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(54) **Titre : NOVIRHABDOVIRUS RECOMBINANTS ET LEURS UTILISATIONS**
(54) **Title: RECOMBINANT NOVIRHABDOVIRUSES AND USES THEREOF**

(57) **Abrégé/Abstract:**

The invention relates to recombinant having at least one sequence encoding a polypeptide of interest added to their genome. Said recombinant novirhabdoviruses are useful as gene vectors, for producing recombinant proteins, or for producing vaccines for fish or for higher vertebrates.



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(57) Abstract: The invention relates to recombinant having at least one sequence encoding a polypeptide of interest added to their genome. Said recombinant novirhabdoviruses are useful as gene vectors, for producing recombinant proteins, or for producing vaccines for fish or for higher vertebrates.



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RECOMBINANT NOVIRHABDOVIRUSES AND USES THEREOF.

The present invention relates to the use of novirhabdoviruses as a gene vector, for producing
5 recombinant proteins, or for producing vaccines useful in fish or in higher vertebrates.

Novirhabdoviruses are negative-strand RNA viruses of the *Rhabdoviridae* family.

The *Novirhabdovirus* genus comprises various
10 pathogenic species for aquatic animals, in particular for fish.

The structure of the novirhabdoviral genome is similar to that of mammalian rhabdoviruses, but differs therefrom by the presence of an additional gene, encoding a
15 non-structural protein, called NV (for "non-virion") protein, the function of which remains unknown at the current time.

The novirhabdoviral genome comprises six genes, the organization of which can be represented
20 diagrammatically as follows:

3'-N-P-M-G-NV-L-5'

N represents the gene encoding the nucleoprotein associated with the viral RNA, P represents the gene encoding the phosphoprotein associated with the viral
25 polymerase, M represents the gene encoding the matrix protein, G represents the gene encoding the envelope glycoprotein G, NV represents the gene encoding the NV protein, and L represents the gene encoding the RNA-dependent viral RNA polymerase.

30 These genes are separated by intergenic regions: each of them comprises a transcription termination/polyadenylation signal and a transcription initiation signal, which allow the transcription of the genes into individual mRNAs, separated by an untranscribed
35 intergenic dinucleotide.

The type species of the genus is Infectious Hematopoietic Necrosis Virus (IHNV) which is the etiological agent of a serious disease in several species of salmonids, mainly in yearling trouts. Other species in the genus

include Hirame rhabdovirus (HRV), Viral Haemorrhagic Septicaemia Virus (VHSV), and Snakehead rhabdovirus (SKRV). The complete genomic sequence of IHNV is available in GenBank under accession number L40883; the complete genomic
5 sequence of VHSV is available in GenBank under accession number Y18263; the complete genomic sequence of HRV is available in GenBank under accession number AF104985; the complete genomic sequence of SKRV is available in GenBank under accession number AF147498.

10 Recombinant novirhabdoviruses can be obtained by reverse genetics, by co-transfecting a host cell with an antigenomic complementary DNA (antigenomic cDNA), i.e. a positive-sense copy of the viral genome, and with DNA molecules encoding the N, P and L viral proteins (BIACCHESSI
15 et al., J Virol, 74, 11247-53, 2000), and modify their genome.

 This approach has also allowed different modifications to the novirhabdoviral genome. For instance, it has been shown that the NV gene of the IHN virus can be
20 deleted and replaced by a foreign gene (BIACCHESSI et al., 2000, cited above; THOULOZE et al., J Virol, 78, 4098-107, 2004; PCT WO 03/097090). It has also been shown that it was possible to replace the major structural proteins (M and G) of IHNV with those of VHSV (BIACCHESSI et al., J Virol, 76,
25 2881-9, 2002).

 It has also been tried to insert an additional gene in a novirhabdovirus. (BIACCHESSI, Doctorate Thesis: "GENERATION DE RHABDOVIRUS AQUATIQUES RECOMBINANTS PAR GENETIQUE INVERSE", UNIVERSITE PARIS XI ORSAY, 5 April
30 2002). A DNA construct containing a foreign gene (encoding rainbow trout IL-1- β) flanked by a transcription initiation signal and a transcription termination/polyadenylation signal recognized by the viral L polymerase, was inserted in the IHNV cDNA, in the intergenic region between the M and G
35 genes of IHNV. More specifically, since this gene was introduced in a naturally occurring *EagI* restriction site situated between the end of the M ORF and the transcription termination signal of the M gene, this construct comprised a sequence (CCAAGACAGAAAAAATGGCAC; SEQ ID NO: 1) consisting

of the predicted transcription termination/polyadenylation site of the M gene of IHNV (CCAAGACAGAAAAAAA; SEQ ID NO: 2) followed by the non-transcribed intergenic dinucleotide TG and by the transcription initiation sequence GCAC, said
5 sequence being immediately followed by the ORF of the IL-1- β flanked in 5' by a *SpeI* restriction site, and in 3' by a *SmaI* restriction site.

The recombinant virus (IHNV-IL-1) thus obtained was able to multiply normally in cell culture and was as
10 pathogenic in juvenile rainbow trouts as the wild type IHNV. However, only IL-1- β mRNA, but not IL-1- β protein was detected in the infected cells. On the other hand, a similar recombinant IHNV, containing a gene encoding the green fluorescent protein (GFP), accompanied by the same
15 transcription initiation signal and the same transcription termination/polyadenylation signal was able to express GFP in the infected cells (BREMONT, Current Topics in Microbiology and Immunology 292: 119-141, 2005).

The inventors have now discovered that when the
20 transcription initiation sequence GCAC disclosed by BIACCHESI or BREMONT is replaced by the sequence GCACTTTTGTGC (SEQ ID NO: 3), the additional gene is not only transcribed but also translated, independently of its nature, allowing the expression of a broad range of foreign
25 proteins.

The present invention thus provides recombinant novirhabdoviruses having one or more additional transcription units inserted into at least one of the intergenic regions of the genome of a host novirhabdovirus.
30 The invention also provides recombinant DNA constructs allowing to obtain said recombinant novirhabdoviruses.

A "transcription unit" (also designated herein as a "cistron") is herein defined as a DNA construct comprising a transcription initiation signal, followed by an ORF
35 encoding a protein of interest, and by a transcription termination/polyadenylation signal.

The invention relates to a recombinant DNA construct comprising:

a) a region comprising a transcriptional termination/polyadenylation sequence of a novirhabdovirus gene;

b) a region comprising a transcription initiation sequence of a novirhabdovirus gene ;

said region a) being followed or said region b) being preceded by a non-transcribed intergenic dinucleotide of a novirhabdovirus,

c) a region comprising an open reading frame encoding a protein of interest.

The termination/polyadenylation sequence of region a) and the initiation sequence of region b) can be derived from a same gene or from two different genes of a novirhabdovirus. Preferably, they are derived from one or two gene(s) of the novirhabdovirus wherein it is intended to insert the construct.

The non-transcribed intergenic dinucleotide is preferably selected among TG, and CG.

Preferably, a subject of the present invention is a recombinant DNA construct comprising:

a) a region comprising a transcriptional termination/polyadenylation sequence derived from the M gene of a novirhabdovirus, said region being defined by the following sequence: VHHAGAYAGAAAAAAA (SEQ ID NO: 4), wherein A, T, G, V, H, and Y have their usual meaning in the IUPAC nucleotide code;

b) a region comprising a transcription initiation sequence derived from the G gene of a novirhabdovirus, said region being defined by the following sequence: GCACDWKWGTGY (SEQ ID NO: 5), wherein A, T, G, C, D, W, K, and Y have their usual meaning in the IUPAC nucleotide code;

said region a) being followed and/or said region b) being preceded by the dinucleotide TG;

c) a region comprising an open reading frame encoding a polypeptide of interest.

According to a preferred embodiment, the termination/polyadenylation sequence of region a) and the initiation sequence of region b) are derived from the novirhabdovirus wherein it is intended to insert the

construct, and preferably are respectively derived from the M and G gene of said novirhabdovirus.

For instance, if it is intended to insert the construct in IHNV, the termination/polyadenylation sequence
5 will be CCAAGACAGAAAAAAA (SEQ ID NO: 2), and the transcription initiation sequence will be GCACTTTTGTGC (SEQ ID NO: 3).

In the same way, if it is intended to insert the construct in VHSV, the termination/polyadenylation sequence
10 will be ATTAGATAGAAAAAAA (SEQ ID NO: 6), and the transcription initiation sequence will be GCACATTTGTGT (SEQ ID NO: 7); if it is intended to insert the construct in HRV, the termination/polyadenylation sequence will be ATCAGATAGAAAAAAA (SEQ ID NO: 8), and the transcription
15 initiation sequence will be GCACATTTGTGT (SEQ ID NO: 7); if it is intended to insert the construct in SKRV, the termination/polyadenylation sequence will be GAAAGACAGAAAAAAA (SEQ ID NO: 9), and the transcription initiation sequence will be GCACGAGAGTGC (SEQ ID NO: 10).

20 In region c) the open reading frame encoding the polypeptide of interest may optionally be fused to an open reading frame encoding a novirhabdoviral structure protein (i.e N,P,M, or G), preferably protein N. The fusion allows the incorporation of the polypeptide of interest in the
25 novirhabdoviral particle. Preferably, the N-terminus of the polypeptide of interest is fused to the C-terminus of said novirhabdoviral structure protein.

However, when the protein of interest which is expressed in a novirhabdovirus of the invention is a
30 membrane protein, such as a membrane glycoprotein of an enveloped virus, it can be incorporated in the viral particle, without need to fuse it to a novirhabdoviral structure protein.

The order of the regions a) b) and c) in the DNA
35 construct depends on the position where one intends to insert said construct into the intergenic region of the host novirhabdovirus.

If the construct is to be inserted between the end of an endogenous ORF and the transcription

termination/polyadenylation signal of the corresponding endogenous gene, the order will be a-b-c. In this case, the transcription of the endogenous gene will be terminated at the termination/polyadenylation sequence of region a) of the construct, and the transcription of the ORF encoding the protein of interest will be initiated at the initiation sequence of region b) of the construct and terminated at the endogenous termination/polyadenylation signal of the endogenous gene.

10 If the construct is to be inserted between the transcription initiation signal and the start codon of an endogenous gene, the order will be c-a-b. In this case, the transcription of the ORF encoding the protein of interest will be initiated at the initiation signal of the endogenous gene, and terminated at the termination/polyadenylation sequence of region a), and the transcription of the endogenous gene will be initiated at the initiation sequence of region b) of the construct.

15 If the construct is to be inserted between the transcription termination/polyadenylation signal of a first endogenous gene, and the transcription initiation signal of a second endogenous gene, the order will be b-c-a. In this case, the transcription of the ORF encoding the protein of interest will be initiated at the initiation sequence of region b), and terminated by the termination/polyadenylation sequence of region a) of the construct.

20 The present invention also provides an antigenomic cDNA of the genome of a novirhabdovirus, characterized in that it contains one or more recombinant DNA constructs of the invention inserted in a portion of said cDNA comprised between the stop codon of a first endogenous ORF and the start codon of a second endogenous ORF of a host novirhabdovirus.

25 According to a preferred embodiment, said antigenomic cDNA contains two constructs of the invention inserted in a portion of said cDNA comprised between the stop codon of a first endogenous ORF and the start codon of a second endogenous ORF; according to still another preferred embodiment, said antigenomic cDNA contains three

constructs of the invention inserted in a portion of said cDNA comprised between the stop codon of a first endogenous ORF and the start codon of a second endogenous ORF.

Preferably the first endogenous ORF is the M ORF, and the second endogenous
5 ORF is the G ORF.

The present invention also provides a recombinant novirhabdovirus containing a genomic RNA complementary to an antigenomic DNA of the invention.

The invention also relates to the use of recombinant novirhabdoviruses having one or more additional transcription units inserted into at least one of the intergenic
10 regions of the genome of a host novirhabdovirus, for producing proteins of interest in vertebrate cells (preferably fish cells) in culture, and/or for obtaining vaccines.

The invention also relates to a recombinant DNA construct comprising:

- 15 a) a region comprising a transcriptional termination/polyadenylation sequence of the novirhabdovirus M gene, said region being defined by the following sequence: VHHAGAYAGAAAAAAA (SEQ ID NO: 4), wherein A, T, G, V, H, and Y have their usual meaning in the IUPAC nucleotide code;
- b) a region comprising a transcription initiation sequence of the novirhabdovirus G gene, said region being defined by the following sequence:
20 GCACDWKWGTGY (SEQ ID NO: 5), wherein A, T, G, C, D, W, K, and Y have their usual meaning in the IUPAC nucleotide code;

wherein said region a) being followed or said region b) being preceded by a non-transcribed intergenic dinucleotide of a novirhabdovirus, and

- c) a region comprising an open reading frame encoding a foreign protein of interest;

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wherein said regions a), b) and c) are arranged in the order a-b-c or b-c-a and wherein the transcription of said open reading frame encoding the foreign protein of interest is initiated at the initiation sequence of said region b).

5 The invention also relates to an antigenomic cDNA of the genome of a novirhabdovirus, characterized in that it contains one or more recombinant DNA constructs as defined by the invention, inserted in a portion of said cDNA comprised between the stop codon of a first endogenous ORF and the start codon of a second endogenous ORF of the host novirhabdovirus.

10 The invention also relates to the antigenomic cDNA of the invention, which contains two constructs of the invention.

The invention also relates to a recombinant novirhabdovirus containing a genomic RNA complementary to the antigenomic cDNA as defined by the invention.

15 The invention also relates to the use of the recombinant novirhabdovirus as defined herein for producing a protein of interest in fish cells in culture.

The invention also relates to the use of a recombinant Infectious Hematopoietic Necrosis Virus (IHNV) or Viral Hemorrhagic Septicaemia Virus (VHSV) comprising the recombinant DNA construct of the invention, encoding an antigenic protein of interest, for expressing said protein *in vitro* in an expression
20 system, at a temperature of 14°C to 20°C.

The invention also relates to a low temperature *in vitro* expression system, characterised in that said expression system comprises a recombinant IHNV or VHSV comprising at least one recombinant DNA construct of the invention, encoding an antigenic protein of interest, and a vertebrate cell susceptible of
25 infection by said recombinant virus and capable of growth at a temperature of 14°C to 20°C.

7b

The invention also relates to a method for expressing *in vitro* an antigenic protein of interest, said method comprising:

- infecting a vertebrate cell susceptible of infection by IHNV or VHSV and capable of growth at a temperature of 14°C to 20°C with a recombinant IHNV or VHSV comprising at least one recombinant DNA construct of the invention, encoding an antigenic protein of interest;
- culturing said cell at a temperature of about 14°C to about 20°C; and
- recovering the antigenic protein of interest produced by said cell.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 schematically represents the different constructs of the invention.

Figure 2 represents the pIHN-LUC construct.

Figure 3 shows examples of viral titer of various recombinant viruses in EPC cell culture.

Figure 4 represents a Western blot using a monoclonal antibody directed against SDV-E1 glycoprotein.

Figure 5 represents a Western blot using a polyclonal antibody directed against ISAV HA glycoprotein.

Figure 6 represents a Western blot using a monoclonal antibody directed against VHSV G glycoprotein.

