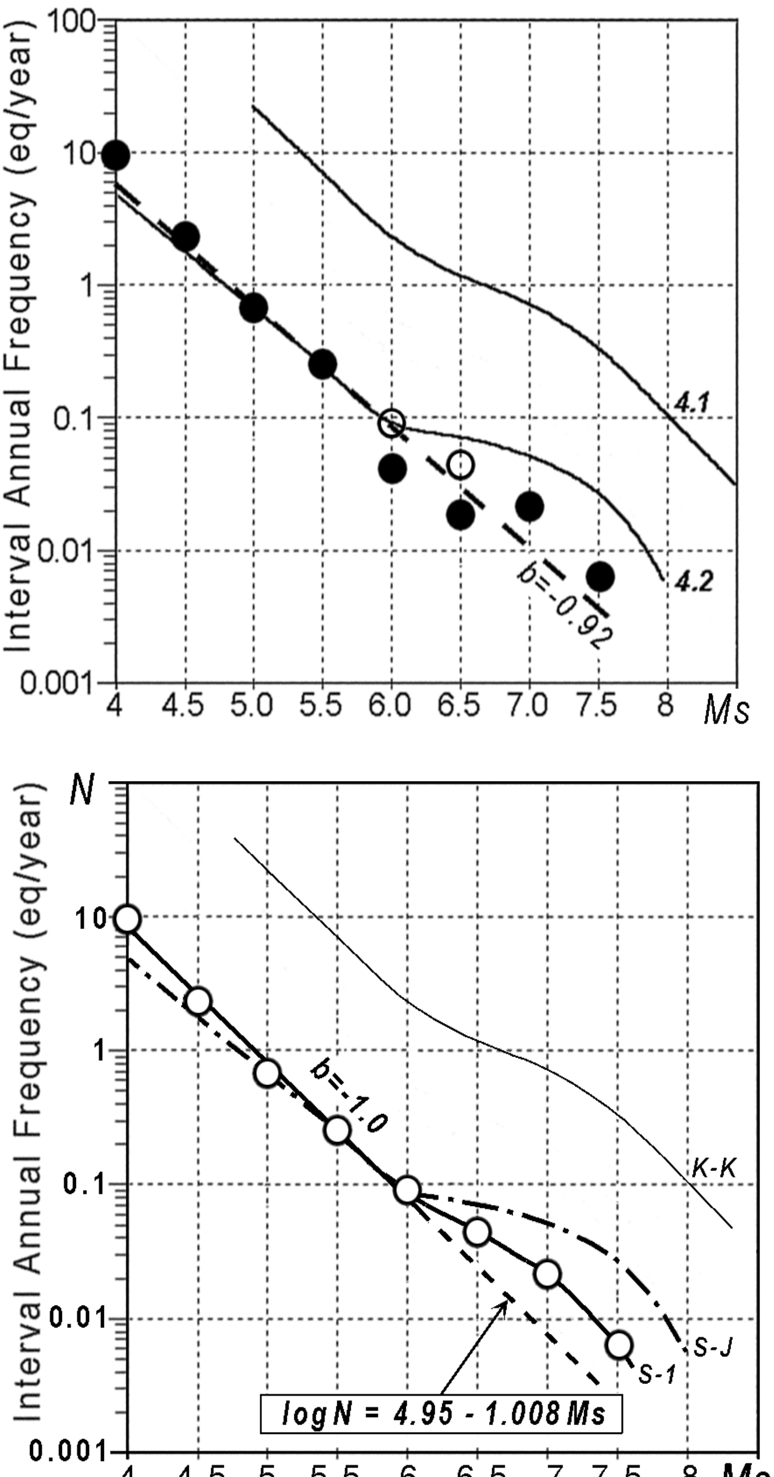
The data on major, “characteristical” earthquakes with $M = 6.5…7.5$ are located above this dotted line and are characterized by high recurrence frequency.

Dot-dash line represents the diagram used in OSR-97 for Sakhalin-Japan Sea Region (S-J).

As it can be seen the new diagram (S-1) at magnitude interval 6.5…7.5 is located below the S-J diagram. By its configuration it is similar to the diagram for Kurils-Kamchatka Region (K-K) used for OSR-97. This is another argument for reliability of S-1 diagram obtained and consequently the reality of seismic regime assessment.

Piltun and Garomay lineaments are indicated in Table 6 with bold (for comparison with Table 3). In the lower line of the Table there are presented the calculated values of earthquake occurrence with magnitude 7.5…6.0, given in diagram (Fig. 14) as frequencies.

Table 7 contains the similar parameters for domains.



RECURRENCE FREQUENCY PLOTS
for the northern Sakhalin Island (S-1); circles - observed data (IMGG-model of source zones, modified after V.I.Ulomov, 2003); S-J - Sakhalin-Japan Sea and K-K - Kuril-Kamchatka Regions from GSZ-97

Fig. 14. Diagrams of Earthquakes Recurrence Frequencies for the Territory under Investigation. Explanation see in text.