Figure 7 shows the specific labeling of VP2 protein in the cytoplasm of IHNV-VP2_{IBDV} infected cells.

Figure 8 represents an indirect immunofluorescence analysis demonstrating the expression of the ISA F protein in in INHV-F5_{ISAV} infected cells.

Figure 9 represents a double immunofluorescence staining showing that IHNV-3C3 infected cells express simultaneously the ISAV HA and the IPNV VP2.

Figure 10 represents a Western blot using a polyclonal antibody directed against ISAV-F glycoprotein.

- 5 Figure 11 represents a confocal laser scanning microscopy (CLSM) analysis for the expression of the EGFP fusion proteins.

Figure 12 represents a luminescence assay.

Figure 13 represents a CCD imaging of fish infected with rIHNVLUC.

- 10 Figure 14 represents the monitoring of the mortality of the trout fish infected with the virus of the invention.

Figure 15 represents the intraperitoneal challenge and the balneation challenge.

Figure 16 represents a luminescence assay.

Figure 17A represents a Western blot with the polyclonal antibody directed against the HA glycoprotein of ISAV.

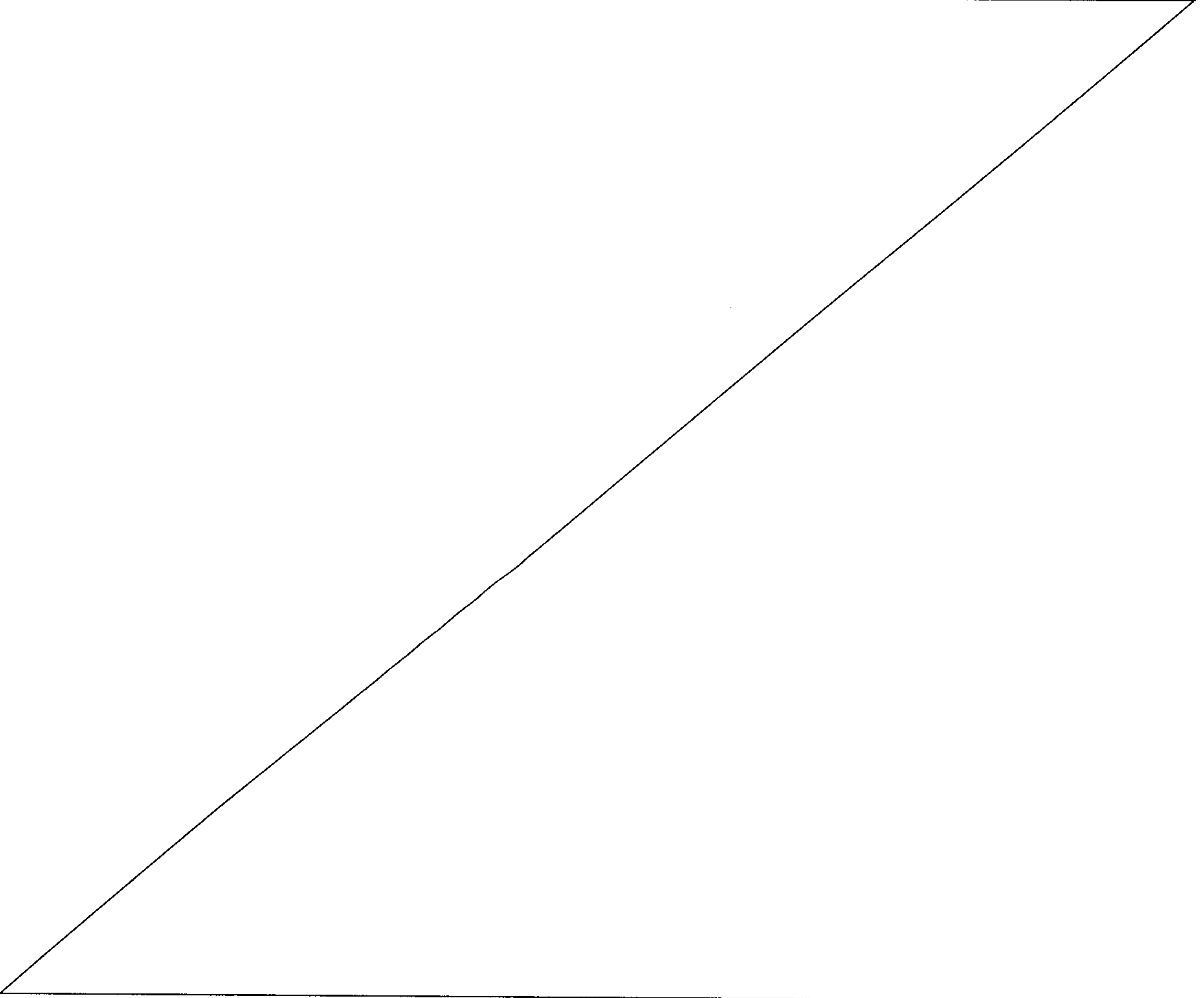
- 15 Figure 17B represents a Western blot with the serum of mice inoculated with recombinant IHNV 3C1.

DETAILED DESCRIPTION

20 The inventors have found that, when containing one construct, novirhabdoviruses of the invention are able to multiply normally in fish cells in culture and keep their pathogenic capacity. When a second construct is added, the ability to multiply in oel cultures is conserved, while the pathogenicity is diminished. The addition of a third construct has no significant effect on the ability to multiply in cell cultures; typically, the recombinant novirhabdovirus of the invention, comprising one, two, or three constructs, can be produced in cell cultures at titers $> 10^8$ p.f.u/ml. On

the other hand, recombinant novirhabdovirus of the invention, comprising three constructs have a considerably reduced pathogenicity.

For the production of proteins of interest in cells in culture, one can use a novirhabdovirus containing one or more constructs, preferably two or three
5 constructs. The use of a novirhabdovirus of the invention having two or more constructs is of particular interest if one wishes to express simultaneously several polypeptides, for instance sub-units of a same enzyme, or an inactive precursor of an active protein, and a second protein able to convert said precursor into the active form. In vaccine development some protective epitopes are
10 formed only when two or more polypeptides are expressed simultaneously. The



use of a novirhabdovirus of the invention will allow such polypeptides to be expressed in order to form the protective epitopes.

Further, as disclosed above, the fact that the expressed proteins can be incorporated in the viral particle, is of particular interest for the production of vaccines.

Novirhabdovirus of the invention containing three or more constructs can be used as live attenuated vaccines, for the vaccination of fish, for instance salmonids in the case of IHNV and VHSV. They can advantageously be administered by balneation, i.e. by simple addition of the vaccine to the water in the breeding tank containing the animals to be immunized.

Alternatively the recombinant novirhabdoviruses or the cells that produce the virus can be used as inactivated vaccine in fish.

The recombinant novirhabdoviruses of the invention, and in particular those that replicate at low temperatures such as IHNV and VHSV, can also be used as a non-replicative antigen delivery system for the vaccination of higher vertebrates, such as birds and mammals. The inventors have indeed observed that when a recombinant IHNV of the invention expressing a foreign antigen is injected in a mammal, said virus is completely unable to replicate in said mammal, while on the other hand, a strong immune response is raised against the foreign antigen incorporated in the viral particle, in complete absence of additional adjuvants.

The inventors have also found that novirhabdovirus that replicate at low temperatures (14 to 20°C), such as IHNV and VHSV, are particularly suitable for the production of thermosensitive proteins that are difficult to produce in classical expression hosts such as *E. coli*, baculovirus, yeast, which generally require temperatures of at least 25-30°C for their growth. They are for instance of particular interest for producing *in vitro* immunoprotective proteins, useful as vaccine components. Many of these proteins, especially those which originate

from fish-pathogenic organisms, cannot be expressed or folded into the right structure at the standard temperature of most bacterial, yeast, eukaryotic and baculovirus-based expression systems.

5 Thus, an object of the invention is the use of a recombinant IHNV or VHSV comprising a heterologous sequence encoding an antigenic protein of interest, for expressing *in vitro* said protein in a low temperature expression system.

10 The invention thus provides a low temperature *in vitro* expression system, characterised in that said expression system comprises a recombinant IHNV or VHSV comprising at least one heterologous sequence encoding an antigenic protein of interest, and a vertebrate cell susceptible of infection by said recombinant virus and
15 capable of growth at low temperature.

 The invention also provides a method for expressing *in vitro* an antigenic protein of interest, said method comprising:

- 20 - infecting a vertebrate cell susceptible of infection by IHNV or VHSV and capable of growth at low temperature with a recombinant IHNV or VHSV comprising at least one heterologous sequence encoding an antigenic protein of interest;
- culturing said cell at a temperature of about
25 14°C to about 20°C;
- recovering the antigenic protein of interest produced by said cell.

 According to a preferred embodiment of the invention, said vertebrate cell is a fish cell, for instance
30 an EPC cell.

 One can use a recombinant IHNV or VHSV wherein the heterologous sequence is inserted in replacement of an endogenous sequence of the host novirhabdovirus; however, one will preferably use a recombinant IHNV or VHSV wherein
35 the heterologous sequence is inserted in addition to the endogenous sequences of the host novirhabdovirus. Still more preferably, one will use a recombinant novirhabdovirus of the invention, wherein the heterologous sequence is a part of an additional transcription unit inserted into one of the

intergenic regions of the host novirhabdovirus. A preferred novirhabdovirus is IHNV.

The present invention will be understood more thoroughly from the further description which follows, which refers to non-limiting examples of construction and of use of recombinant novirhabdoviruses in accordance with the invention.

EXAMPLE 1 : CONSTRUCTION OF RECOMBINANT NOVIRHABDOVIRUSES COMPRISING ONE, TWO, OR THREE ADDITIONAL CISTRONS IN THE M-G INTERGENIC REGION.

Figure 1 schematically represents the different constructs described below.

Legend of Figure 1:

A : is the initial pIHN construct containing the full length IHNV cDNA genome. The following elements are represented for this construct and will be omitted in the schemas showing the other constructs: T7 prom = T7 RNA polymerase promoter, δ = ribozyme hepatitis delta sequence, T7t = T7RNA polymerase terminator sequence.

B : pIHN-LUC.

C: pIHN-X.

D: pIHN-LUC- Δ G

E: insert generated through restriction of pIHN-X with *EagI*

F: pIHN-X-LUC- Δ G.

G: insert generated through digestion of pIHN-LUC by *SpeI/NsiI*

H: pIHN-X-LUC

I: insert *EagI/EagI* generated through digestion of pIHN-Y.

J: pIHN-X-Y-LUC

Construction of the recombinant cDNAs :

The constructions were carried out using the plasmid pIHNV described by BIACCHESI et al. (2000, cited above. This plasmid contains the complete cDNA of the IHN virus genome, cloned downstream of the T7 phage RNA polymerase promoter and upstream of a ribozyme sequence of the hepatitis δ virus and of the T7 phage RNA polymerase transcription terminator, in the vector pBlueScript SK (Stratagene).

pIHNV cDNA genome contains a unique *EagI* restriction site located in the M-G intergenic region. This restriction site is used to insert an additional cistron, encoding a gene of interest, as schematized in Figure 1. At the beginning and the end of the gene of interest a *SpeI* and *SmaI* restriction enzyme sites have respectively been introduced, to allow the replacement of the gene of interest by another gene. The plasmid pIHNV is schematized in Figure 1A.

Construction of recombinant antigenomic cDNAs with one additional cistron

pIHN-LUC (Figure 1B):

pIHN-LUC results from the insertion of the Renilla luciferase expression cassette gene into the *EagI* site of pIHNV.

It is obtained as follows:

Renilla Luciferase gene was PCR amplified from the pBind vector (Promega GenBank, accession number AF264722) using the following oligonucleotides:

EagI SpeI RnLuc:

ggggCGGCCGCAAGACAGAAAAAATGGCACTTTTGTGCACTAGTATGACTTCGAAAGT
TTATGATCCA (SEQ ID NO: 11).

This oligonucleotide contain the *EagI* restriction site (CGGCCG) followed by the transcription termination/polyadenylation sequence of the M gene (CCAAGACAGAAAAA; SEQ ID NO: 2), by the dinucleotide TG and by the transcription initiation sequence of the G gene (GCACTTTTGTGC; SEQ ID NO: 3) followed by the last 24 nucleotides of the Renilla luciferase.

EagI SmaI RnLuc:

ggggCGGCCGCCCCGGGTATTGTTTCATTTTGAGAACTCG (SEQ ID NO: 12).

This oligonucleotide contain an *EagI* restriction site (CGGCCG).

The PCR product was digested with *EagI* enzyme and inserted into the *EagI* site of pIHNV, leading to the pIHN-LUC construct, as shown in Figure 2.

The final plasmid was sequenced to check the orientation and the sequence of the inserted *EagI* fragment.

All these plasmids were sequenced to check the orientation and or the sequence of the inserted fragments.

pIHN-X or pIHN-Z (Figure 1C)

These constructs result from the replacement of the luciferase gene by any other gene of interest (exemplified by X or Z). They are obtained by PCR amplification of the gene of interest with a set of primers containing the *SpeI* site in one side (or a compatible restriction site like *NheI*) and in the other side the *SmaI* site (or a compatible blunt end restriction site).

For pIHN-X, the *SpeI/SmaI* fragment containing the luciferase open reading frame is replaced with a compatible *NheI/EcoRV* PCR fragment containing the gene of interest X. The resulting pIHN-X construct has lost the *SpeI* and the *SmaI* restriction sites.

Similarly the pIHN-Z construct is obtained from pIHN-Luc by replacement of *SpeI/SmaI* fragment containing the Luc gene by the *SpeI/SmaI* PCR fragment containing the Z gene. This construct is termed pIHN-Z.

Construction of recombinant antigenomic cDNAs with two additional cistrons

pIHN-X-LUC (Figure 1D to 1H)

The *SmaI/AgeI* fragment is removed from the pIHN-LUC plasmid, resulting in the elimination of one of the two *EagI* site and the deletion of the G gene. The intermediate construct thus obtained is named pIHN-LUC-ΔG (Figure 1D).

The X expression cassette is obtained by the *EagI* restriction enzyme digestion of pIHN-X (Figure 1E).

This insert is ligated with pIHN-LUC-ΔG digested with *EagI*, resulting in the construct pIHN-X-LUC-ΔG (Figure 1F). Incidentally after the ligation of the two *EagI* fragments that led to the pIHN-X-LUC-ΔG construct a unique *NotI* restriction site is generated between the X and the Luc expression units.

Finally the *SpeI/NsiI* fragment of the pIHN-X-LUC-ΔG construct is replaced with the corresponding fragment containing the G gene obtained from the pIHN-LUC construct,

by digestion with *SpeI*/*NsiI* (Figure 1G). The resulting construct is termed pIHN-X-LUC (Figure 1H).

Construction of recombinant antigenomic cDNAs with three additional cistrons

5 **pIHN-X-Y-LUC (Figure 1I and 1J)**

The plasmid pIHN-Y is obtained as described for pIHN-X.

pIHN-Y is digested with *EagI* and the insert *EagI*/*EagI* is recovered (Figure 1I), and inserted in pIHN-X-LUC previously digested with *NotI*. The construct thus
10 obtained is termed pIHN-X-Y-LUC (Figure 1J).

pIHN-X-Y-Z

This construct is obtained by replacement of *SpeI*/*SmaI* fragment of pIHN-X-Y-LUC containing the Luc gene
15 by the *SpeI*/*SmaI* fragment containing the Z gene recovered from pIHN-Z

Production of the recombinant viruses:

Three expression plasmids comprising respectively the genes encoding the nucleoprotein N, the phosphoprotein
20 P, and the RNA-dependent RNA polymerase L of IHN were constructed, as described by BIACCHESE et al. (2000, publication mentioned above). These constructs are respectively called pT7-N, pT7-P and pT7-L.

The 3 plasmids, pT7-N, pT7-P and pT7-L (at
25 respective doses of 0.25 µg; 0.2 µg and 0.2 µg, and either of the plasmids pIHN-LUC, pIHN-X or Z, pIHN-X-LUC, pIHN-X-Y-LUC, or pIHN-X-Y-Z at the dose of 1 µg are introduced, by transfection in the presence of lipofectamine (GIBCO-BRL), into EPC cells (epithelioma papulosum cyprinid) infected
30 beforehand with a recombinant vaccinia virus expressing the T7 phage RNA polymerase (vTF7-3, FUERST et al. Proc. Natl. Acad. Sci. USA, 92, 4477-4481, 1986).

After transfection, the cells are incubated for 5 hours at 37°C and then washed with MEM culture medium
35 (without serum) and incubated for 7 days at 14°C in MEM culture medium containing 2% of fetal calf serum. The cells and the supernatant are frozen/thawed, and clarified by centrifugation for 10 minutes at 10 000 rpm. The supernatant

is used at a 1/10 dilution to infect a layer of EPC cells. The viruses are produced in the supernatant 3-4 days post-infection.

5 Different recombinant INH viruses, having one, two, or three additional cistrons were produced. They are respectively listed in Tables I, II, and III below.

TABLE I

rIHNV	Cassette	Aim
CAP	CAP	SDV protection
6KE1	6KE1	SDV protection
CAP-E3E2	CAP-E3E2	SDV protection
E3E2	E3E2	SDV protection
E3E2-6KE1	E3E2-6KE1	SDV protection
IL1 β	IL1 β	Immuno stimulation
G _{VHSV}	G _{VHSV}	VHSV protection
Δ G-G _{VHSV}	G _{VHSV}	VHSV protection
LUC _{FF}	LUC _{FF}	Bioluminescence
LUC _{RN}	LUC _{RN}	Bioluminescence
EGFP	EGFP	Reporter protein
N-LUCi	N-LUC	Foreign protein incorporation
N-EGFP	N-EGFP	Foreign protein incorporation
P-Luci	P-Luci	Foreign protein incorporation
P-EGFP	P-EGFP	Foreign protein incorporation
M-Luci	M-Luci	Foreign protein incorporation
M-EGFP	M-EGFP	Foreign protein incorporation
G _{VHSV} -LUC	G _{VHSV} -LUC	Foreign protein incorporation
G _{VHSV} -EGFP	G _{VHSV} -EGFP	Foreign protein incorporation
NV-EGFP	NV-EGFP	Foreign protein incorporation
NVmyc	NV myc	NV role
HA _{ISAV}	HA ISAV	ISAV protection
F5 _{ISAV}	F5 ISAV	ISAV protection
VP2 _{IPNV}	VP2 IPNV	IPNV protection
VP2 _{IBDV}	VP2 IBDV	IBDV protection

TABLE II

rIHNV	1 st cassette	2 nd cassette	Aim
2C G _{VHSV} /LUC	G _{VHSV}	LUC	VHSV protection/Bioluminescence
2C VP2/LUC	VP2 _{IPNV}	LUC	IPNV protection/Bioluminescence
2CHA/LUC	HA ISAV	LUC	ISAV protection/Bioluminescence
2C HA/CAP-E3E2	HA ISAV	CAP-E3E2	SDV/ISAV protection
2C HA/E3E2-6KE1	HA ISAV	E3E2-6KE1	SDV/ISAV protection

TABLE III

rIHNV	st 1 cassette	nd 2 cassette	rd 3 cassette	Aim
3C2 G _{VHSV} /HA/LUC	G _{VHSV}	VP2 IPNV	LUC	IHNV/VHSV/IPNV protection
3C G _{VHSV} /IL1 β /LUC	G _{VHSV}	IL1 β	LUC	IHNV/VHSV immunostimul.
3C1 HA/F5/LUC	HA ISAV	F5 ISAV	LUC	IHNV/ISAV protection
3C3 HA/VP2/LUC	HA ISAV	VP2 IPNV	LUC	IHNV/ISAV, IPNV protection
3C20 HA/IL1 β /LUC	HA ISAV	IL1 β	LUC	Immuno-stimulation and IHNV/ISAV protection.
3C14 HA/VP2/CAP-E3E2	HA ISAV	VP2 IPNV	CAP-E3E2	IHNV/ISAV/IPNV/SDV protection
3C15 HA/VP2/E3E2-6KE1	HA ISAV	VP2 IPNV	E3E2-6KE1	IHNV/ISAV/IPNV/SDV protection
3C10 HA/F5/CAP-E3E2	HA ISAV	F5 ISAV	CAP-E3E2	IHNV/ISAV/VHSV protection

Legend of the tables

SDV: Sleeping Disease Virus

ISAV: Infectious Salmon Anaemia Virus

5 VHSV: Viral haemorrhagic Septicaemia Virus

IBDV: Infectious Bursal Disease Virus

IPNV: infectious pancreatic necrosis virus

6KE1 : SDV E1 glycoprotein gene

CAP : SDV capsid gene

10 E3E2 : SDV E2 glycoprotein gene

EGFP: Enhanced green fluorescent protein

F5: ISAV F gene

G_{VHSV}: VHSV G glycoprotein gene

HA: ISAV HA gene

15 IL1 β : Interleukin 1 from rainbow troutLUC_{FF}: Firefly luciferase LUC_{RR}: Renilla luciferase

VP2: IPNV VP2 gene

 Δ G: deletion of IHNV G gene

**EXAMPLE 2 : MULTIPLICATION IN CELL CULTURE OF RECOMBINANT
NOVIRHABDOVIRUSES COMPRISING ONE, TWO, OR THREE ADDITIONAL
CISTRONS.**

Viral stocks of each of the viruses produced are constituted by successive passages in (EPC) cell culture of the supernatant taken 7 days after transfection (supernatant PO). The cells are infected with 1/100 dilution of the clarified supernatant. After 3 passages, the supernatants are removed, when the cells layer is destroyed by the virus cytopathic effect; this usually occurs 3 to 6 days post-infection. The viral stocks are then titrated by limiting dilution.

Figure 3 shows examples of viral titer of various recombinant viruses in EPC cell culture. Although the viral titer for all the recombinant viruses is in the same range (10^8 PFU/ml), the recombinant viruses comprising three additional expression units have a slower growth compared to

the wild type virus. In general it takes six days to get a complete cytopathic effect in EPC cells instead of three days for the wild type IHNV.

**EXAMPLE 3: EXPRESSION OF PROTEINS OF INTEREST IN RECOMBINANT
5 NOVI RHABDOVIRUSES OF THE INVENTION.**

Proteins of interest were produced using the recombinant IHNVs listed in Tables I, II, and III.

**Recombinant IHNV expressing the Sleeping Disease Virus
structural proteins**

10 EPC cells are infected with wild-type IHNV, IHNV-6KE1, IHNV-CapE3E2, or IHNV-E3E26KE1, at an MOI (multiplicity of infection) of 0.02 (0.02 PFU/cell). The cells are lysed 48 hours post-infection, and the lysates are analyzed by Western blot using a monoclonal antibody
15 directed against SDV-E1 glycoprotein.

The results are shown in Figure 4: Lane 1: IHNV-E3E26KE1; Lane 2: IHNV-CapE3E2; Lane 3: IHNV-6KE1; Lane 4: wild type IHNV.

**Recombinant IHNV expressing Infectious Salmon Anemia Virus
20 (ISAV) hemagglutinin (HA) glycoprotein**

EPC cells are infected with wild type IHNV, or IHNV- HA_{ISAV}, as described above. The cells are lysed 2 days post-infection, and the lysates are immunoprecipitated with anti HA monoclonal antibody and analyzed by Western blot
25 using a polyclonal antibody directed against ISAV-HA glycoprotein.

The results are shown in Figure 5: Lane 1: wild type IHNV; Lane 2: IHNV-ISAV HA.

**Recombinant IHNV expressing Viral Hemorrhagic Septicemia
30 Virus (VHSV) G glycoprotein fused to a reporter protein**

EPC cells are infected, as described above, with wild type IHNV, IHNV-G_{VHSV}, IHNV-G_{VHSV}/LUC_{RR}, IHNV-G_{VHSV}/EGFP, or with the supernatant of non-infected EPC cells (mock infected). The cells are lysed 2 days post-infection, and
35 the lysates are analyzed by Western blot using a monoclonal antibody directed against VHSV G glycoprotein.

The results are shown in Figure 6: Lane 1: wild type IHNV; Lane 2: IHNV-G_{VHSV}; Lane 3: IHNV-G_{VHSV}/LUC_{RR}; Lane 4:

IHNV-G_{VHSV}/EGFP. The bands observed are consistent with the expected size for respectively VHSV G glycoprotein and the fusion proteins G_{VHSV}/LUC_{RR} and G_{VHSV}/EGFP.

Recombinant IHNV expressing VP2 of Infectious Bursal Disease

5 **Virus (IBDV)**

EPC cells are infected, as described above, with IHNV-VP2_{IBDV} or with the wild type IHNV. 24 hours post-infection the expression of VP2 IBDV is detected using indirect Immunofluorescence assay. The cells are fixed and
10 permeabilized in a bath of -20°C 50%methanol 50%acetone for 15 minutes in freezer. The fixed cells are then incubated for one hour with 1:400 dilution of a monoclonal antibody directed against VP2 IBDV after a washing step the cells are incubated for 45 minutes with a fluorescein (FITC)
15 conjugated antimouse IgG antibody. After a washing step to eliminate unbound antibodies the cells are examined for fluorescein staining with a UV light microscope and photographed with a computer-coupled camera (Nikon).

Figure 7 shows the specific labeling of VP2
20 protein in the cytoplasm of IHNV-VP2_{IBDV} infected cells.

No fluorescence can be detected in IHNV infected cells.

Recombinant IHNV expressing protein F of ISAV

EPC cells are infected, as described above, with
25 IHNV-F5_{ISA}. 36 hours post-infection, the cells are treated for indirect immunofluorescence as described above using an antibody directed against protein F of ISAV.

The results shown in Figure 8 demonstrate the expression of the ISAV F protein in IHNV-F5_{ISAV} infected
30 cells.

Recombinant IHNV expressing ISAV HA and IPNV VP2

EPC cells are infected, as described above, with IHNV-3c3 (HA/VP2/LUC). 36 hours post-infection, the cells are treated as described above using a polyclonal antibody
35 directed against protein HA of ISAV and a monoclonal antibody directed against protein VP2 of IPNV. The primary monoclonal antibody is revealed with fluorescein (FITC) conjugated anti-mouse IgG antibody and the primary rabbit

polyclonal antibody against protein HA is revealed with TRITC conjugated anti-rabbit antibody.

The results are shown in Figure 9: left panel: mAb anti IPNV VP2; right panel: Polyclonal anti ISAV HA.

5 This double immunofluorescence staining shows that IHN-3c3 infected cells express simultaneously the ISAV HA and the IPNV VP2.

EXAMPLE 4: INCORPORATION OF A FOREIGN MEMBRANE GLYCOPROTEIN INTO THE RECOMBINANT IHN VIRAL PARTICLE.

10 EPC cells are infected, as described in Example 3, with IHN-F5_{ISA}, or mock infected.

3 days post-infection, the cell-free supernatant is recovered, and the recombinant virus is purified from said supernatant using a sucrose gradient. The purified
15 virus is loaded onto a SDS-PAGE gel. The viral proteins are analyzed by Western blot using a polyclonal antibody directed against ISAV-F glycoprotein. ISAV infected cells were used as a positive control.

The results are shown in Figure 10. These results
20 demonstrate that the ISAV F protein is incorporated into the recombinant IHN viral particles.

Similar results were obtained when incorporation analyses were conducted with ISAV HA and VSHV G glycoprotein respectively in purified IHN-ISA HA and IHN-VSHV G
25 recombinant viruses.

EXAMPLE 5: INCORPORATION OF A FOREIGN NON-MEMBRANE PROTEIN INTO THE RECOMBINANT IHN VIRAL PARTICLE.

The possibility to incorporate physically a non-membrane protein into the IHN viral particle is evaluated
30 using two reporter non-membrane proteins: the EGFP and the renilla luciferase.

Chimeric genes encoding either one of the structural proteins of the IHN virus (N,P,M,G) or the non structural protein NV, fused by its C-terminal end to the N
35 terminal end of the EGFP or of the renilla luciferase are constructed.

A *SpeI* restriction enzyme site was introduced at both ends of each chimeric gene to allow its insertion into

the unique *SpeI* restriction site of the pIHNV LUC or the pIHNV EGFP constructs.

The following constructs were obtained: pIHNV N-EGFP, pIHNV G-EGFP, pIHNV M-EGFP, or pIHNV NV-EGFP pIHNV N-LUC, pIHNV G-LUC, pIHNV P-LUC, pIHNV M-LUC, or pIHNV NV-LUC

Recombinant IHNVs are obtained from these constructs, as described in Example 1 above.

Recombinant IHNV expressing protein N, G, M, or NV in fusion with the N terminal part of the EGFP

EPC cells are infected with IHNV N-EGFP, IHNV G-EGFP, IHNV M-EGFP, or IHNV NV-EGFP. 24 hours post-infection, the cells are directly examined for the expression of the EGFP fusion proteins using a confocal laser scanning microscopy (CLSM).

The results are shown in Figure 11: A: IHNV N-EGFP; B: IHNV G-EGFP; C: IHNV M-EGFP; D: IHNV NV-EGFP. The G-EGFP and the M-EGFP have membrane localization in accordance with the expected localization of the G and the M proteins, whereas the NV-EGFP seems to accumulate in the nucleus of the infected cells and the N-EGFP is found to be cytosolic.

Recombinant IHNV expressing protein N, G, M, or NV in fusion with the N terminal part of the Luciferase

EPC cells are infected with IHNV Luc, IHNV N-LUC, IHNV G-LUC, IHNV M-LUC, or IHNV NV-LUC. 4 days post-infection, the cell-free supernatant is recovered, and the recombinant virus is purified from said supernatant using a sucrose gradient. The total protein concentration of each purified virus was measured using a colorimetric dye-binding assay (Bradford). Then one microgram of each purified virus was tested for the luciferase activity in order to determine which structural protein is best suited for luciferase incorporation into the viral particle.

The result in Figure 12 shows that fusing a foreign non-membrane protein (luciferase in this case) to the N protein is the best strategy for incorporating this protein into the IHNV viral particle.