Table 6

Seismic Lineaments Parameters in Final Revision of IMGG Model of Earthquake Sources of Northern and Central Sakhalin
(complied using the data from A.I. Ivaschenko and updated by V.I. Ulomov)

Name	M_{max}	H_{min}	H_{max}	$T_{7.5}$	$T_{7.0}$	$T_{6.5}$	$T_{6.0}$	Az	e1	d1	e2	d2	l, km
7501	**7,5**	**1-6**	**7-11**	**953**	**644**	**499**	**305**	**178**	**90**	**20**	**0**	**0**	**127**
7502	**7,5**	**1-6**	**7-11**	**2110**	**1427**	**1105**	**675**	**175**	**90**	**20**	**0**	**0**	**115**
7503	7,5	1-6	7-11	1667	1129	874	534	154	90	20	0	0	95
7504	7,5	1-6	7-11	1934	1307	1014	618	155	90	20	0	0	82
7505	7,5	1-6	7-11	2525	1408	752	364	164	90	20	0	0	66
7506	7,5	1-6	7-11	2941	1642	876	424	178	90	20	0	0	57
7507	7,5	1-6	7-11	1242	693	370	179	170	90	20	0	0	134
7508	7,5	1-6	7-11	2252	1255	670	324	189	90	20	0	0	74
7509	7,5	1-6	7-11	1923	885	472	228	191	90	20	0	0	66
7510	7,5	1-6	7-11	1880	864	461	223	175	90	20	0	0	67
7511	7,5	1-6	7-11	2825	1299	693	335	185	90	20	0	0	45
7512	7,5	1-6	7-11	1730	796	425	205	188	90	20	0	0	73
7001	7	1-6	7-11		1916	1482	906	194	90	20	0	0	56
7002	7	1-6	7-11		1160	899	549	179	90	20	0	0	92
7003	7	1-6	7-11		1727	1335	817	169	90	20	0	0	62
7004	7	1-6	7-11		2667	2069	1261	184	90	20	0	0	40
7005	7	1-6	7-11		2268	1756	1073	156	90	20	0	0	47
7006	7	1-6	7-11		1100	686	360	232	90	20	0	0	91
7007	7	1-6	7-11		1751	1658	1154	176	90	20	0	0	57
7008	7	1-6	7-11		1346	1274	887	165	90	20	0	0	74
7009	7	1-6	7-11		2092	1117	540	183	90	20	0	0	45
7010	7	1-6	7-11		926	494	239	174	90	20	0	0	101
7011	7	1-6	7-11		2058	1097	530	192	90	20	0	0	45
7012	7	1-6	7-11		1192	636	308	175	90	20	0	0	78
7013	7	1-6	7-11		1035	552	267	174	90	20	0	0	56
7014	7	1-6	7-11		606	323	156	190	90	20	0	0	96
6501	6,5	1	7			1331	1425	145	90	20	0	0	84
6502	6,5	1	7			910	975	175	90	20	0	0	123
6503	6,5	1	7			1471	1571	161	90	20	0	0	76
6504	6,5	1	7			1431	1531	175	90	20	0	0	78
6505	6,5	1	7			1817	1841	158	90	20	0	0	45
6506	6,5	1	7			1306	1325	162	90	20	0	0	62
6507	6,5	1	7			1899	1325	161	90	20	0	0	50
6508	6,5	1	7			1734	524	172	90	20	0	0	67
6509	6,5	1	7			1247	378	161	90	20	0	0	94
6510	6,5	1	7			4221	1571	134	90	20	0	0	120
6511	6,5	1	7			1215	452	181	90	20	0	0	419
6512	6,5	1	7			2804	1040	204	90	20	0	0	182
6513	6,5	1	7			1274	474	237	90	20	0	0	401
6001	6	1	7				1332	149	90	20	0	0	90
6002	6	1	7				1183	158	90	20	0	0	101
6003	6	1	7				1502	167	90	20	0	0	80
6004	6	1	7				1648	176	90	20	0	0	72
6005	6	1	7				2296	160	90	20	0	0	36
6006	6	1	7				985	164	90	20	0	0	84
Return periods in the region				**151,3**	**44,9**	**22,1**	**11,0**						

As seen, the recurrence periods for seismic events with M=7.5±0.2 – 6.0±0.2 along all lineaments within the whole territory under study look entirely realistic. The same relates to the events within the domains as well (Table 7).

Table 7

Parameters of Seismic Domains in the Final IMGG Model of Earthquake Sources for Northern and Central Parts of Sakhalin
(compiled using the data from A.I. Ivaschenko)

Name	M_{max}	H_{min}	H_{max}	$T_{5.5}$	$T_{5.0}$	$T_{4.5}$	$T_{4.0}$	Az	e1	de1	e2	de2
D 01-02	5,5	1	7	23,46	5,71	1,17	0,22	0-360	90	20		
D 03	5,5	1	7	36,20	13,69	5,42	1,29	0-360	90	20		
D 04	5,5	1	7	57,14	17,39	5,41	1,23	0-360	90	20		
D 05	5,5	1	7	117,65	22,21	3,64	0,67	0-360	90	20		
D 06	5,5	1	7	13,60	5,02	1,97	0,92	0-360	90	20		
D 07	5,5	1	7	16,96	12,57	7,90	2,35	0-360	90	20		
D 08	5,5	1	7	124,15	33,20	8,88	2,38	0-360	90	20		
D 09-10	5,5	1	7	86,58	28,47	9,36	3,08	0-360	90	20		
Return periods in the region, years				**4,026**	**1,440**	**0,425**	**0,101**					

Where: 7501 — lineament numbers, D-01 — domain numbers; H_{min} — minimum depth of seismic source upper boundary, km; H_{max} — maximum depth of earthquake hypocenter, km; T_M — recurrence period of earthquakes with different magnitudes; Az — azimuth of lineament axis; e1 — tilt angle relative to lineament plane horizon and its deviation de1; e2 — other possible tilt angles and their deviations de2; 1 — lineament horizontal length, km.

5. SEISMIC EFFECT ATTENUATION WITH DISTANCE

Fig. 15 represents the comparison of diagrams of seismic intensity attenuation with the increase of distance from earthquake sources with M = 7.0 and M = 8.0, constructed using OSR-97, ABS-Consulting and IMGG data. These curves are described by the following equations developed by ABS Consulting (1) and IMGG (2) [Chernov, Ivaschenko, 1992]:

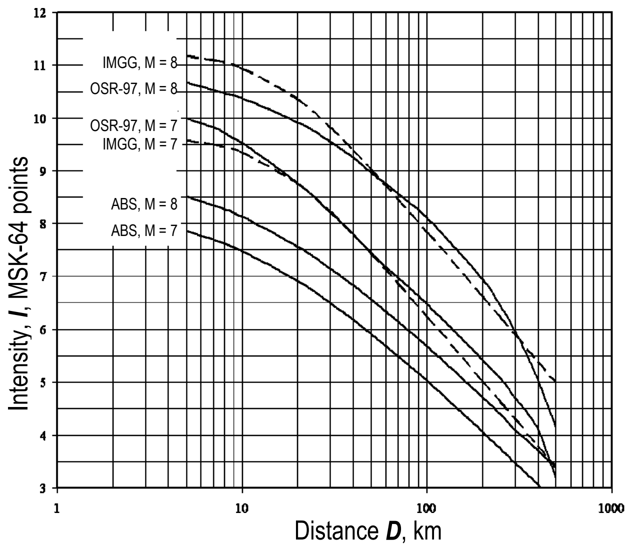


Fig. 15 Comparison of Seismic Intensity Attenuation with the Increase of Distance from Earthquakes with M = 7 and M = 8 according to OSR-97, ABS Consulting (USA) and IMGG Data (1992), Sakhalin-1.

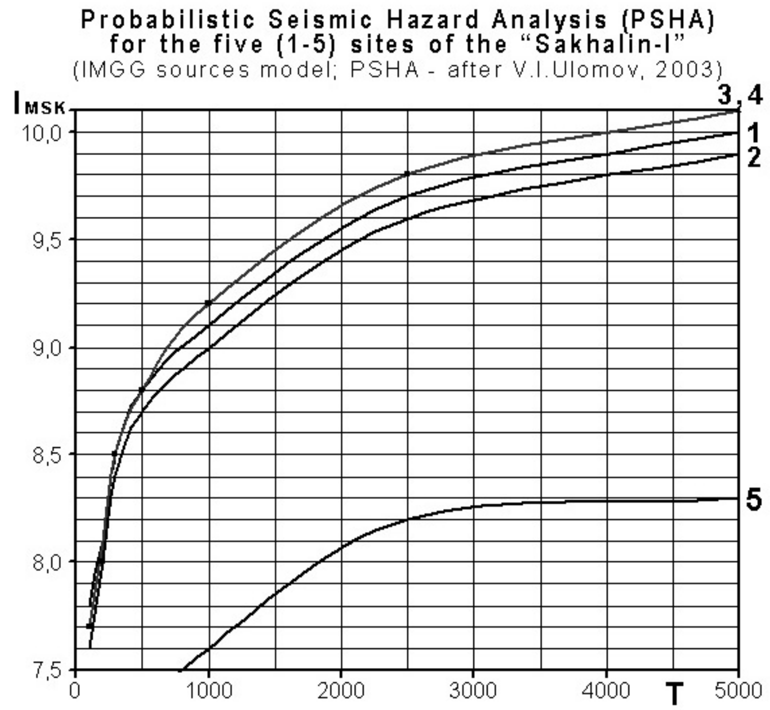
(1). $I_{MSK} = 1.23 + 2.35M_W - 0.113M_W^2 - 1.51\ln(R + 12.0)$; $\sigma = 0.77$, where M_W — momentum magnitude, R — epicentral distance, σ — standard deviation.