EXAMPLE 5: EXPRESSION OF A PROTEIN OF INTEREST IN LIVING TROUTS

Fish are infected by bath immersion with rIHNVLUC, according to the following protocol: the young
 5 fish are placed in breeding tanks in a small volume of water (3 liters of water per 100 young fish, average weight 1 g). The rIHNVLUC is added to the water of the tank at a final concentration of 5×10^4 PFU/ml (PFU = plaque forming unit). After incubation for 2 hours, the tanks are filled and the
 10 water circulation is re-established.

At 4 days post-infection, fish are immersed in a bath containing a luciferase substrate (EnduRen™ Live Cell Substrate, Promega) and submitted to CCD imaging after being anesthetized, in order to evaluate the luciferase activity.

15 The results are shown in Figure 13.

A: i: rIHNVLUC-infected fish, luciferase substrate bath; 1: mock-infected fish, no luciferase substrate bath; 2: mock-infected fish, luciferase substrate bath; 3: rIHNV-infected fish, luciferase substrate bath; 4:
 20 rIHNVLUC-infected fish, no luciferase substrate bath.

B: Original image of the light produced by the renilla luciferase oxidation of its substrate coelenterazine. The intensity of the emitted light is directly correlated with the level of the renilla luciferase
 25 expression and with the IHNV-LUC viral replication in the living trout.

C: Bioluminescence signals surimposed on the image A.

30 **EXAMPLE 6: PATHOGENICITY OF THE RECOMBINANT NOVIRHABDOVIRUSES COMPRISING ONE OR THREE ADDITIONAL CISTRONS.**

The pathogenicity of novirhabdoviruses obtained as described in Example 1 above is evaluated by experimental infections in rainbow trout (*Oncorhynchus mykiss*).

35 The viruses tested are as follows:

rIHNV: wt

rIHNV: 6K-E1 SDV

rIHNV: E3-E2 SDV

rIHNV: Cap-E3-E2 SDV
rIHNV: E3-E2-6K-E1 SDV
rIHNV: LUCRN
rIHNV: G-VSHV
5 rIHNV 3C1: HA/F5/LUCRN;
rIHNV 3C20: HA/ILB/LUCRN;
rIHNV 3C14: HA/VP2/Cap-E3-E2;
rIHNV 3C15: HA/VP2/E3-E26KE1.

10 Young trout fish are infected by balneation with
5 x 10⁴ PFU/ml of either of these viruses, according to the
protocol described in Example 5 above, and the mortality is
monitored.

The results are shown in Figure 14.

15 These results show that the pathogenicity of the
viruses is linked to the number of additional cistrons.
While the presence of one additional cistron only induces in
most of cases a slight or moderate decrease in
pathogenicity, the presence of three additional cistrons
induces a drastic attenuation of the pathogenic capacity.

20 **EXAMPLE 7: VACCINE PROPERTIES IN FISH OF THE RECOMBINANT
NOVIRHABDOVIRUSES OF THE INVENTION.**

In order to establish whether the recombinant
viruses attenuated by the presence of three additional
cistrons can be used for preparing vaccines, their capacity
25 of protecting young fish against a subsequent challenge with
the pathogenic IHNV viral isolate 32/87 was tested.

In a first experiment, young trout fish immunized
by balneation with rIHNV 3C1, 3C20, 3C14, or 3C15, under the
same conditions as in the pathogenicity trials described in
30 Example 6, are challenged, with IHNV 32/87 either by
balneation 46 days later, or by intraperitoneal injection
two months later. The mortality is monitored over a period
of 58 days.

Challenge by balneation:

35 46 days after having received either IHNV 3C1,
3C20, 3C14, or 3C15, or nothing the fish are infected by
balneation with 10⁵ pfu/ml of IHNV 32/87.

Challenge by injection:

Two months after having received either IHN_V 3C1, or a mock immunization, batches of 20 young trout the vaccine candidate recombinant are challenged by intraperitoneal injection with the pathogenic IHN_V viral isolate 32/87 (10^6 pfu/fish).

The results are shown in Figure 15.

In the case of challenge by balneation, 100% of the challenged trouts immunized with IHN_V 3C1, 3C20, 3C14, or 3C15, and 98% of those immunized with IHN_V 3C20 survive the challenge, while only 20% of the mock immunized trouts survive.

In the case of the challenge by injection, 100% of the challenged trouts immunized with IHN_V 3C1 survive, while only 6% of the mock immunized trouts survive.

EXAMPLE 8: USE OF RECOMBINANT IHN_V SYSTEM AS A VACCINE VECTOR IN MAMMALIAN SPECIES.**Replication of recombinant IHN_V in cultured cells from various species**

EPC cells, as well as cells from various higher vertebrates species (human lung epithelial cells A549; porcine kidney cells PK15; rabbit kidney cells RK13; mouse fibroblasts 3T3; intestine chick embryo Cells CEV-I (ATCC CRL10495) are infected with recombinant IHN_V-LUC at high multiplicity of infection (5 PFU/cell). The cells are incubated at 14 and 28°C for three days.

At the end of the incubation time the luciferase expression is measured using a luminometer and the Renilla luciferase Assay system (Promega) following the manufacturer's protocol.

The results are shown on Figure 16.

The light intensity, which is represented on the Y-axis in Luciferase Units (RLU), is proportional to the luciferase concentration in the cell lysate and thus to the viral replication.

The luminescence detected in the non-infected cells corresponds to the background luminescence caused by

nonenzymatic oxidation of the Renilla substrate coelenterazine.

These results show that significant replication of recombinant IHN-V-LUC does occurs in several cell lines at 14°C compared with the replication in the fish cells EPC. However, at 28°C the cells tested including the EPC cells are unable to replicate the IHN-V-LUC virus.

Administration of recombinant IHN-V in vivo in mice

To test the replication of IHN-V in living mammals, mice are inoculated with a large amount of recombinant IHN-V-LUC virus ($5 \cdot 10^8$ pfu/mouse).

28 days after inoculation, the luciferase activity in the sera of mice is checked. No luciferase activity is detected, confirming the results obtained in the cell cultures.

Thus, IHN-V is indeed a naturally inactivated virus in higher vertebrates.

In a second experiment, 15 mice are inoculated intra-dermal with the recombinant IHN-V 3C1 (HA/F5/LUC) (1 µg of purified virus/mouse) 5 control mice receive the TNE buffer. Four weeks post-inoculation the serum from the inoculated mice was tested for the presence of antibody response against wild type IHN virus using ELISA test with a plate coated with purified IHN virus.

15 out of 15 mice inoculated with recombinant IHN-V 3C1, and none of the 5 mice in the control group tested seropositive for IHN-V.

Further, the serum of one of the mice inoculated with recombinant IHN-V 3C1 diluted at 1/500 was tested in Western blot against a lysate of ISAV infected cells, a lysate of mock infected cells, and a whole protein extract of recombinant IHN-V-HA.

As a control, a polyclonal antibody directed against the HA glycoprotein of ISAV diluted at 1/500 was tested in Western blot against the same antigens.

The results are shown on Figure 17.

A: Western blot with the polyclonal antibody directed against the HA glycoprotein of ISAV;

B: Western blot with the serum of mice inoculated with recombinant IHNv 3C1.

These results show that the serum of the inoculated mice contains antibodies directed against
5 different proteins of IHNv 3C1, and in particular, contains antibodies directed against the HA glycoprotein of the ISA virus.

Thus the IHNv system offers the possibility to economically produce high levels of antigens that will be
10 safely presented in their native form for vaccination of mammalian species against diverse pathogens.

CLAIMS

1) A recombinant DNA construct comprising:

a) a region comprising a transcriptional termination/polyadenylation sequence of the novirhabdovirus M gene, said region being defined by the following sequence: VHHAGAYAGAAAAAAA (SEQ ID NO: 4), wherein A, T, G, V, H, and Y have their usual meaning in the IUPAC nucleotide code;

b) a region comprising a transcription initiation sequence of the novirhabdovirus G gene, said region being defined by the following sequence: GCACDWKWGTGY (SEQ ID NO: 5), wherein A, T, G, C, D, W, K, and Y have their usual meaning in the IUPAC nucleotide code;

wherein said region a) being followed or said region b) being preceded by a non-transcribed intergenic dinucleotide of a novirhabdovirus, and

c) a region comprising an open reading frame encoding a foreign protein of interest;

wherein said regions a), b) and c) are arranged in the order a-b-c or b-c-a and wherein the transcription of said open reading frame encoding the foreign protein of interest is initiated at the initiation sequence of said region b).

2) An antigenomic cDNA of the genome of a novirhabdovirus, characterized in that it contains one or more recombinant DNA constructs as defined in claim 1, inserted in a portion of said cDNA comprised between the stop codon of a first endogenous ORF and the start codon of a second endogenous ORF of the host novirhabdovirus.

3) The antigenomic cDNA of claim 2, which contains two constructs as defined in claim 1.

4) The antigenomic cDNA of claim 2, which contains three constructs as defined in claim 1.

- 5) A recombinant novirhabdovirus containing a genomic RNA complementary to the antigenomic cDNA as defined in claim 2 or 4.
- 6) A recombinant novirhabdovirus containing a genomic RNA complementary to the antigenomic cDNA as defined in claim 4.
- 7) The recombinant novirhabdovirus of claim 5 or 6, which is a recombinant Infectious Hematopoietic Necrosis Virus (IHNV).
- 8) Use of the recombinant novirhabdovirus as defined in any one of claims 5 to 7, for producing a protein of interest in fish cells in culture.
- 9) The recombinant novirhabdovirus of claim 6 or 7, for use as a live attenuated vaccine.
- 10) The recombinant novirhabdovirus of any one of claims 5 to 7, for use as an antigen delivery system for the vaccination of birds or mammals.
- 11) Use of a recombinant IHNV or Viral Hemorrhagic Septicaemia Virus (VHSV) comprising the recombinant DNA construct as defined in claim 1, encoding an antigenic protein of interest, for expressing said protein *in vitro* in an expression system, at a temperature of 14°C to 20°C.
- 12) A low temperature *in vitro* expression system, characterised in that said expression system comprises a recombinant IHNV or VHSV comprising at least one recombinant DNA construct as defined in claim 1, encoding an antigenic protein of interest, and a vertebrate cell susceptible of infection by said recombinant virus and capable of growth at a temperature of 14°C to 20°C.
- 13) A method for expressing *in vitro* an antigenic protein of interest, said method comprising:
 - infecting a vertebrate cell susceptible of infection by IHNV or VHSV and capable of growth at a temperature of 14°C to 20°C with a recombinant IHNV

or VHSV comprising at least one recombinant DNA construct as defined in claim 1, encoding an antigenic protein of interest;

- culturing said cell at a temperature of about 14°C to about 20°C; and
- recovering the antigenic protein of interest produced by said cell.