(2). $I_{MSK} = 3.31 + 1.6M_{LH} - 4.12 \log[(R^2 + H^2)^{1/2}]$, where M_{LH} — magnitude determined by surface waves practically coinciding with M_W value, R — epicentral distance, H — hypocenter depth (for diagrams it is accepted H = 15 km).

As it can be seen ABS-Consulting diagrams sufficiently decrease seismic intensity assessment in comparison with OSR-97 data. ABS-Consulting and IMGG data also differ. The most realistic are attenuation parameters used for OSR-97. These parameters form the basis for final seismic hazard assessment for Sakhalin-1 Project facilities according to the final revision of IMGG model for earthquakes sources.

6. PROBABILISTIC SEISMIC HAZARD ANALYSIS

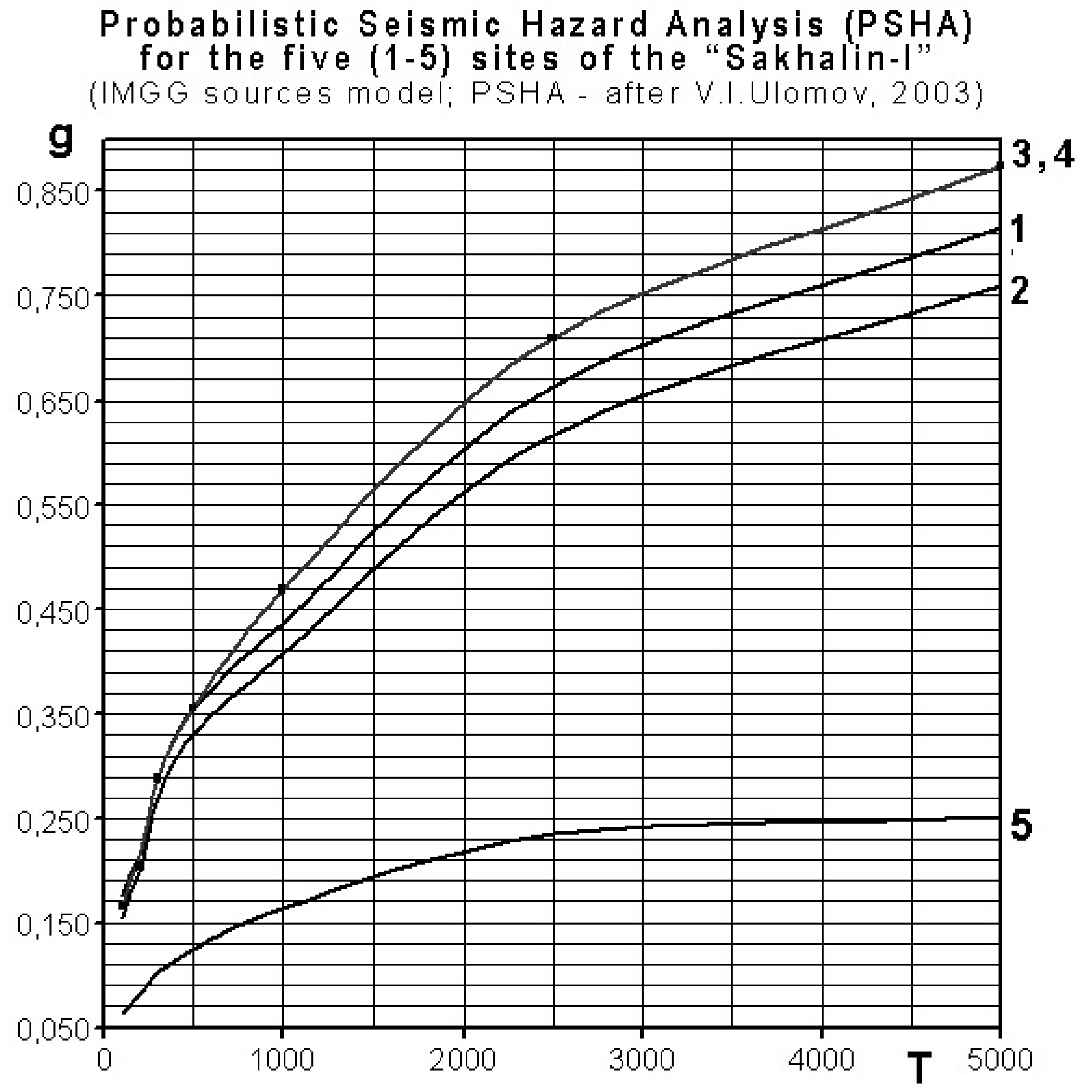
Based on the obtained data the probabilistic seismic hazard analysis (PSHA) was carried out for each of Sakhalin-1 Project facilities. Probabilistic seismic hazard analysis results are presented in figures 16 and 17 and Table below each of figure. They characterize the value of seismic impact for different recurrence periods. Probabilistic seismic hazard analysis considers the uncertainties of different nature that are present in earthquake sources models and models of seismic effect attenuation with distance, and also the errors in other initial data. Figures and Tables below are represented as in parameters of seismic intensity, as in Category II soil oscillation accelerations as per SNiP-II-7-81*.