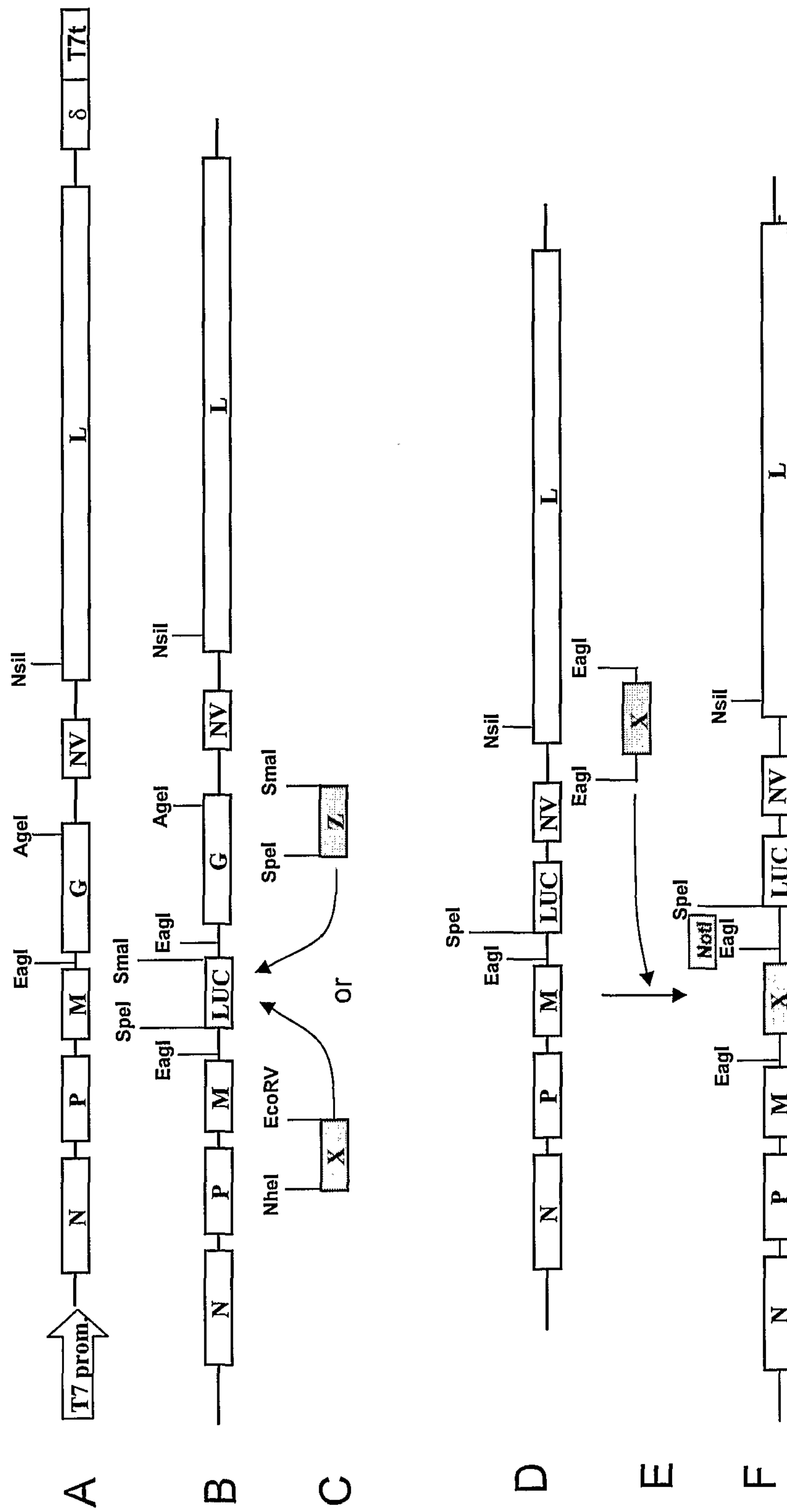


Figure 1

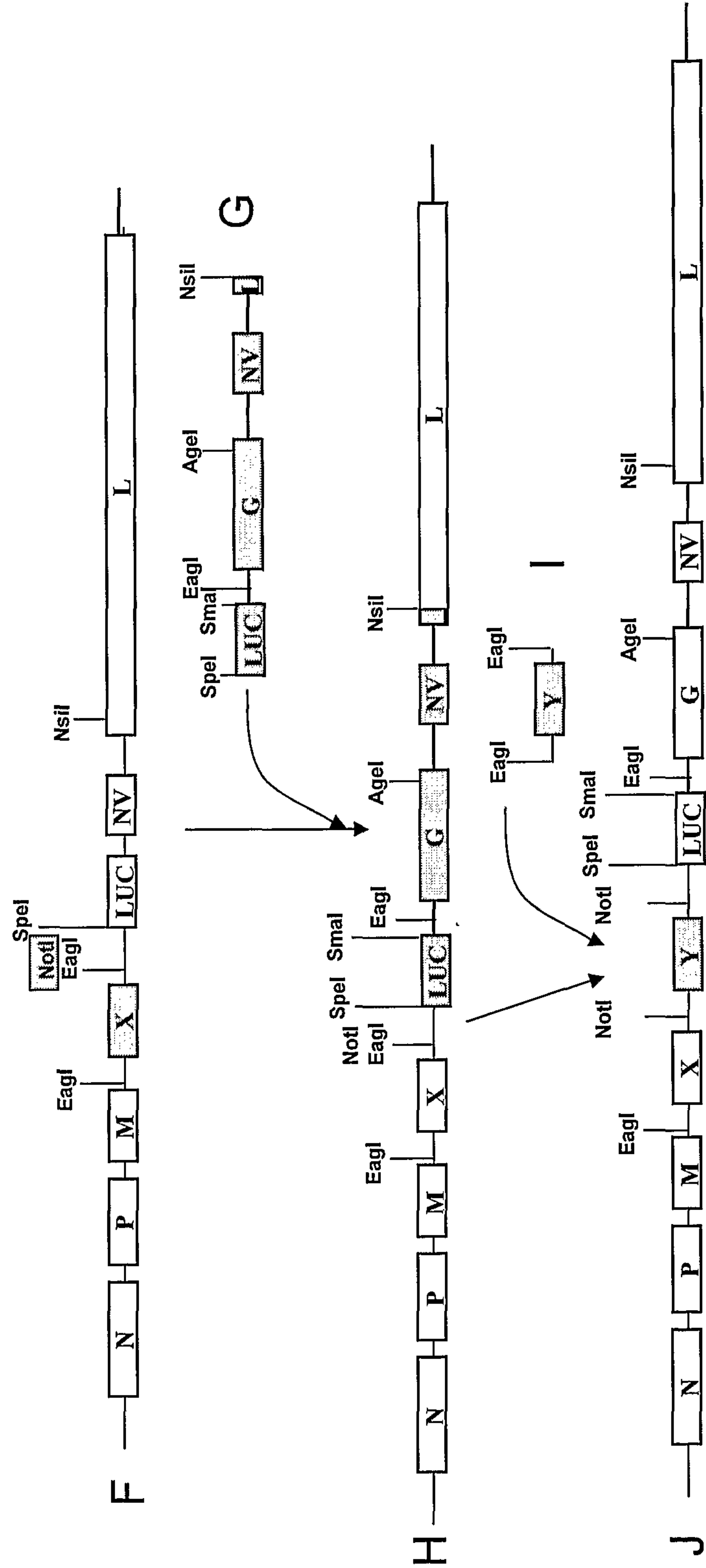


Figure 1 (suite)

Wild-type IHNV sequence

End of M ORF
.....GGGGGAAGGAAAAA TAGGAGTCGACCATGCCGTCTCTCACTCACCCATCCATCGGCCGCAA
G K E K
EagI
CCCTCCTCCATCCCCAGAGTCCCTCCACTCCTCACTCCGTCCAAGACAGAAAAAAATG.....G gene
Transcription Stop

Additional cassette

EagI Transcription Stop Transcription Start SpeI SmaI
CGGCCGCCAAGACAGAAAAAAATGGCACTTTTGTGCACTAGTATGgene of interestTAGCCCGGG

EagI
CGGCCGACCCAACCCTCCTCCATCCCCAGAGTCCCTCCACTCCTCACTCCGTCCAAGACAGAAAAAAATG...
Transcription Stop

.....G gene

Figure 2

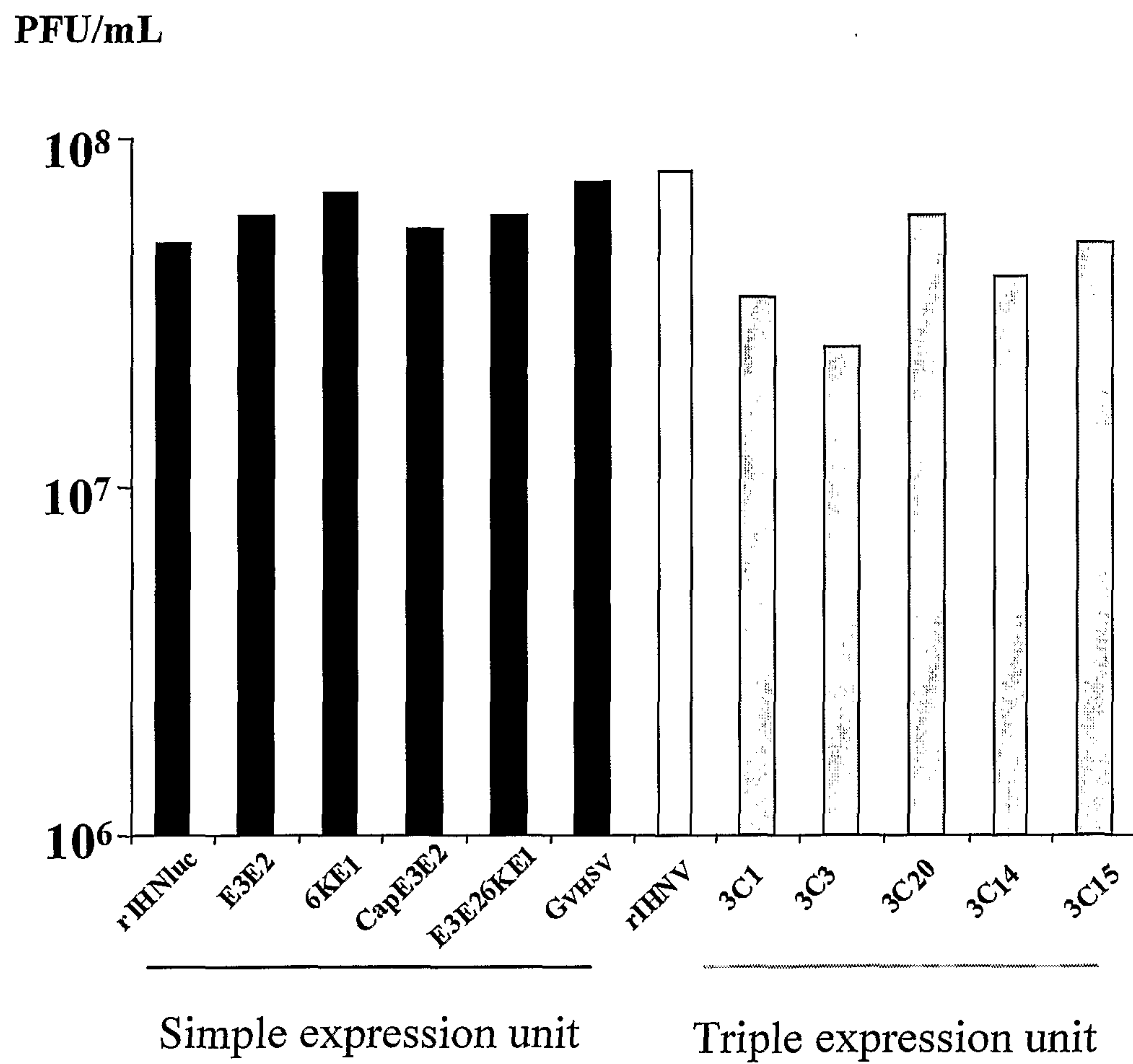


Figure 3

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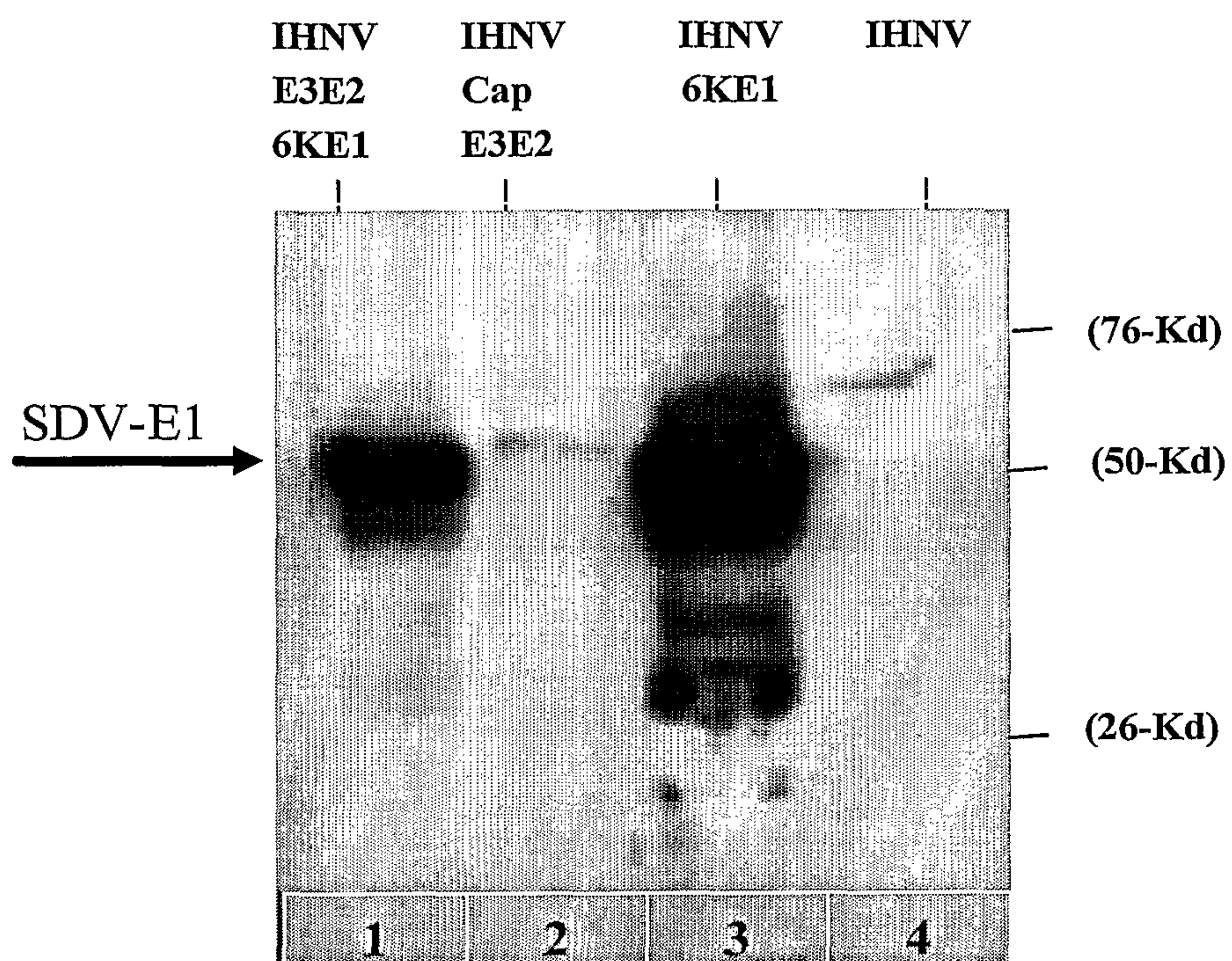


Figure 4

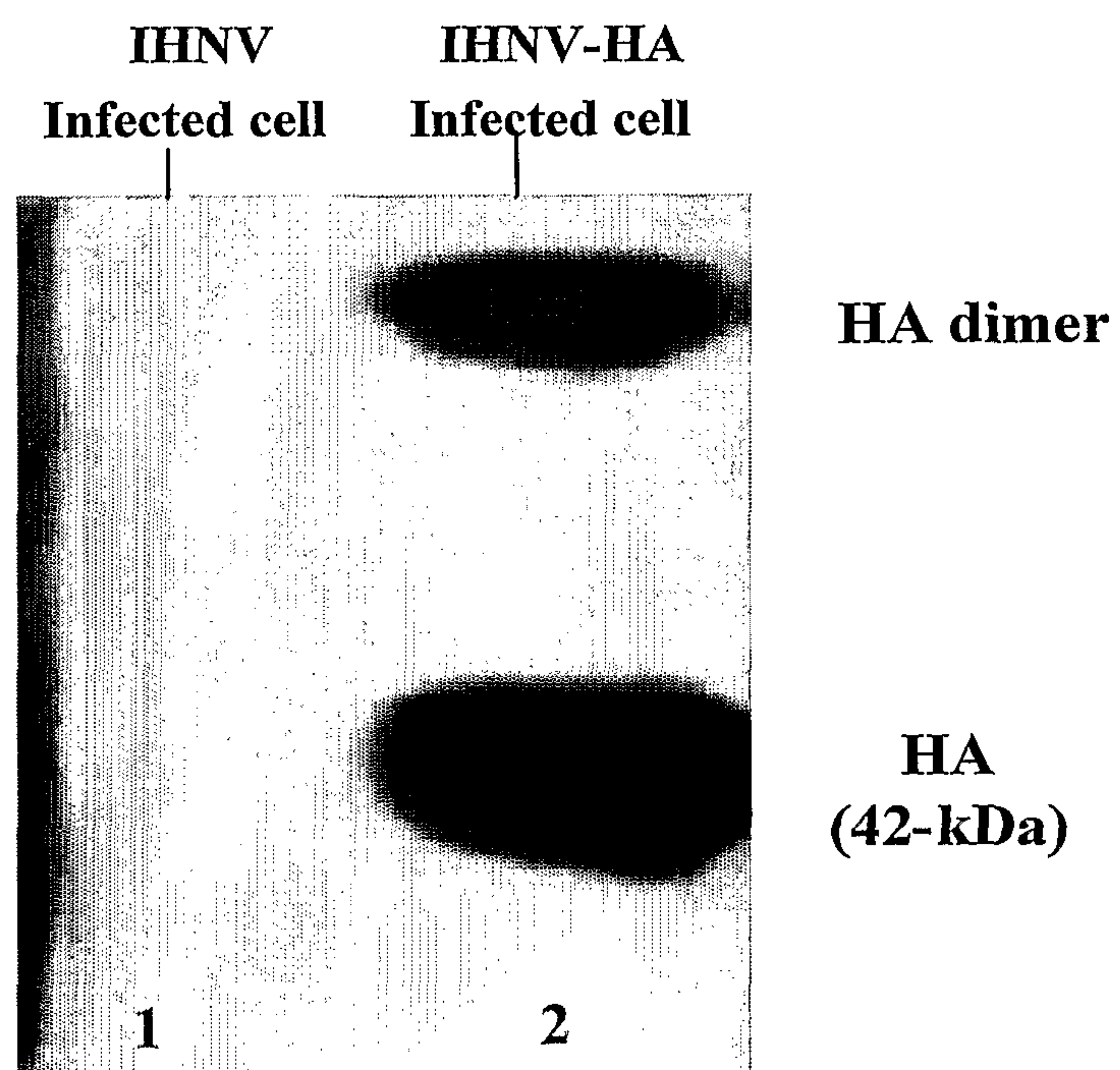


Figure 5

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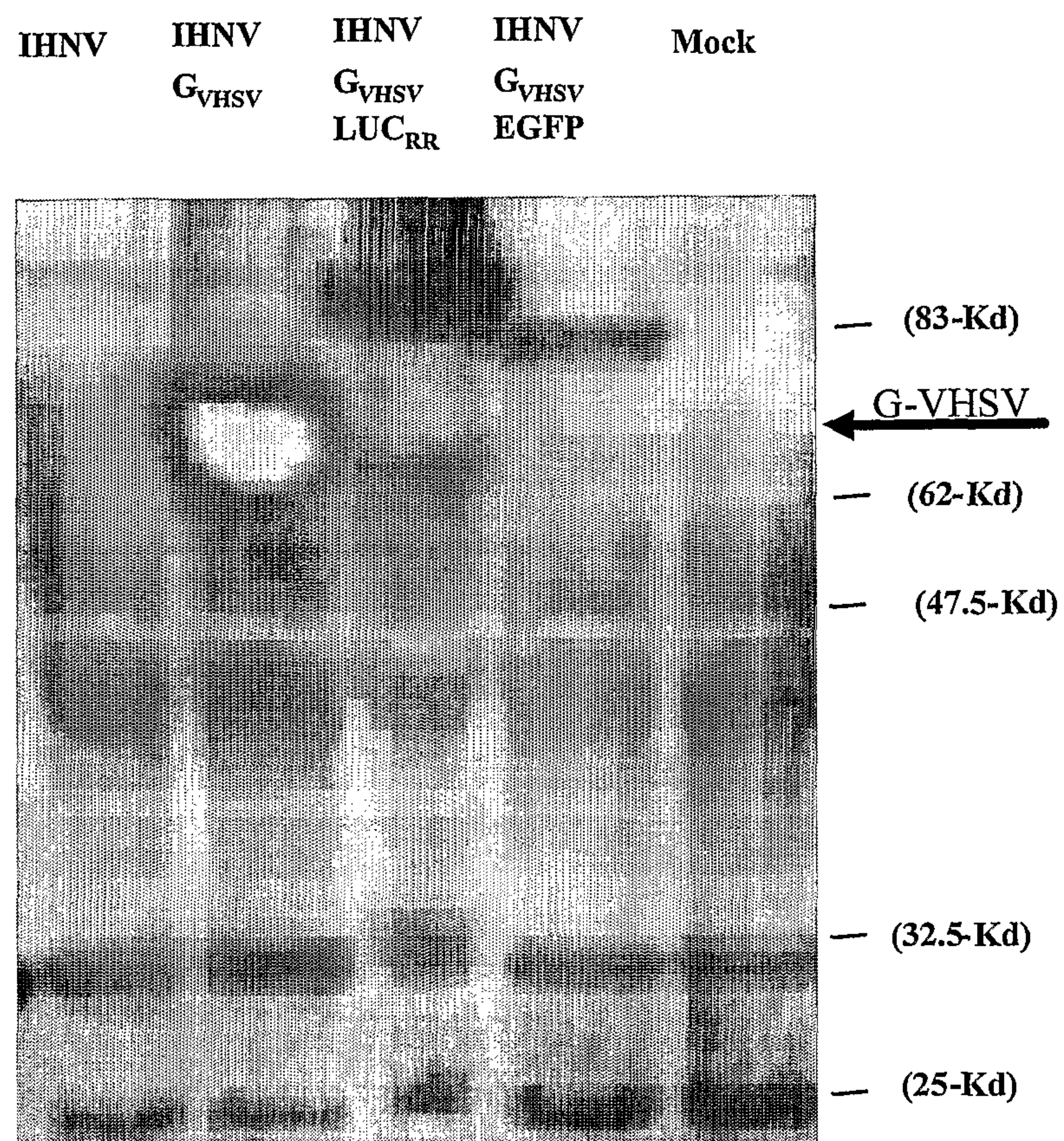


Figure 6



Figure 7

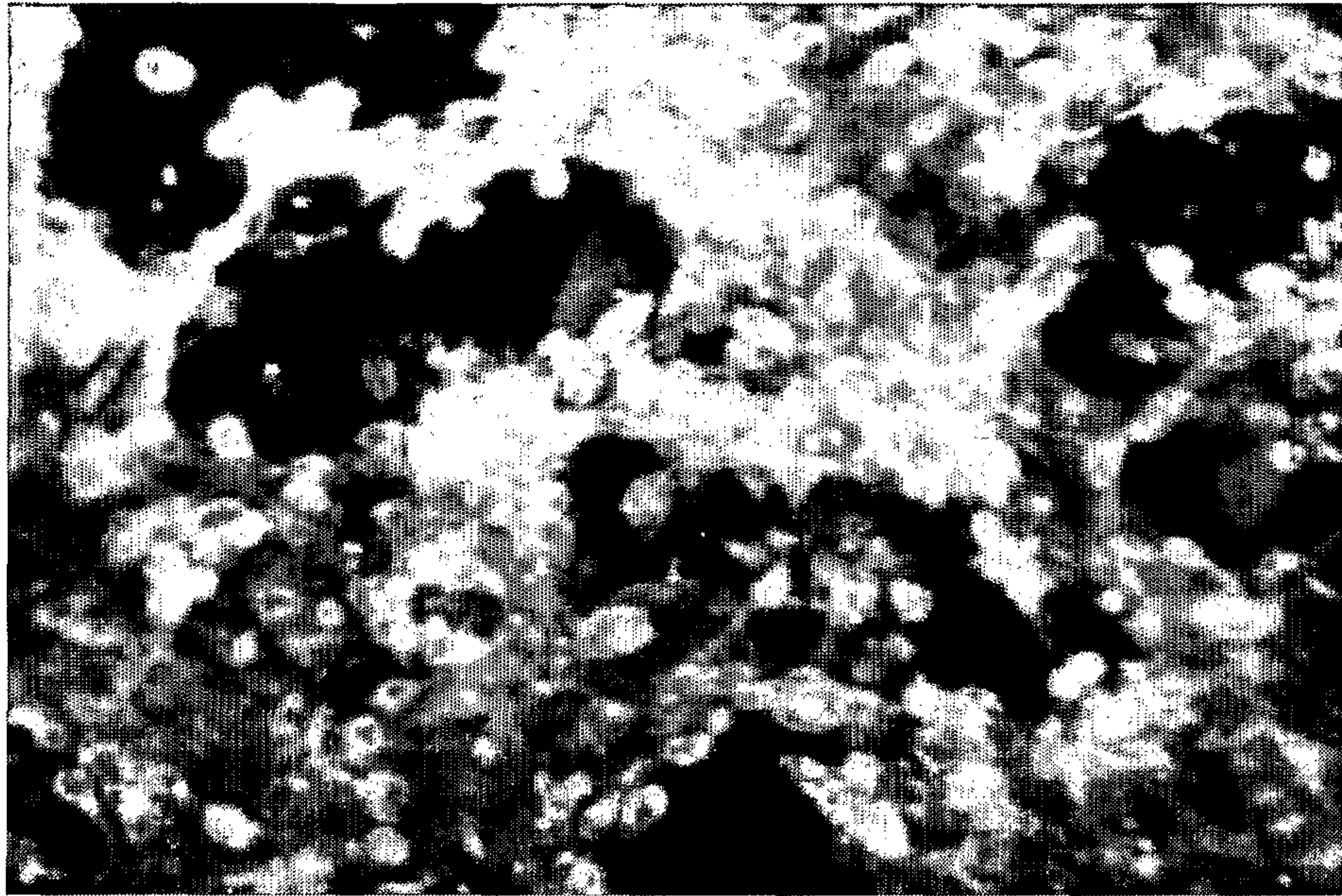
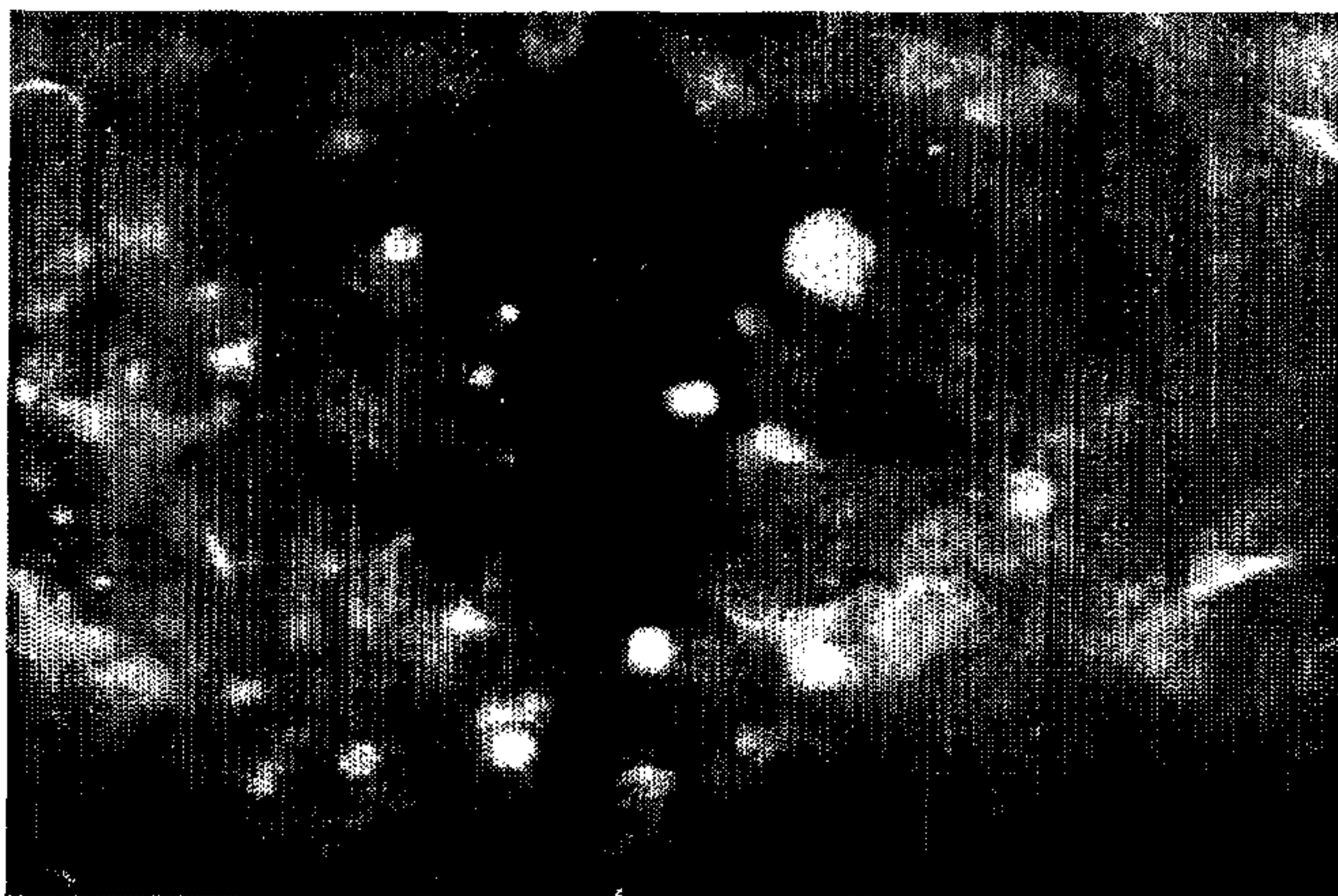
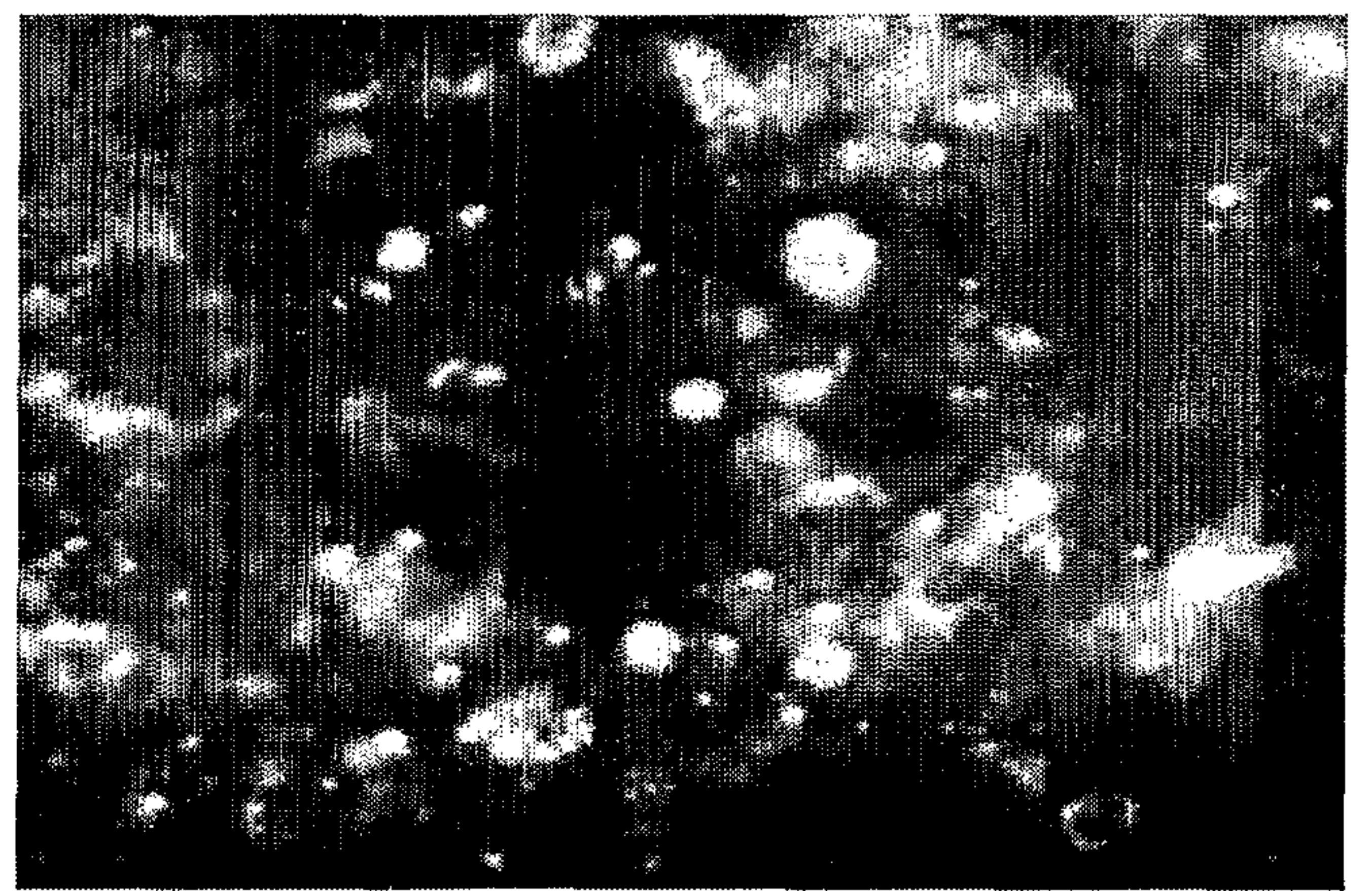