No	Facility	Latitude (°N)	Longitude (°E)
1	Chaywo OPF	52.505	143.185
2	Chaywo Drill Pad	52.477	143.284
3	Odoptu South Drill Pad	53.066	143.277
4	Odoptu North Drill Pad	53.146	143.260
5	DeKastri Export Terminal	51.497	140.832

T	№1	№2	№3	№4	№5
100	7,8	7,6	7,7	7,7	6,3
200	8,1	8,0	8,0	8,1	6,7
300	8,5	8,4	8,5	8,5	7,0
500	8,8	8,7	8,8	8,8	7,3
1000	9,1	9,0	9,2	9,2	7,6
2500	9,7	9,6	9,8	9,8	8,2
5000	10,0	9,9	10,1	10,1	8,3

Figure 16. Probabilistic Seismic Hazard Analysis for 1-5 Facilities of Sakhalin-1 Project Represented in Parameters of Seismic Intensity.



No	Facility	Latitude (°N)	Longitude (°E)
1	Chaywo OPF	52.505	143.185
2	Chaywo Drill Pad	52.477	143.284
3	Odoptu South Drill Pad	53.066	143.277
4	Odoptu North Drill Pad	53.146	143.260
5	DeKastri Export Terminal	51.497	140.832

T	№1	№2	№3	№4	№5
100	0,178	0,155	0,166	0,166	0,063
200	0,219	0,204	0,204	0,219	0,083
300	0,288	0,269	0,288	0,288	0,102
500	0,355	0,331	0,355	0,355	0,126
1000	0,437	0,408	0,468	0,468	0,164
2500	0,662	0,618	0,710	0,710	0,234
5000	0,816	0,761	0,874	0,874	0,251

Fig. 17. Probabilistic Seismic Hazard Analysis for 1-5 Facilities of Sakhalin-1 Project Represented in g Fractions (Gravity Acceleration), g = 980.665 cm/sec^2.

Table 8

SEISMIC HAZARD ASSESSMENT SUMMARY TABLE FOR SAKHALIN-1 PROJECT FACILITIES
Based on the Data of Different Earthquake Source Models and Processing Methods
(Compiled by V. I. Ulomov, IPE, November 02, 2003)

No.	**Sakhalin-1 Project Facilities and Their Coordinates**	Seismic Hazard Assessment Based on the Regulatory Data		Seismic Hazard Assessment Based on the Existing Regulatory Map OSR-97-B (Return Period 1,000 Years), 1997		Assessments Based on Preliminary Version of IMGG Earthquake Source Model With Attenuation Based on OSR-97, but with Scattering of Focuses Relative to Seismic Lineaments Axis Based on:				Seismic Hazard Assessment Based on ABS (Data from ABS Reports 2002 w/o Multiplication by 2/3)		Calculation on the Basis of ABS Earthquake Source Model, Using OSR-97 Technology				Seismic Hazard Assessment Based on OSR-97 technology and using IMGG Model with Distributed Sources in the Band of 5 km, October 2003		**Final Seismic Hazard Assessment for Sakhalin-1 Facilities Using OSR-97 Technology, October 2003**	
		Former Seismic Zoning Map, 1978	Provisional Seismic Zoning Map of Sakhalin, 1995			IMGG, 2003		OSR-97, 1997				Cumulative Diagram with Pitch 0.05 of Magnitude Unit (Empirical Calculation Strictly Based on ABS Data)		Interval Diagram with Pitch 0.05 of Magnitude Unit (ABS Data Adapted to OSR-97 Method)					
		MSK-64 Seismic Intensity on the Basis of Various Models Data for **1000** Year Return Period (in Fractions and in Integral Values of Intensity)																	
1.	**Chayvo OPF Onshore Facility 52.505°N; 143.185°E**	**7**	**9**	9.89	**10**	8.89	**9**	8.79	**9**	8.8	**9**	11.8	**12**	8.11	**8**	9.09	**9**	9.09	**9**
2.	**Chayvo Well Site 52.477°N; 143.284°E**	**7**	**9**	9.66	**10**	8.67	**9**	8.75	**9**	8.6	**9**	11.6	**12**	7.97	**8**	8.96	**9**	8.98	**9**
3.	**Odoptu South Well Site 53.066°N; 143.277°E**	**7**	**9**	9.68	**10**	8.71	**9**	8.65	**9**	8.4	**8**	10.1	**10**	7.95	**8**	9.11	**9**	9.01	**9**
4.	**Odoptu North Well Site 53.146°N; 143.260°E**	**7**	**9**	9.81	**10**	8.48	**8**	8.62	**9**	8.5	**8**	9.9	**10**	7.79	**8**	9.22	**9**	9.16	**9**
5.	**De Kastri Export Terminal 51.497°N; 140.832°E**	**—**	**—**	8.19	**8**	7.34	**7**	7.45	**7**	6.1	**6**	8.8	**9**	5.79	**6**	7.42	**7**	7.59	**8**
Numbers of columns:		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**