Figure 8



Anti IPNV VP2



Anti ISAV HA

Figure 9

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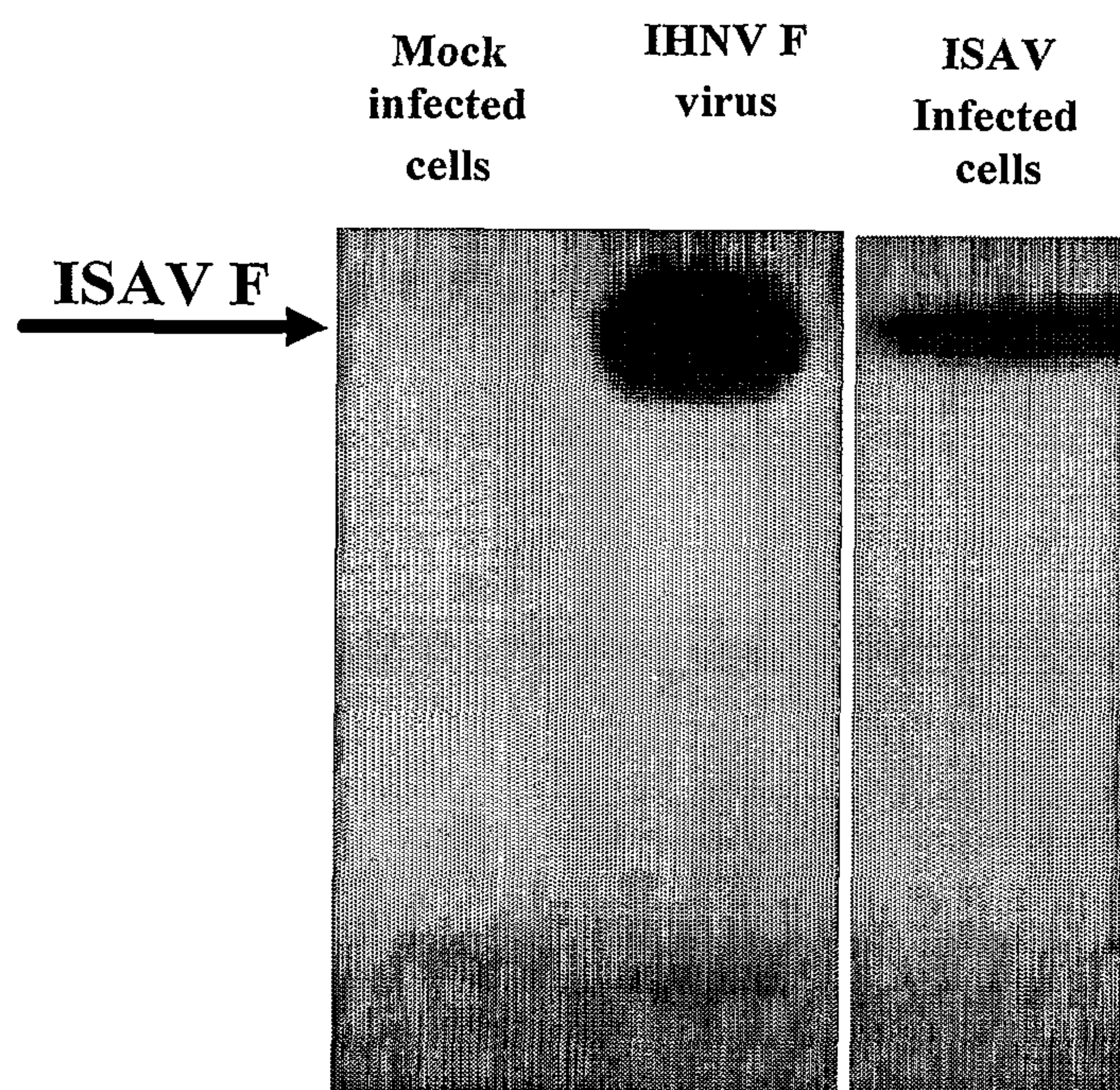


Figure 10

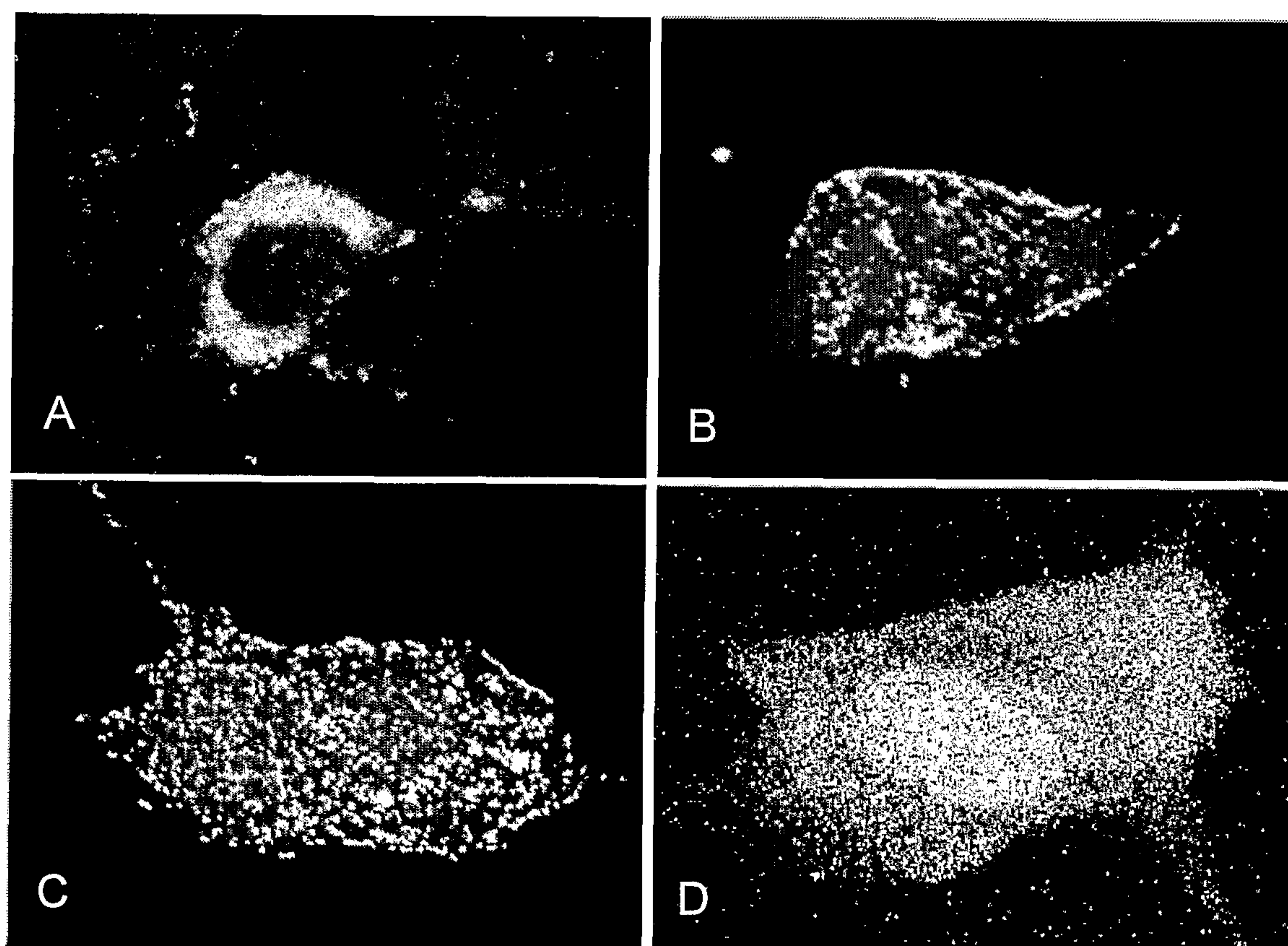


Figure 11

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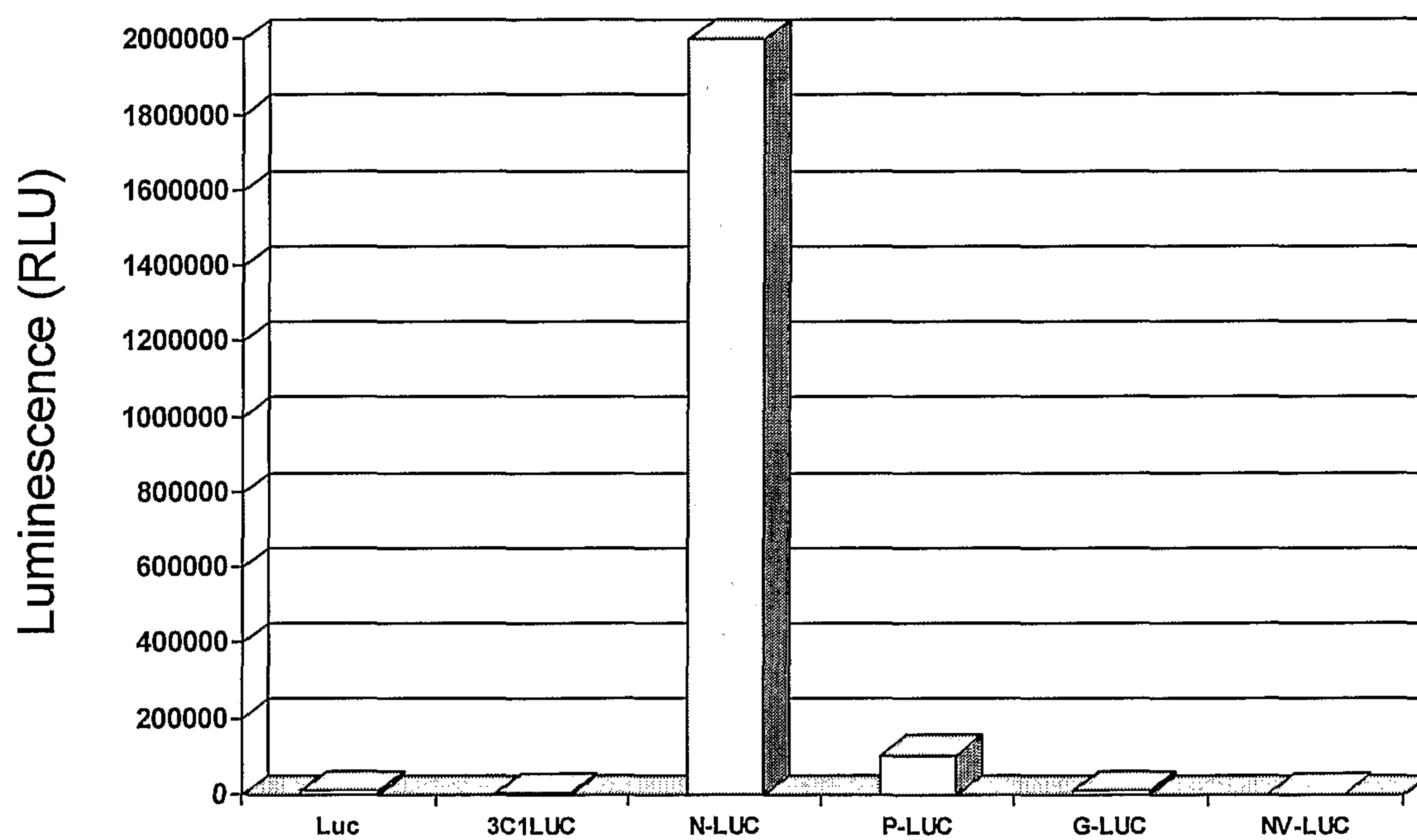


Figure 12

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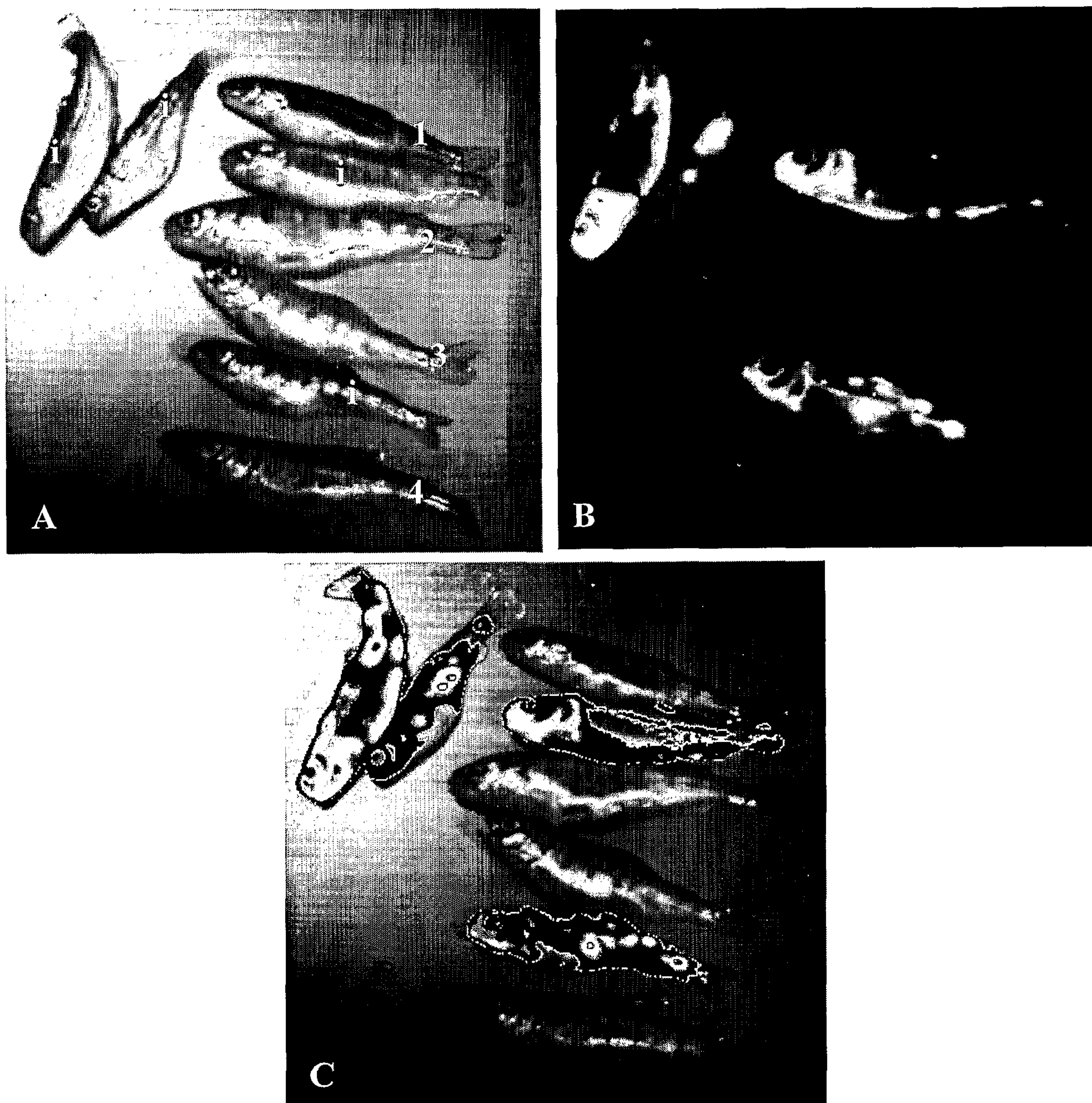