6. CONCLUSION

Due to expert investigations, the results of Studies and Reports on seismic hazard assessment performed by Russian and foreign companies for the area of Sakhalin-1 Project facilities future construction were studied, revised and generalized. The list of these Studies and Reports supplied by the Customer which was considerably extended to provide more detailed and clear information is given in the Attachment.

Calculations of seismic hazard assessment for five (1–5) sites of Sakhalin-1 Project facilities are performed based on the data from Studies and Reports and selected and revised by the Expert.

Main attention was paid to the analysis of earthquake sources probabilistic models justification because all the consequent results depend on this model reliability. Two the most justified models of earthquakes source zones where distinguished among other models and approaches — the model developed by ABS-Consulting (Dr. Paul C. Thenhaus), and the model presented by Institute of Marine Geology and Geophysics (IMGG, Dr. A.I. Ivaschenko). The main accent was put on the application of the seismic hazard assessment methodology adopted in Russia and developed during construction of regulatory probabilistic set of General Seismic Zoning Maps for the Russian Federation — OSR-97 (see SNiP-II-7-81*, 2000). Methodology and earthquakes sources model used in OSR-97 were described in brief.

Considerable attention was paid to IMGG model presented by Dr. A.I. Ivaschenko in different revisions that were tested, modified and improved in the course of joint investigations.

The significant amount of calculations and diagrams were performed for justification of various results. The Summary Table 8 was compiled for comparison of the results.

Finally, for 1000 years period of seismic events recurrence (probability of 5% exceedance within 50 years) at five facilities of Sakhalin-1 Project the results from Table 9 were selected for consideration. These results are presented in fractions and integer units of seismic intensity (points), officially accepted in Russia. Herein the previous assessments by OSR-97-B, corresponding to the same return period, ABS assessment, and assessments obtained using the final IMGG model both with Seisrisk-III software and OSR-97 technology are provided for comparison.

Table 9

No	Facilities	OSR-97	ABS		IMGG + Seisrisk-3		IMGG + OSR-97	
1	Chayvo OPF	10	8.8	**9**	9.03	**9**	9.09	**9**
2	Chayvo Drill Pad	10	8.6	**9**	8.71	**9**	8.98	**9**
3	Odoptu South Drill Pad	10	8.4	**8**	8.75	**9**	9.01	**9**
4	Odoptu North Drill Pad	10	8.5	**8**	8.82	**9**	9.16	**9**
5	De-Kastri Export Terminal	8	6.1	**6**	7.22	**7**	7.59	**8**

As it is shown all newly obtained assessments do not reach the value of 10 points and correlate well with each other.

IMGG assessment made by OSR-97 technology (the right column of Table 9) is taken as the final one for seismic hazard at the five indicated Sakhalin-1 Project facilities.

Prof. V.I. Ulomov
UIPE RAS, November 4, 2003

Attachment:

LIST OF STUDIES AND REPORTS
Supplied to ABB and Revised in Course of Expert Review

No.	Report	By	Year	Stage	Location of the Original
1	Record of Interdepartmental Commission for Seismic Zoning and Antiseismic Construction on Project Specific Design Code for Engineering Surveys			Preliminary	
2	Technical Report. Compilation and Interpretation of the Initial Data on Seismicity and Related Events for Environmental Protection Sections under Sakhalin-1 Project, Territory of Preferable Development — Arkutun-Dagi, Russia. Document No. I/sc–1662–09, IMGG, 1997	IMGG	1997	Preliminary	ENL Mosc. hard AEL, hard/electr
3	EQE International Inc., Phase I, Seismic Hazard Assessment for Selected Offshore and Onshore Oil and Gas Processing Facilities on Sakhalin Island, Russia, Phase I, Seismotectonic Parameters Determination. Final Report compiled for Sakhalin Energy Investment Company Ltd. and Exxon Neftegas Ltd., August 1996	EQE	1996	Preliminary	Houston, hard, en
4	Investigation of Technogenic Earthquakes Potential for the Areas of Oil and Gas Fields on Sakhalin Island, EQE, May 1998	EQE	1998	preliminary	Houston, hard, en
5	Scientific and Technical Report. Paleoseismotectonics of Chayvo and Odoptu Onshore Processing Facilities and Well Sites. Document No. YL 000057, IMGG, 2001–2002	IMGG	2001-2002	JOI-TEO	ENL Mosc. hard AEL, hard/electr
6	Scientific and Technical Report. On Possible Relationship Between Odoptu, Chayvo and Arkutun-Dagi Oil and Gas Fields Production with Induced Seismicity. Document No. YL 000057, IMGG, 2001	IMGG	2001	JOI	ENL Mosc. hard, ru AEL, hard; engl. only
7	Technical Report. Seismic Hazard Assessment for Sakhalin-1 Project Facilities, ABS Consulting (EQE), 2002	ABS Consulting	2002	Feasibility Study	AEL, hard
8	Technical Report. Engineering and Geological Surveys and Seismic Microzoning along Sakhalin-1 Pipeline Route at the Phase of Justification of Investments. Document No. 3375/ROS–1, FGUP Rosstroyiziskaniya (RSI), Gosstroy RF, 2002	RSI	2002	JOI	AEL, hard/electr
9	Geological Structure and Engineering and Seismic Conditions of Main Pipeline Route between Odoptu OPF and De-Kastri Marine Terminal. Document No. CG-25147-01, FGUP Rosstroyiziskaniya (RSI), Gosstroy RF, 2003	RSI	2003	Feasibility Study	ENL AEL, hard/electr
10	Seismic Microzoning Report. Seismic Microzoning of Odoptu OPF, Odoptu-1 and Odoptu-2 Well Sites, (DD Phase) Sakhalin-1 Project. FGUP Rosstroyiziskaniya (RSI), Gosstroy RF, 2003	RSI	2003	Feasibility Study	ENL AEL, hard/electr
11	Seismic Microzoning Report. Seismic Microzoning of Chayvo OPF, Chayvo Well Site, (DD Phase) Sakhalin-1 Project. FGUP Rosstroyiziskaniya (RSI), Gosstroy RF, 2002	RSI	2003	Feasibility Study	ENL AEL, hard/electr

No.	Report	By	Year	Stage	Location of the Original
12	Seismic Microzoning Report. Seismic Microzoning of De-Kastri Oil Export Terminal Site. (DD Phase), Sakhalin-1 Project, FGUP Rosstroyiziskaniya (RSI), Gosstroy RF, 2002	RSI	2003	Feasibility Study	ENL AEL, hard/electr
13	Scientific and Technical Report. Forecast for Induced Seismicity in the Course of Associated and Utility Water Injection on Chayvo OPF (Injection Process Modeling) (against Exxon Neftegas Limited order), IMGG, 2003	IMGG	2003	Feasibility Study	

ADDITIONAL LIST OF STUDIES AND REPORTS
on Seismic Hazard Assessment for Sakhalin Island Territory Reviews during Expertise