Figure 13

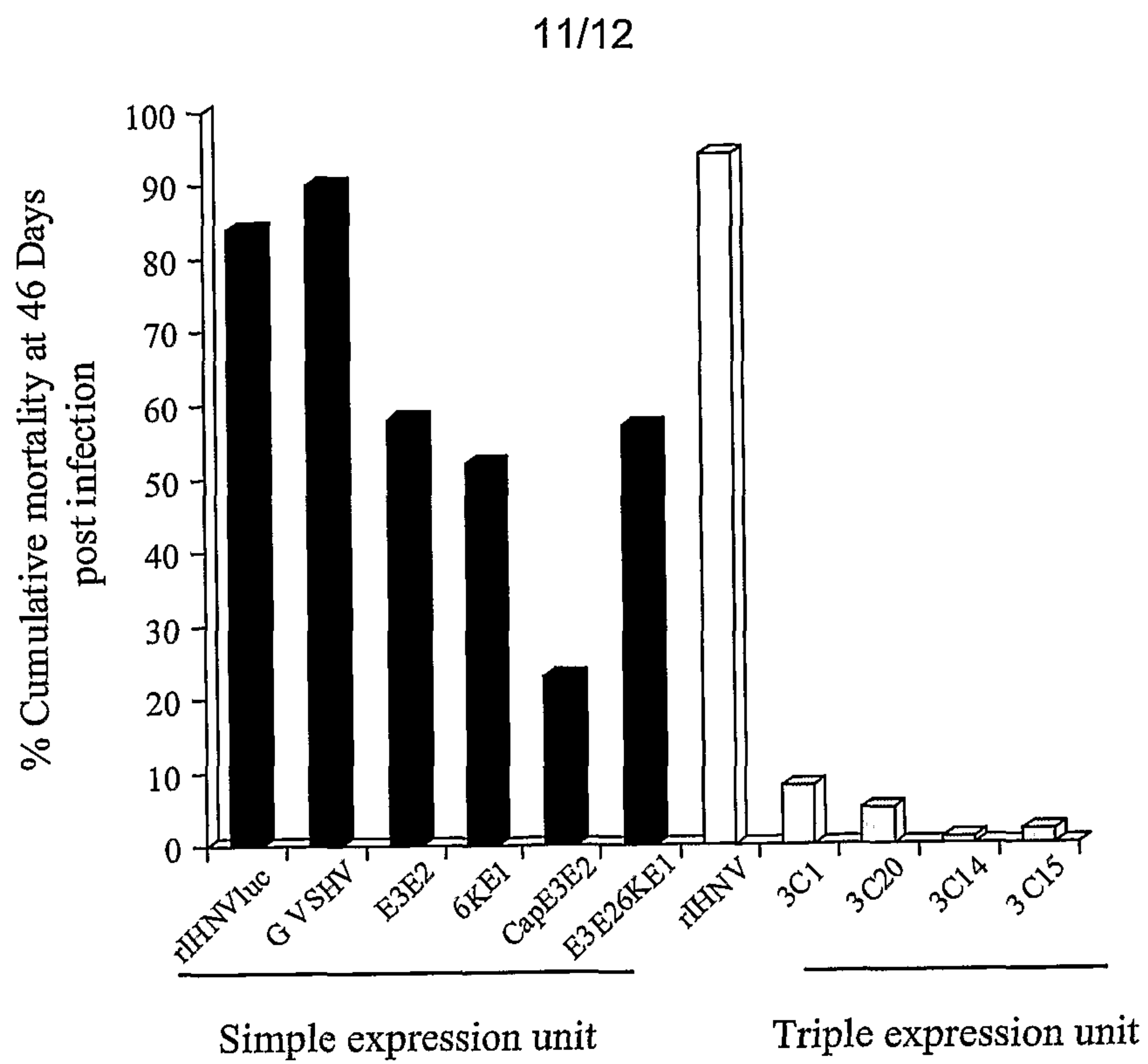


Figure 14

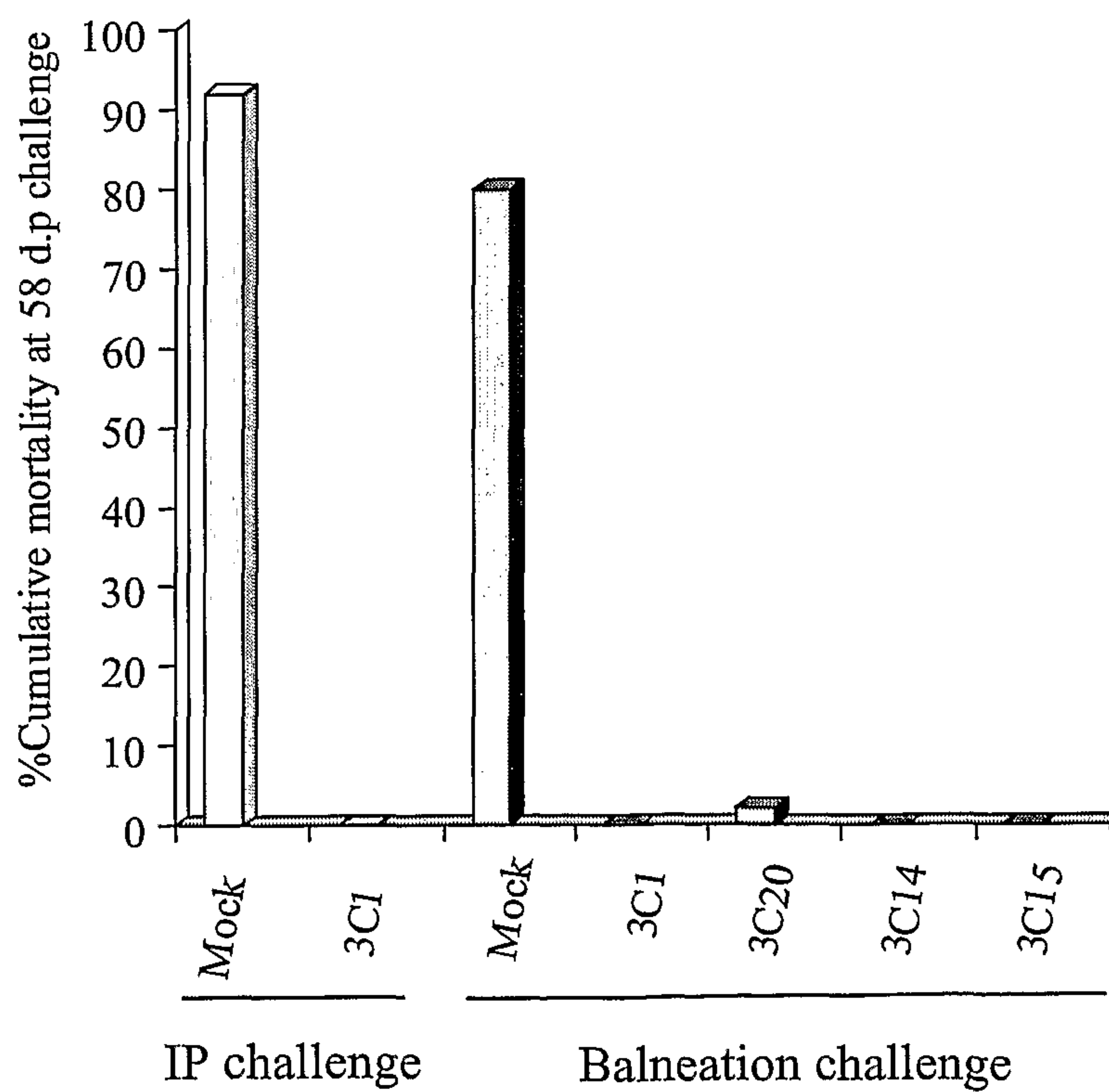


Figure 15

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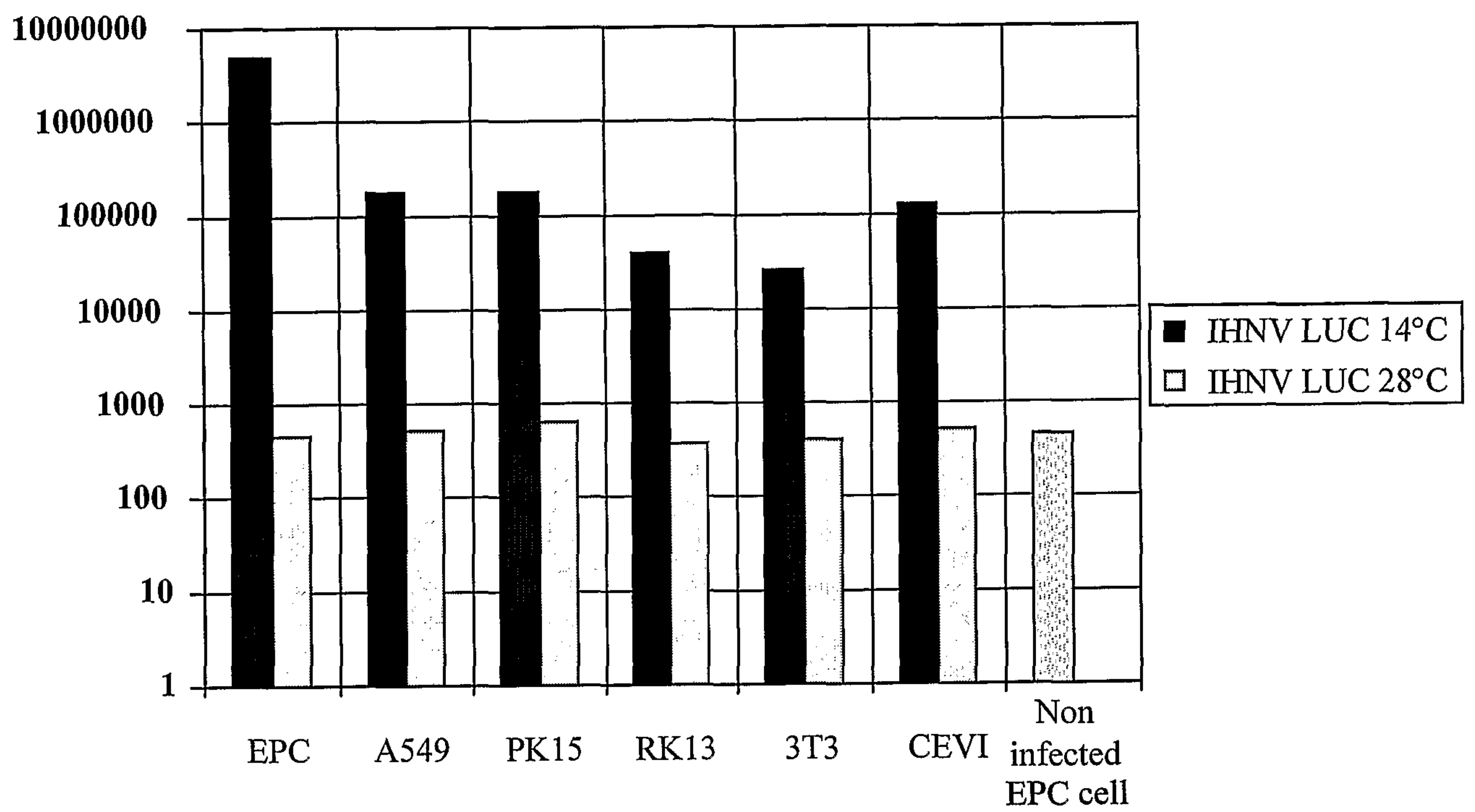


Figure 16

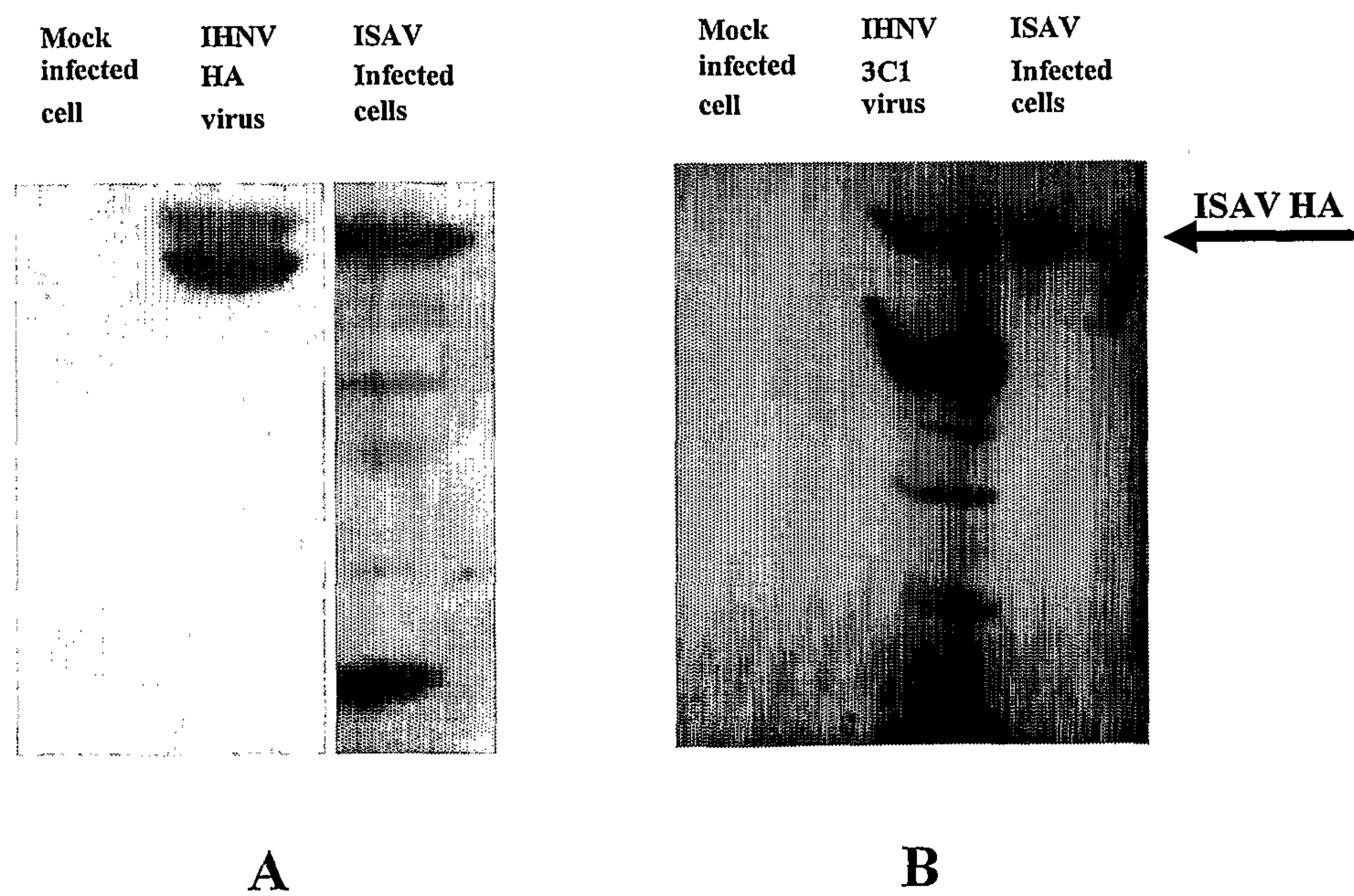


Figure 17