1. Report on Scientific Research. Systematization of Initial Geological, Geophysical and Seismological Data for the Sea of Okhotsk Area and Construction of Provisional Seismic Zoning Map of the Sakhalin Oblast (Contract No. 16-08-217/95-C-3 dated October 2, 1995, with GO Rosstroyiziskaniya of Minstroy of the RF, Stage 1), Principal Investigator — V.I. Ulomov (JIPE RAS), Investigators: A.I. Ivaschenko (IMGG FED RAS), A.I. Zakharova (JIPE), A.I. Kozhurin (GIN), G.L. Koff (ILS), I.P. Kuzin (IO), A.I. Lutikov (PNIIIS), N.S. Medvedeva (JIPE), S.A. Nesmejanov (PNIIIS), L.S. Oskorbin (IMGG), O.V. Potapova (JIPE), Yu.L. Rebetsky (JIPE), E.A. Rogozhin (JIPE), V.V. Sevostianov (PNIIIS), M.I. Streltsov (IMGG), V.G. Trifonov (GIN), E.V. Fursova (JIPE), G.V. Chernysheva (JIPE), N.V. Shebalin (JIPE), I.P. Shpak (VNIIGeophysica), L.S. Shumilina (JIPE), Yu.K. Schukin (VNIIGeophysica). Moscow, 1995.
2. Report on Scientific Research. Systematization of Initial Geological, Geophysical and Seismological Data for the Sea of Okhotsk Area and Construction of Provisional Seismic Zoning Map of the Sakhalin Oblast (Contract No. 13-09-10/96-C-3 dated July 18, 1996, with GO Rosstroyiziskaniya of Gosstroy of Russia, Final Stage), Investigators: V.I. Ulomov (JIPE RAS), A.I. Ivaschenko (IMGG FED RAS), I.P. Kuzin (IO RAS), L.S. Shumilina (JIPE RAS), N.S. Medvedeva (JIPE RAS), Sh.S. Anderzhanov (JIPE RAS), Moscow, 1998.
3. Neftegorsk Earthquake of May 27 (28), 1995//Federal System of Seismological Observations and Earthquakes Forecast. Informational and Analytical Bulletin. Extra Issue, October 1995, Moscow. Russian Federation Ministry of Emergencies, Russian Academy of Science. 236 pages
4. Seismic Hazard Assessment and Provisional Seismic Zoning Map. Author — V.I. Ulomov//Federal System of Seismological Observations and Earthquakes Forecast. Informational and Analytical Bulletin. Extra Issue, October 1995, Moscow. Russian Federation Ministry of Emergencies, Russian Academy of Science, pp. 18-26.
5. Report. Preliminary Summary and Analysis of Geological and Geophysical Data Available for the Project Area: Lazarev Cape — Pogibi Cape. Investigator — Institute of Tectonics and Geophysics after Yu.A. Kosygin FED RAS, Khabarovsk, 2000, 57 pages.
6. Report. Geodynamical Conditions Assessment for the Construction Area of Tunnel or Bridge Crossing of Nevelsky Bay and Komsomolsk-on-Amur — Sakhalin-Nogliki (Nysh) Rail Road. Executors: I.M. Petukhov, I.M. Batugina. Moscow State Mining University, Center of Subsurface Geodynamics (CGN), Moscow, 2001.
7. Report. Complex Geophysical Surveys in Order to Determine Rail Road Crossing Gate across Nevelsky Bay. (Volume I: Seismotectonical Conditions, Deep Structure, Initial

Seismicity Justification. Volume II: Complex Geophysical Surveys at Northern, Southern and New Gates. Seismic Microzoning of the Project Area (Water Area). Volume III: The Results of High Resolution Seismic Surveys Processing in the course of Scientific and Methodological Support of Operations). Center for Regional Geophysical and Geoecological Investigations — GEON after V.V. Fedynsky (GP TsRGGI GEON). Principal Investigator — Yu.V. Konovalov, Moscow, 2001.

8. Report of SZF TsRGGI GEON on Seismic Surveys at Rail Road Crossing across Nevelsky Bay. Volume 13 Books 1 and 2, St.-Petersburg, 2001.

9. Technical Report. Engineering and Geological Surveys and Seismic Microzoning along Sakhalin-1 Pipeline Route at the Phase of Justification of Investments. Document No. 3375/ROS–1, FGUP Rosstroyiziskaniya (RSI), Gosstroy RF, 2002.

10. Report on Engineering Surveys for the Facility: “Seismic Microzoning for Chayvo OPF, Chayvo Well Site, Odoptu OPF, Odoptu-1 Well Site, Odoptu-2 Well Site (Sakhalin-1 Project)”. “Seismic Microzoning of Chayvo OPF, Chayvo Well Site. Stage 2”//Contract No. 13004-2721//Gosstroy of Russia, FGUP Rosstroyiziskaniya, Perf. By Prof. S.P. Nikiforov, Yu.I. Baulin, Moscow, 2002.

11. Research-Technical Report. Paleoseismotectonics of Odoptu and Chayvo Onshore Processing Facilities and Well Sites Areas (Northeast of Sakhalin). Final Report//Contract YL-000057-2001 dated July 15, 2001. (Supplementary Contract)//Perf. By A.I. Ivaschenko, M.I. Streltsov, Kim Chun Un (IMGiG FED RAS), A.I. Kozhurin (GIN RAS). Yuzhno-Sakhalinsk, 2003.

12. Geotechnical survey on De-Kastri Construction Site, Russia. Revision 1.//AMEC Overseas (Cyprus) Limited with AMEC Earth and Environmental Limited, Calgary, Alberta, Canada. May 2002.

13. Geotechnical Survey on the Site of Odoptu Onshore Processing Facility and Odoptu Well Site, Sakhalin Island, Russia. Second Revision.//AMEC Overseas (Cyprus) Limited with AMEC Earth and Environmental Limited, Calgary, Alberta, Canada. June 2002.

14. Geotechnical survey on Odoptu-2 Well Site, Sakhalin Island, Russia. Second Revision.//AMEC Overseas (Cyprus) Limited with AMEC Earth and Environmental Limited, Calgary, Alberta, Canada. July 2002.

15. Geotechnical Report. Intrasite, Gathering, Main/Export Pipelines. Sakhalin-1 Project. Sakhalin Island, Russia. Second Revision.//AMEC Overseas (Cyprus) Limited with AMEC Earth and Environmental Limited, Calgary, Alberta, Canada. May 2002.